Federal Republic of Germany

Unesco Programme on Man and the Biosphere (MAB)

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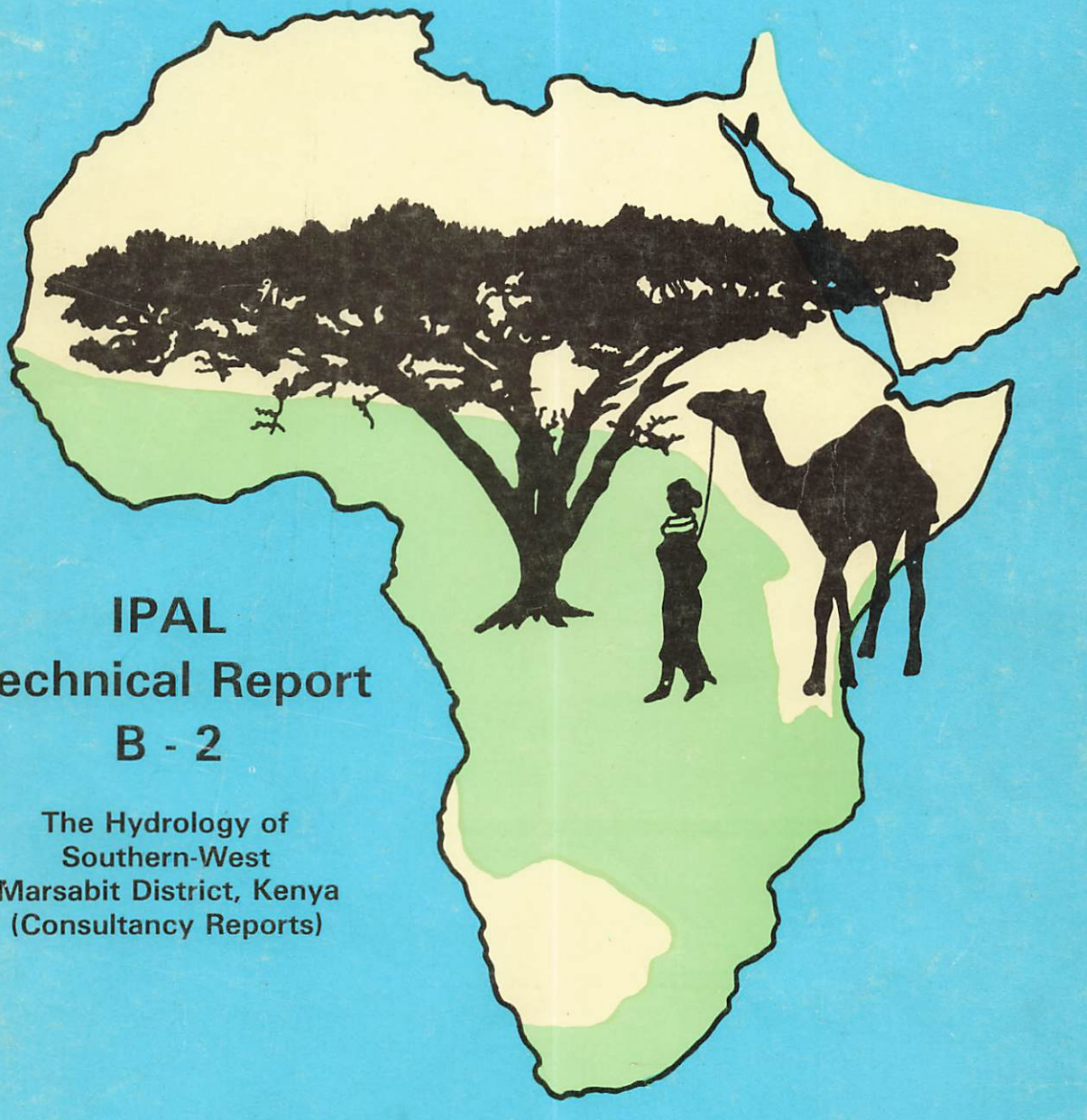
Integrated Project in Arid Lands (IPAL)



IPAL Technical Report B - 2

The Hydrology of Southern-West Marsabit District, Kenya (Consultancy Reports)

MAN AND THE BIOSPHERE PROGRAMME

Project 3: Impact of Human Activities and Land Use Practices on Grazing Lands

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IPAL Technical Report No. B - 2

A PRELIMINARY ACCOUNT OF EROSION, SEDIMENT TRANSPORT AND SURFACE-WATER RESOURCES OF PARTS OF MARSABIT DISTRICT

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UNESCO - MAB FRG Integrated Project in Arid Lands

SUMMARY INTRODUCTION TO IPAL AND THE TECHNICAL REPORT SERIES

The Integrated Project in Arid Lands (IPAL) was established by UNESCO with financial support from UNEP in 1976 with the aim of finding direct solutions to the most urgent environmental problems associated with desert encroachment and ecological degradation of arid lands. It forms part of the international UNESCO programme, Man and the Biosphere (MAB) which has links not only with UNEP's Desertification Unit but also with FAO, in response to the Plan of Action adopted by the 1977 United Nations Conference on Desertification. It is an example of the type of pilot activity that UNESCO and UNEP, together with other organizations and a number of governments, are trying to promote to provide the scientific basis for the rehabilitation and rational management of arid and semi-arid zone ecosystems, through integrated programmes of research (including survey, observation and experimentation), training and demonstration. Phase III of the project, 1980-1983, is supported by funds in trust to UNESCO provided by the Federal Republic of Germany.

During the first phases of IPAL, a co-ordination unit was established in Nairobi and the initial field work started in the arid zone of northern Kenya in a working area of 22,500 km² situated between Lake Turkana and Marsabit Mountain. The project now operates five field stations at Mount Kulal, Olturot, Kargi, Korr and Ngurunit, with the project headquarters in Marsabit which is the administrative centre of the District. Since its establishment the project has researched several aspects of experimental management of the region, concentrating upon 'human ecology' of the nomadic pastoralists in dynamic inter-relationship with the animals, plants and the other resources of a drought-prone, uncertain environment.

During the next three years (1980-1983), the investigations in progress will be extended and intensified to develop resource management plans of models for the area, taking into account the increasing human population, the trend towards sedentarization, the degradation of primary productivity, and the increasing incidence of soil erosion, all of which are factors resulting in the necessity for constant famine relief measures in this region. Results obtained in the project are the subject of a number of training workshops and seminars in which Kenyan and regional scientists from the Sudano-Sahelian region participate.

This report is one of a series published by IPAL describing technical findings of the Project and, where appropriate, giving management recommendations relating to the central problems of ecological degradation in the arid zone. The reports are divided into the following categories distinguished by the base colours of their covers:

A. General, introductory and historical: white

B. Climate and hydrology: blue

C. Geology, geomorphology and soils: brown

D. Vegetation: green

E. Livestock and other animal life: red

F. Social anthropological: yellow

Figure 1. Location of Study area

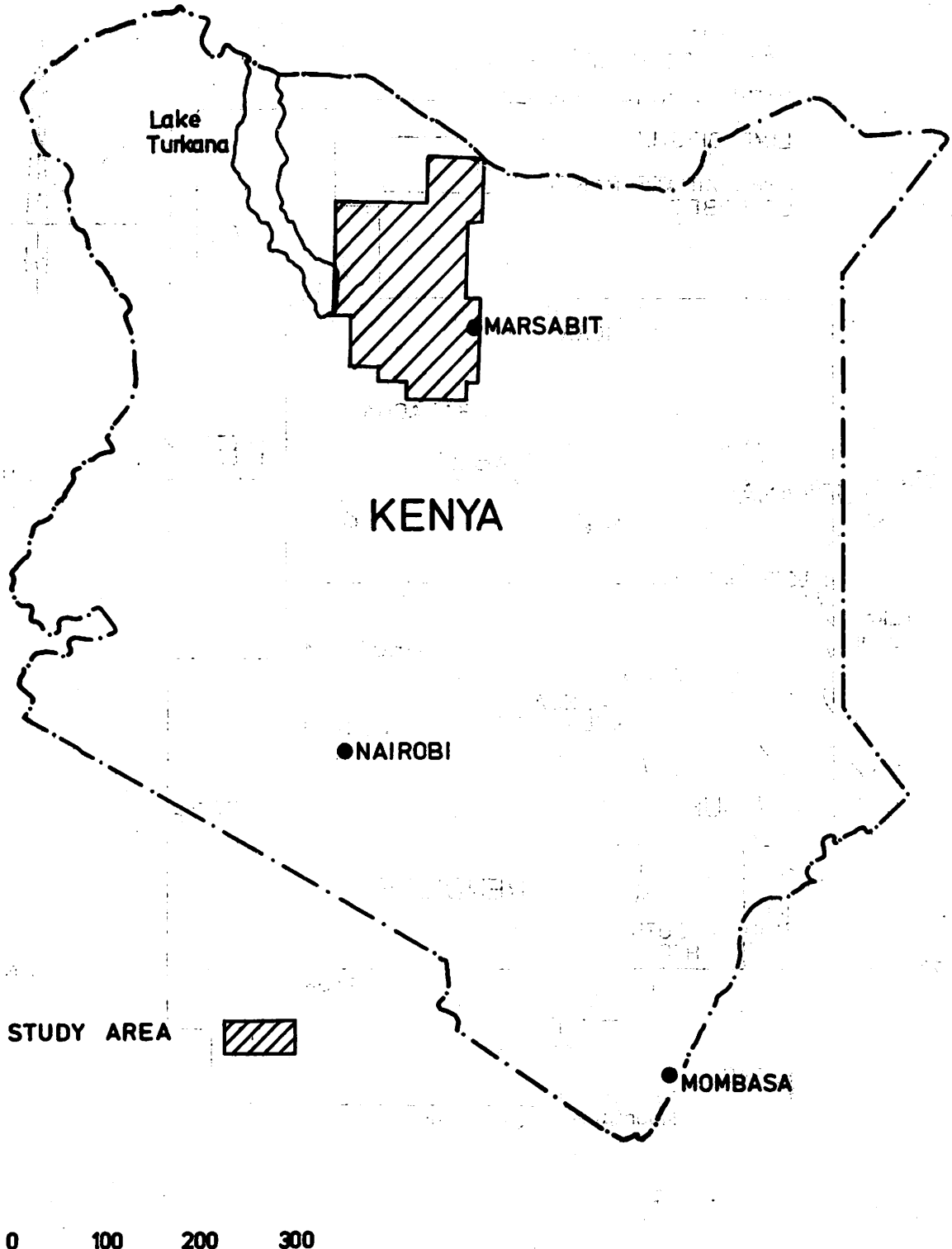
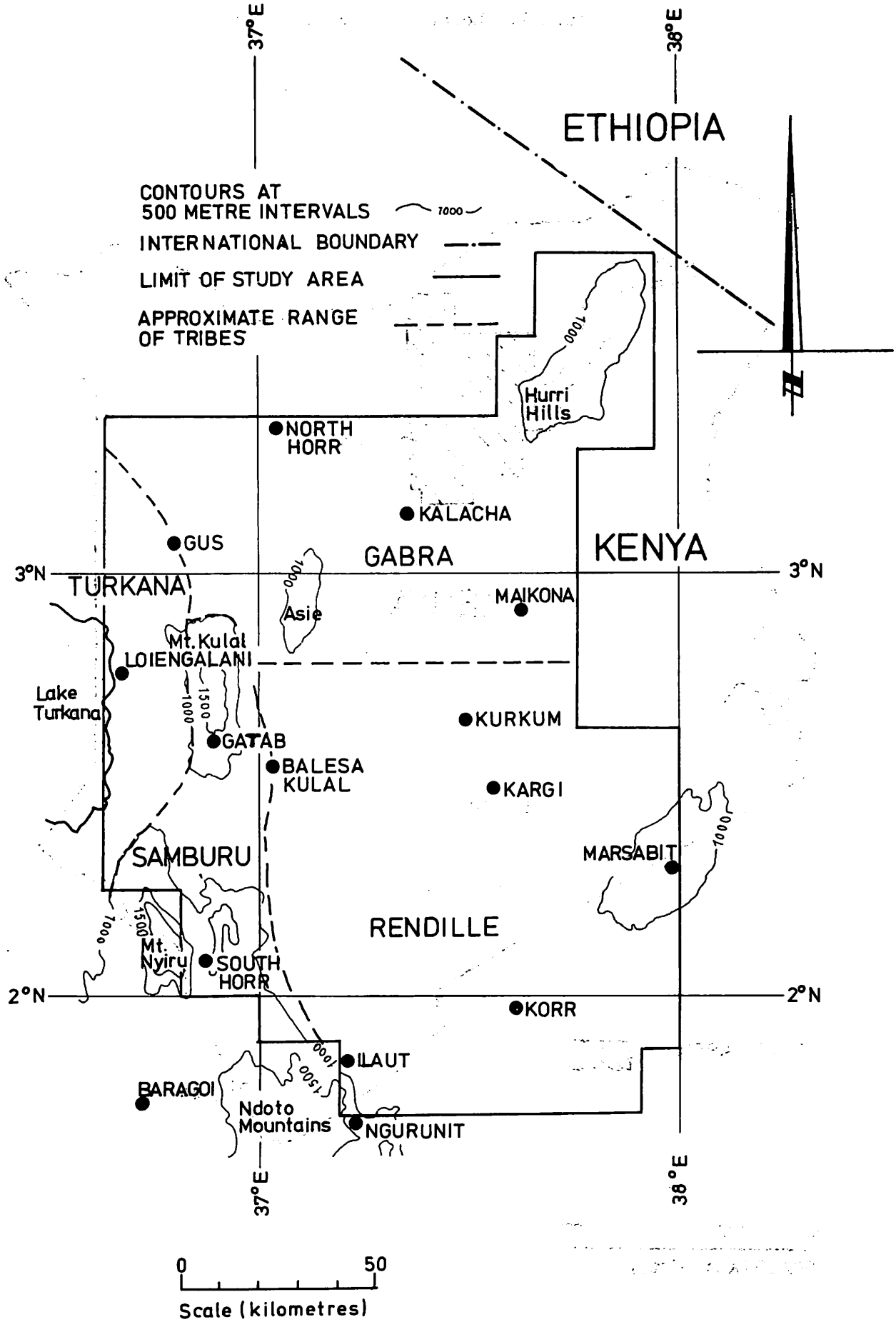


Figure 2. The Study area



A PRELIMINARY ACCOUNT OF EROSION, SEDIMENT TRANSPORT AND SURFACE-WATER RESOURCES OF PARTS OF MARSABIT DISTRICT

by

George S. Ongweny
(IPAL hydrology consultant)

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ACKNOWLEDGEMENTS

This consultancy report is the result of an intensive three-month period of field work in an area of Marsabit District covering nearly 20,000 km².

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I was constantly inspired by my wife and brothers Tom and Sirweri.

George S. Ongweny

Nairobi
January 1982

Chapter I

GEOLOGIC, TOPOGRAPHIC, DRAINAGE AND SOIL CHARACTERISTICS OF PARTS OF MARSABIT DISTRICT

GEOLOGY AND TOPOGRAPHY

The IPAL study area and Marsabit District as a whole is characterized by three main mountain piles, Mt. Kulal (over 2290 m) in the west, Mt. Marsabit (1836 m) in the central part, the Hurri Hills (1310 m) in the north, and two other mountain ranges, the Ol doinyo Mara range flanking the Horr Valley and the Charihashi range (1310 m) to the north-east of Mt. Kulal (see Figures 1 and 2).

Mt. Marsabit, Mt. Kulal and the Hurri Hills are volcanic piles surrounded by Tertiary lava flows. To the north, south, east and west, the Mt. Marsabit slopes drop dramatically forming lava and Quaternary sedimentary plains (see Figures 1 and 2). To the south, the plains are dotted with isolated lava plateaux. Westwards from the Mt. Marsabit lava flows, the plains rise to meet the hill range flanking Ol doinyo Mara Range with the Horr Valley. North of the plain lies the Chalbi Desert which is characterized by a closed drainage system receiving water from the various drainage basins, including those emanating from the Ethiopian plateaux.

On the Kenya-Ethiopia border in the northern part of the District, there are a series of plateaux, but south of these are the Turbi Hills and from Turbi the plains stretch to the west. North-west of this section are the Hurri Hills. South-west of the Chalbi desert the dominant feature is Mt. Kulal which forms an elongated north-south mass particularly steep and broken in the western side. The slope is fairly high, favouring high erosion rates within the lower portion of this catchment.

DRAINAGE

The drainage pattern of the study area, and that of Marsabit District in general, has been very much governed by the geological and topographic framework of the area (see Figures 1 and 2). Mt. Kulal mass forms a major watershed in that from the slopes of this mountain water flows

Figure 1. A simplified topographic, drainage, river-gauging and sediment-monitoring framework of parts of Marsabit District.

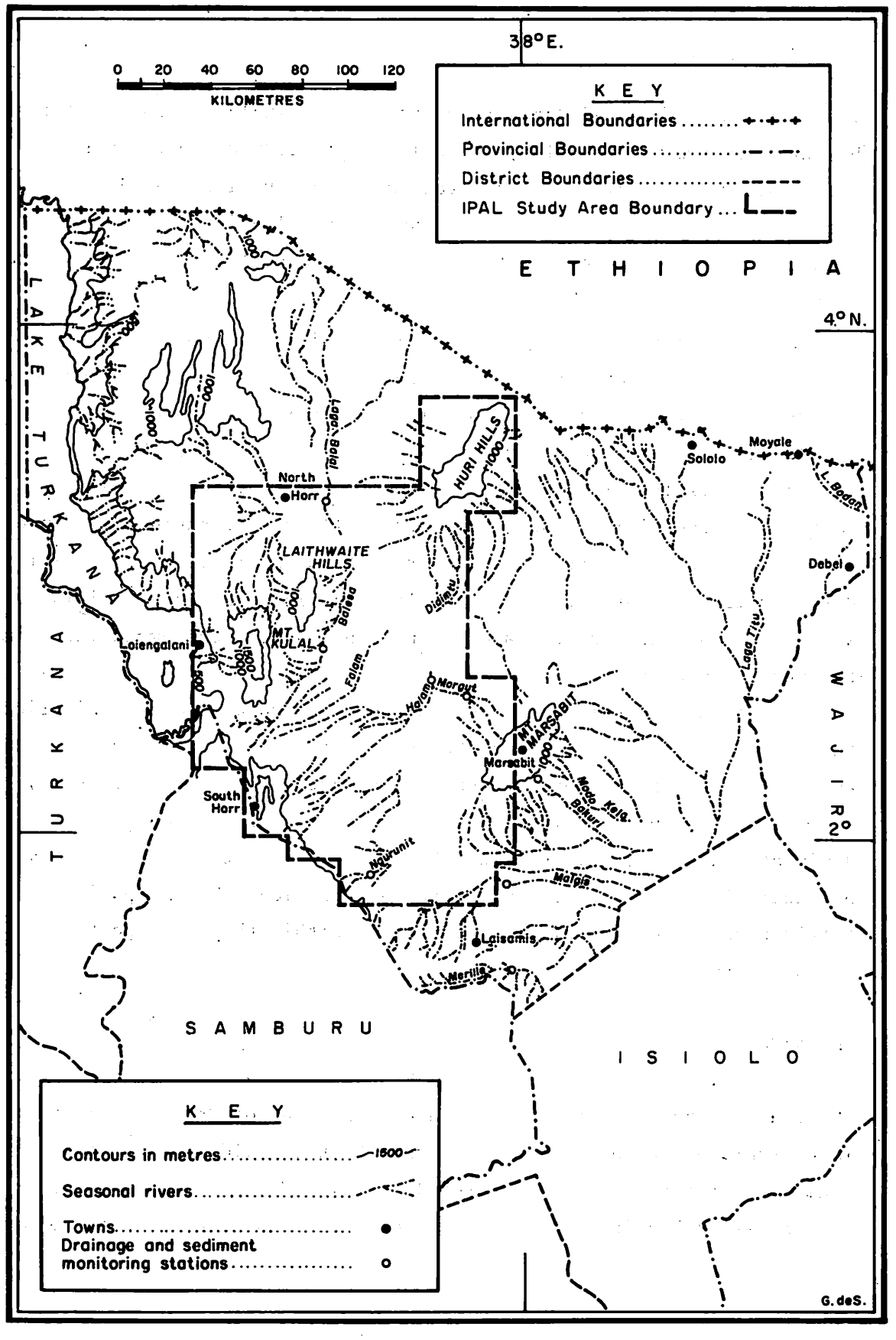
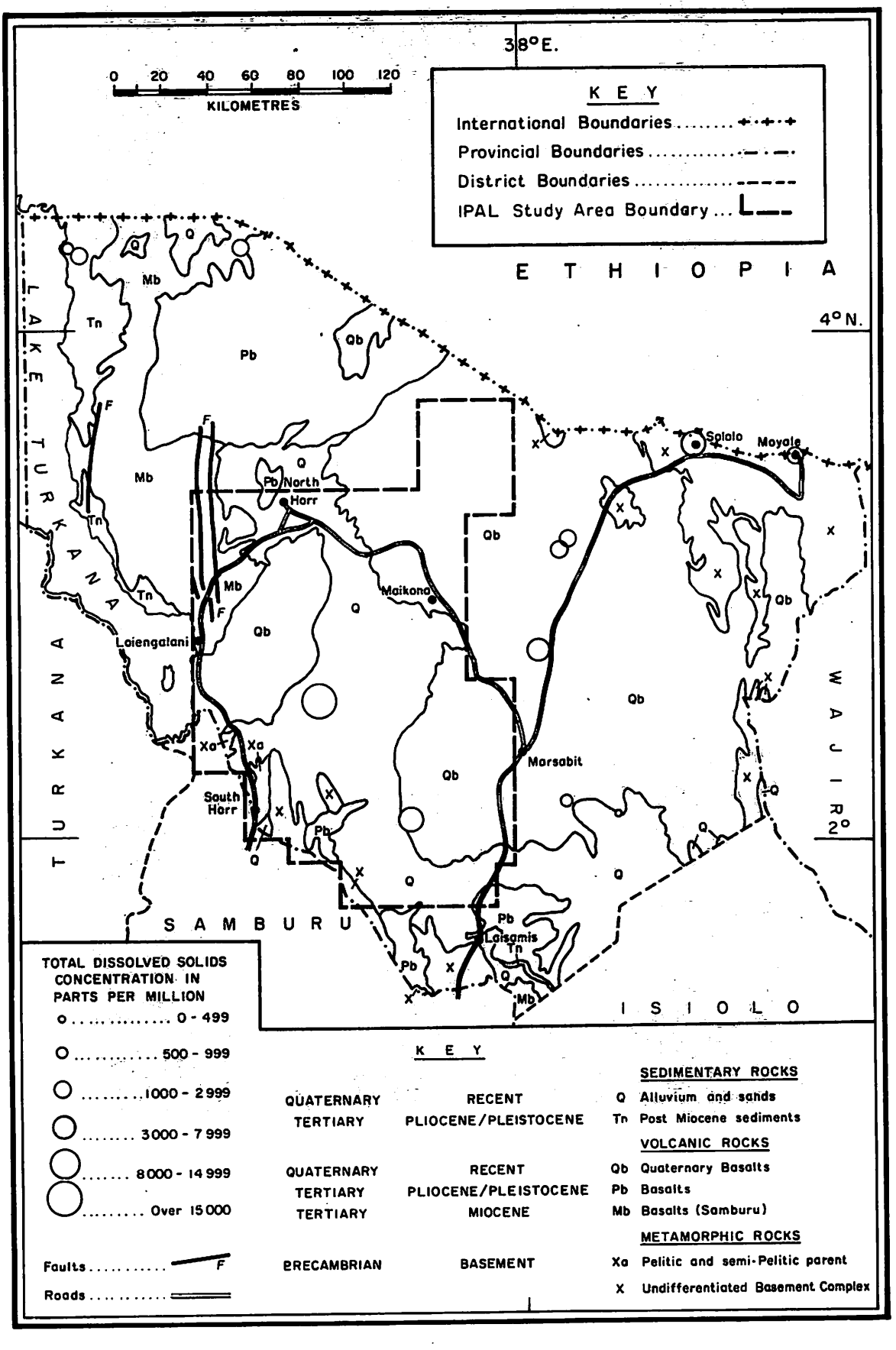


Figure 2. The geology and spatial concentration of total dissolved solids in Marsabit District's ground-water resources.

Source: Ongweny, 1973



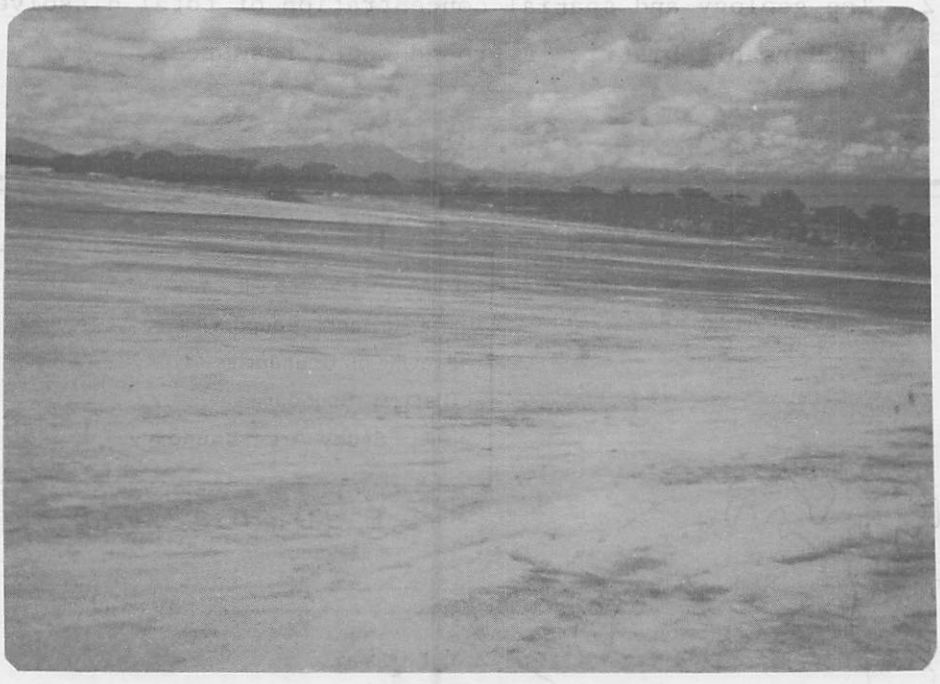


Figure 3. The sand-bedded Balessa River near Olturot.



Figure 4. The sand-bedded Merille River.

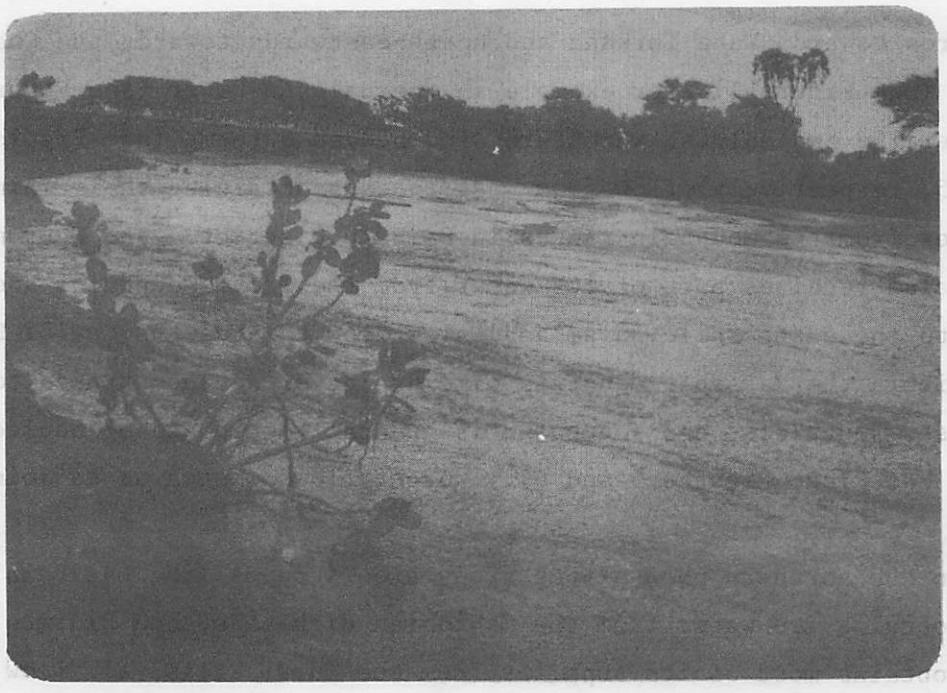


Figure 5. The sand-bedded Malgis River.

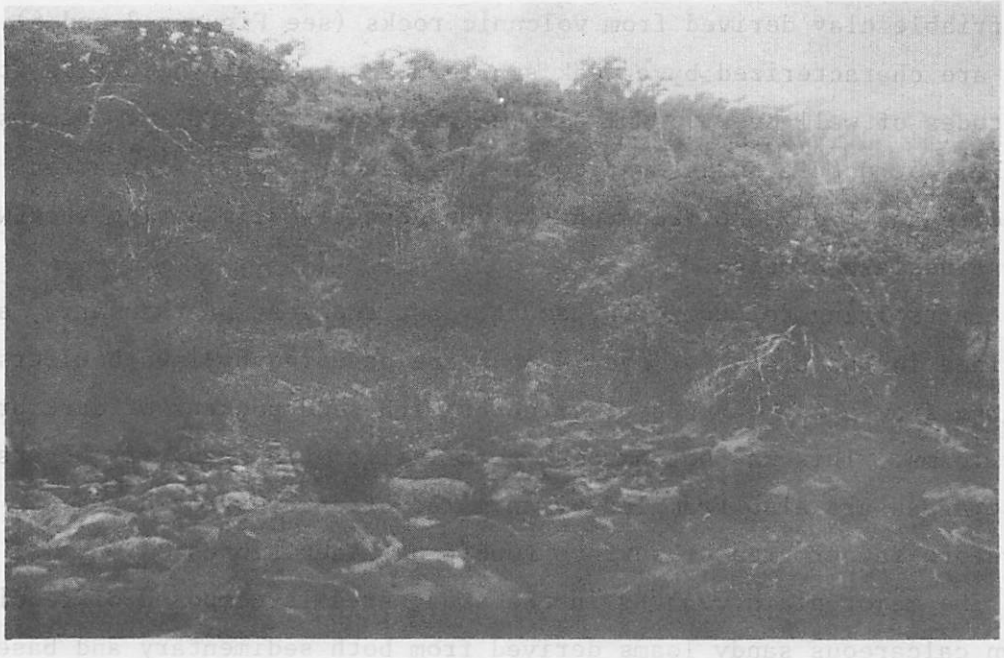


Figure 6. The boulder-bedded Bakuri River.

westwards towards Lake Turkana and north-eastwards towards the Chalbi Desert (see Figure 1), for example in the Balessa River (see Figure 3)

Merille and Malgis, which are sand-bedded streams (see Figures 4 and 5, respectively) flow from west to east obtaining their main supplies from the mountain ranges in Samburu District. The Ngurunit River also receives part of its water from the Ndoto Mountains and flows to the east, while Halam and Falam flow towards the Chalbi Desert.

Within the Marsabit mountain pile drainage is concentrated to the east, south-east and south and is generally composed of boulder stream beds (see Figures 5 and 6). Morgut flows westwards to join Halam.

In the northern part of the study area streams like Lag Balal, which obtains its water from the Ethiopian Highlands, and Didimtu, which obtains most of its supplies from the Hurri Hills, all flow towards the Chalbi basin.

SOILS

A large portion of the Marsabit and Kulal volcanic pile is composed of red friable clay derived from volcanic rocks (see Figures 2 and 6). They are characterized by a weak sub-angular structure occurring at altitudes of well over 1000 m with rainfall of over 800 mm. Because of their structure and ground cover they favour high infiltration capacity and reduce surface runoff, consequently eliminating sheetwash and rainsplash erosion.

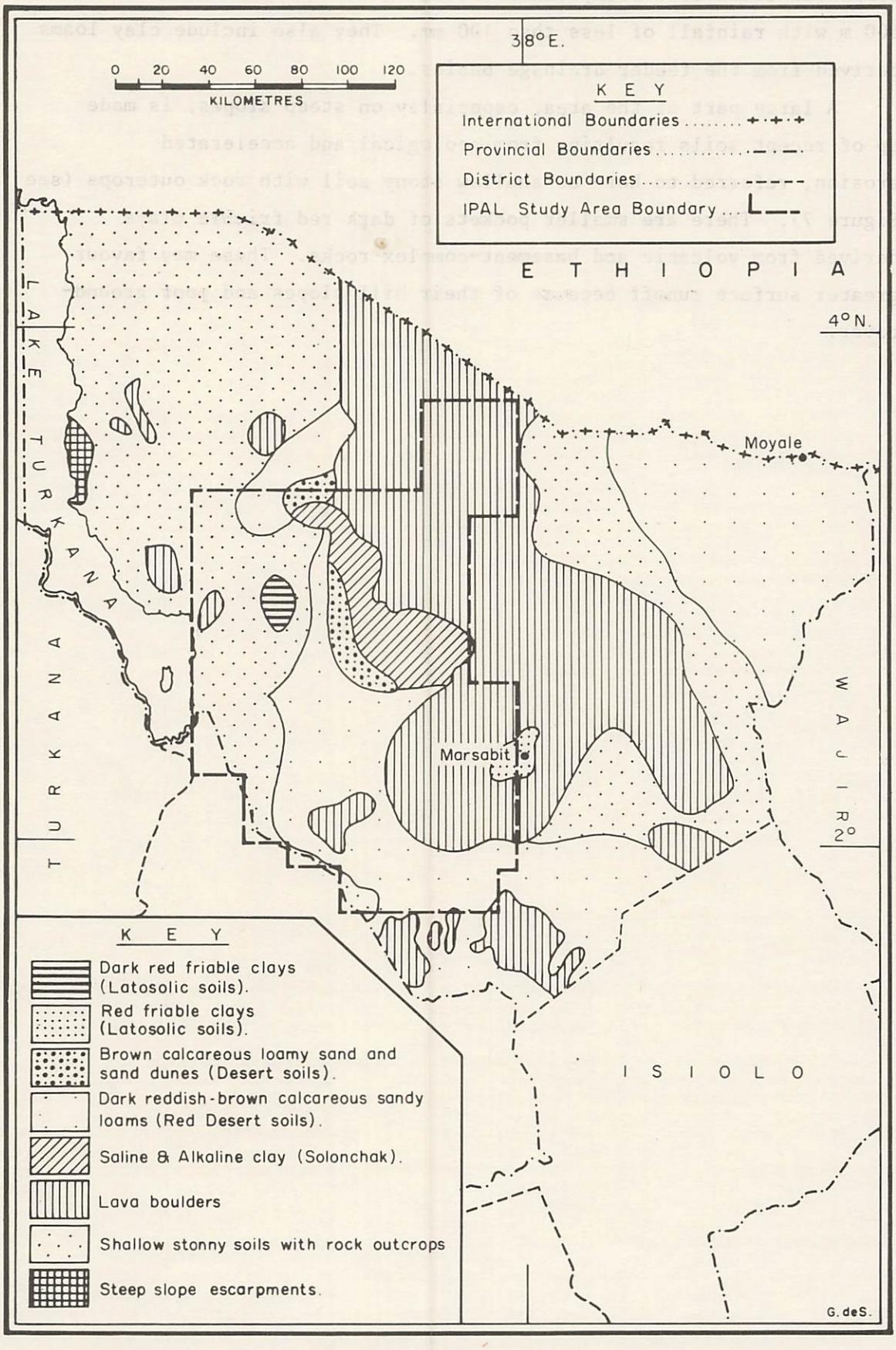
Parts lying to the north, south, east and west of this area, as outlined in the *Kenya National Atlas*, are occupied by lava boulders ranging from a continuous boulder cover with good pockets of dark brown clay loams. This may not have as good infiltration capacity because these areas are also trampled by animals, often overgrazed and therefore favour greater surface runoff on steep slopes.

The major plain country in the study area is composed of reddish brown calcareous sandy loams derived from both sedimentary and basement-system rocks. These plains range in altitude from 300 to 1500 m with rainfall of between 120 and 250 mm. They are characterized by high infiltration capacity but when they are saturated some degree of runoff may take place. Generally they form major basins of deposition in parts of Marsabit District.

Bordering these soils in the vicinity of the Chalbi Desert are compacted calcareous loamy sands occurring at altitudes of below 600 m with rainfall of less than 100 mm. They also include clay loams derived from the feeder drainage basins.

A large part of the area, especially on steep slopes, is made up of recent soils resulting from geological and accelerated erosion, referred to here as shallow stony soil with rock outcrops (see Figure 7). There are smaller pockets of dark red friable clays derived from volcanic and basement-complex rocks. These may favour greater surface runoff because of their hill slopes and poor ground-cover.

Figure 7. A simplified soil map of Marsabit District.



Chapter II

ECOLOGY

Atwoki (1981) contends that in Kenya one commonly hears that upto two-thirds of the land area of the Republic is arid. He says that this is commonly based on the extent of certain vegetation types or a combination of this with other crude ecological indices. He continues to underline the fact that while such gross estimates may be useful in highlighting the magnitude of the problem of aridity, it is important to recognize that until detailed analysis of the definitive climatic parameters is completed, it is difficult to ascertain the exact extent and character of the arid lands.

However, in the Swynnerton Plan semi-arid and arid lands were considered as those having less than 635 mm of rainfall and lying at an altitude of 1219 m above sea level. Brown (1963), on the other hand, suggests that land with less than 762 mm of rainfall should be regarded as semi-arid. Woodhead (1968) has demonstrated the complicated problem of water balance in the arid and semi-arid lands. Ominde (1971), and Dunne and Leopold (1978) have noted that in these areas evaporation from open water (Penman EO) ranges from 2000 to 2600 mm. Ominde shows further that within the northern parts of Marsabit District, values of 2600 mm have been recorded. He concludes that perhaps the most useful definition of the semi-arid and arid lands is to be found in Dow (1961) *The Royal Commission Report* where, on the basis of 762 mm of rainfall, the arid lands were divided into categories taking into account the rainfall reliability factor.

Nyenzi, Kiangi, and Rao (1981) analysing actual evaporation values in East Africa have documented annual East African values ranging from 500 mm to 1000 mm in parts of Marsabit District.

However, Pratt, Greenway and Gwynne (1966) have recognized six eco-climate zones, four of which are identified in the present study area (see Figure 8). These have been discussed by FAO (1971) in the Marsabit District as in the following four sections.

ECOLOGICAL ZONE II

This is a sub-humid ecological zone with a moisture index of not less than -10. It includes the parts of Mt. Marsabit above 1500 m and

Figure 8. A simplified ecological and land-systems map of part of Marsabit District.

Source: FAO, 1971.

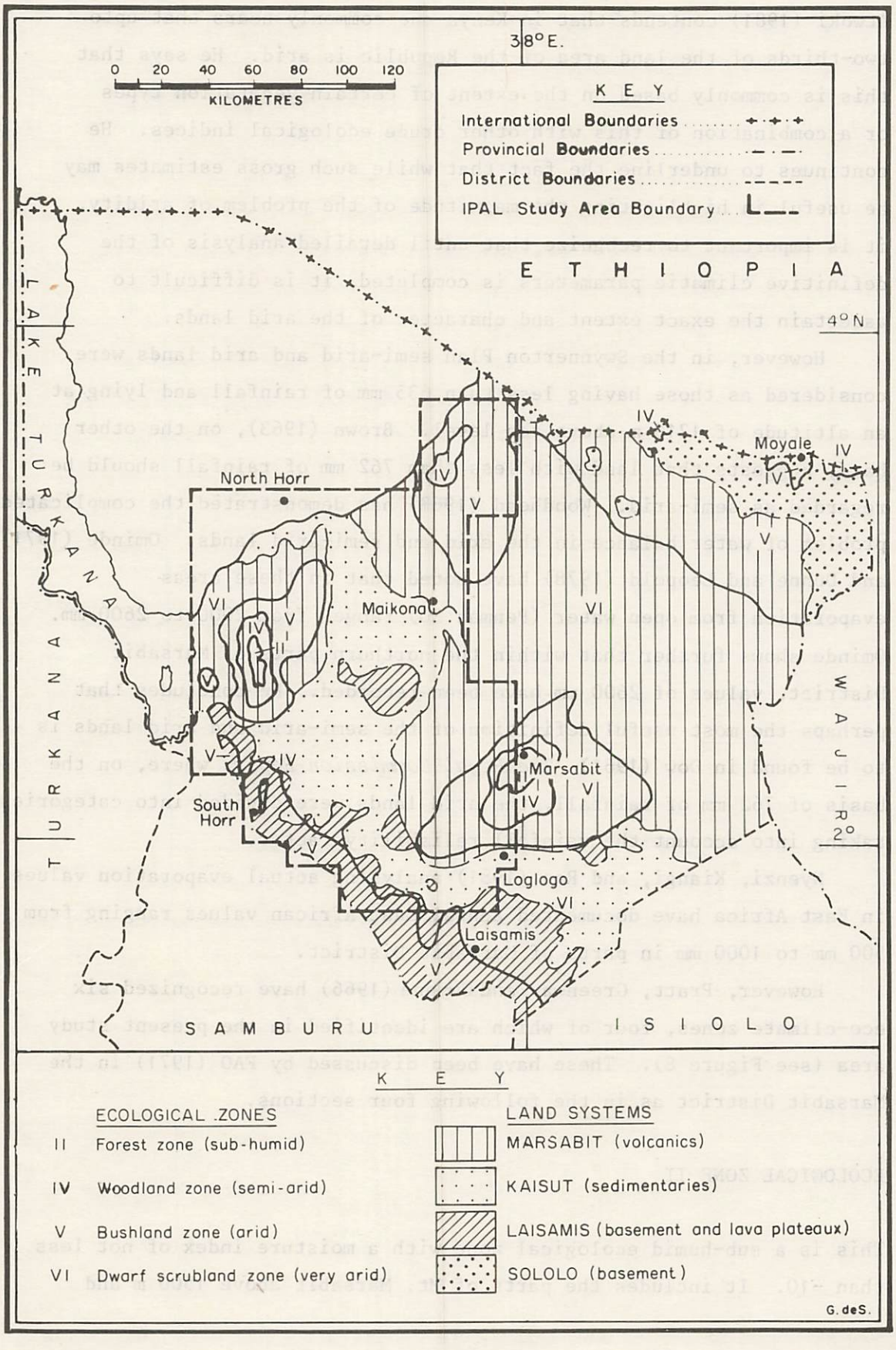




Figure 9. The dense undisturbed Marsabit Forest with good ground-cover



Figure 10. The undisturbed forest cover at Gatab.

Mt. Kulal above 1700 m which support dense evergreen forests whose species have been documented by Herlocker (1977) in the IPAL Technical Report No. DI. As will be further documented below this is an important water catchment area where, because of the dense vegetation cover and surface litter (see Figures 9 and 10), the rain-drop kinetic energy is very much reduced (Moore, 1978; Dunne and Leopold, 1978; Ongweny, 1978, 1979; FAO, 1965, 1976, 1977; Pereira, 1962, 1973).

The disturbed forest roads can be a major source of sediment (see Figure 11). This means that with the types of clay loams developed on Tertiary lava existing in the area, the infiltration capacity is high (Horton, 1933), i.e. there is little surface runoff and therefore most of the flow is sub-surface. In such a situation sub-surface flow predominates (Dunne, 1978) and consequently little or no sheetwash or rainsplash erosion is experienced (Ongweny, 1978).

ECOLOGICAL ZONE IV

This is essentially a woodland zone with moisture indices of -30 to -40 covering parts of Sololo, Moyale (see Figure 12), undisturbed upper slopes of Mt. Marsabit (see Figure 13), Hurri, Kulal and parts of South Horr whose vegetation cover has been determined by IPAL (1979). The hydrological processes in these areas will largely be governed by the soils (Hills, 1971), some of which include the lava boulders and calcareous sandy loams, slopes (Figure 1), geological formations (Figure 2), precipitation (Langbein and Schumm, 1958), the varying vegetation (Douglas, 1967), and most important of all, land use (Ongweny, 1978; Pereira, 1962; Dagg and Blackie, 1965; Copeland, 1965; Dunne, 1977; Rapp et al., 1972).

ECOLOGICAL ZONE V

As shown in Figure 8, this zone includes the lower slopes of volcanic and basement piles lying between 700 and 1000 m (see Figure 1) characterized by a moisture index of -42 to -51 and underlain by Tertiary basalts and undifferentiated basement-complex rocks (see Figure 2). The soils are shallow and stony with rock outcrops as well as clay loams in places (see Figure 7). The flatter areas are

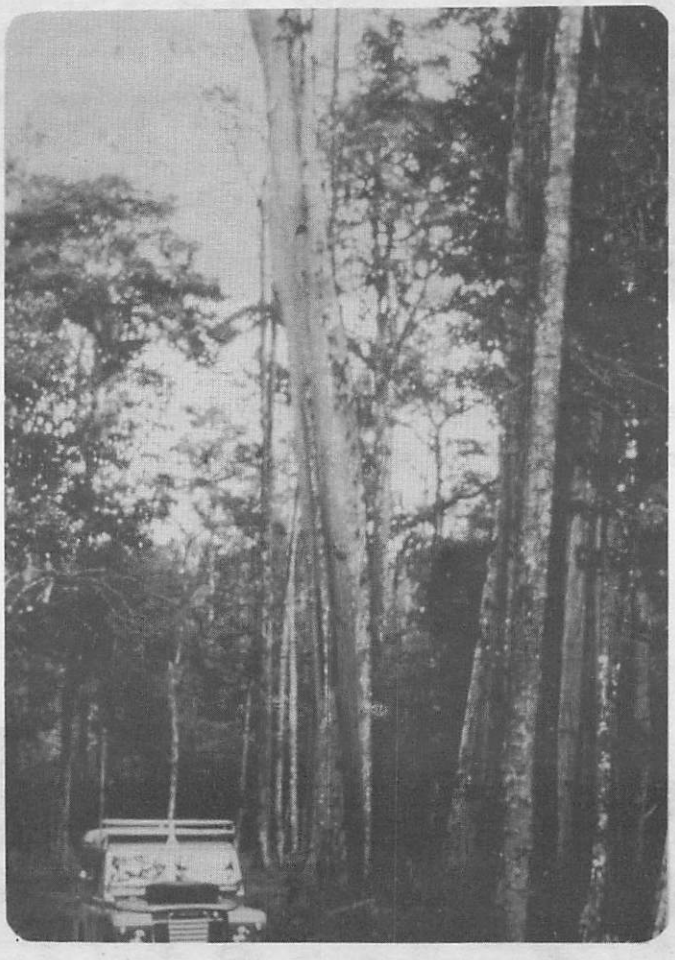


Figure 11. Dense Marsabit forest. Note that forest roads can be a major source of sediment.



Figure 12. The disturbed upper Sololo-Moyale slopes. The flat parts are used for maize cultivation.



Figure 13. The upper slopes of Marsabit. Note the crater storing floodwater.

are covered by grass (see Figure 14). These areas are characterized by steeper slopes which may favour greater surface runoff and hence may experience greater sheetwash erosion. This is essentially a bushland zone whose vegetation characteristics have been mapped by IPAL (1979) and FAO (1971). They state that the dominant physiognomy is mixed *Acacia* wooded bushland on stony soils (see Figure 15) or *Acacia-Commiphora* bushland on deeper soils (except the dense mixed *Acacia* wooded bushlands in deep cracking clays in the Moyale area).

ECOLOGICAL ZONE VI

This is an extensive zone not only in the study area but also the whole of Marsabit District (see Figure 8). The typical vegetation is dwarf-shrub grassland, or a very dry form of bushed grassland. In the very dry areas it may be properly termed "bushed stoneland" (see Figures 7, 16 and 17). It includes all the foot hills and plains below 700 m (Figures 1 and 8). As was pointed out in the Marsabit Development Plan (1979-1983), the grazing season in these areas is extremely short, lasting not more than two months after the rains. When the rains fail, the area cannot be used by cattle but only by goats and camels (see Figure 18), if the dwarf shrubs are abundant. This area is often much trampled by livestock and this greatly reduces the infiltration capacity thus favouring greater surface runoff and hence enhancing greater sheetwash erosion. However, since most of this area is relatively flat more deposition takes place *in situ*.

The Chalbi Desert (see Figure 19) is an old lake bed without any vegetation (see Figure 20), but it acts not only as a deposition basin but a temporary lake storing water from Lag Balal, Didimtu, Balessa, Morgut, Halam, Falem and other streams (see Figure 21). The moisture index of this zone lies between -51 and -57.

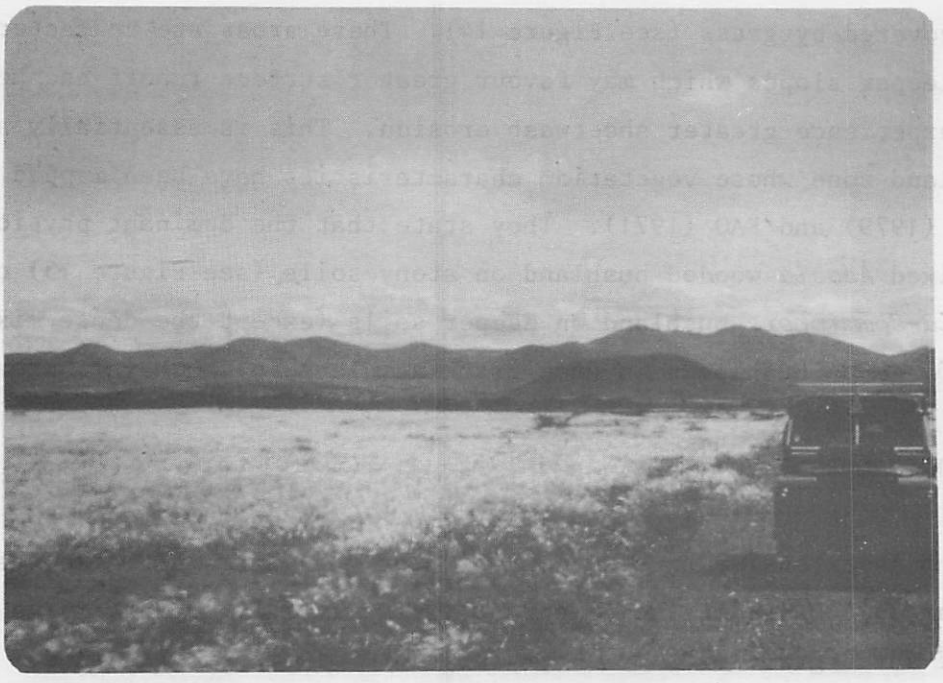


Figure 14. Grassland a few kilometres from Marsabit on the Marsabit-Moyale Road. The shallow volcanic soils can be seen with small boulders on flatter parts of this zone favouring dense grass cover.

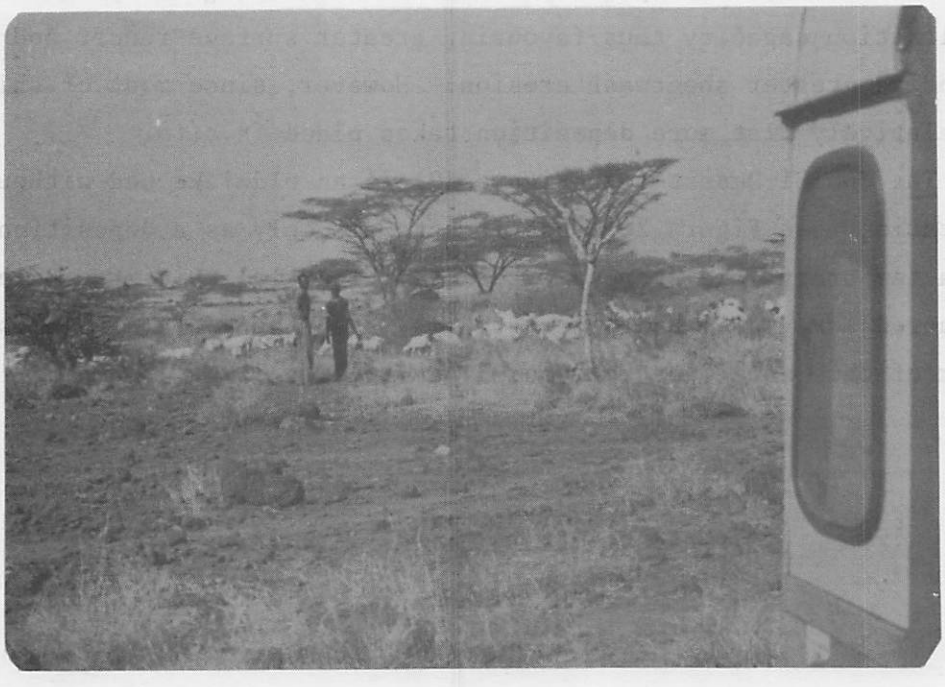


Figure 15. Open wooded grassland lying on Tertiary volcanics near the Morgut River gauging and sediment-monitoring station. Note a few outcrops.

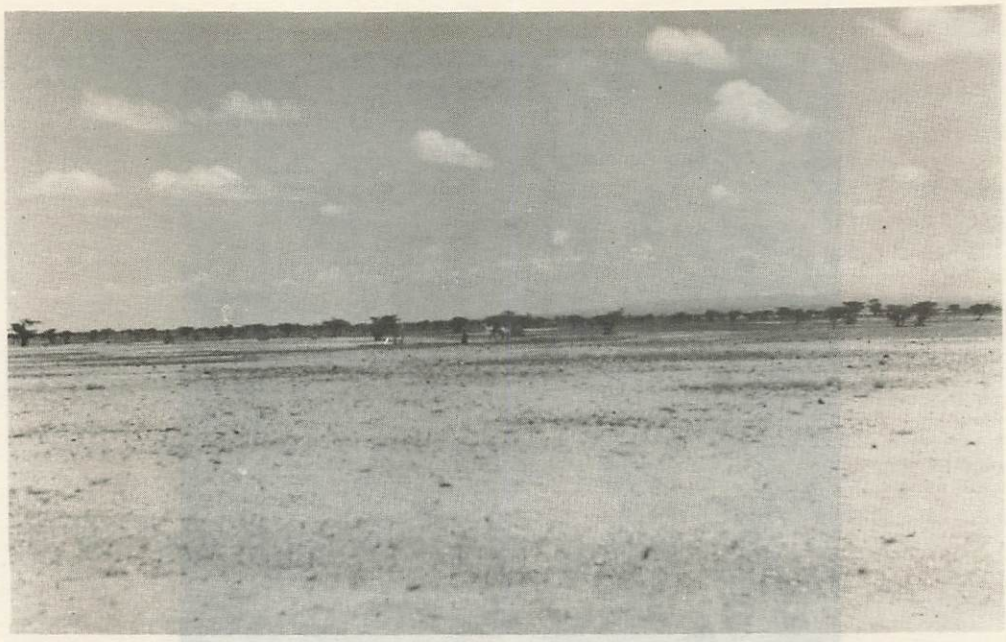


Figure 16. Bushed dwarf shrubland on volcanic formations between North Horr and Lag Balal.

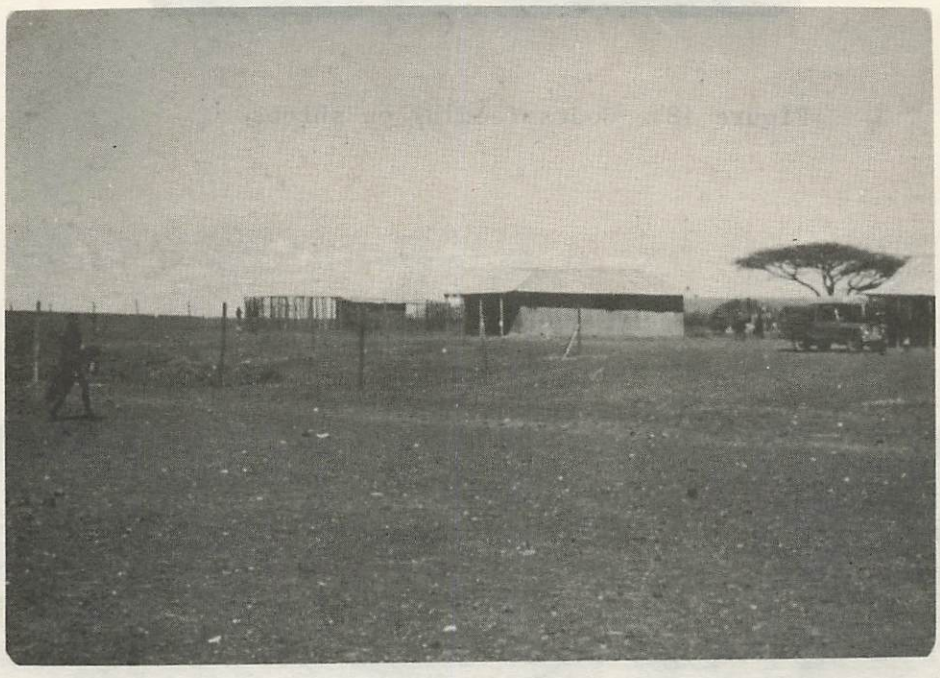


Figure 17. Bare ground at Kargi.

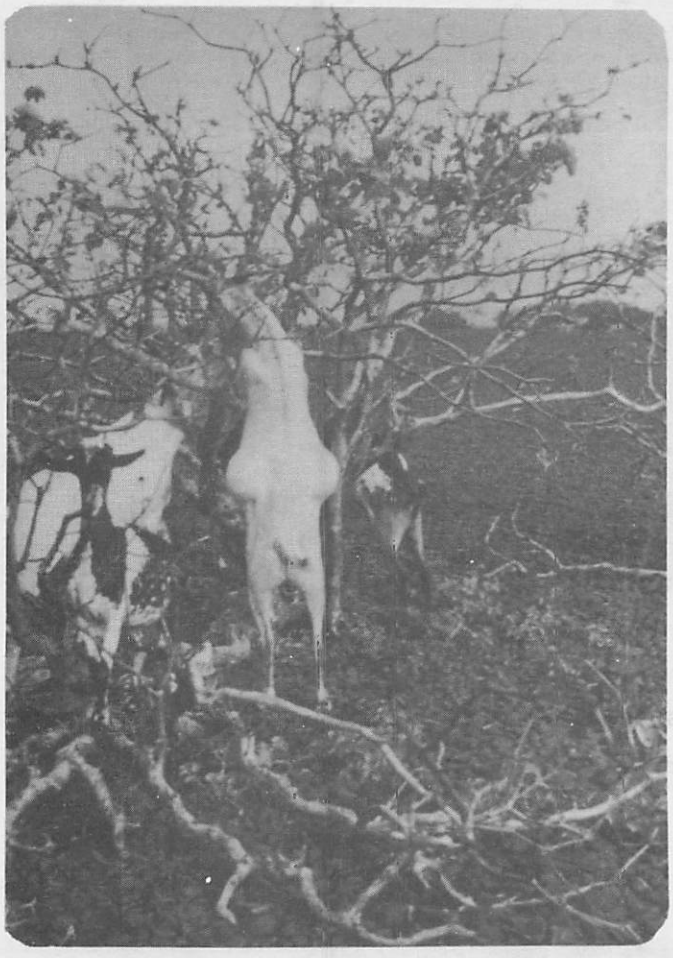


Figure 18. Goats feeding on shrubs.



Figure 19. The Chalbi Desert when completely dry.



Figure 20. In the vicinity of the Chalbi Desert the grass can grow during flood periods but dries quickly.

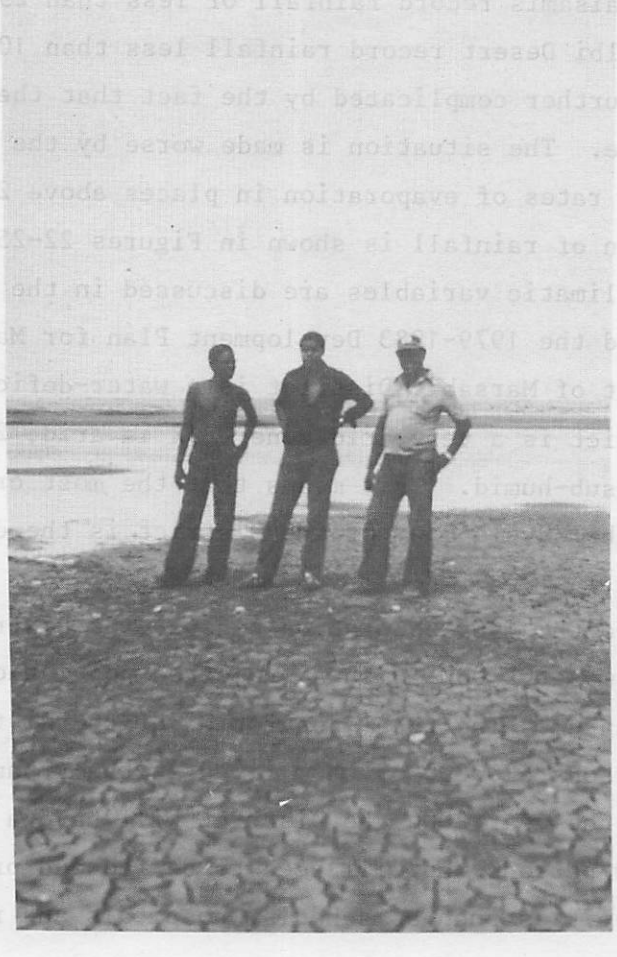


Figure 21. The flooded Chalbi Desert in the background.

Chapter III

PURPOSE AND SCOPE OF THE STUDY

INTRODUCTION

Kenya's surface area is some 584,000 km², of which about 113,000 km² is covered by water. Two-thirds of the total area is arid and semi-arid. This is an area of close on 390,000 km² of which about 25%, or close to 80,000 km² is taken up by Marsabit District. These areas are generally characterized by moisture deficiency and high rates of evaporation. Overall they receive less than 500 mm of rainfall in a year and the more arid parts receive much less than 250 mm of rainfall in a year.

A study of rainfall distribution within Marsabit District reveals that most areas receive less than 500 mm of rainfall, but the high areas such as Mount Kulal, with an altitude of over 2000 m, and Marsabit at an altitude of over 1836 m, receive an annual rainfall of about 800 mm, while Moyale receives about 700 mm of rainfall. The lower areas, such as Maikona and Laisamis record rainfall of less than 250 mm, while areas close to the Chalbi Desert record rainfall less than 100 mm. This variability is further complicated by the fact that the rainfall is highly unreliable. The situation is made worse by the fact that the area experiences high rates of evaporation in places above 2600 mm. The mean monthly variation of rainfall is shown in Figures 22-25 and in Table 1. This and other climatic variables are discussed in the IPAL Technical Report No. BI and the 1979-1983 Development Plan for Marsabit. In other words, most of Marsabit District is a water-deficient area, about 65% of the District is a very arid zone, 31% is arid, 2.5% is semi-arid and about 1% is sub-humid. This means that the most critical natural problem facing the development of the District is the deficiency of water.

According to the 1969 population census, the District has a population of almost 52,000, with a projected population growth rate of about 1.2% per annum. The total population of the district in 1979 was about 96,000 persons, 20,000 of whom lived in the urban areas (see Figure 26). By the year 2000 the District will have a population of close to 150,000 persons who will need to be fed and provided with other social amenities such as schools, hospitals and roads. In addition,

Figure 22. Average monthly rainfall for parts of Marsabit area for March-May 1977.

Source: IPAL

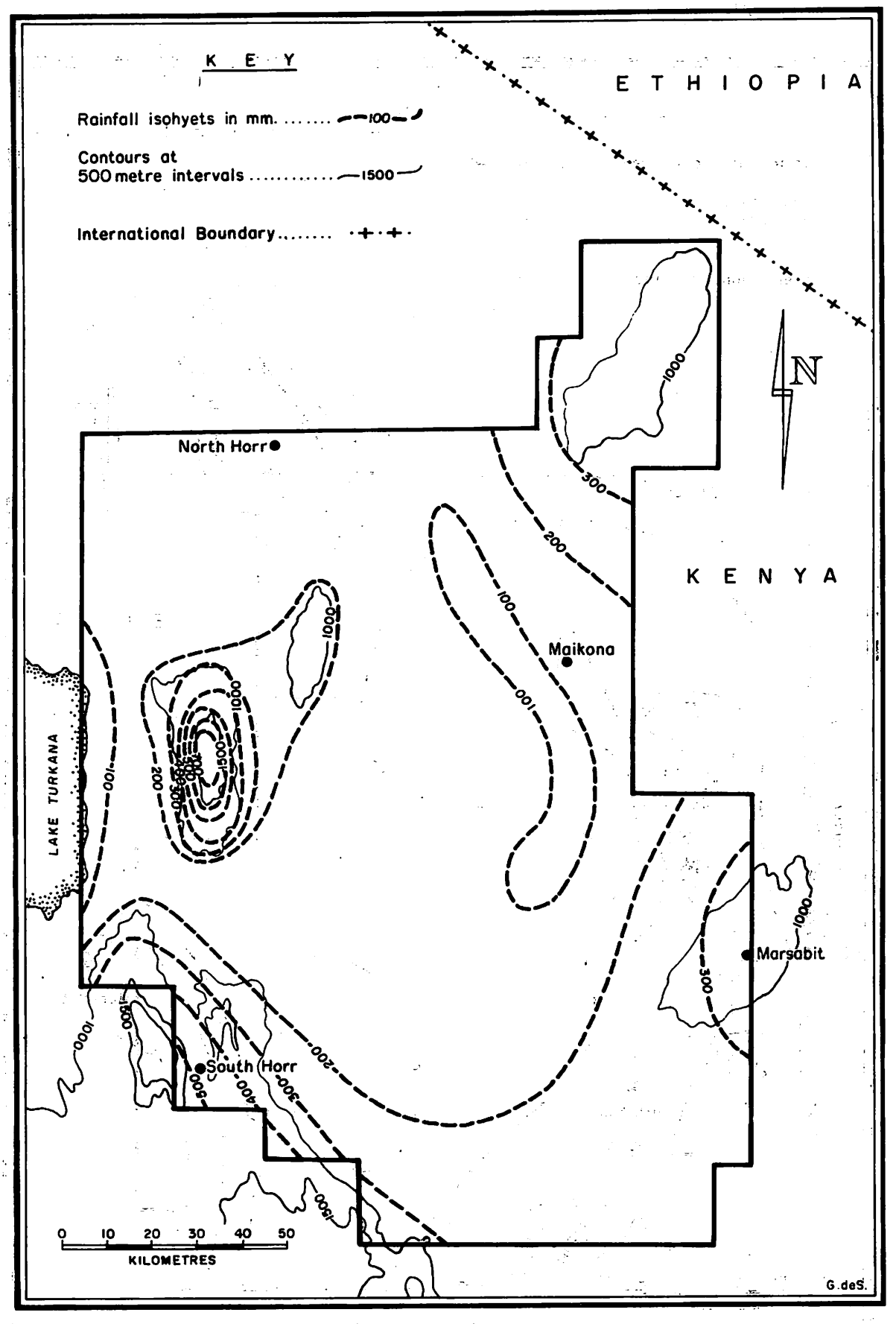


Figure 23. Average monthly rainfall of parts of Marsabit area for October-December 1977.

Source: IPAL

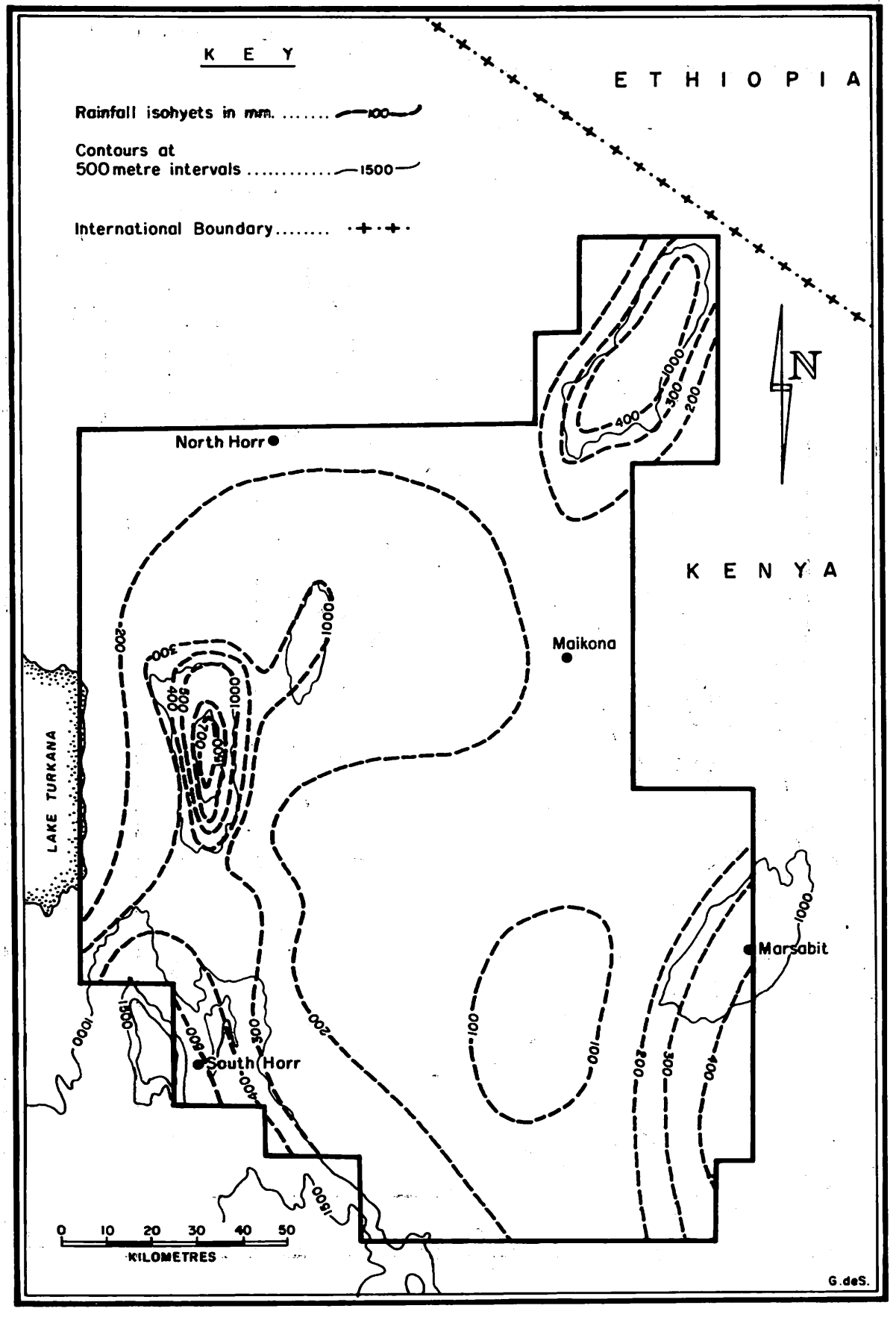


Figure 24. Average monthly rainfall for parts of Marsabit area for February-April 1978.

Source: IPAL

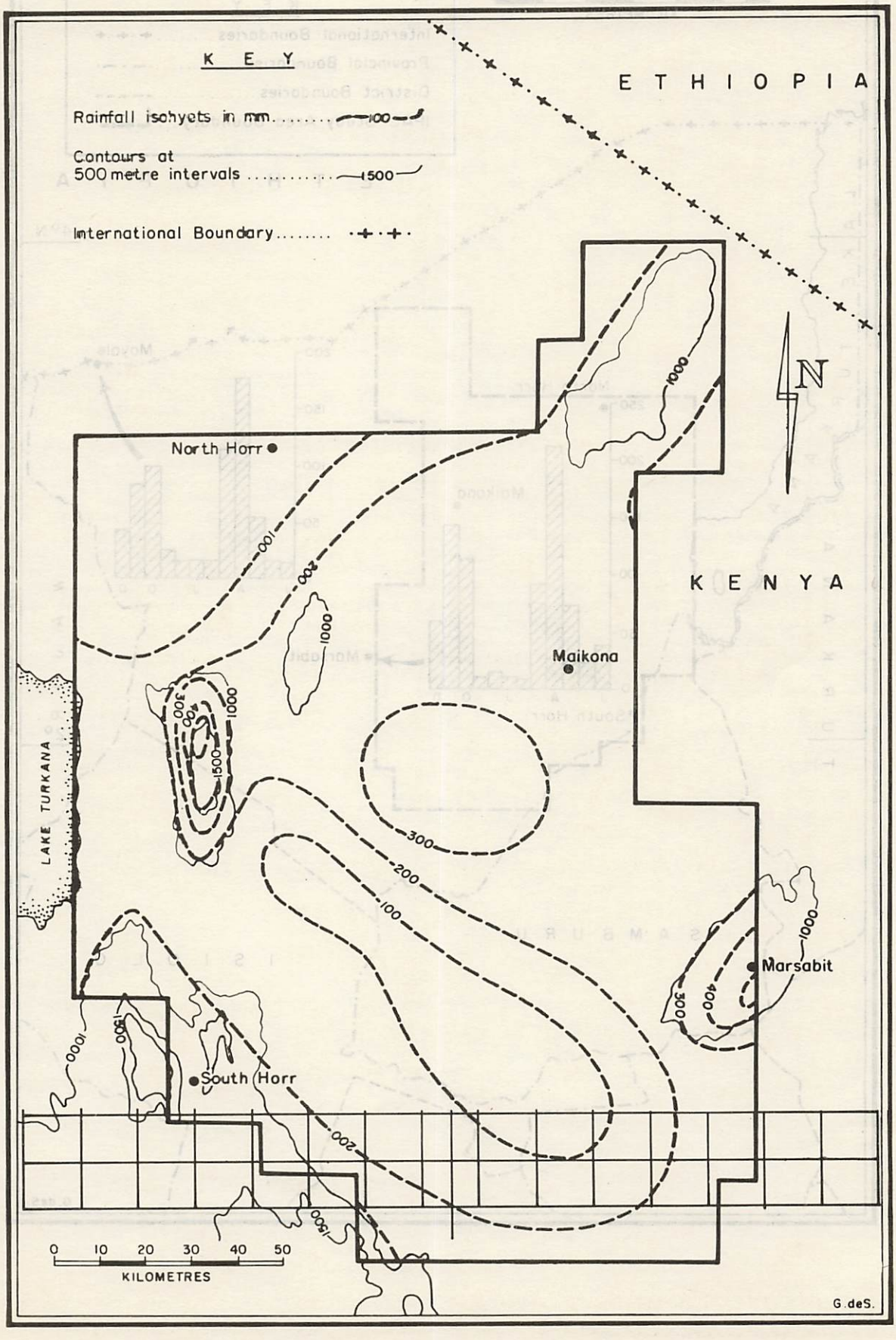
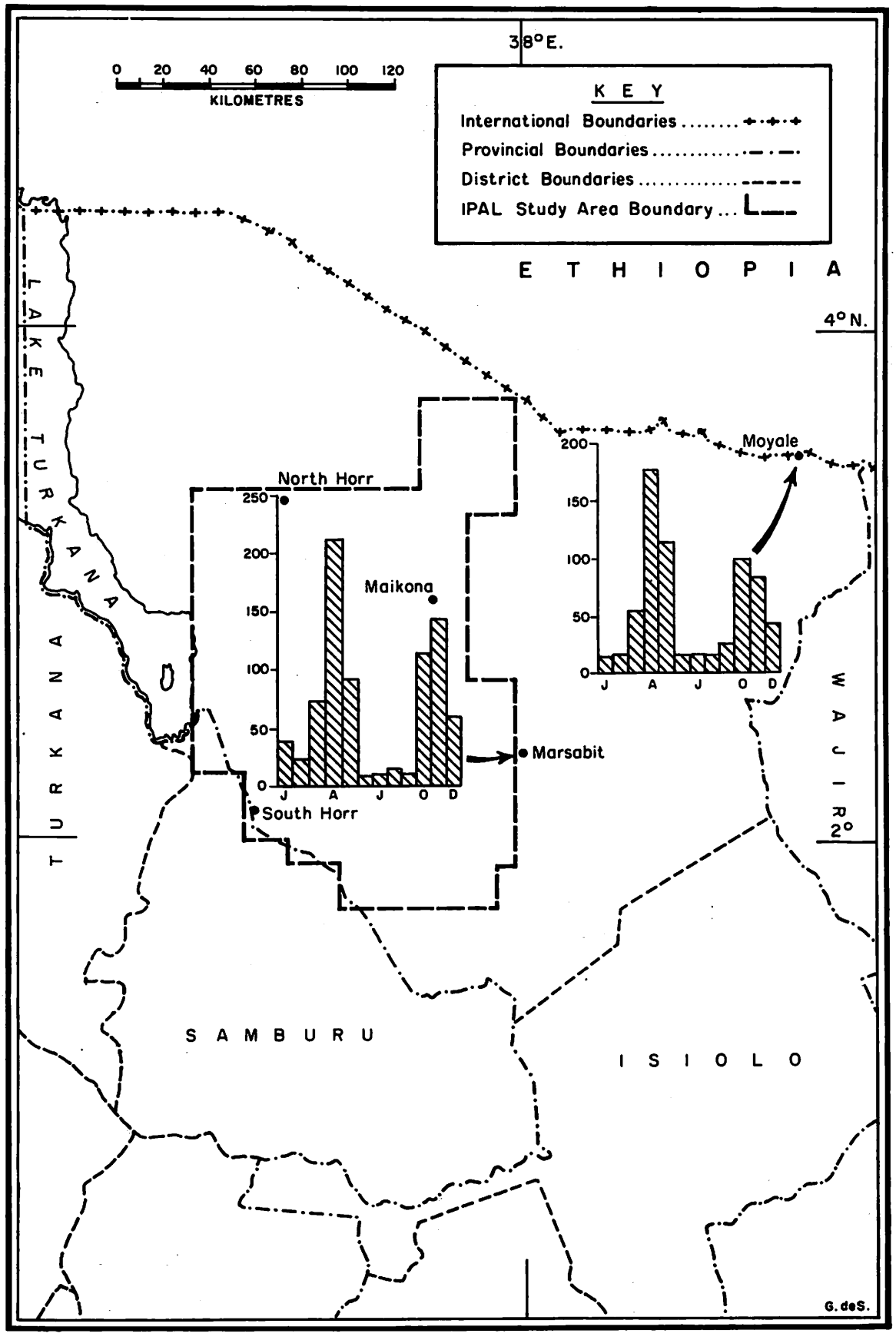


Figure 25. Month-to-month variation of rainfall for Moyale and Marsabit.



water and pasture will have to be found for close to 500,000 livestock. Also, water will have to be found for small-scale irrigation, industry, sewerage and other areas of multi-purpose development activities.

The above facts clearly show that no sound rehabilitation of the arid and semi-arid areas of the District can be achieved without finding ways of providing adequate and good-quality water supplies and improved pastures because these underly the pastoral pattern of settlement in the district.

The importance of water is clearly spelt out in the Marsabit District Development Plan 1979-1983 and it states, "Marsabit District is probably the driest district in the Republic. It has an average of less than 500 mm of rain per annum except in high altitude areas like Mt. Marsabit, Kulal and Moyale. Although the rainfall reliability in these areas is relatively high, we find that during the severe drought they are as hard hit as any other part of the district. The 1971-1973 drought is a good example when water shortage was at its maximum. This means that people and livestock in Marsabit rely on surface or ground water. However, due to the lack of hydrological study we have to rely on this field. No hydrological study of the district has been done and this makes it really very hard to know where to plan for horeholes and other water facilities".

Erosion rates in the arid and semi-arid parts of Kenya are already high enough to generate concern about the thinning of soil profiles (Figures 29 to 30), (Dunne, 1977, 1979; Dunne et al., 1978, 1979), the rate of sedimentation in reservoirs and dams (Figures 31 to 21), (Dunne and Ongweny, 1976; Ongweny, 1978), and the spoiling of coastal beaches (National Environmental Secretariat, 1972; Ongweny, 1981) and degradation of the arid and semi-arid lands (see Figures 33 to 34) (IPAL, 1981). The highest rates of soil loss occur in the most densely settled agricultural lands of Central and Eastern Provinces and in the wetter margins of the arid and semi-arid lands, some of which are periodically cleared, cultivated and grazed on a shifting basis. The surviving vegetation cover of forest, woodland, bush, and grass in these areas reduces the soil erosion rate to varying degrees. Rural roads are also a major source of sediment and can account for 5-20 per cent of total sediment yields of a basin (Ongweny, 1978) as illustrated in Figures 35 to 36.

Table 1. Rainfall summaries, 1980.

Gauge Square	J	F	M	A	M	J	J	A	S	O	N	D	Total	Comments
N. Horr	0.0	0.0	0.0	101.65	87.39	0.0	0.0	0.0	0.0	0.0	38.02	0.0	227.06	Daily gauge
Loiengalani	0.0	0.0	0.0	24.0	99.8	0.0	0.0	0.0	0.0	16.0	19.1	0.0	158.9	Daily gauge
Marsabit	12.6	2.5	3.5	102.1	137.6	0.0	10.7	28.9	2.0	10.8	44.9	2.5	358.1	Daily gauge
Logologo	23.9	0.0	0.0	42.0	48.7	0.0	0.0	0.0	0.0	2.3	53.9	1.0	171.8	Daily gauge
Gatab	6.1	1.8	4.3	150.6	86.7	0.0	0.0	0.2	0.0	16.4	86.4	16.6	369.1	Daily gauge
Kargi	0.0	0.0	12.2	30.5	56.6	0.0	0.0	0.0	0.0	7.7	30.2	0.0	137.2	Daily gauge
Balesa/Olturot	1.3	0.0	6.6	45.3	49.8	0.0	0.0	0.0	0.0	1.8	67.6	0.0	172.4	Daily gauge
El Kajarta	1.0	-	88.0	-	11.0	0.0	0.0	0.0	0.0	20.0	29.0	0.0	149.0	Monthly gauge
Falam	13.0	0.0	3.0	4.0	102.0	0.0	0.0	0.0	7.0	58.0	0.0	0.0	187.0	Monthly gauge
Kobatal	4.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	9.0	0.0	23.0	0.0	47.0	Monthly gauge
Kurkum	0.0	0.0	11.0	37.0	7.0	0.0	0.0	0.0	0.0	0.0	N.R	N.R	-	Monthly gauge
Luai	13.0	2.0	72.0		65.0	3.0	0.0	0.0	5.0	25.0	19.0	0.0	204.0	Monthly gauge
Maeri	8.0	0.0	0.0	90.0	156.0	0.0	0.0	0.0	0.0	9,0	74.0	0.0	337.0	Monthly gauge
Ngurunit	5.4	0.0	1.5	78.3	60.74	0.0	0.0	2.3	0.0	0.0	72.0	0.0	220.24	Daily gauge
Nine Km	0.0	0.0	0.0	100.0	0.0	0.0	18.0	9.0	1.0	2.0	52.0	5.0	187.0	Monthly gauge
Maikona	3.3	0.0	3.5	2.5	23.3	0.0	0.0	3.8	0.0	0.0	16.3	0.0	52.7	Daily gauge
Reserve boundary	0.0	0.0	0.0	56.0	41.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	98.0	Monthly gauge
South Horr	4.8	0.0	0.0	95.1	120.5	0.0	0.0	0.0	0.0	0.4	208.2	0.0	429.0	Daily gauge
Kalacha	2.8	0.0	0.1	8.6	44.0	0.0	0.0	0.0	0.0	0.8	0.8	6.7	63.8	Daily gauge
Arabel	34.0	0.0	0.0	125.0	128.0	7.0	0.0	21.0	0.0	18.0	11.0	0.0	344.0	Monthly gauge
Gus	0.0	0.0	0.0	185.0	0.0	0.0	0.0	4.0	0.0	N.R	N.R	N.R	-	Monthly gauge

Table 1. (contd)

Gauge	Square	J	F	M	A	M	J	J	A	S	O	N	D	Total	Comments
Junction		6.0	0.0	31.0		31.0	0.0	5.0	0.0	6.0	0.0	36.0	0.0	115.0	Monthly gauge
Korr		19.0	0.0	0.0	0.0	27.0	0.0	0.0	4.0	0.0	0.0	18.9	0.0	68.9	Daily gauge
Longipi		0.0	1.0	161.0		9.0	2.0	0.0	0.0	0.0	15.0	10.0	0.0	198.0	Monthly gauge
Ol Donyo Mara		1.0	0.0	6.0	15.0	23.0	0.0	3.0	0.0	1.0	3.0	0.0	0.0	52.0	Monthly gauge
Sirima		3.0	15.0	110.0		25.0	0.0	0.0	14.0	0.0	6.0	9.0	0.0	182.0	Monthly gauge
Sirimano		9.0	0.0	0.0	22.0	77.0	0.0	3.0	0.0	11.0	8.0	20.0	0.0	150.0	Monthly gauge
Tirrkeidahr		0.0	0.0	106.0		28.0	0.0	0.0	0.0	10.0	0.0	5.0		149.0	Monthly gauge
Ilim		3.0	2.0	0.0	0.0	123.0	0.0	0.0	3.0	5.0	22.0	18.0		176.0	Monthly gauge
Ilaut		0.0	0.0	0.0	47.8	116.5	0.0	0.0	0.0	0.0	0.0	53.7	0.0	218.0	Monthly gauge
Ndigiripus		12.0	0.0	0.0	14.0	28.0	0.0	0.0	6.0	1.0	0.0	14.0	0.0	75.0	Monthly gauge
El Dere		0.0	0.0	0.0	39.0		0.0	0.0	0.0	0.0	5.0	N.R	N.R	-	Monthly gauge
Namarei		0.0	0.0	1.6	21.4	18.0	0.0	0.0	0.0	18.0	10.0	0.0	0.0	69.0	Monthly gauge

N.R. = No Record.

Source: IPAL

Figure 26. Kenya population distribution, 1979.

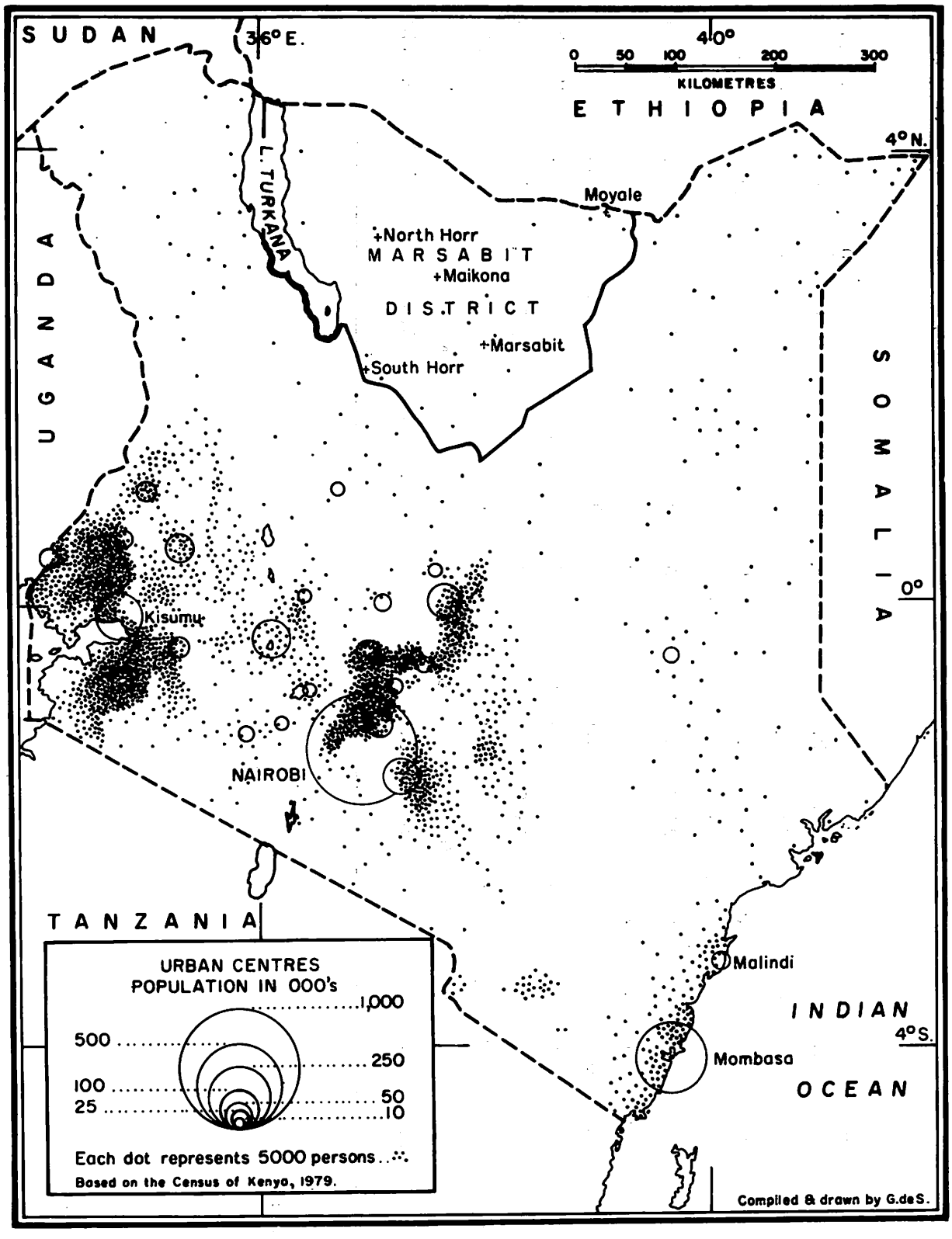




Figure 27. Thin soil cover in Kargi due to degradation.



Figure 28. Eroded hill slope 4 km from Marsabit on the Marsabit-Moyale Road.



Figure 29. The polluted unprotected Horo Boha dam near Marsabit township. Trampling by livestock is apparent.



Figure 30. The badly polluted Goff Jirime dam near Marsabit.



Figure 31. Arbadana dam completely silted up with about 15,000 m^3 of sediment.



Figure 32. Arbagaza dam is completely unserviceable because of high rates of sedimentation.



Figure 33. Gully erosion in the lower slopes of Mt. Kulal.

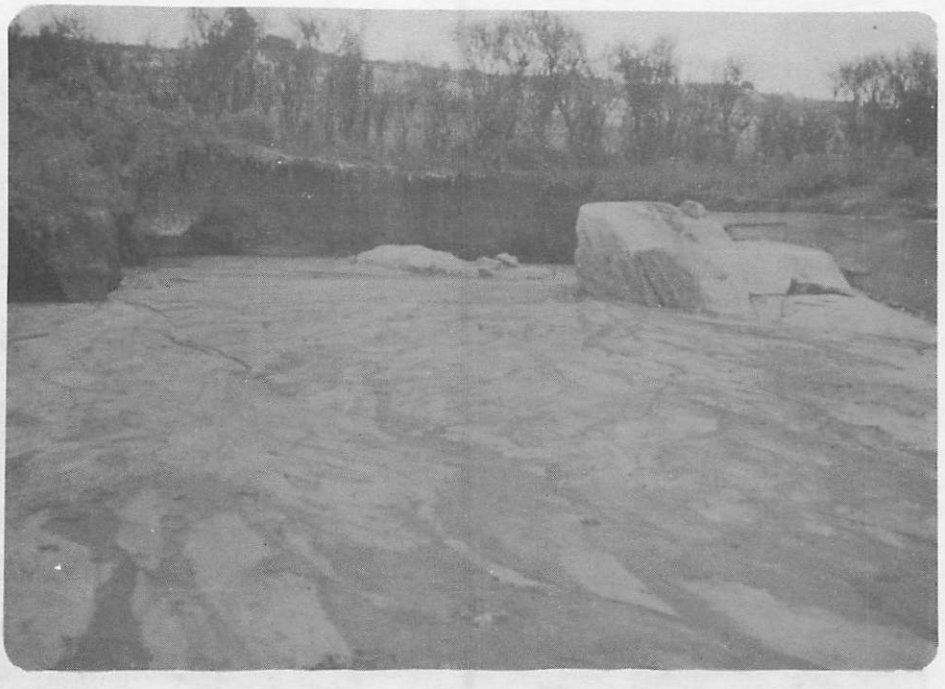


Figure 34. River erosion by Laga Sera (note the high concentration of sediment in the stream).

As the demand for pasture, food, fuelwood and charcoal grows, forest, woodland and bush are removed, and this trend is likely to accelerate dramatically before the end of the century. As IPAL (1981) points out 'Three-quarters of Kenya's land is arid and semi-arid, and supports over one-quarter of its population, including ten major ethnic groups who are solely nomadic pastoralists. Modern influences on these groups have resulted in the increase in both human and livestock populations and increased sedentarization. Resulting pressure has deteriorated the productivity of the land through overgrazing which, combined with the effect of droughts, has led to the need for famine relief'.

FACTORS AFFECTING EROSION

The major controls of erosion have been studied under both experimental and uncontrolled conditions in laboratories and the field for more than half a century. It is generally acknowledged that the following controlling factors are important:

Rainfall intensity and kinetic energy

Rainfall intensity determines the amount of storm runoff generated on a particular soil and vegetation cover, and therefore the amount of water available for transporting soil to and along river channels. Intensity is also correlated with the kinetic energy of rainfall, which depends on the mass and fall velocity of rain drops. A rain drop falling on bare ground generates a splash which disperses and mobilizes soil, allowing it to be transported downslope by storm runoff. The size of the splash and the amount of soil moved are largely determined by the kinetic energy of the rain drop. Thus, the kinetic energy of rainstorms during a year has been shown to be highly correlated with the annual soil erosion rate (Smith and Wischmeier, 1978; Elwell and Stockin, 1975).

Soil characterisitcs

The infiltration capacity of a soil determines the amount of erosive runoff for a particular rainfall intensity. The erodibility of the soil expresses its resistance to dispersion and splashing by raindrops and to



Figure 35. Eroded road (a major source of sediment) near Logologo.

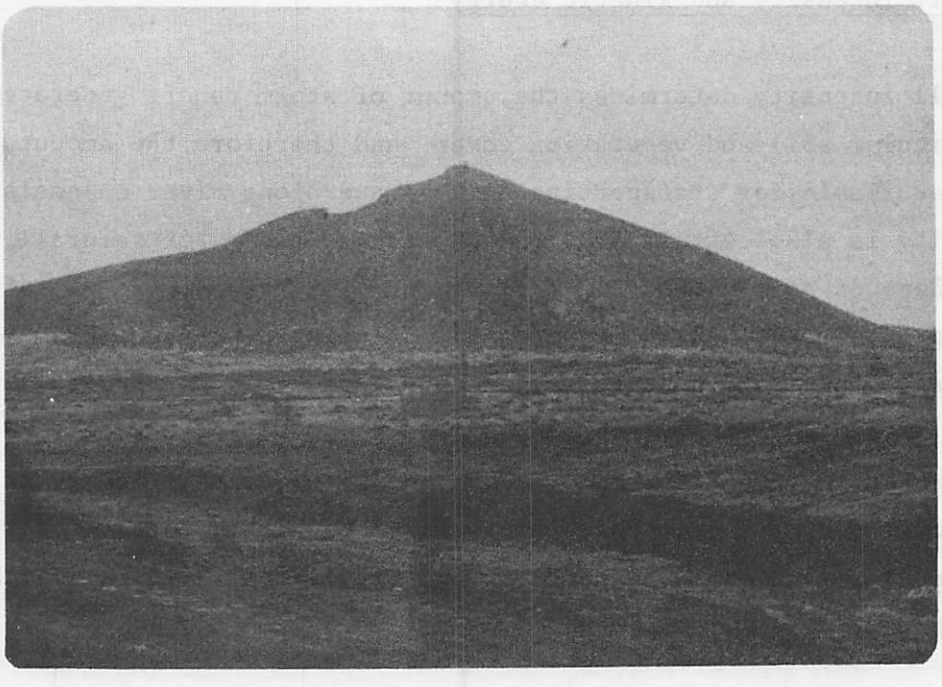


Figure 36. Unprotected Marsabit-Moyale road bank (4 km from Marsabit) is a major source of sediment.

shearing by surface runoff. Both infiltration and erodibility have been correlated with a bewildering array of soil characteristics, but the dominant variables are the texture, structure, and organic content of the surface layer.

Hill-slope gradient

The local gradient of the soil surface affects the velocity of runoff and the shearing force which it can apply towards mobilizing and transporting soil.

Vegetation cover

Vegetation cover and associated litter intercept rainfall kinetic energy and thereby decrease the mobilization of soil particles. Organic litter and shade stimulate micro-faunal activity in the soil, improving soil aggregation and infiltration. It is generally agreed that soil erosion is extremely sensitive to the type and density of vegetation cover.

Land use practices

Land use is commonly associated with radical alteration of the vegetation cover, often resulting in an increased erosion rate. On the other hand, soil-conservation practices such as terracing, bounding, crop-residue management, scarification of the soil after removal of woodlands or bush, and the decision to harvest fuelwood in strips along the contour may decrease soil loss. Another set of land use effects is associated with the extension, intensity of use, and maintenance of rural roads, which appear to be major sediment sources in some parts of Kenya (Dunne, 1979; Ongweny, 1981).

Because of the short duration of this consultancy, it was not possible to use the most obvious and reliable means of assessing soil erosion, namely direct monitoring over many years. Instead, sediment monitoring at particular sites forming outlets of given drainage areas was used. Results of earlier investigations of the effect of land use and other variables on the sediment yields from river drainage basins

in Kenya (Dunne, 1979; Ongweny, 1978) were used to assess the reasonableness of the foregoing computations.

It is on the basis of the facts outlined above that the Man and Biosphere (MAB) programmes and the Integrated Project in Arid Lands (IPAL) started operating in certain areas of the District with the aim of finding direct solutions to the most urgent environmental problems associated with desert encroachment and ecological degradation of arid lands. On this basis, then, the present study has the following aims and objectives.

AIMS AND OBJECTIVES

1. Definition of the rates of sediment production for various catchment areas within the IPAL study area in Marsabit District and in adjacent areas.
2. Relating rates of sediment production to the major controlling variables, most of which are factors of land use.
3. Investigation of the sources of sediment with different land use types as a means of emphasizing the most important problems requiring remedial action.
4. Evaluation of the surface-water resources of the area and methodology for harnessing and conserving such surface water.
5. Examination of the chemical and bacteriological characteristics of water in order to define the hydrologic, geomorphological and human processes governing the quantity and quality of the water.
6. Consideration of the most appropriate and useful techniques for soil and water conservation in the given catchments of the IPAL study area.

SUMMARY OF RESULTS

The present investigations have yielded valuable information in the following areas:

1. The pattern of sediment production in given catchments has been documented in a preliminary manner. This has never been done in these catchments or in any other catchments in the arid regions of Kenya.
2. Computation of sediment transport in streams within the given catchments.

3. Definition of the order of magnitude of sediment production for different land use types.
4. Determination of surface-water resources in streams and small-scale dams.
5. Determination of the chemical and bacteriological characteristics of the surface-water resources of the given catchments of the Marsabit IPAL study area.
6. Recommendations for the conservation of soil and water resources and in particular the harnessing of the surface-water resources for multipurpose uses.
7. Recommendation of areas for further investigations and research.

PAST STUDIES OF EROSION AND SURFACE-WATER HYDROLOGY IN MARSABIT DISTRICT

In 1971 the United Nations Development Programme, in collaboration with the Food and Agriculture Organization of the United Nations, carried out rangeland surveys as part of range development in Marsabit District. This included general discussions about the water resources of some parts of Marsabit District, with particular emphasis on ground-water resources. These findings as related to the terms of the present study include:

1. Within the Marsabit South unit the Malgis River may carry water of the order of 30,000 m^3.
2. In Kulal unit springs were estimated to have flows of between 6 and 60 litres per minute. The springs showed yields of 156-180 litres per minute. It was not possible to estimate the Balessa waters.
3. In the Hurri Hills unit ground water would be struck at deep depths. However, they concluded that within this unit individual water supplies are found at the western base of the Turbi Hill where runoff and shallow seepage from the hill catchments collects in a pool about 1 m deep. They have not given any quantitative statement about the amount of water.
4. In the Sololo-Moyale unit there are 13 structures, the most successful capturing flood flow within the Sololo Valley. They estimated that the total maximum combined volume that these structures could store was about 230,000 m^3. They also noted that the most significant of the natural water occurrences were contained in the valley leading to Arba Johan. However it was difficult to give a quantitative estimate of this water.

5. In the Marsabit North unit the borehole yields are lower and rest levels are of the order of 65 m from the surface. However, down on the lower slopes and lava plains, the yields were shown to be greater; but the last levels declined remarkably up to 230 m.

The following surface-water estimates were given:

Ref. No. (see Fig. 97)	Surface water	Capacity (m^3)
	MARSABIT UNIT	
41	Karate Dam	85,500
49	Getu Nyencha (small well)	2,500
53	Gudus North (tank site)	11,400
54	Gudus South (tank site)	11,400
56	South of Mado Kelo (tank site)	11,400
57	Malgis River	45,000
58	Bule tank	11,400
59	Ntalarwa tank	11,400
60	Dabesamoga tank on L. Siriwa	11,400
72	Kaisut SE (tank site)	11,400
73	Kaisut SW (tank site)	13,700
90	Halisiruwa (tank site)	11,400
91	NW 90 tank site	11,400
92	NW 91 tank site	11,400
	Total	186,000
	KULEL TANK	
123	Tank site SW of Kalama	5,100
124	Tank site at Kalama	3,700
125	Tank site NE Hedad	4,100
126	Tank site SW Korgi	400
127	Falam Pan	13,700
	Total	48,000 m^2

Ref. No.	Surface water	Capacity (m^3)
	HURRI HILLS UNIT	
150	Afgab rock pool	20,000
153	Tank site SE	5,100
154	Tank site of Sele	11,400
156	Tank site in another drainage area just west of the road	5,100
157	Tank site at Tehaha	3,000
158	Tank site at Tehaha (breached dam)	4,000
160	Maika Sororo	1,200
168	Tank site at Nurumun	5,100
	Total	53,900
	MOYALE-SOLOLO UNIT	
205	Tank site in main (eastern) Sololo Valley	21,200
209	Tank site at Rusel	7,900
211	Tank site at Adedi	4,100
214	Tank site at Kukubar	32,000
216	Tank site at Laga Walmur	13,700
237	Tank site at Dololo Chake	3,100
239	Tank site at Dololo Dikicha	11,400
240	Tank site at Laga Didachi	79,000
241	Tank site at Kumbe Boria	79,000
244	Tank site at Diribsoi	13,700
245	Tank site at Laga Titu	25,000
252	Tank site Laga Afgudud	11,400
255	Tank site Laga Walde	7,900
256	Tank site Turbi West	5,100
257	Tank site Turbi East	5,100
	Total	177,400

Ref. No.	Surface water	Capacity (m^3)
	MARSABIT NORTH UNIT	
10	Tank site Laga Sangar	11,400
16	Tank site Joldesa	7,900
18	Tank site Mado Kelo	32,000
19	Tank site Bule Tetesa	7,900
20	Tank site Tamsa	11,400
21	Tank site Baji	11,400
		82,000
7	Ulamule well	4,000
9	Kile well	4,000
		8,000
1	Badesa spring	4,000

This makes a total of 627,300 m^3, say 600,000 m^3,surface-water capacity.

Shackleton (1946), investigating the geology of the country between Nanyuki and Maralal, noted that within the basement system rocks, the surface storage of water by dams is usually in deeper valleys where the rock is scoured clean and small dams can profitably be constructed. He notes further that borehole statistics in the Basement system show about 70% success. He shows that the Miocene sediments could prove to be an important source of water as they include porous grits and diatomites. On the other hand the Samburu basalt and tuffs are not good sources of water. He further indicates that several springs emerge from Rumuruti phonolites. He concludes that Losiolo and Thomson Falls phonolites, the Laikipia series of basalts, Mount Kenya volcanic suite and Pleistocene tuffs could yield an average amount of water.

Randel (1970), mapping the geology of the Laisamis area, noted that the only flowing water in the area occurs at Laisamis due to the pressure of Basement-system rocks which form a natural sub-surface dam across the river. He continues to indicate that quantities of water can be

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held by the sand of river beds throughout the year where the sand cover above the metamorphic rocks is sufficiently thick for it to become sub-surface water again. He shows that at Laisamis the water flows on the surface for about 150 days and the amount is sufficient to serve the needs of the people and their animals. He further notes that elsewhere in the area water can be obtained by digging in some of the sand rivers. He finally noted two boreholes which had been drilled at Lokulolo and Halisiruriva and shows that at Halisiruriva a large shallow lake forms after rains and water is available there for short periods. One of the boreholes had a depth of 280 feet, water having been struck at 229 feet, a water rest level of 218 feet, and estimated yields of 1750 gallons per hour.

Rix (1973), examining the geology of the Kauro-Merille area, shows that the region is relatively well endowed with water supplies compared with areas further north and north-west, where semi-deserts of lava and sand occur. He continues to show that water is held in the sandy beds of the Kauro and Merille systems and that there are a number of points along the lagas where the supply is permanent although the level drops considerably in the dry season. He shows that these permanent watering points include Kauro and Sereolipi where trading centres have been established, and Kinya, Lankaya, Kapai and Sera, all of which are in the southern part of the region. These watering points are in Samburu country and are used for watering cattle, sheep and goats. The permanent watering places in the north are along the Merille-Lodosoit drainage system. He concludes that Merille is very important as a watering place for camels owned by the Rendille who inhabit the region to the north of this river. He points out clearly that the source of sub-surface water is more obvious in the case of the Merille Laga than in the case of the Kauro system. The former drains the slopes of the Mathews Range.

Dodson (1963), carrying out geological work in the South Horr area, and Walsh (1972), noted that none of the rivers in the Moyale area contain water for more than a few weeks. He, however, showed that permanent water, usually in small amounts in the dry season, is available in hand-dug wells and further points out that around the foot of many of the hills are small wells dug in the sand or grit, some of which give a trickle of water throughout the dry season. This is normally reserved

for human consumption. They noted that Howard Humphreys and Sons (1958) Consulting Engineers built eight shallow water tanks with a total capacity of 37.5 million gallons of water.

Chapter IV

FIELD AND LABORATORY ANALYSIS OF DATA

FIELD MEASUREMENTS

Stream gauging

The selection of gauging sites was of necessity dictated by the needs of the project, which were essentially to take into account the geologic, topographic, climatic, land use and other hydrological characteristics of parts of the Marsabit District and more particularly that area within the IPAL study area. After a reconnaissance survey of the area, and taking into account all the parameters mentioned above, including the time, technical and financial aspects, and after evaluating the factors necessary in establishing a gauging site (Carter and Davidian, 1968) stations for river gauging and sediment sampling were established (see Figures 37 and 38).

River gauging and sediment monitoring were carried out on a daily basis, but because of the highly seasonal flows, and the distances involved, not all the stations could be reached during the same day (see Figure 39).

The objective of establishing river-gauging stations was to obtain a regular record of the stage and discharge of the given site in order to develop a discharge-rating curve for each station (Corbett, 1943; Gregory and Walling, 1973) within the respective basins (see Figures 40 to 45).

The stage of a stream is the height of water surface above an established plane, and in this particular study use was made of non-recording staff gauges (see Figures 46 to 48) established at suitable sites of the respective river gauging and sediment-monitoring station. The non-recording gauges are cheap to install but they suffer from the disadvantages of having an observer taking regular readings and from the consequent lack of accuracy of the continuous stage graph that must be sketched through the points of observation. For long-term operations, the advantages of the recording gauge far outweigh those of the non-recording gauge, but for purposes of the present investigations the latter proved adequate.



Figure 37. Installation of a staff gauge on Bakuri River in Marsabit Forest Reserve.



Figure 38. Installation of the staff gauge on Morgut River (note the heavy concrete used in order to stabilize the staff).

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Figure 39. Stuck a few kilometres from Halam River due to floods.

Figure 40. A Preliminary Discharge-Rating Curve for the Merille River.

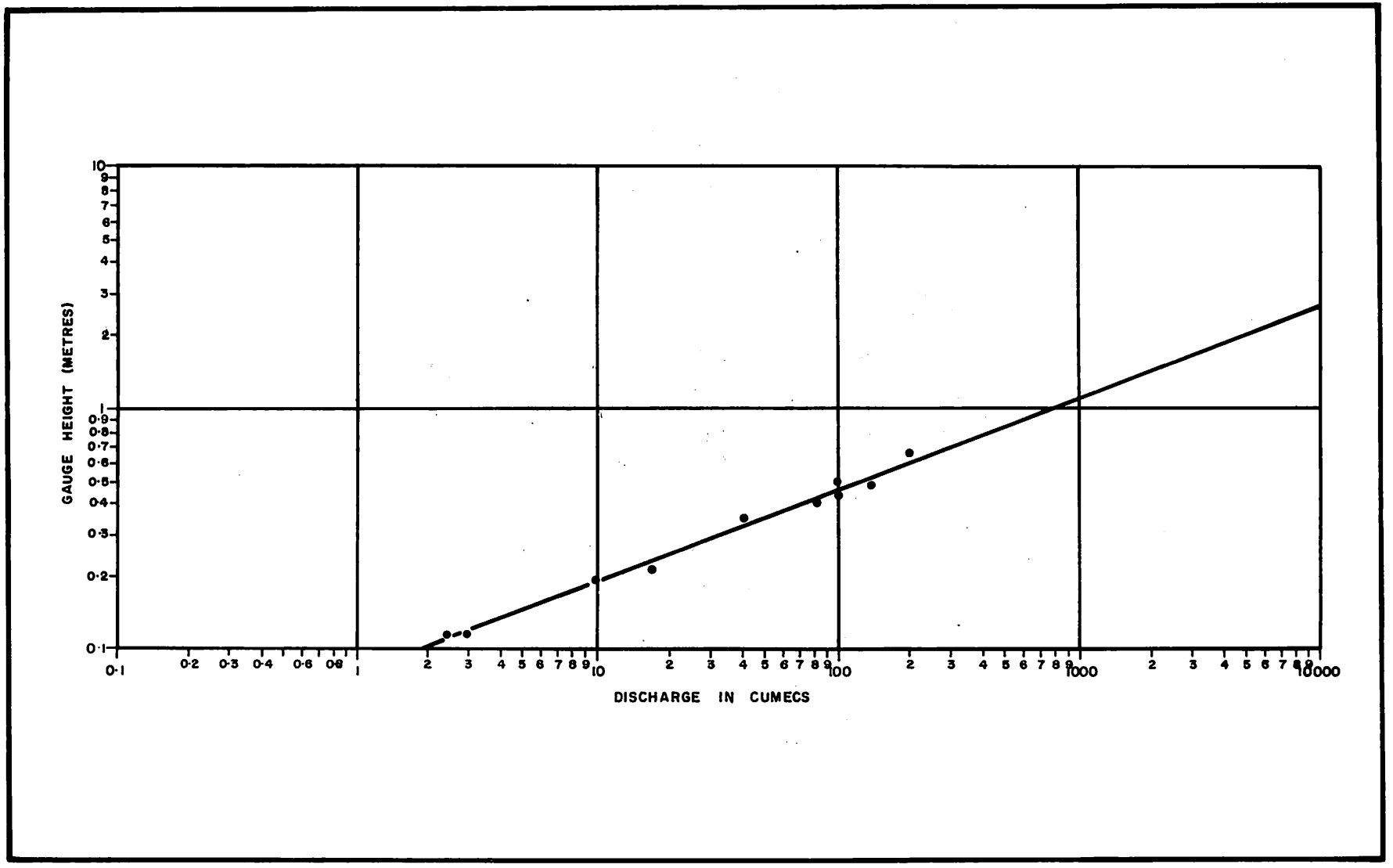


Figure 41. A Preliminary Discharge-Rating Curve for the Malgis River.

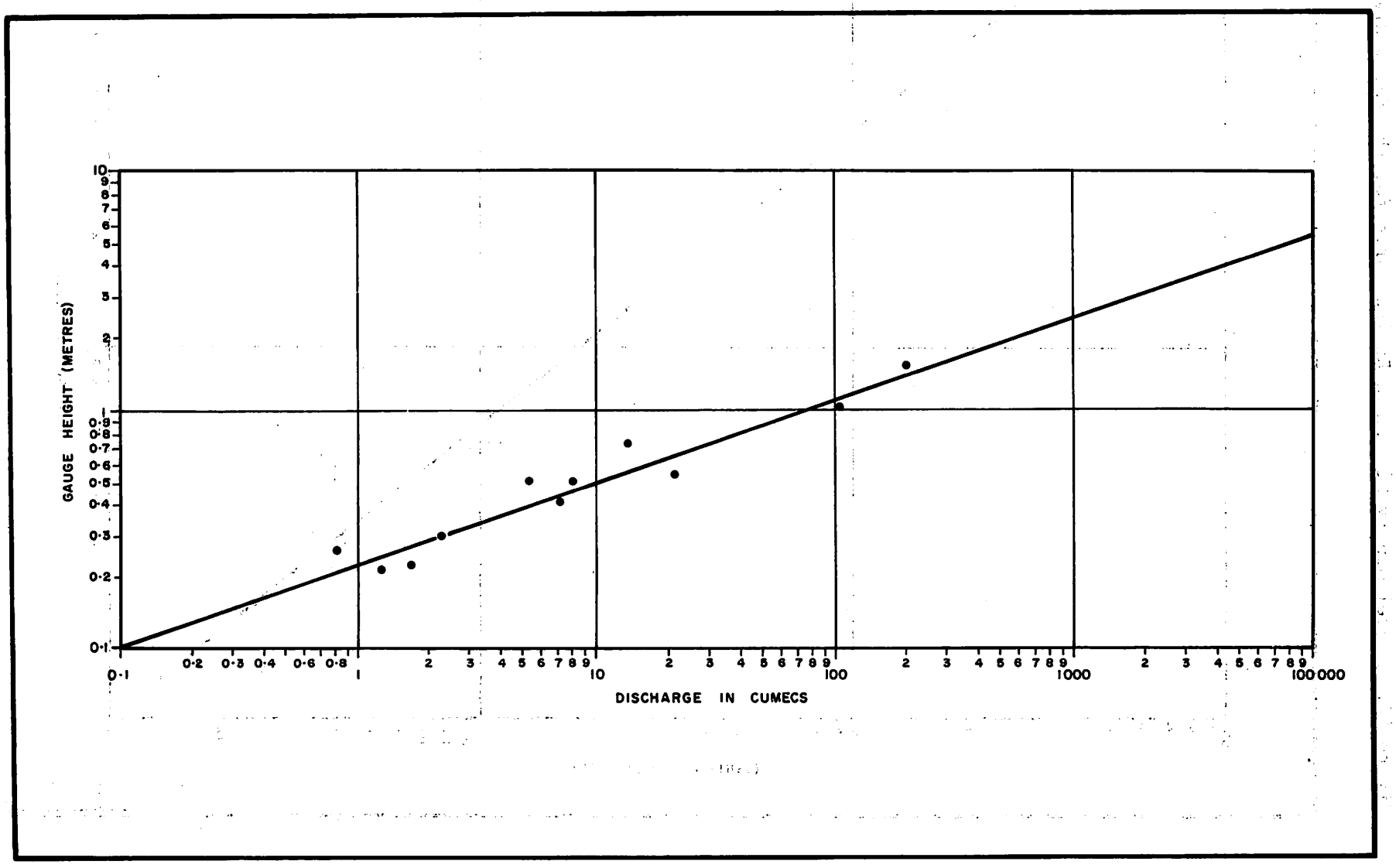


Figure 42. A Preliminary Discharge-Rating Curve for the Halam River.

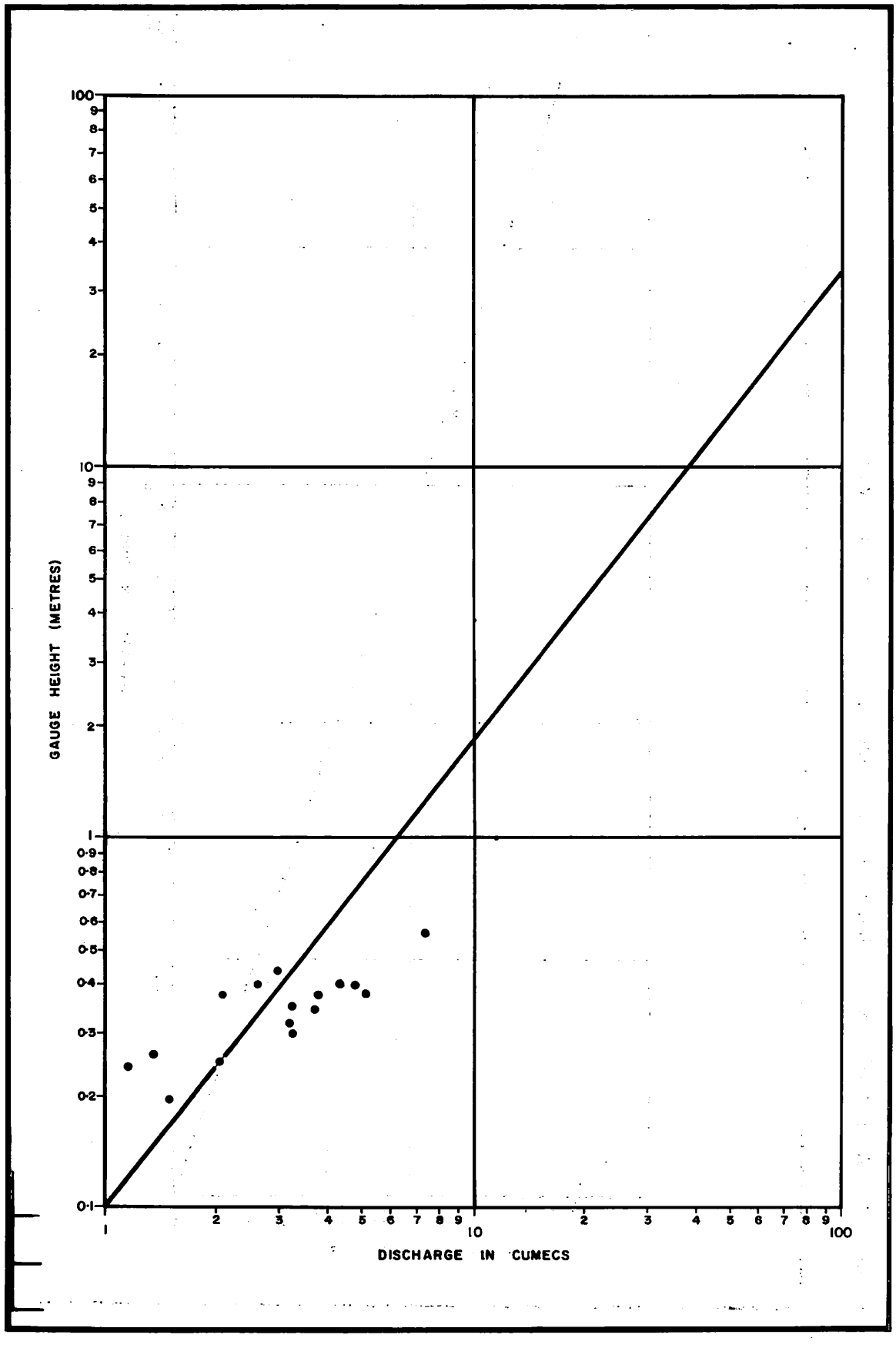


Figure 43. A Preliminary Discharge-Rating Curve for the Morgut River.

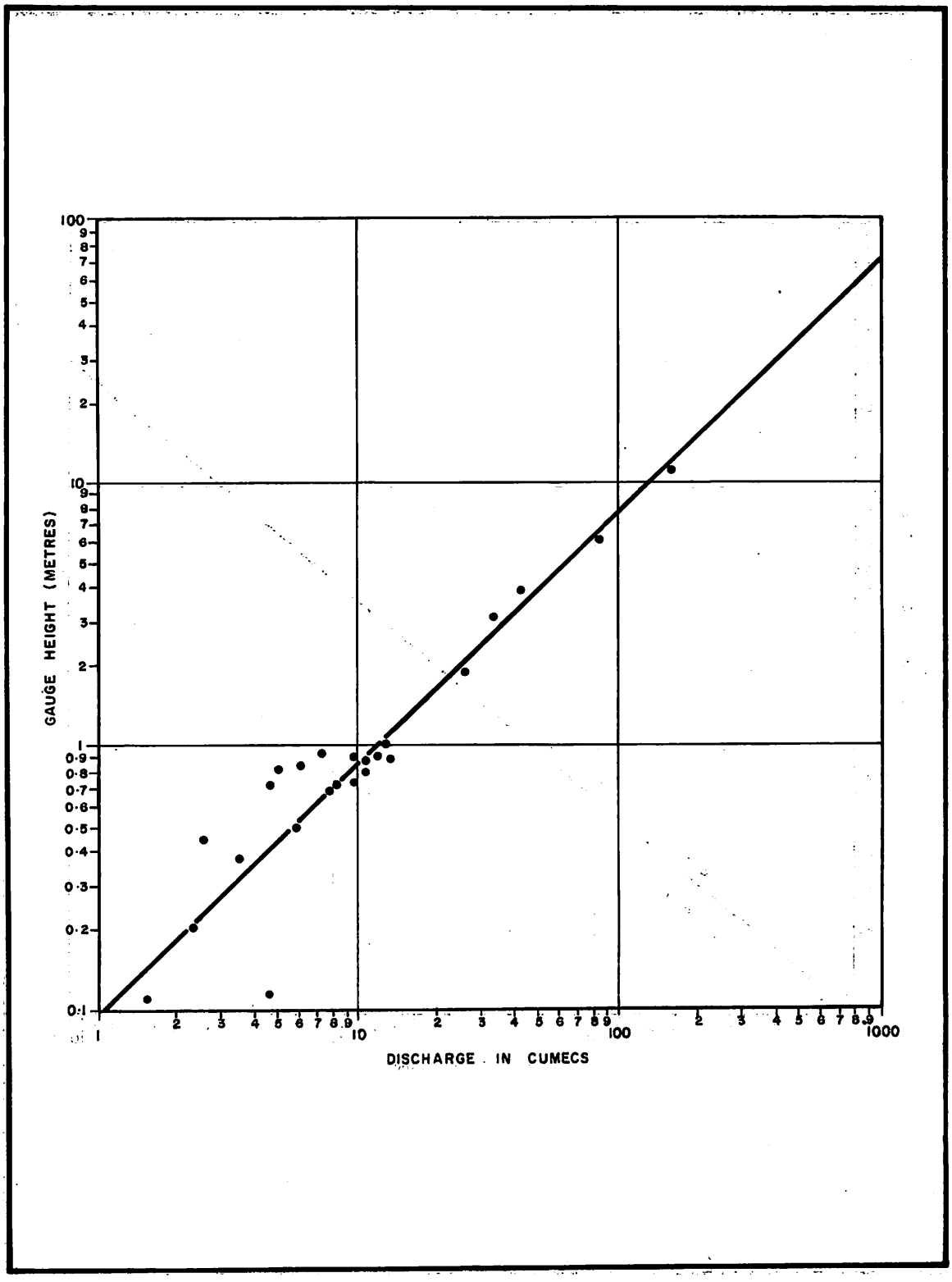


Figure 44. A Preliminary Discharge-Rating Curve for the Ngurunit River

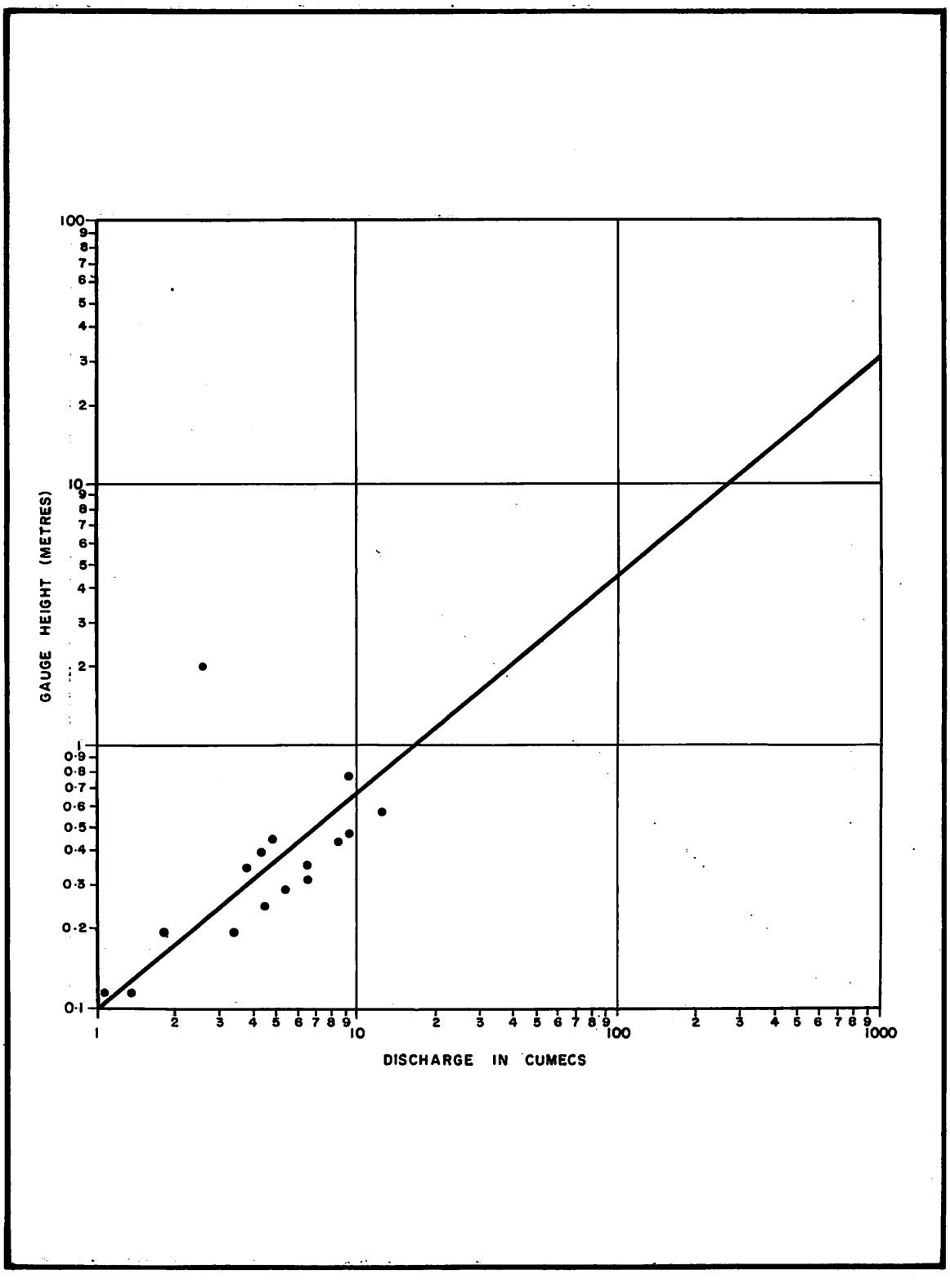
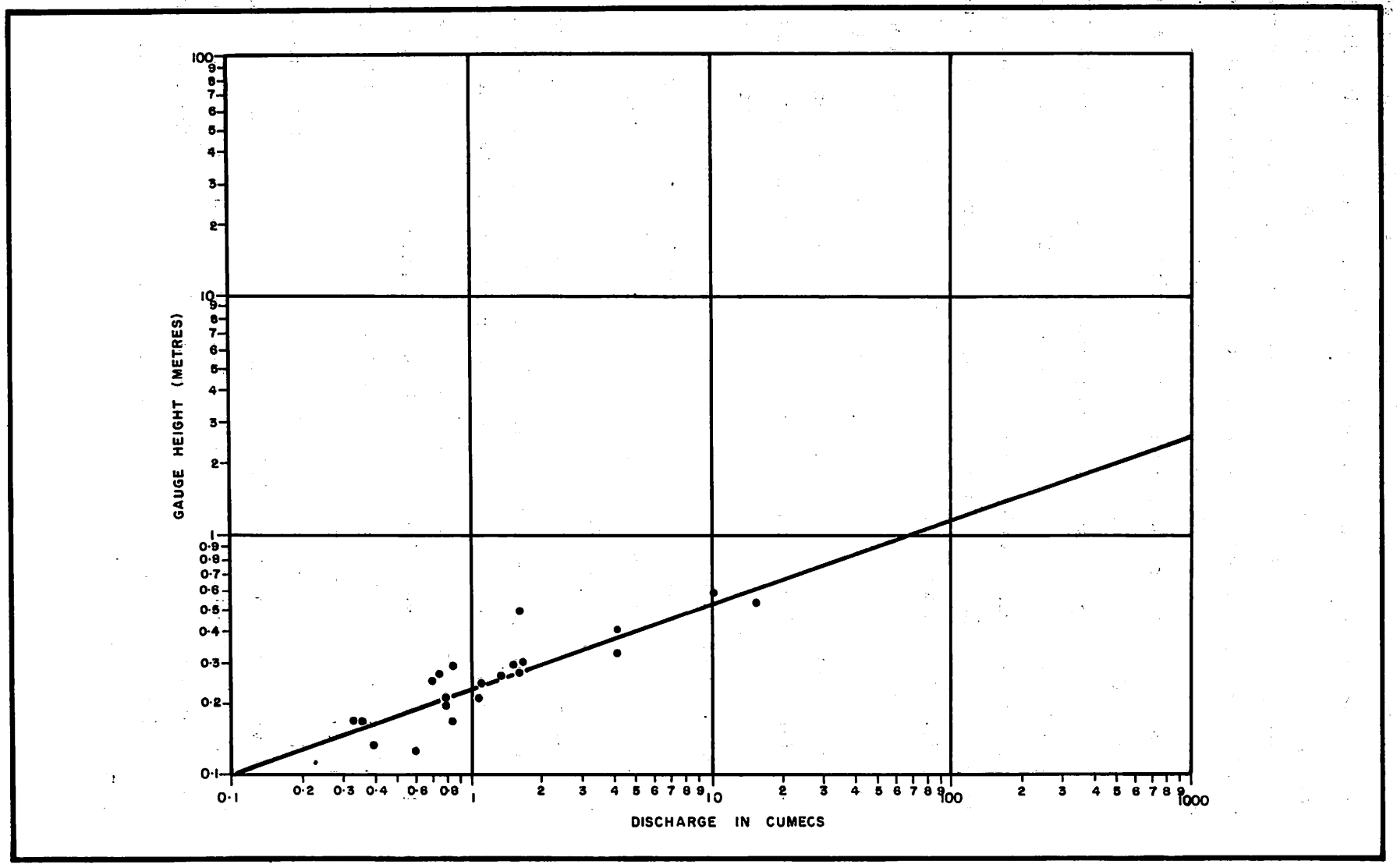


Figure 45. A Preliminary Discharge-Rating Curve for the Bakuri River.



At most of the stations a relationship was defined between stage height and measured discharge at a few times. The resulting discharge-rating curves (see Figures 40 to 45) could then be used together with the regular stage height reading to generate a record of discharge. No discharge-rating curves were developed for Balessa and Falam because of the limitations of the scope of study, but current meter gaugings were carried out for the purpose of computing discharges of the streams and for sediment sampling at Lag Balal.

The discharge measurements were made by the use of an Ott 11617/1 current meter and in making the measurements the cross-sectional area of each stream was divided into convenient equal partial sections (depending on the width of the stream channel) and the area and mean velocity of each was determined separately at each measuring point whose position was fixed by measuring the distance to a reference point on the bank (see Figure 49). The depth of the cross-section at the given vertical, the distance between verticals and then the mean flow velocity of the vertical (indicated by the current meter at 0.6 depth) were all recorded. The discharge in each partial section was then computed as the product of the partial cross-section area times the velocity. This process was followed for the entire stream cross-section and the sum of the discharge in all partial sections gave the total discharge of a stream.

At most of the stations the current-meter measurements were made by wading through the stream (see Figures 50 to 51). However, at high flows the measurements were made from an inflatable Avon 5400 rubber dinghy supported by a temporary cable attached to pegs at both sides of the river bank (see Figure 52). Thus the entire operation required the services of an instrument man, boatman, recorder, and the safety-cable operator at any given time.

The readings, thus obtained, were computed and related to stage. There was, however, the problem of generating adequate data in some stations as meaningful discharge-rating curves can only be obtained from those periods of observations which take into account the flow pattern and variability of discharge in relation to other physical characteristics of the environment within the basin.



Figure 46. Installing a staff gauge on the Halam River.



Figure 47. Staging a staff gauge on the Merille River. (Note the eroded nature of the stream.)

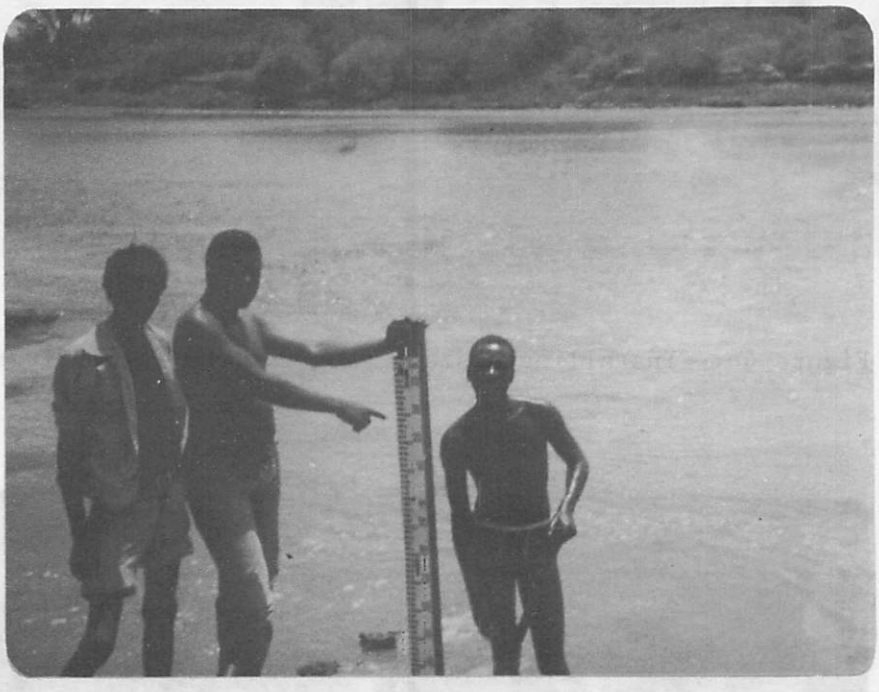


Figure 48. Staging a staff gauge on the Merille River.

In view of the practical and economic significance of the Malgis and Merille rivers, more time and attention was paid to these stations and hence many current-meter gaugings and other measurements were carried out at these particular stations.

The current-meter gauging proved a tedious and time-consuming process for a single worker. Measurements of the vital high flow proved exceedingly difficult and risky, especially in the main stream, i.e. Merille, Malgis, Lag Balal and Halam, because of the high velocities of the flows and the load carried by the streams. For example, the high-flow velocities exceed 0.605 m/sec for Malgis, 1.059 m/sec for Merille and 0.70 m/sec for Morgut. It was essential for the study to obtain gauging at these high velocities and the gauging could not be done using the 5400 boat. Neither were there convenient and appropriate structures from which the streams could be gauged by other methods. However, the creation of temporary cableways was at least feasible in the present study, and this enabled a number of measurements to be made.

This problem was made even more complex by the inaccessibility of the most important gauging sites by road, especially during flood periods. This was particularly the case with Lag Balal, Halam and Balessa where on occasions it could take more than a day to get to one of these stations despite the use of a four-wheel drive Landrover. The situation was worsened because of the inability to predict flow patterns since most of these catchments obtain their flows outside the area of study (see Figure 1). Nevertheless, every attempt was made to obtain as many representative samples as was practicable and close to 60 gaugings were carried out in all.

In order to avoid repetition it is important to note here that the conditions outlined above affected other measurements as well and in particular the measurements of suspended sediment and the solution level to be discussed below.

SUSPENDED-SEDIMENT MEASUREMENTS

For each sediment-monitoring station, three measurements of suspended sediment were carried out at three main verticals along the stream cross-section; the first vertical was close to the left bank, the second at the centre and the third vertical was close to the right bank of the



49. Current meter gauging of Morgut River using the Ott 11617/1 current meter.

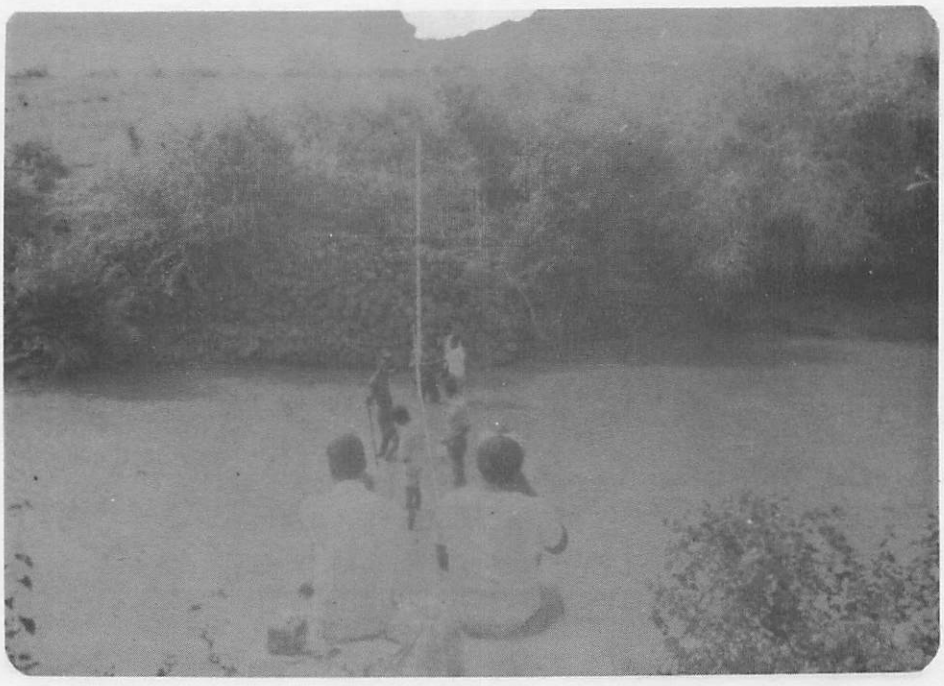


Figure 50. Current-meter gauging of the Malgis River being carried out by wading through the stream. (Note the heavy sediment concentration of the water.)



Figure 51. Current-meter gauging of Merille River by wading through the stream. (Note the heavy sediment concentration in the water.)



Figure 52. Current-meter gauging by boat during high flows on the Malgis River.



Figure 53. Suspended sediment measurements on the Malgis River using DH-48 suspended sediment sampler.

stream (see Figure 53) using US PH-48 depth integrating suspended sediment sampler (Guy and Norman, 1970, Federal Interagency Sedimentation Project, 1972). This sampler was designed for use in streams about 15 feet in depth and allows for the accumulation of a 440-cc sample of the water sediment mixture during the period of submergence. For this study it was necessary for any one stream vertical to be integrated five times at each vertical in order to obtain a 2-litre sample for analysis in the laboratory in Nairobi.

The sampler consisted of a streamlined aluminium casting 13 inches long which partially enclosed a bottle sample container and weighs about 4½ lb, including the sample container. A brass intake nozzle extends horizontally from the nose of the sampler body and four standard ½-inch pieces of wading rod about 3 feet long had to be threaded into the top of the sample body for suspending it above the streambed. The number of pieces to be fitted together and threaded into the sampler body was determined by the water depth at each sediment-monitoring station. A nozzle with ¼-inch bore was used in the entire sampling programme. One of the limitations of the sampler was that it was designed in such a way that it can only sample within 3½ inches of the stream bed.

In a sampling operation the intake nozzle was oriented into the current and held in a horizontal position while the sampler was lowered at a uniform rate from the water surface to the bottom of the stream and then instantly reversed towards the water surface at a uniform rate and the process repeated (see Figure 53) until the required quantity of the sample was obtained and then transferred into the larger sample bottles for onward transmission to Nairobi for laboratory analysis.

Operation of the sampler became difficult during the period of high flows because of high velocities of the moving water, especially at the main streams, and yet it was preferred not to use the heavier US-59 depth integrating sampler because the observations were carried out from an inflatable rubber boat and this could easily overload the boat at the critical point of sampling. In all, however, close to 300 suspended-sediment samples were collected.

WATER CHEMISTRY (QUALITY)/SOLUTION LOAD

Measurements of solution load (water chemistry/quality) were carried out in the same way as that described for suspended-sediment measurement

(see Figure 53). At each station, therefore, three samples were collected for suspended sediment analysis and three samples for solution-load measurements at the same vertical point within the stream cross-section.

In all close to 300 water chemistry samples were collected from the field for full chemical analysis in the laboratory in Nairobi. These exclude 10 samples collected from various surface dams in the study area.

BACTERIOLOGICAL ANALYSIS OF WATER

Here ten samples were collected in specially sterilized containers for full bacteriological analysis at the Medical Research Laboratory in Nairobi. They were stored and transported in a cooler.

BED-MATERIAL MEASUREMENTS

Efforts to obtain a suitable bedload sampler proved impossible for the present study for, as Hubbell (1964) observes, 'No single apparatus or procedure, whether theoretical or empirical, has been universally accepted as completely adequate for the determination of bedload discharges'. One of the major problems was that the direct measurements of bedload included the alteration of the pattern of flow and transport by the presence of the sampling device. Another problem was associated with the difficulty of positioning the measuring equipment in a variable stream flow and the sampling efficiency coupled with the irregular movement of bedload material.

Attempts were made in the study to measure bed-material load by a locally-designed bed-material sampler and this was used to scoop out the bed-material load from the various verticals of a given stream cross-section. In all 9 bed-material samples were collected for laboratory analysis which, if combined with other hydraulic parameters of the stream in question, could hopefully facilitate the computation of bedload (Einstein, 1942; Einstein, 1950).

This is a major limitation because bedload can account for 5-50% of the total load of a stream, and this amount may vary from one stream to another depending on the hydraulic and hydrological characteristics of the stream in question, and the geology, land use, slope and climate of

the drainage area. But with adequate bed-material and other necessary data a good computation of bedload material is possible (Einstein, 1950).

HYDRAULIC DESCRIPTIONS

In the course of the field observations all the hydraulic geometry variables of the individual streams were measured, conventional surveying was carried out using three surveyor's levels to give information regarding gradient, longitudinal profile, etc. (see Figures 54 to 56).

LABORATORY ANALYSIS

Suspended sediment determination

The suspended sediment concentration contained in a 2-litre water sample was obtained by filtration through a weighed glass-fibre filter paper (G/FA Whatman). The residue was dried at 105°C and then weighed and the results of the concentration expressed in mg/l. The method was very much in agreement with those designed, for example, by the Federal Inter-Agency Sedimentation Project of the U.S. (Guy, 1969). The samples were analysed at the Environmental Health Laboratory at the University of Nairobi.

Physical and chemical tests

Water collected from the field was initially subjected to physical and chemical tests at the Environmental Health Laboratories at the University of Nairobi. Only a brief account of the methods will be attempted here as the methods used are described by Brown, Skovgstad and Fishman (1970), APHA (1971), Rainwater and Thatcher (1960), and Hem (1970).

The colour of the water was determined by comparison in Lovinbond nessleriser using a disc calibrated in Hazen units with distilled water as the reference.

Turbidity was determined instrumentally by use of a Hach model 2100A turbidimeter and results expressed in JTU. The electrical conductivity was measured with a Wheatstone bridge mark V and results were reported in micro/mhos/cm^3 at 25°C.

The pH of the water, which is a measure of the effective hydrogen ion activity, was measured using a Pye model 79-pH meter. All the results

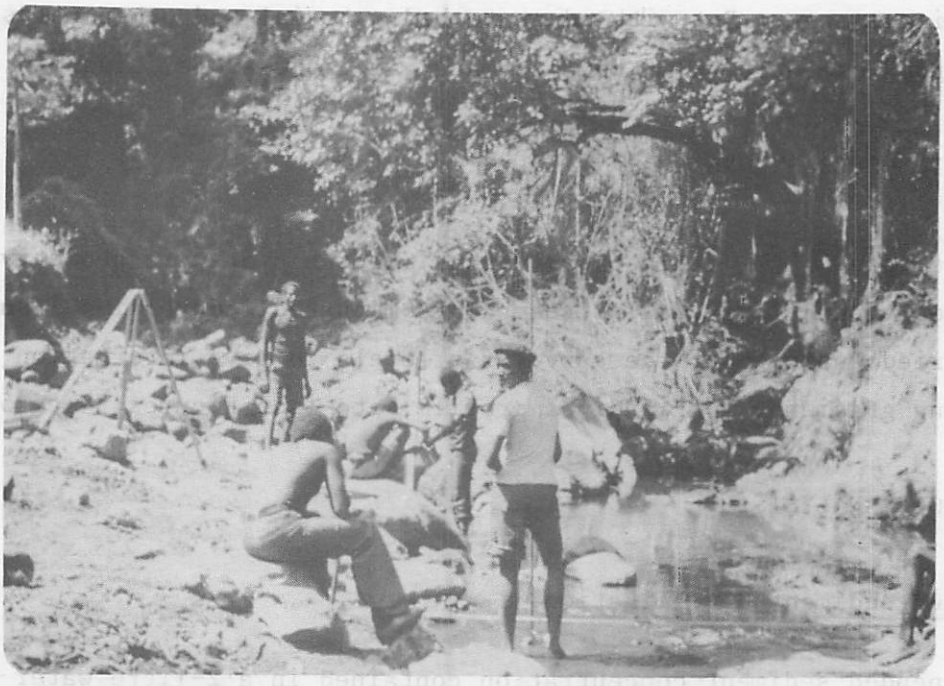


Figure 54. Surveying of the stream geometry on the Bakuri River within the Marsabit Forest Reserve.

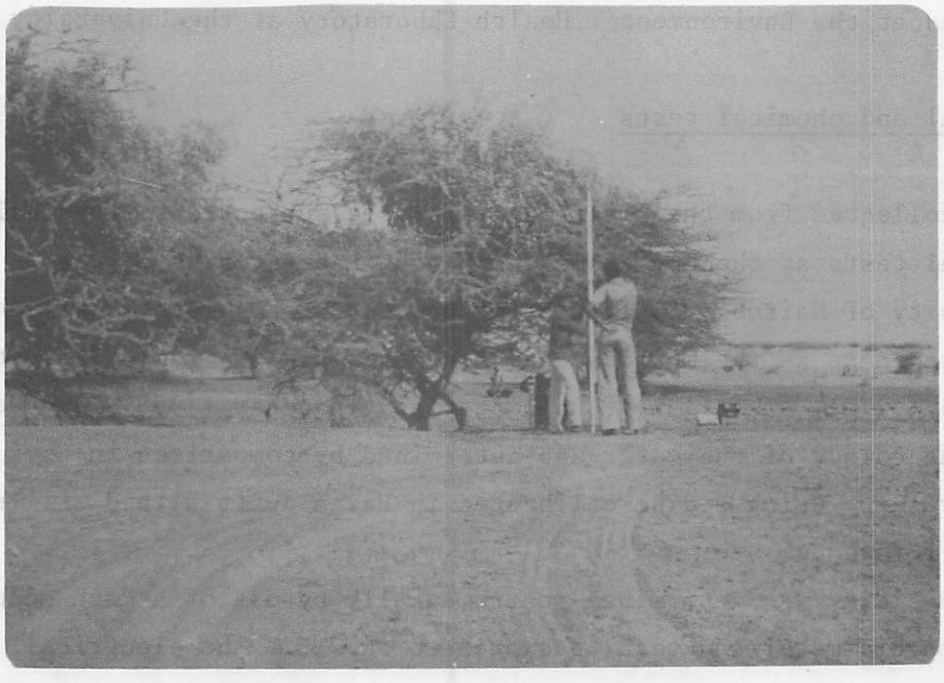


Figure 55. Surveying of the profile and stream cross-section of Halam River.



Figure 56. Surveying of the left bank of the Merille River to site the bench mark.

of other chemical tests were expressed in mg/l.

Free carbon dioxide was determined volumetrically by titrimetric method using N/22 sodium carbonate with phenolphthalein as the indicator. Free and saline ammonia was determined by the sample being made alkaline (buffer to a pH of about 9.5) distilled and then nesslerized to allow determination. In the case of albuminoid ammonia, however, the residue was treated with alkaline potassium permanganate in order to convert the unsubstituted amino groups to ammonia. Then the sample was distilled and nesslerized. Nitrate concentration was determined using the phenol-disulphonic acid method and colour allowing for the concentration to be computed and read with a BDH nitrate disc, while the nitrate component was determined by the diazotization method and the colour read with a BDH nitrate disc.

The concentration of oxygen absorbed in 4 hours at 27° was measured by acidifying the sample and adding N/80 potassium permanganate and incubating the sample. The $KMNO_4$ remaining was determined using N/80 sodium thiosulphate.

The alkalinity was determined by titration with N/50 hydrochloric acid using phenolphthalein as the indicator. The carbonate hardness was measured by N/50 EDTA titration while the chloride and sulphate concentrations were measured using 'EEL' chloride meter and 'EEL' nephelometer head respectively.

Silica was measured using the colorimetric molbosilicate method using a BDG silica disc while the fluorides were determined by anion-specific ion meter.

Potassium and sodium were determined photometrically using a Gallenkamp flame photometer, while calcium was obtained by N/50 EDTA titrition.

The difference between total hardness and calcium hardness was computed to give the magnesium concentration in the water samples. Manganese was determined using the persulphate method and the colour was compared with standards to enable concentration determination. Iron was determined by the ammonium thiocyonate method and the colour of the solution was read on a SP600 spectrophotometer, while lead and copper were determined by the dithizone extraction method. Zinc was determined by adding a solution of dilute sulphuric acid, sodium sulphate, ammonium chloride and potassium ferrocyanide which leads to formation of a precipitate and this is compared with given standards to allow computation of zinc concentration.

The total-dissolved-solids (TDS) concentration was obtained by the sample being evaporated on a previously weighed dish and the residue being dried at 180°C and weighed.

Bed-material analysis

The river samples collected from Balessa, Ngurunit, Merille, Malgis, Halam and Morgut were subjected to sieving tests using a laboratory rotary screen shaker. The samples were dried and screened on 8, 25, 72, 120 and 240 B sieves representing 2.057, 0.599 0.2111, 0.124 and 0.066 mm respectively. Each sample was left on the sieving machine for 15 minutes and the amount in each size fraction was weighed.

Bacteriological analysis

The bacteriological analysis in the laboratory took into consideration the fact that the number of coliform organisms in such water may be so small that very large volumes of water need to be taken for examination in order to detect a single organism. The procedure followed was the multiple tube method outlined in Report No. 71 of the Reports on Public Health and Medical Subjects of the Department of Health and Social Security Office, London, 1970.

Chapter V

SEDIMENT TRANSPORT IN GIVEN DRAINAGE BASINS OF MARSABIT DISTRICT

INTRODUCTION

Some of the characteristics of the drainage basins studied are given in Table 2. From this table it is clear that the largest drainage basin is Lag Balal, followed by Malgis, while the smallest is that of Bakuri.

The monitoring station with the highest sediment and discharge is that of Bakuri, followed by Ngurunit, and this also applies to gradient and relief ratio.

The profile characteristics of some of the streams are indicated in Figures 57 - 62. With the exception of profiles for Ngurunit and Bakuri (see Figures 59 and 60 respectively) which are relatively steep, the rest are fairly flat and as such will not favour high sediment transport. On the other hand, the cross-sections of the rivers referred to above in Figures 63 to 67 indicate that, again with the exception of Morgut (Figure 63), Bakuri (64) and Ngurunit (65), the rivers are generally wide indicating that the velocity distribution will not be uniform along the river cross-section and therefore the suspended sediment transport will also not be uniform, hence the need for representative samples. The channel beds of some of the streams are characterized by ridge and trough topography (see, for example, Figures 64 and 65). This will naturally affect sediment transport and especially bedload.

Figure 57. Profile Along the Malgis River.

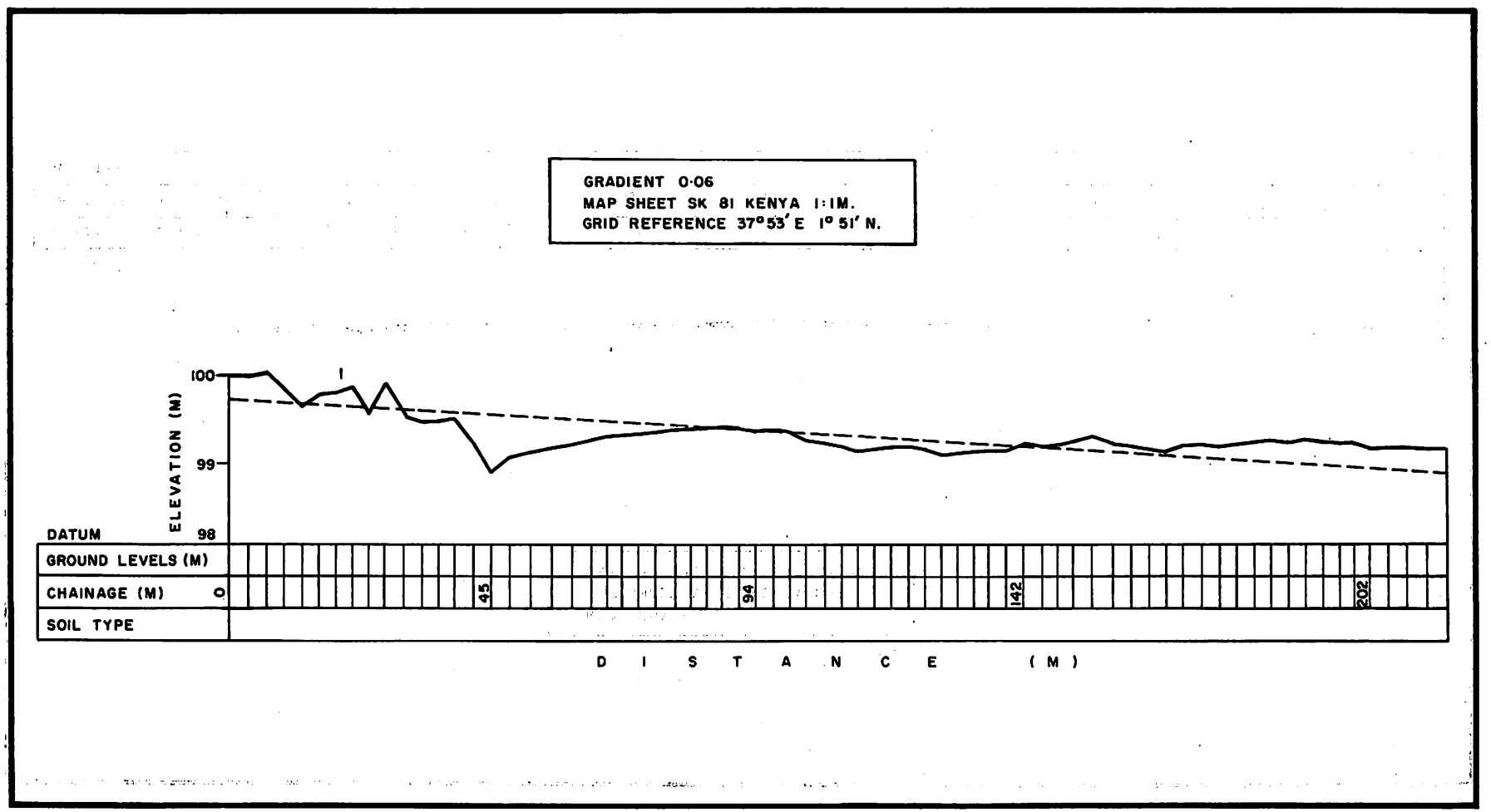


Figure 58. Profile Through the Centre of Morgut River.

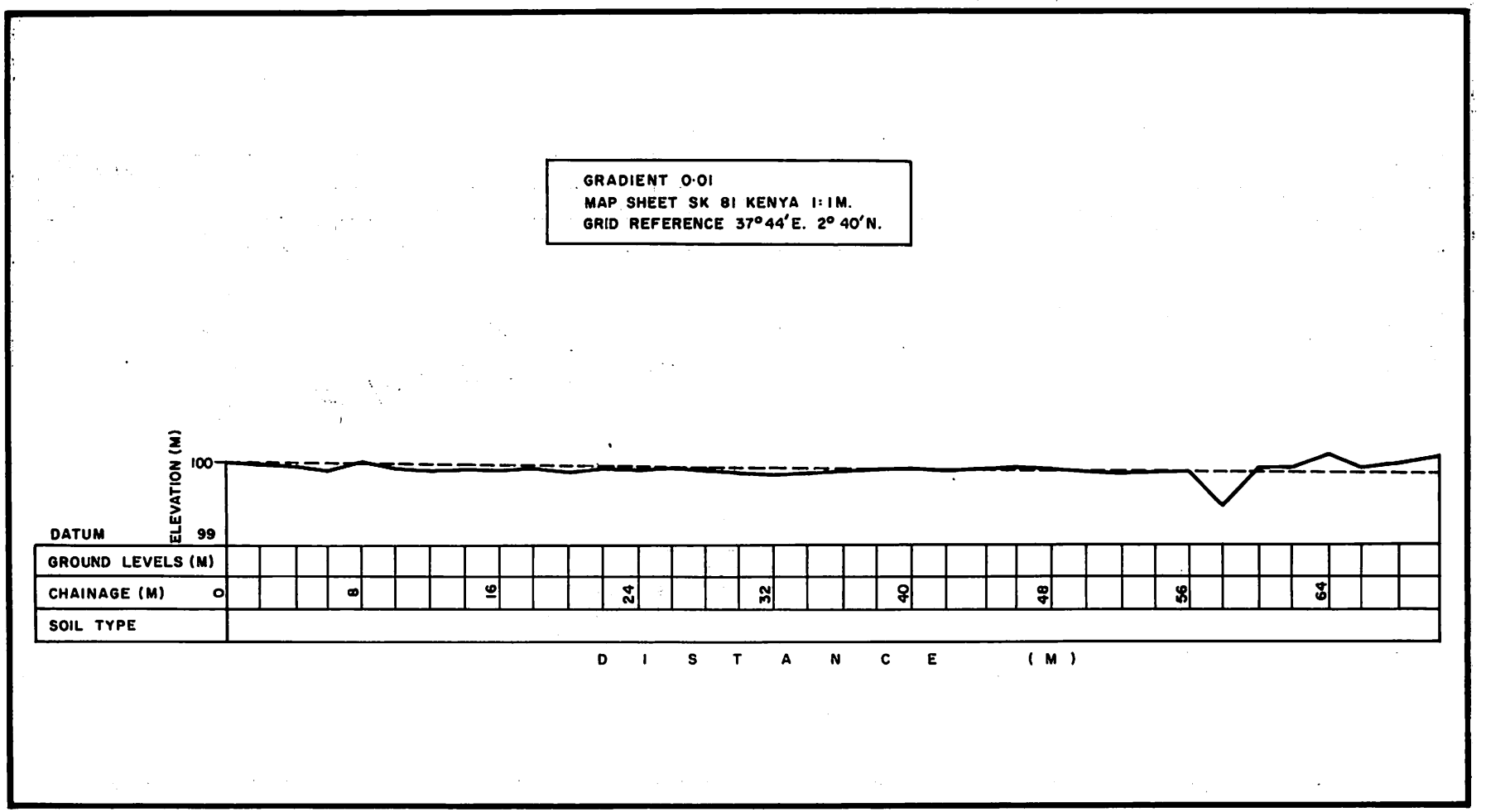


Figure 59. Profile Along the Bakuri River.

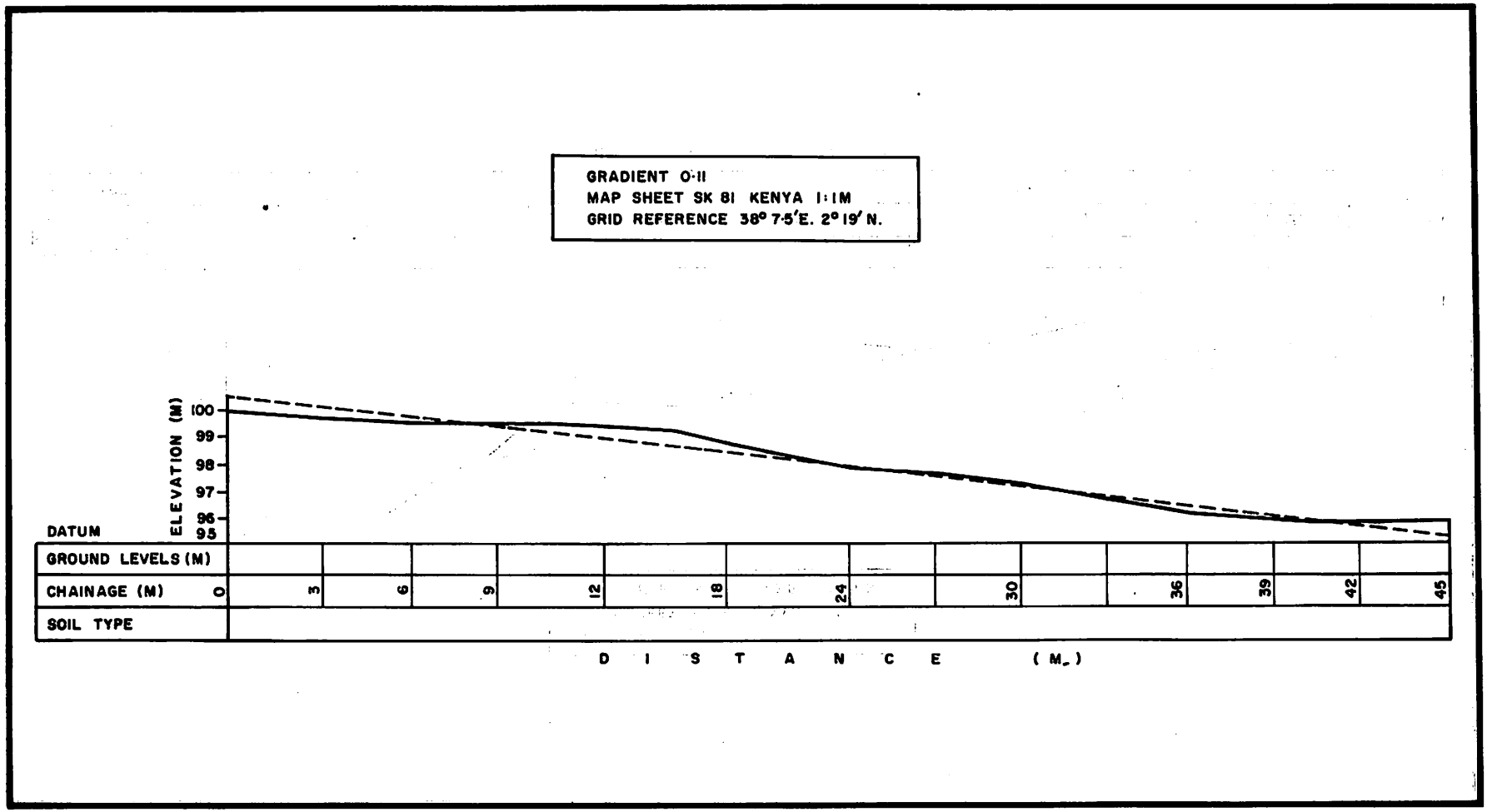


Figure 60. Profile Along Ngurunit River.

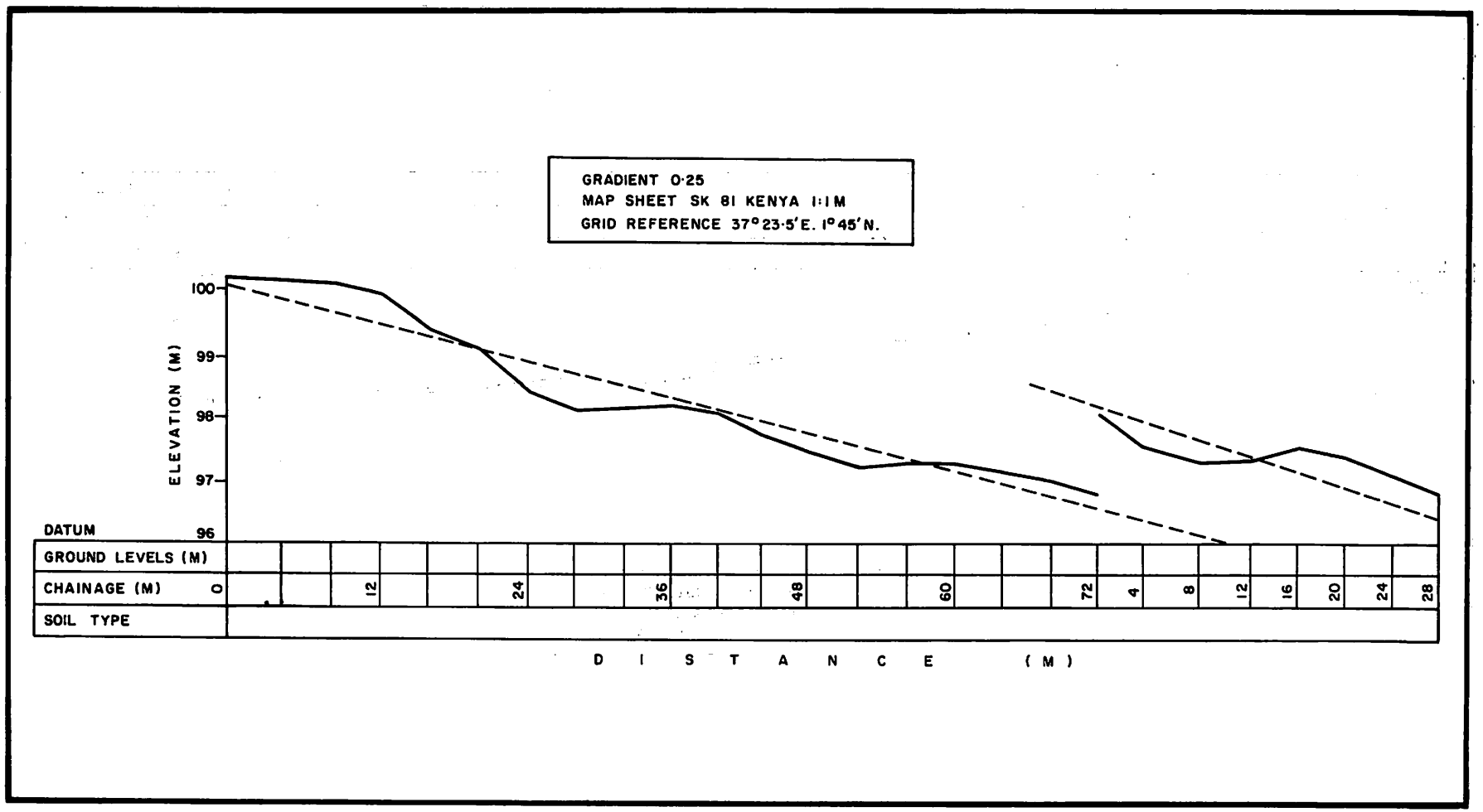


Figure 61. Profile Through the Centre of the Halam River.

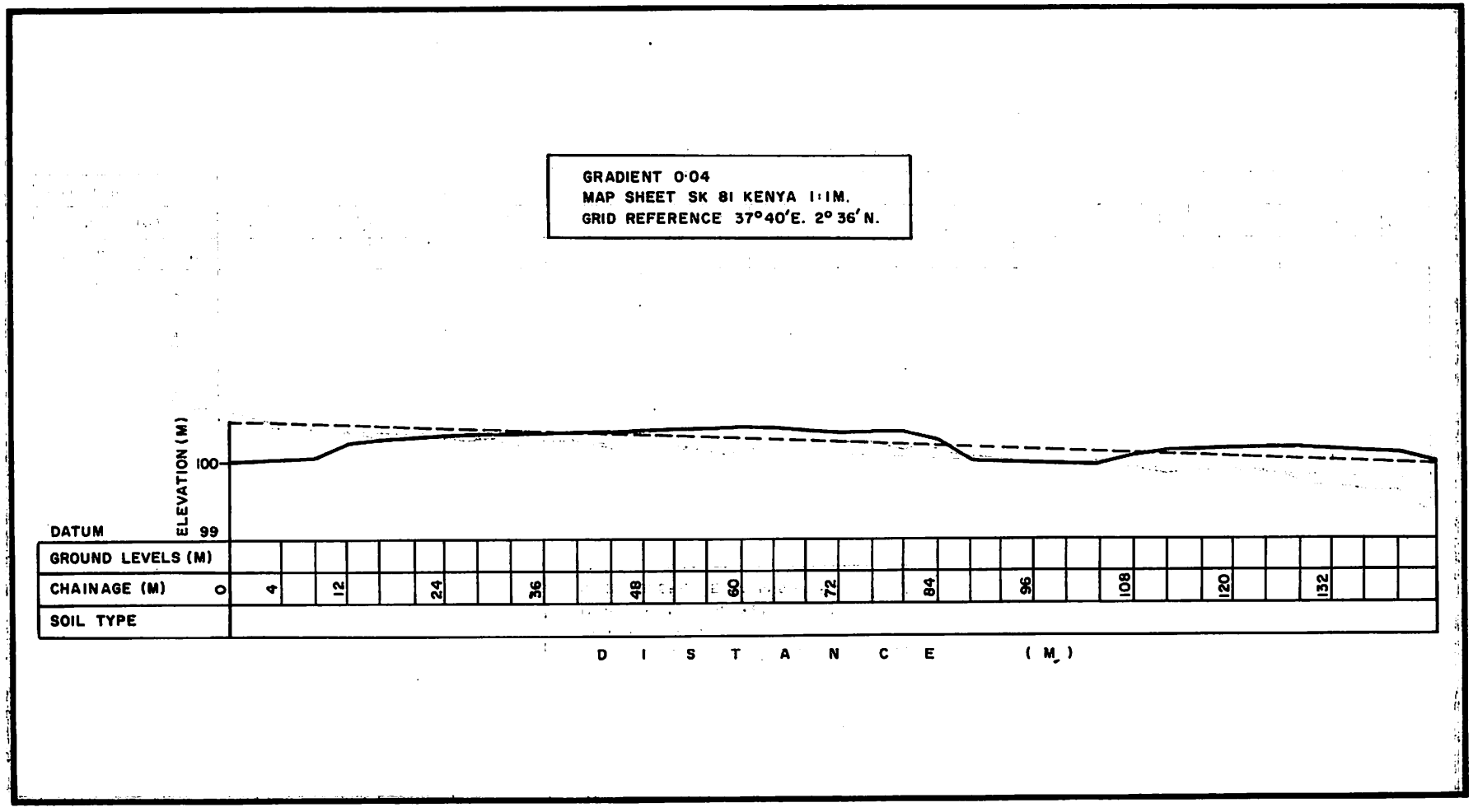


Figure 62. Profile Along the Balesa River.

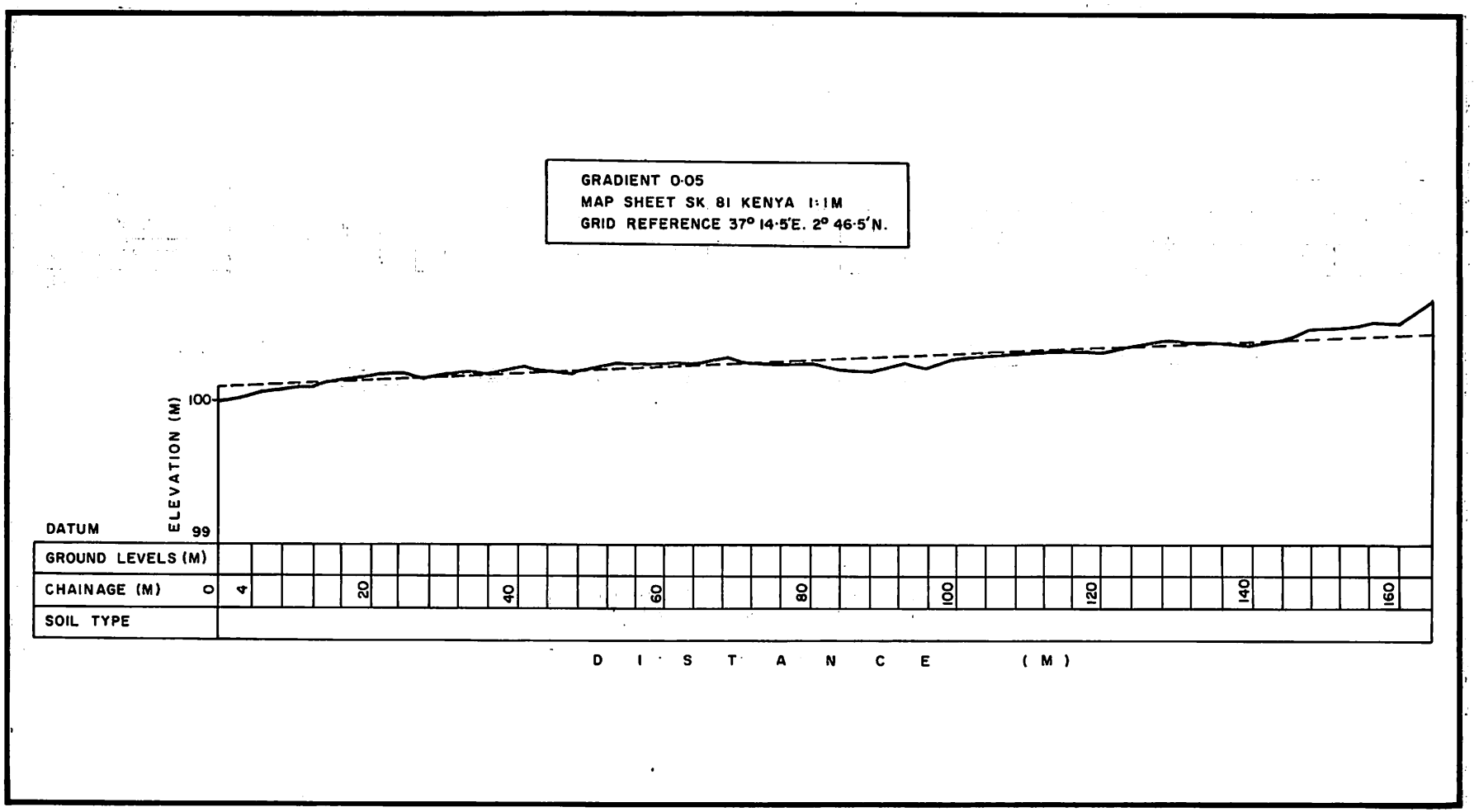


Figure 63. Cross-Section of the Morgut River.

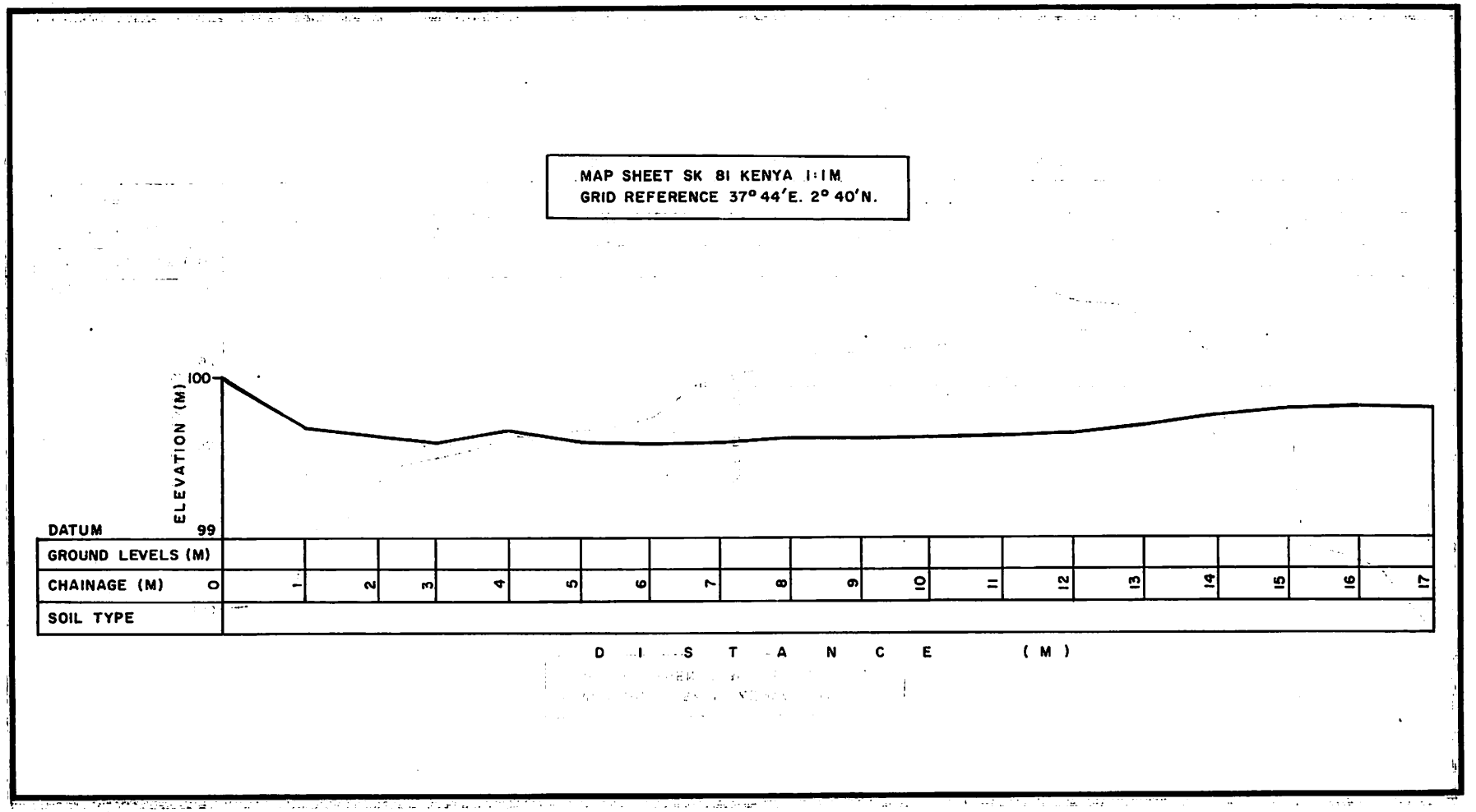


Figure 64. Cross-Section of the Bakuri River.

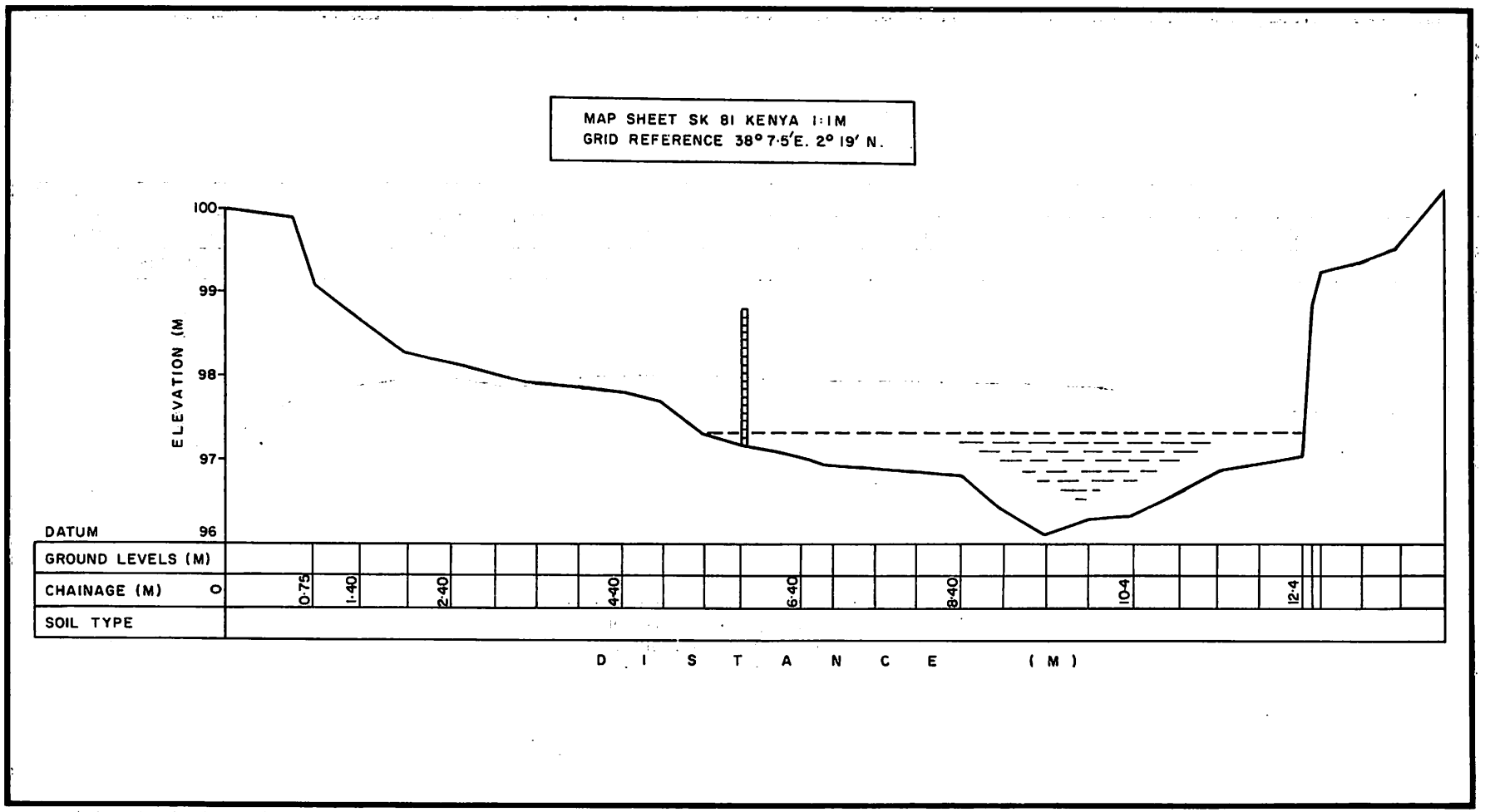


Figure 65. Cross-Section of the Ngurunit River.

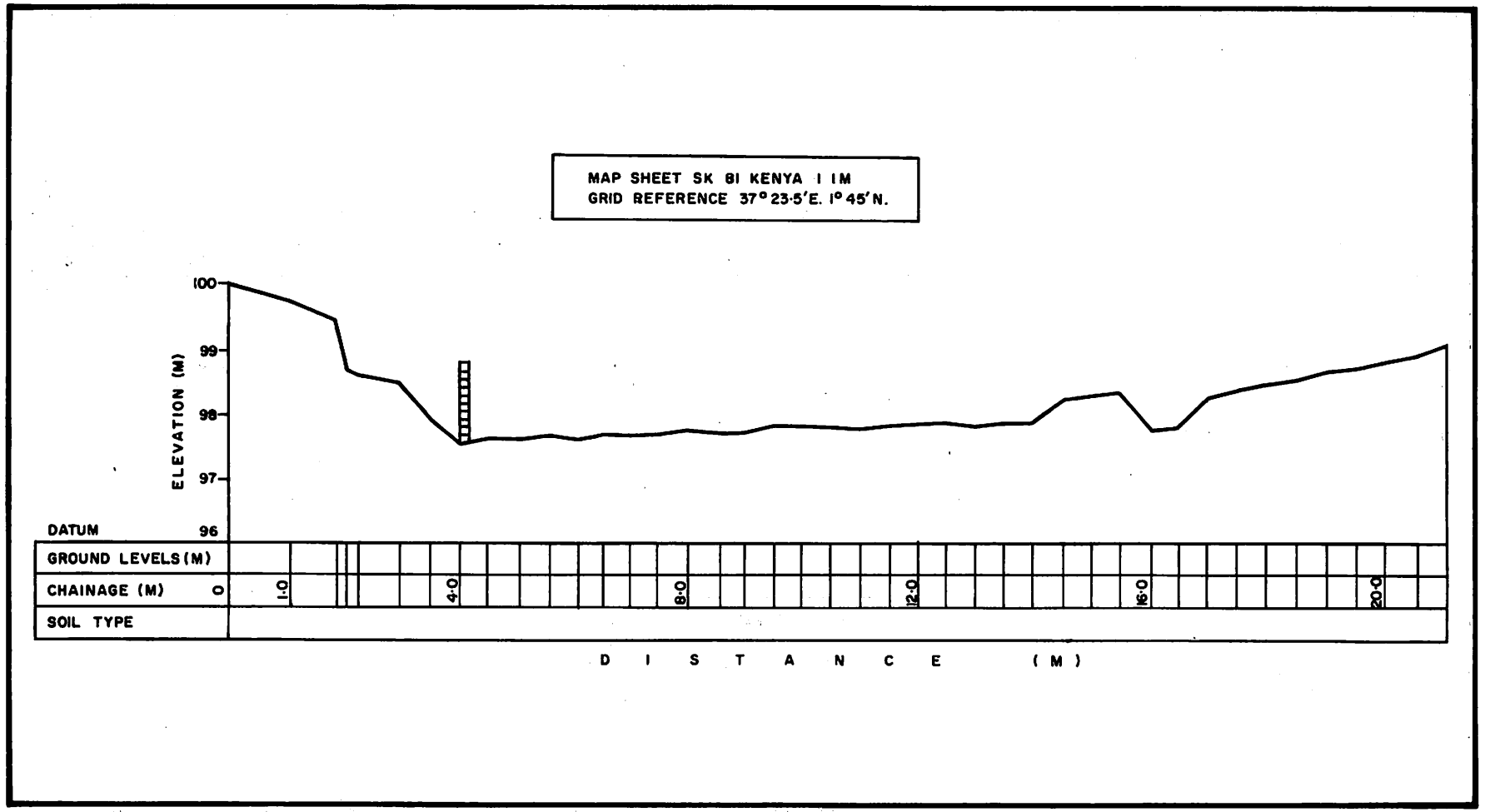


Figure 66. Cross-Section of the Halam River.

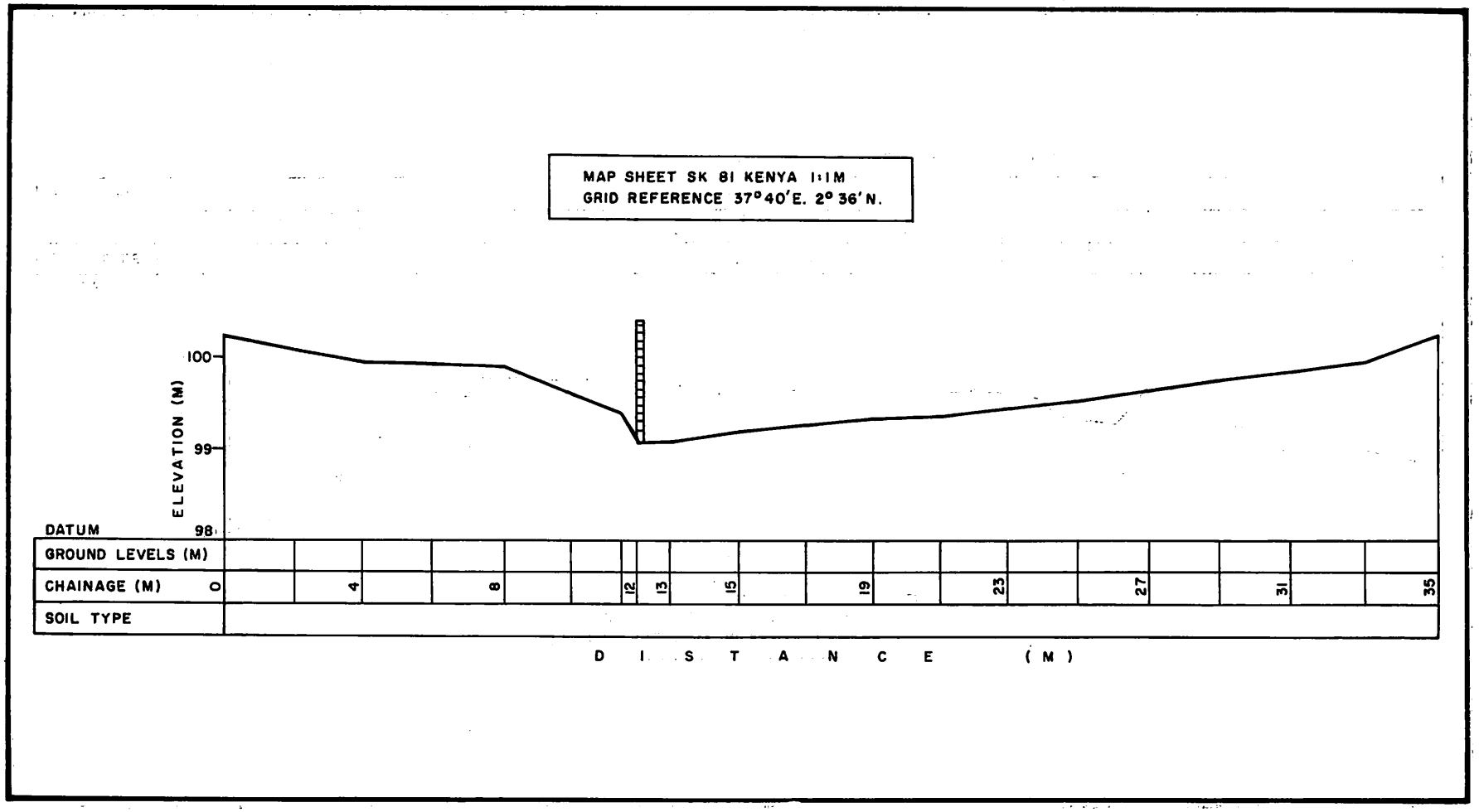


Figure 67. Cross-Section of the Balesa River.

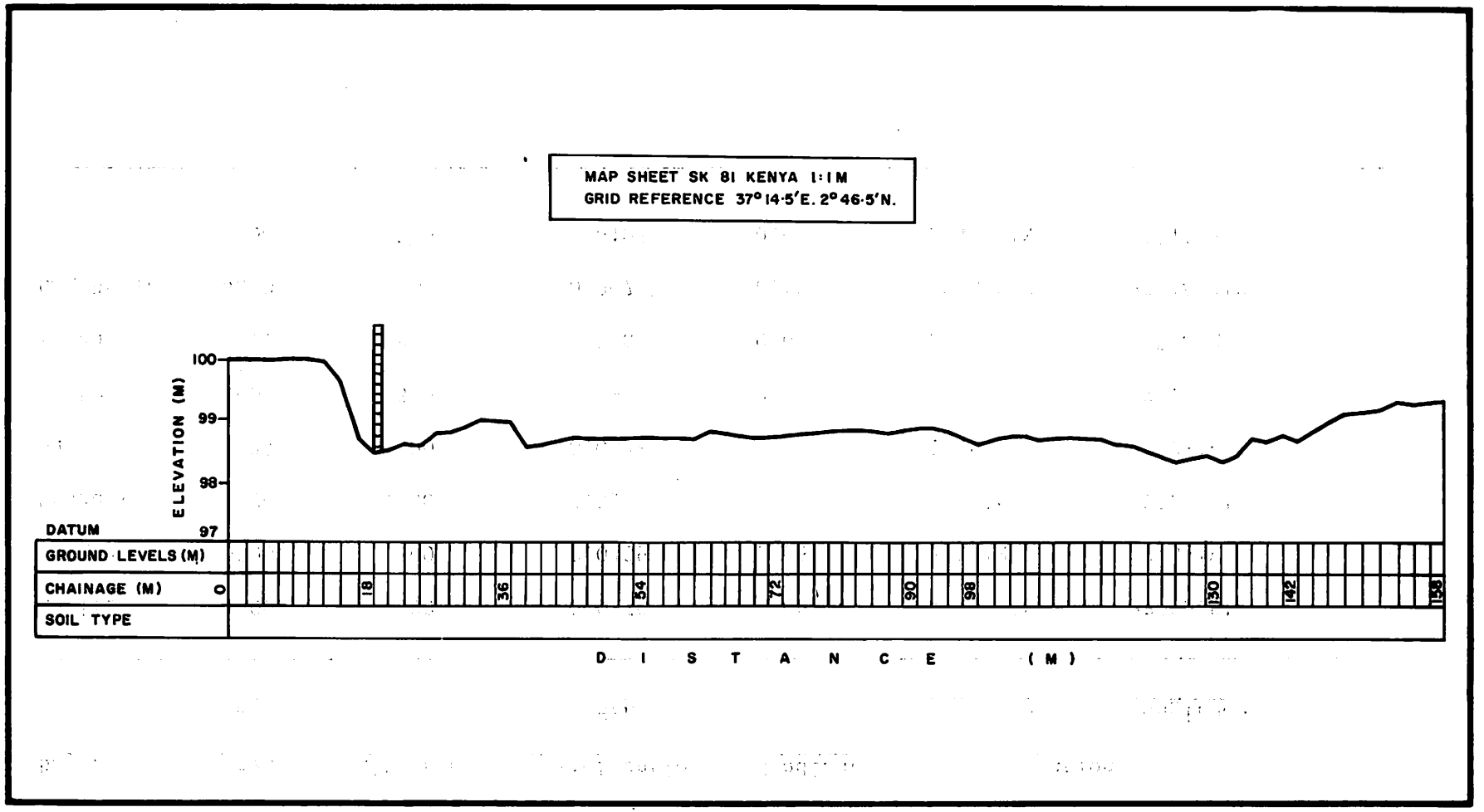


Table 2. Characterisitics of respective drainage basins of Marsabit district.

Basin	Area	Altitude	Relief ratio	Gradient	Location	
	km²	m	H/L		Latitude	Longitude
Merille	1500	600	0.0378	0.09	1°45.4'N	37°50.5'E
Malgis	9300	500	0.0139	0.06	1°51'N	37°53'E
Ngurunit	100	1200	0.0577	0.25	1°45'N	37°23.5'E
Bakuri	24	1500	0.0636	0.21	2°19'N	38°75'E
Halam	1000	500	-	0.04	2°36'N	37°40'E
Morgut	125	800	0.036?	0.01	2°40'N	37°44'E
Lag Balal	4800	500	0.0079	0.13	3°26.3'N	37°14.3'E
Balesa	1600	500	0.0106	0.05	2°46.5'N	37°14.5'E

MODES OF SEDIMENT TRANSPORT

Sediment transport within basins is accompanied by three main types of transportation of sediment. In streams these include washload, suspended bed-material load and bedload (Einstein, 1964).

The washload consists of the finest particles of silt and clay that are washed into the rivers. These particles remain in suspension until they reach their destination. Suspended bed-material load consists mainly of silt and fine sand and a little coarse sand which is deposited intermittently on the bed as it moves down stream. The washload material and suspended load constitute what is often referred to as the suspended sediment load of a stream. The suspended material then represents the sediments that are continuously supported by eddies and do not sink down because their weight is compensated for by the upward force of the flow. Within the basins listed in Table 2 this material is mostly silt and fine and coarse sand.

The bedload of a stream refers to the larger grains carried by the drag-force of the water on its bed. The particles roll and slide over each other but hardly rise from the bottom of the stream bed. The bed material that could be moved as bedload is shown in Table 3 and for Morgut, Ngurunit, Malgis, Balessa and Merille is shown in Figures 68 to 72. This ranges from fine to coarse sand whereas for Halam it ranges from coarse silt to medium sand (see Figure 73).

In many catchments elsewhere (Leopold, 1974; Trimble, 1975; Renfro, 1975; Hagget, 1961) it has been shown that not all the material that is eroded from the hill slopes gets to the streams; some of it could be deposited in troughs, basins, fans and flood plains before reaching streams. One measure of the ability of a watershed to store sediment between hill-slope sources of production and down stream points in the river channels is the sediment-delivery ratio, which is essentially the ratio of the soil loss from hill sides and gullies to the sediment yields of a given catchment. In general, it has been shown that this ratio varies with the overall steepness of the catchment, and some workers in the field (Schumm, 1955) have related sediment loss in a catchment to the relief ratio. This relationship has been partially used to check the documentation of the sediment-production sources of some of the basins in the present study.

Figure 68. Bed-Material-Particle-Size Distribution Curve for the Morgut River.

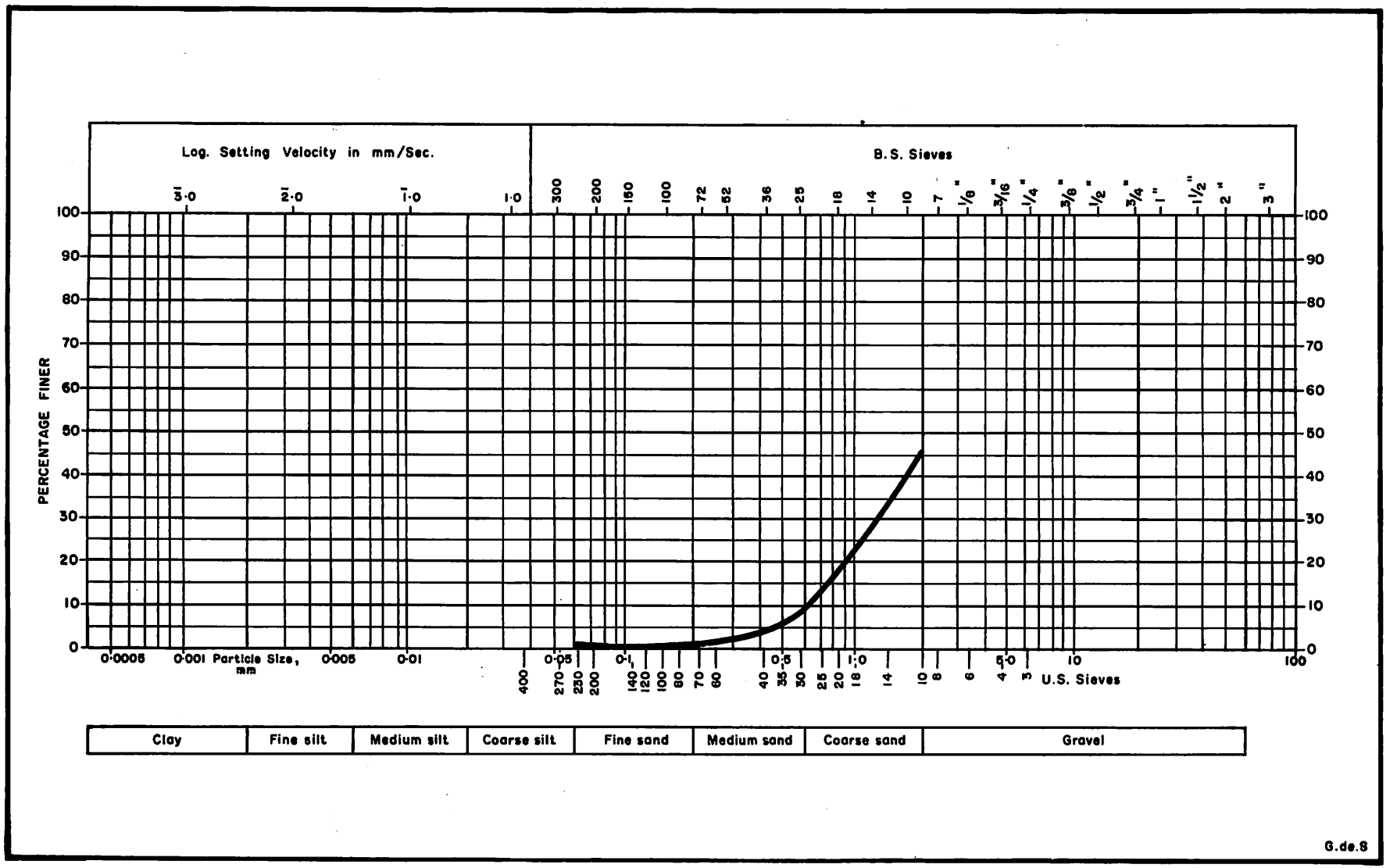


Figure 69. Bed-Material-Particle-Size Distribution Curve for the Ngurunit River.

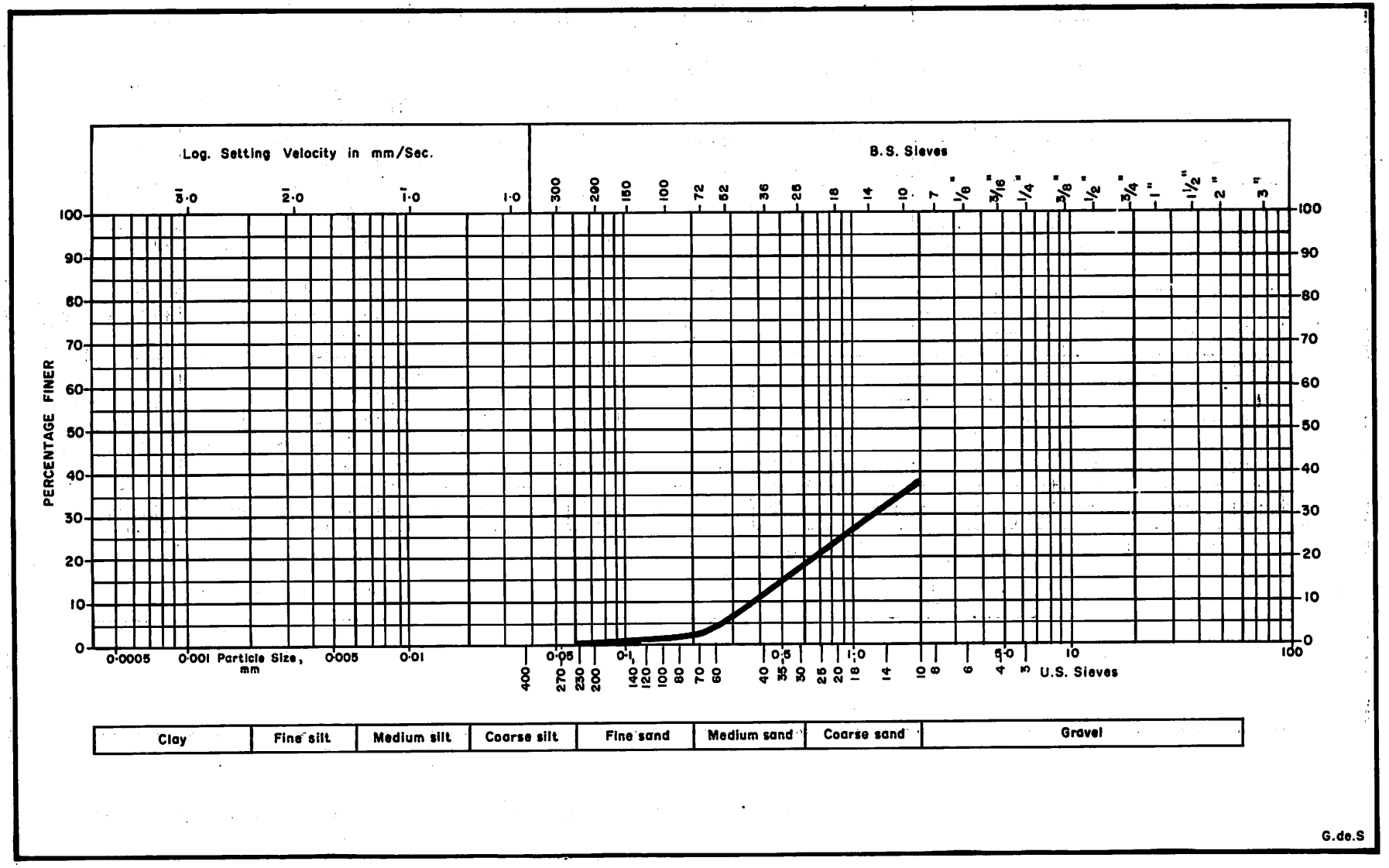


Figure 70. Bed-Material-Particle-Size Distribution Curve for the Balesa River.

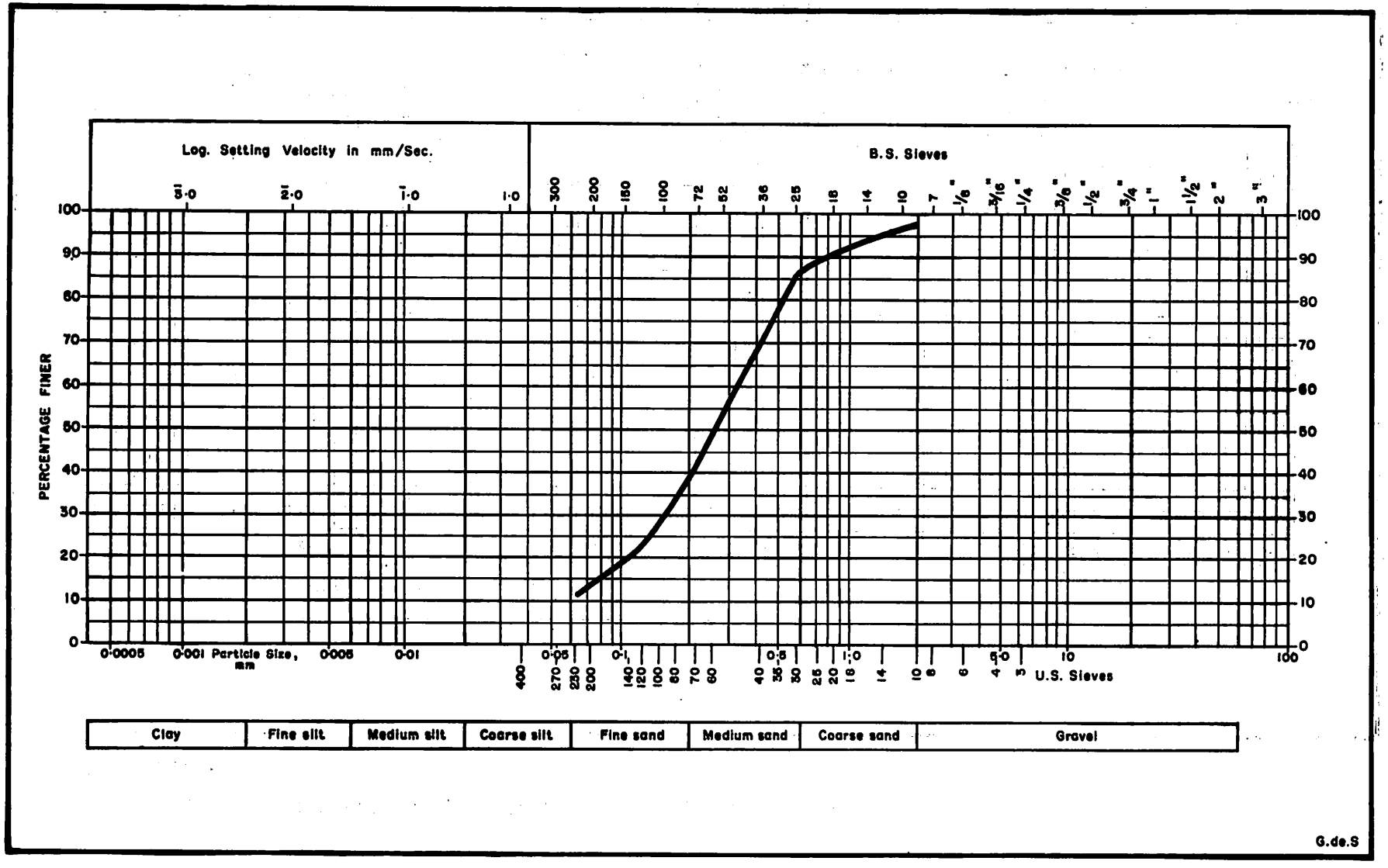


Figure 71. Bed-Material-Particle-Size Distribution Curve for the Malgis River.

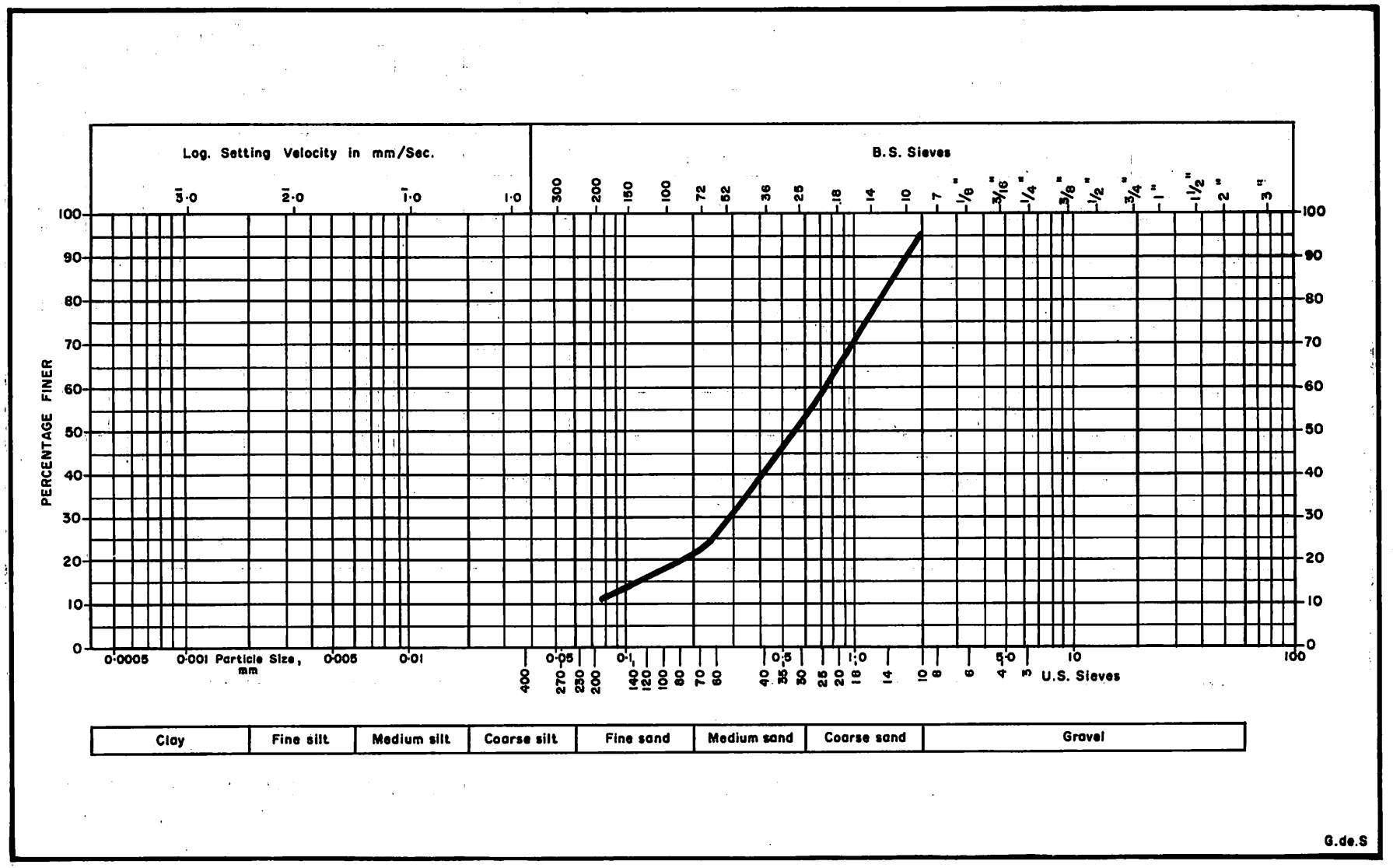


Figure 72. Bed-Material-Particle-Size Distribution Curve for the Merille River.

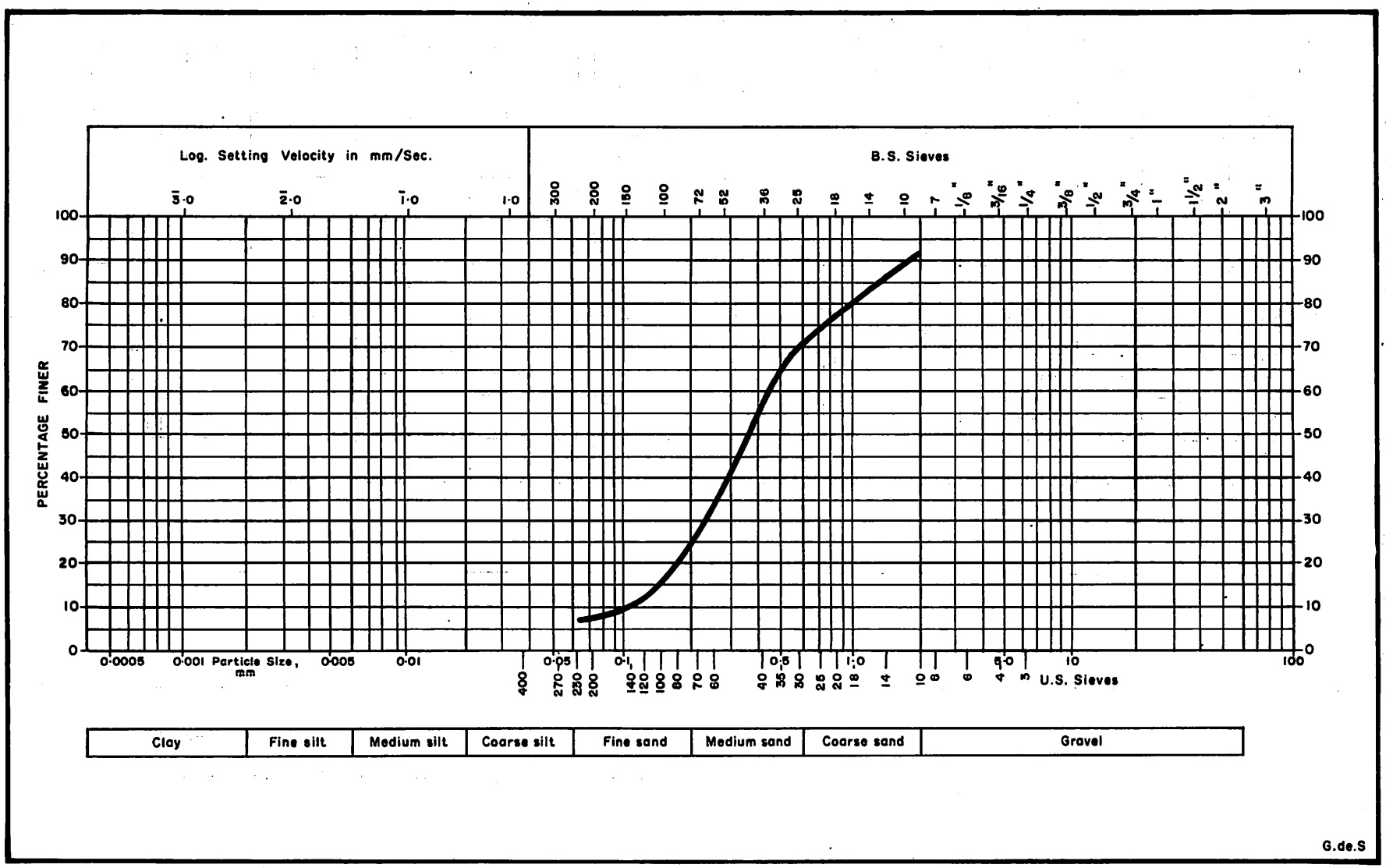


Table 3. Particle-size distribution of river samples.

(a) Balesa River Sample

Product in mesh BSS	Weight %	Cumulative % weight finer
+ 8	1.5	98.5
- 8 + 25	12.4	86.1
- 25 + 72	43.4	42.7
- 72 + 120	19.5	23.2
- 120 + 240	11.3	11.9
- 240	11.9	-
-	100.0	-

(b) Ngurunit River sample

Product in mesh BSS	Weight %	Cumulative % weight finer
+ 8	61.5	38.5
- 8 + 25	21.3	17.2
- 25 + 72	14.4	2.8
- 72 + 120	2.1	0.7
- 120 + 240	0.5	0.2
- 240	0.2	-
-	100.0	-

(c) Merille River sample

Products in mesh BSS	Weight %	Cumulative % weight finer
+ 8	7.7	92.3
- 8 + 25	21.3	71.0
- 25 + 72	44.8	26.2
- 72 + 120	14.9	11.3
- 120 + 240	4.2	7.1
- 240	7.1	-
-	100.0	-

(d) Malgis River sample

Product in mesh BSS	Weight %	Cumulative % weight finer
+ 8	3.8	96.2
- 8 + 25	44.7	51.5
- 25 + 72	24.4	27.1
- 72 + 120	11.3	15.8
- 120 + 240	6.8	9.0
- 240	9.0	-
-	100.0	-

(e) Halam River sample

Product in mesh BSS	Weight %	Cumulative % weight finer
+ 8	Nil	Nil
- 8 + 25	7.2	92.8
- 25 + 72	9.0	83.8
- 72 + 120	37.2	46.6
- 120 + 240	22.9	23.7
- 240	23.7	-
-	100.0	-

(f) Morgut River sample

Product in mesh BSS	Weight %	Cumulative % weight finer
+ 8	52.4	47.6
- 8 + 25	39.6	8.0
- 25 + 72	6.9	1.1
- 72 + 120	0.5	0.6
- 120 + 240	0.3	0.3
- 240	0.3	-
-	100.0	-

Within the minor catchments under study, except for Halam, the hill slopes on the upper reaches of basins bordering the forest areas are quite steep, mostly exceeding gradient values of 0.40 which, with poor ground cover, favour high rates of sediment production (Ongweny, 1978; Douglas, 1967; Dunne, 1976, 1977, 1978; Dunne et al., 1978; FAO, 1979; Hills, 1971; IFIAS, 1977; IPAL, 1981; IPAL, 1979; Moore, 1978). These are areas lying just below 1500 m with rainfall well over 1000 mm.

However, in the lower-lying slopes of the respective basins the gradient is reduced to below 0.35. In areas of over 1000 m with reduced ground cover there is still a good source of sediment due to overgrazing, and reduced infiltration capacities with rainfall below 1000 m (Ongweny, 1979; Dunne 1962; Pereira, 1962; Philips, 1975).

In the lower lying areas (below 560 m) the respective basins are relatively flat such that in such places like those shown in Table 4 and Figure 74 there is still some sediment being transported but some of it is deposited *in situ* (see Figure 75).

It is worth noting that in forest margins the rivers have comparatively steep longitudinal gradients and straight channels with only a very thin layer of large gravels along their courses. There is exposed rock in places along the channels (see Figure 6) and no flood plains have been developed where deposition could take place.

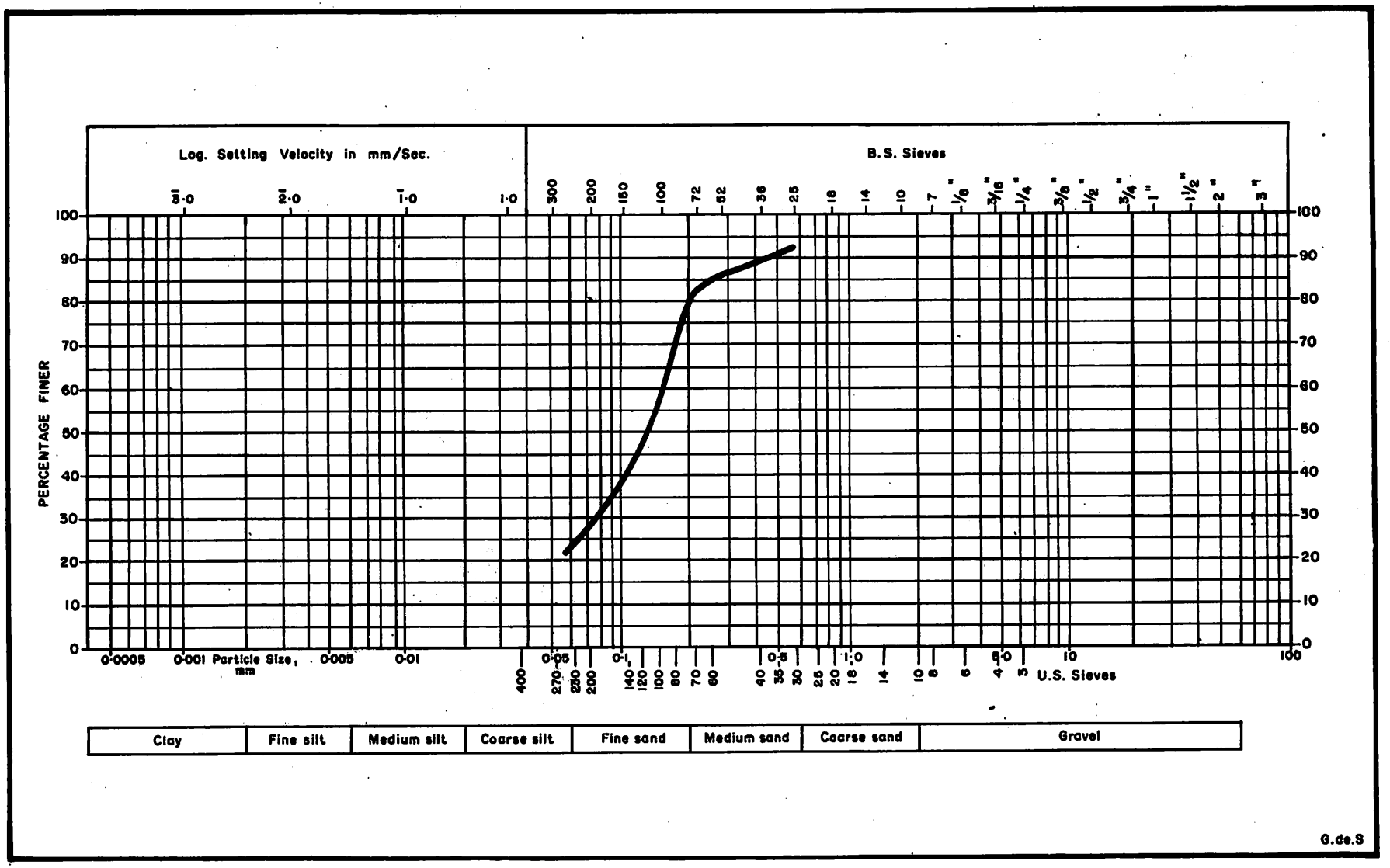
In the lower reaches of the respective catchments the hill slopes have concave profiles but do not provide gentle foot slopes for deposition. Dunne (1977) and Ongweny (1978) have shown that there is little or no deposition on such foot slopes in the grazed semi-arid areas. Ground checking of the areas and aerial photography observations showed no evidence of any significant deposition in these areas.

SEDIMENT TRANSPORT AND ANNUAL SEDIMENT YIELDS

Field and laboratory measurements of discharged and suspended sediment described in the previous chapter were used in constructing suspended-sediment rating curves for each drainage basin, as listed in Table 2. The resulting suspended rating curves are shown in Figures 76 to 82.

The rating curves indicate that there is a high correlation between discharge and sediment load for the respective stations. Although these

Figure 73. Bed-Material-Particle-Size Distribution Curve for the Halam River.



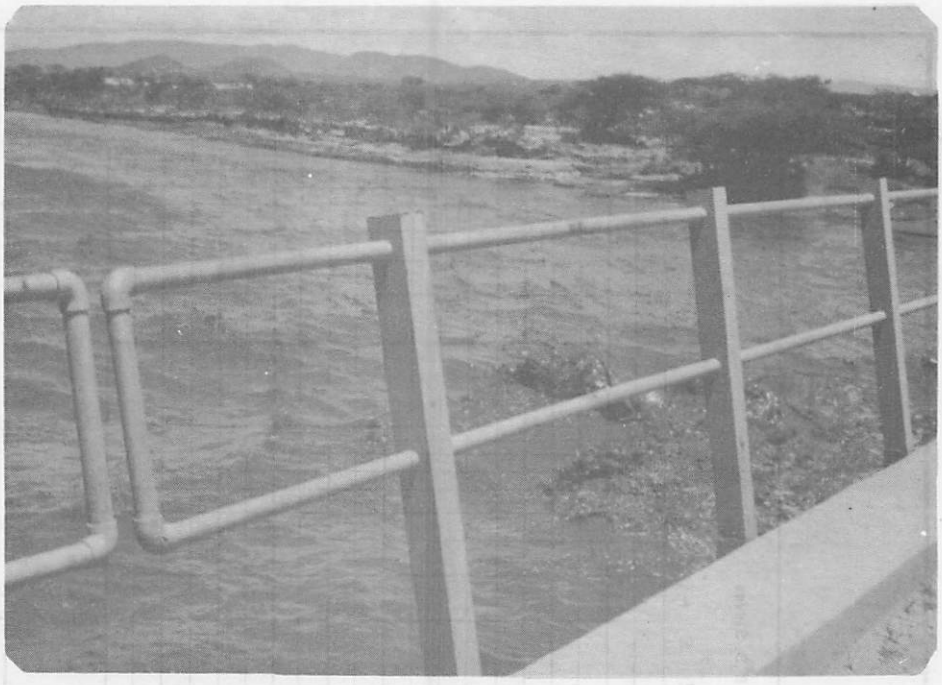


Figure 74. Merille River continues to transport some sediment even below 500 m.

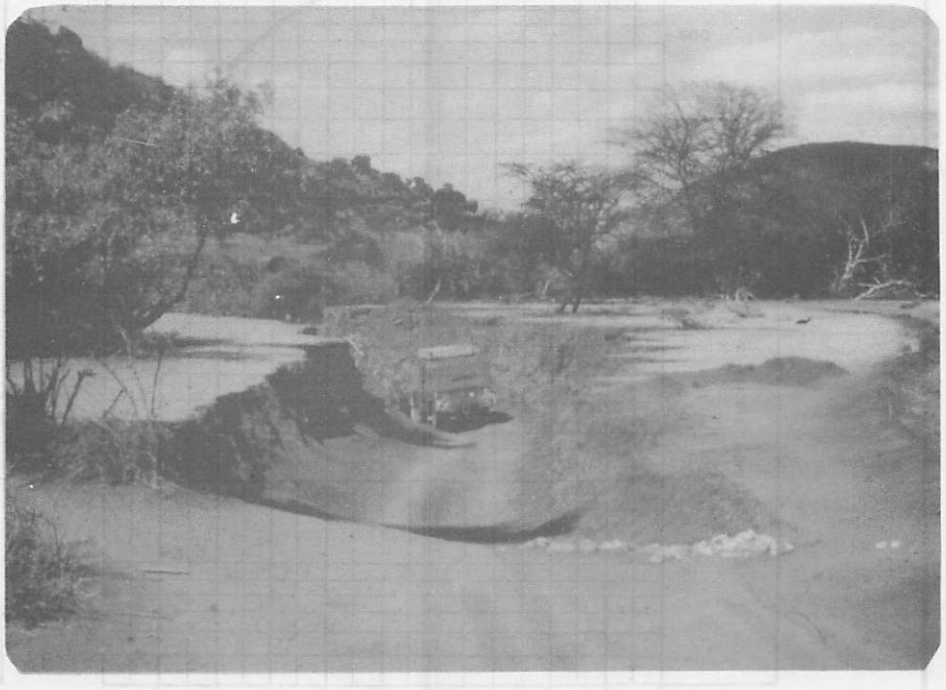


Figure 75. Deposition in the lower parts of the Halam River.

Figure 76. A Preliminary Sediment-Transport Rating Curve for the Malgis River.

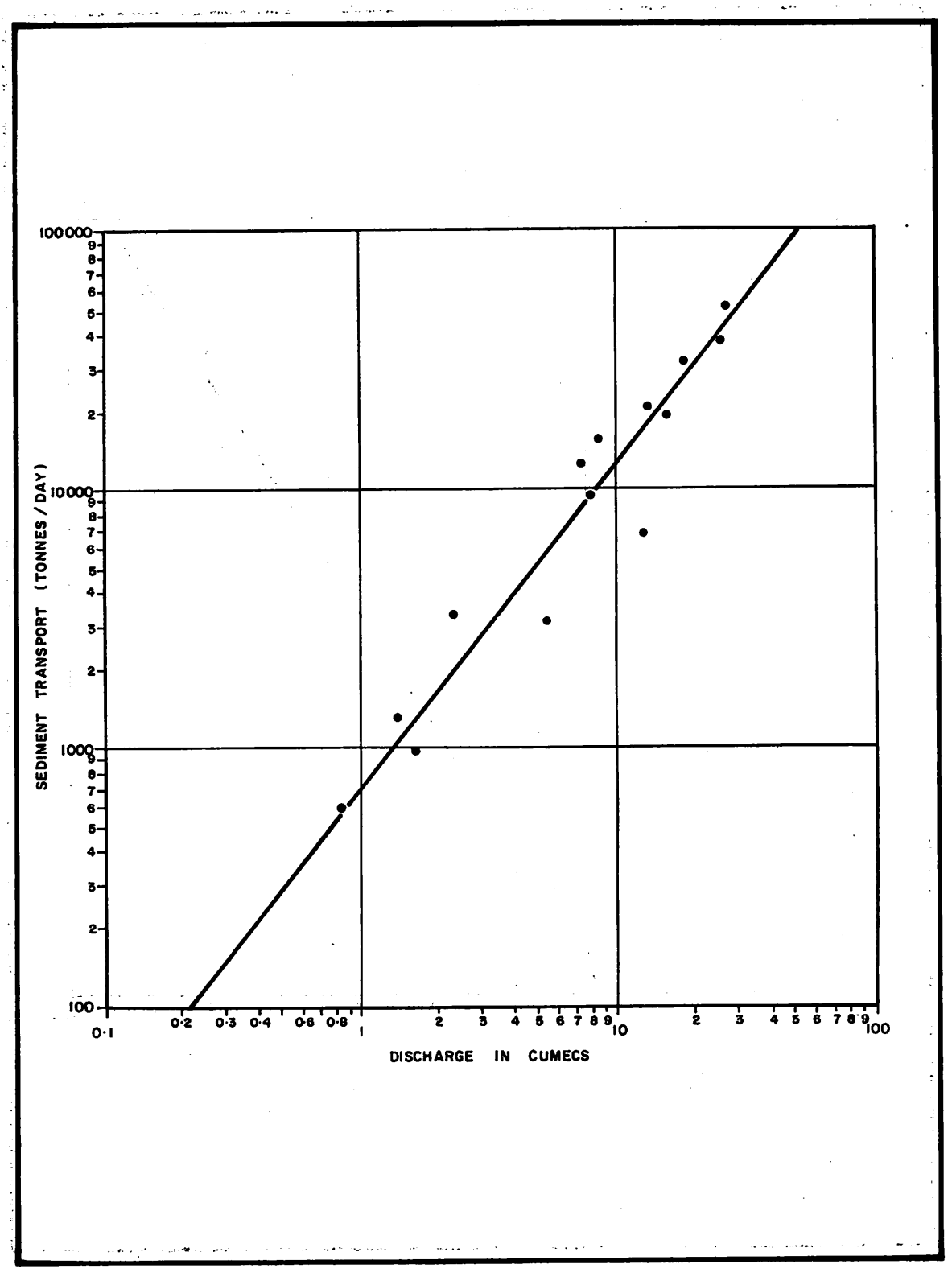


Figure 77. A Preliminary Sediment-Transport Rating Curve for the Merille River.

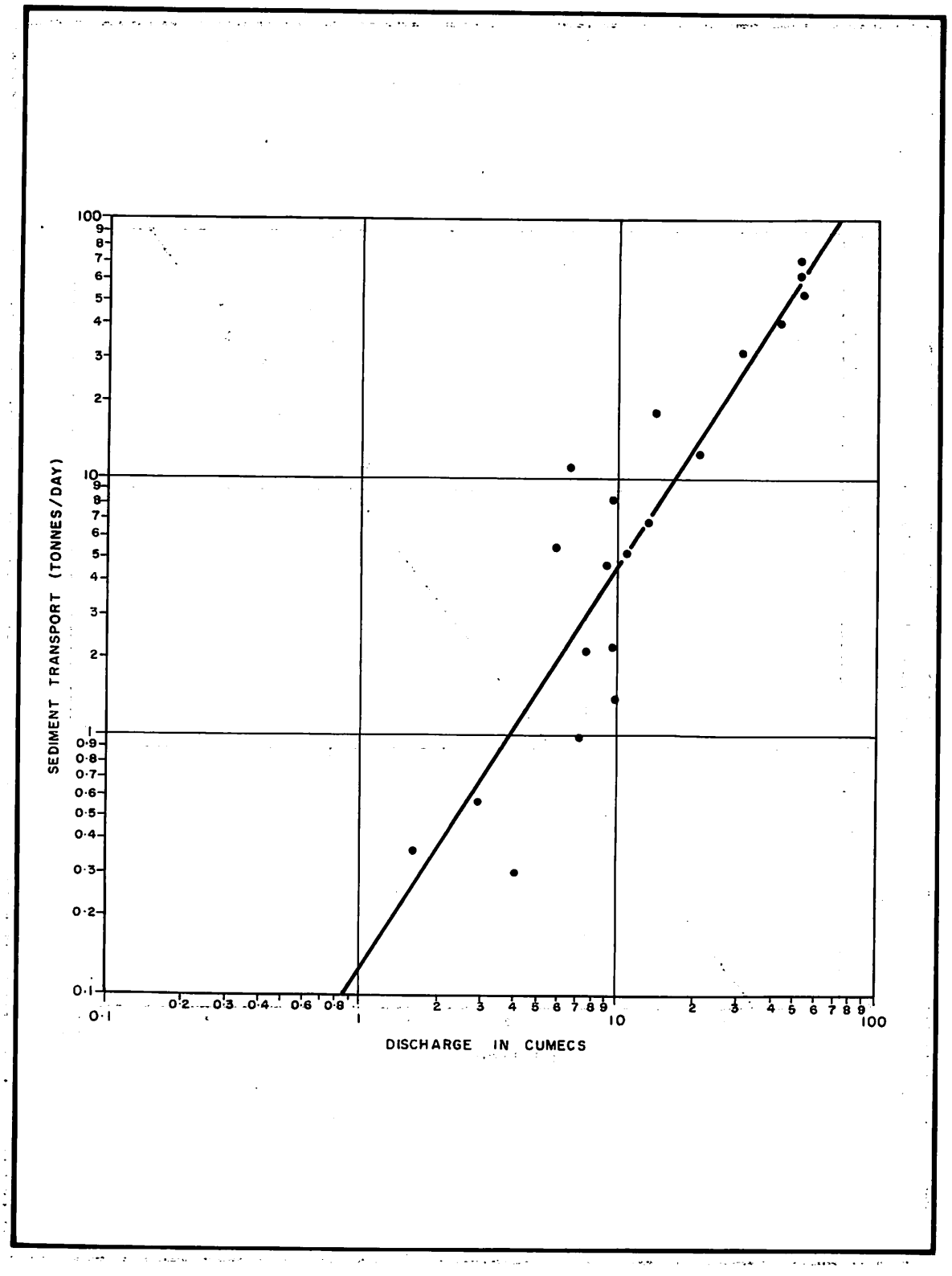


Figure 78. A Preliminary Sediment-Transport Rating Curve for the Morgut River.

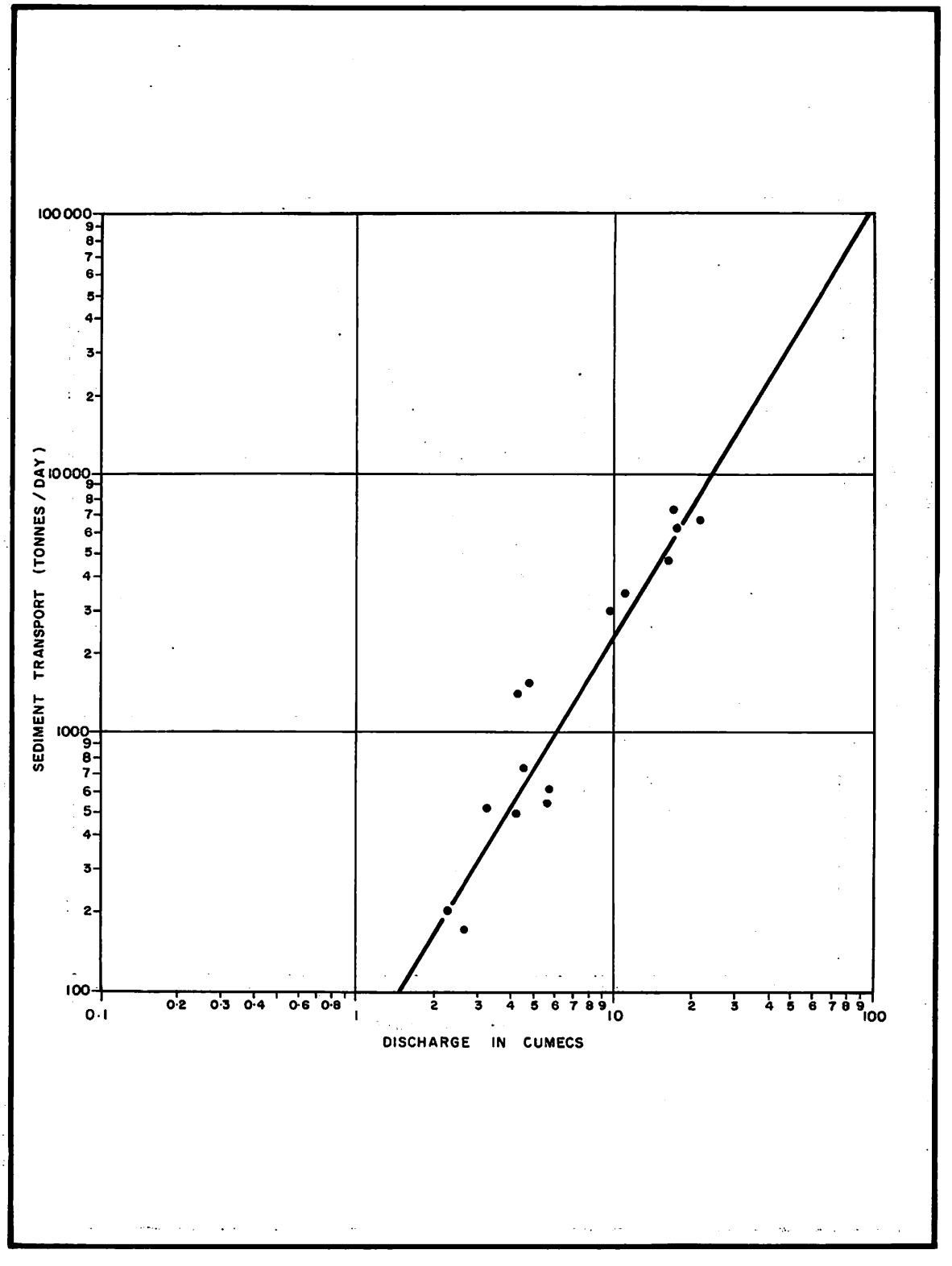


Figure 79. A Preliminary Sediment-Transport Rating Curve for the Ngurunit River.

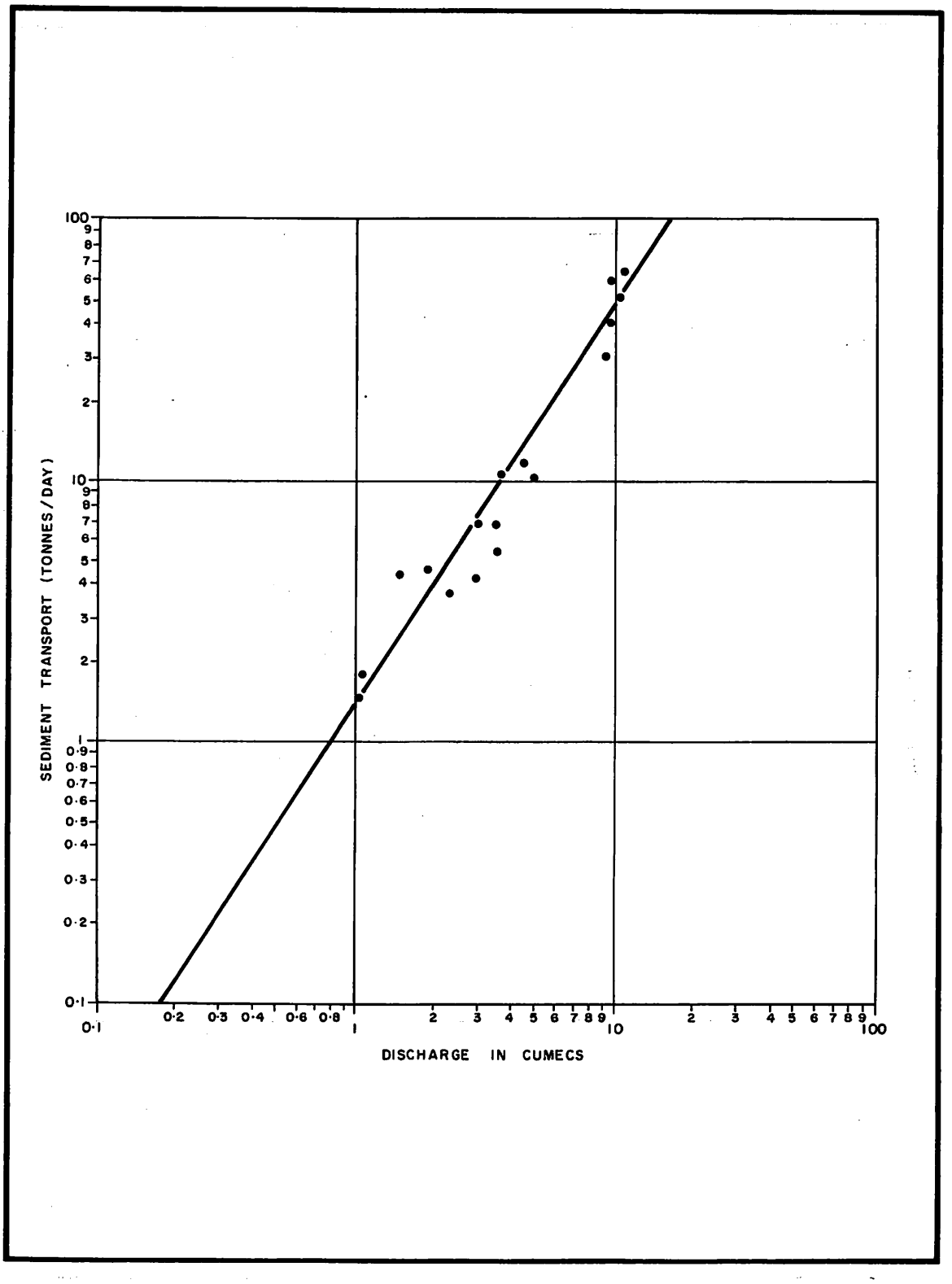


Figure 80. A Preliminary Sediment-Transport Rating Curve for Lag Balal.

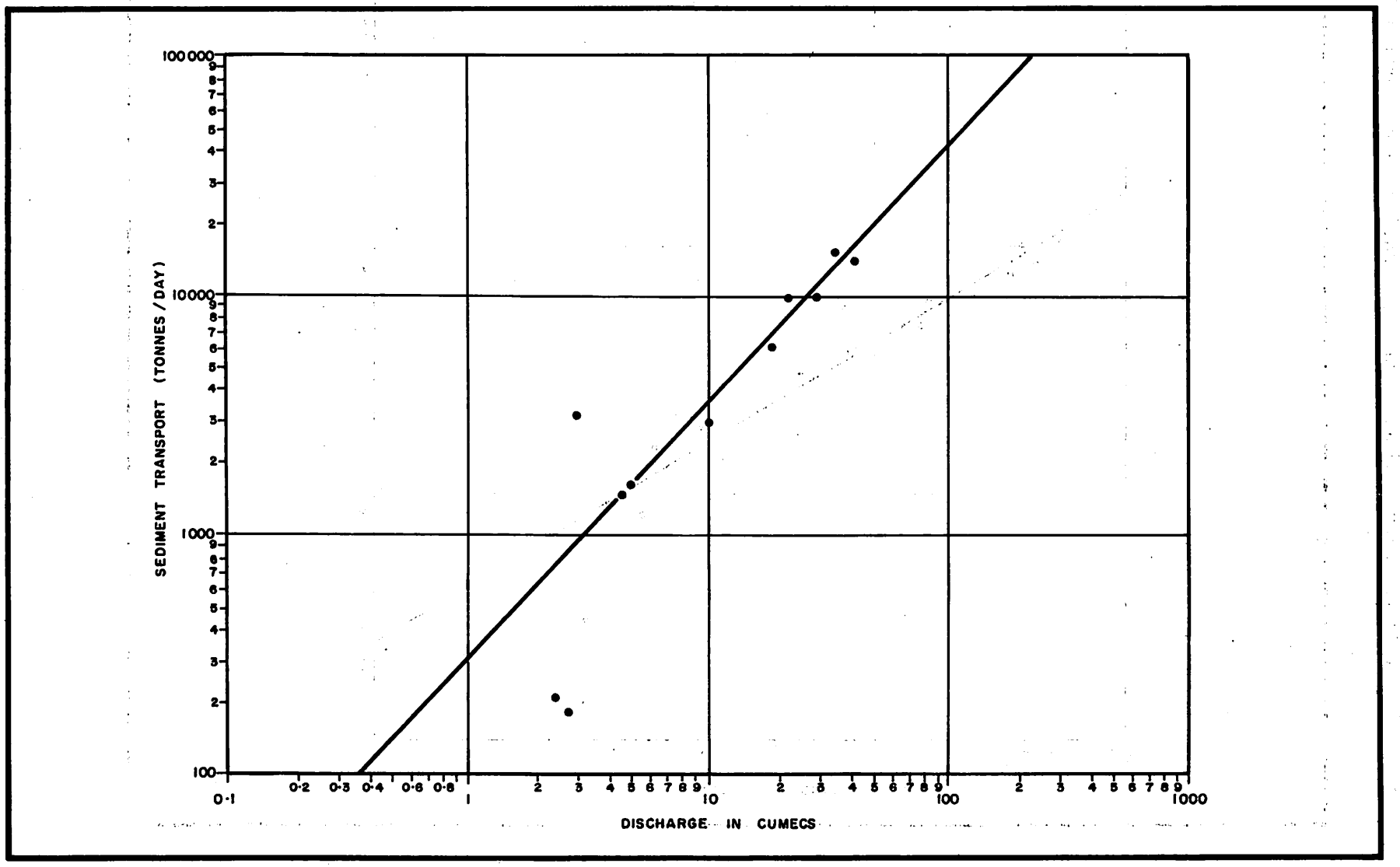


Figure 81. A Preliminary Sediment-Transport Rating Curve for the Halam River

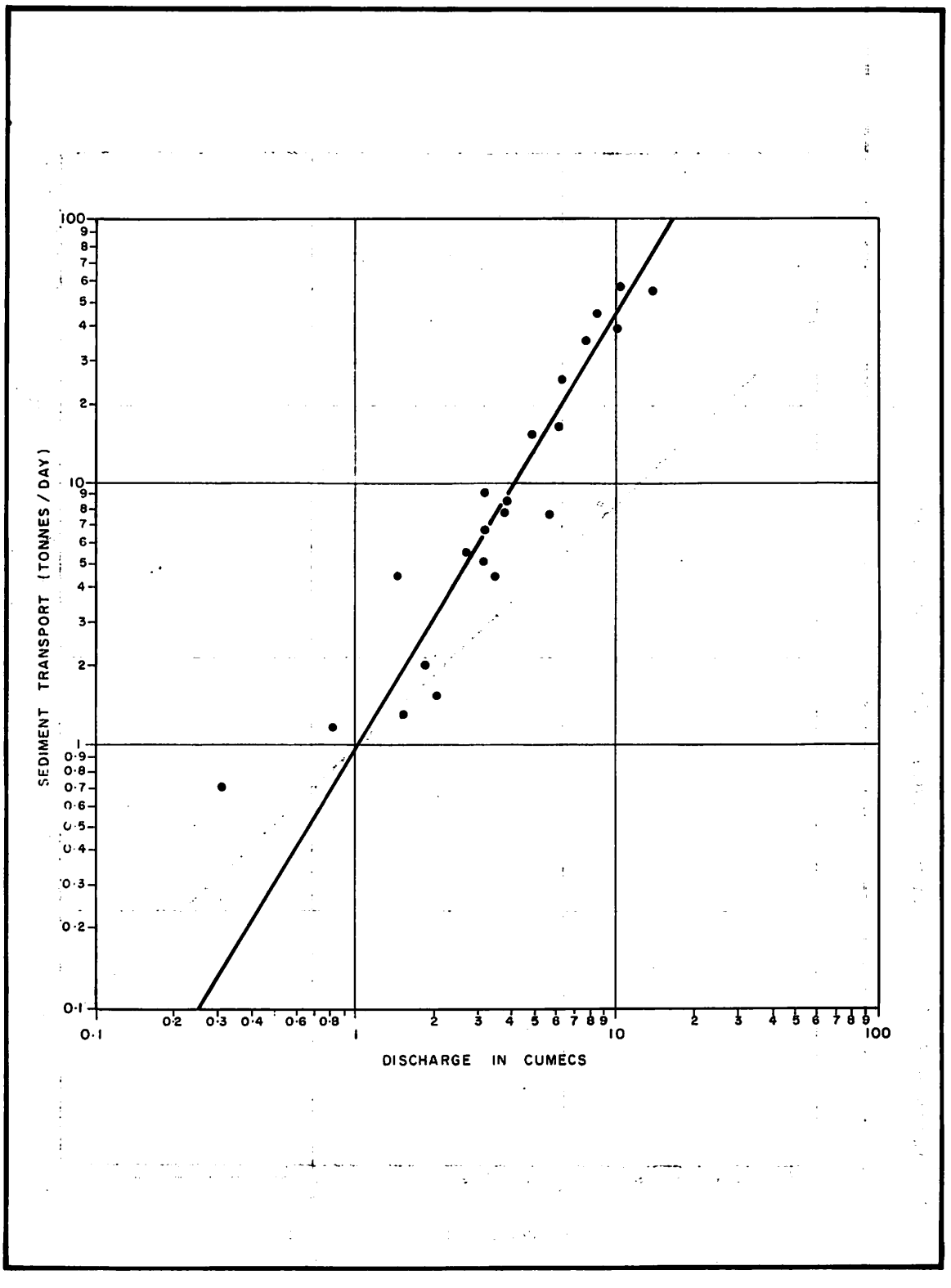
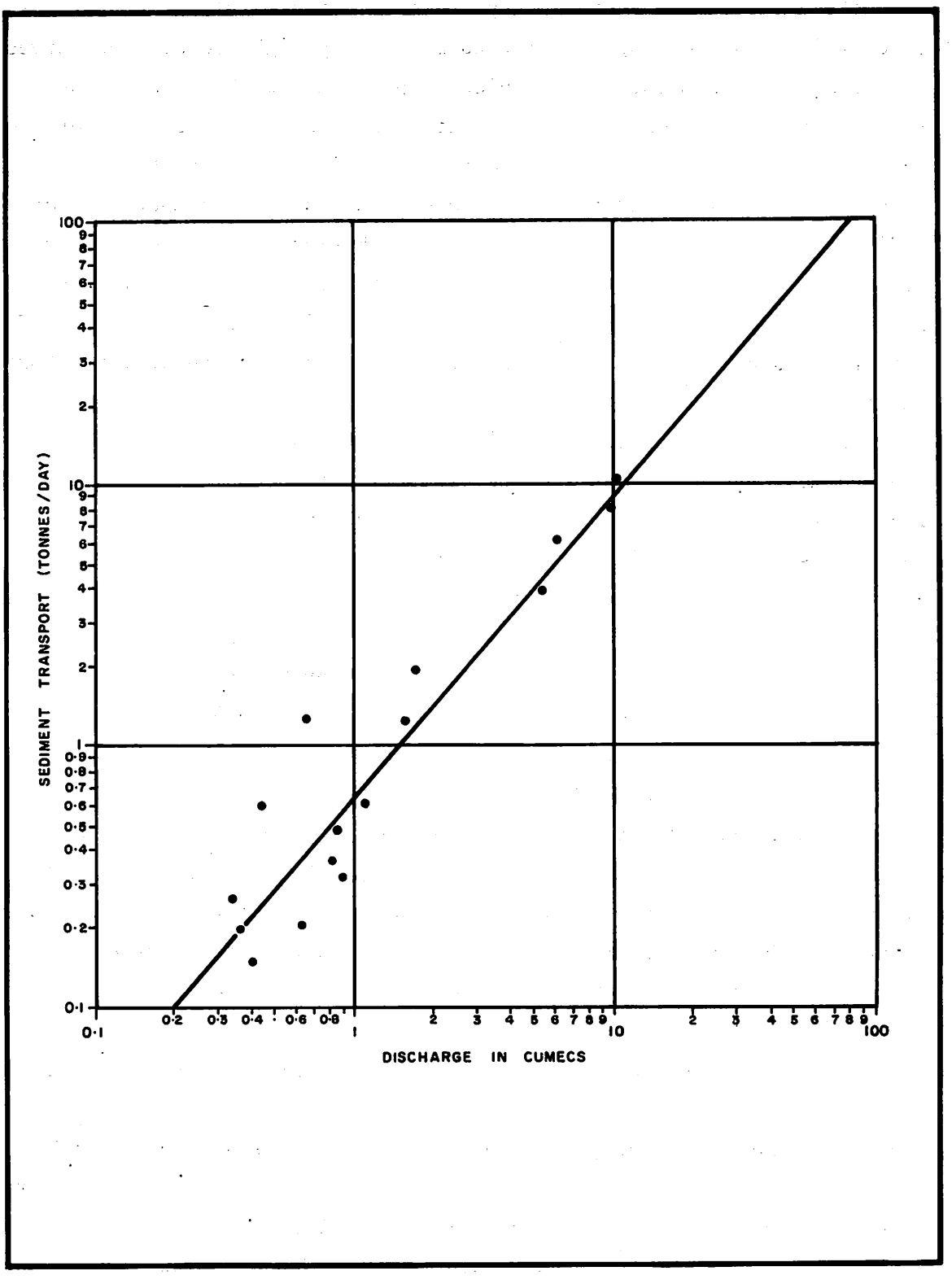


Figure 82. A Preliminary Sediment-Transport Rating Curve for the Bakuri River.



curves have been constructed using only a few observations, they are representative of the flow and sediment concentration trends for the respective sub-basins because they are based on a fairly wide range of observations made during very low to moderately high flows. The curves have remarkably similar slopes which compare well with those of Dunne (1977) for 97 catchments in Kenya. It is not unreasonable therefore to accept the present preliminininary curves as being representative of long-term conditions and therefore to use them for all computation of sediment-transport rates in the respective basins. As in any similar study there remains some uncertainty about the computed sediment yields because of inter-annual fluctuations in the sediment-rating curves. This situation is compounded by the fact that flow records are of very short duration.

The annual suspended yields shown in Table 4 were computed by using the sediment rating curves and the daily flow frequencies. These figures were, however, checked by Langein-Schumm and Douglas curves relating suspended sediment and runoff and also using the Dunn-Ongweny curves relating mean annual suspended sediment and annual runoff catchment of dominant land-use types in Kenya (FAO, 1977; Ongweny, 1978; and the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965) and applied to Kenya conditions by Ongweny (1978) and Dunne et al., 1981) and all justified the computations above.

The suspended sediment-rating curves shown in Figures 76 to 82 indicate seasonal variability (see Table 5) with Malgis leading with a sediment yield of 14.6 million tonnes, followed by Merille with about 1.8 million tonnes, and 109 tonnes for Bakuri, 3650 for Morgut and 7300 tonnes for Ngurunit, representing low flows. These are governed by flow characteristics.

THE SPATIAL DISTRIBUTION OF SEDIMENT YIELDS AND AREA PRODUCTION RATES

The mean annual sediment yields and production rates are mapped in Figures 83 to 90. In constructing the maps all the forested areas were computed to have sediment yields of less than 30t/km^2 (Ongweny, 1979; Dunne, 1977, 1979; Nyambok and Ongweny, 1979, 1980; Douglas, 1967; Dunne et al., 1972; Rapp, 1975). The least cultivated and highly grazed areas were also demarcated in the same manner taking into account the ecological considerations shown in Figure 8 and discussed in Chapter 2 of the IPAL 'Preliminary report on ecology, and management of goats, sheep and camels

Figure 83. A preliminary sediment-production pattern for Malgis drainage basin.

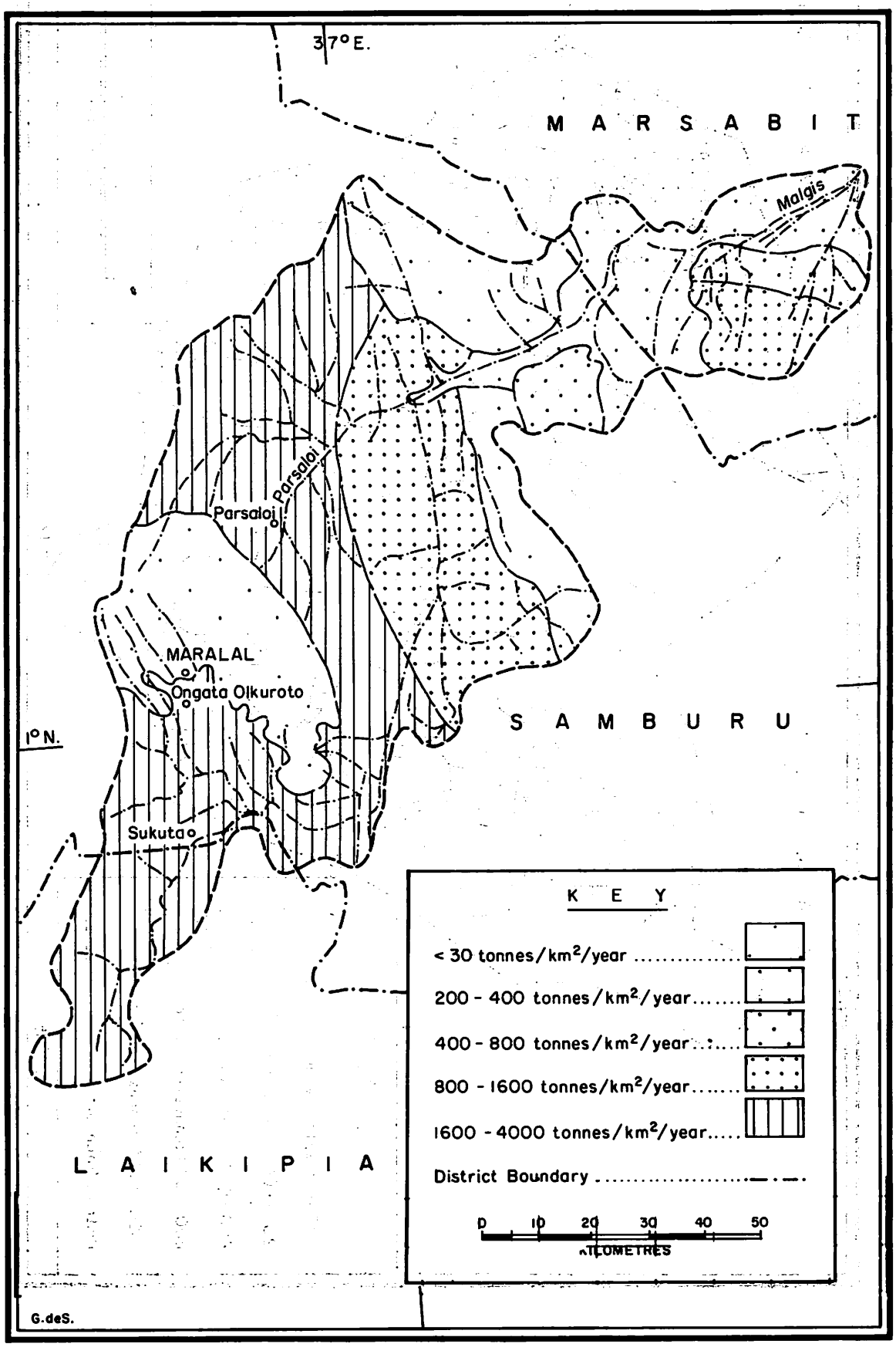


Figure 84. A preliminary sediment-production pattern for Merille drainage basin.

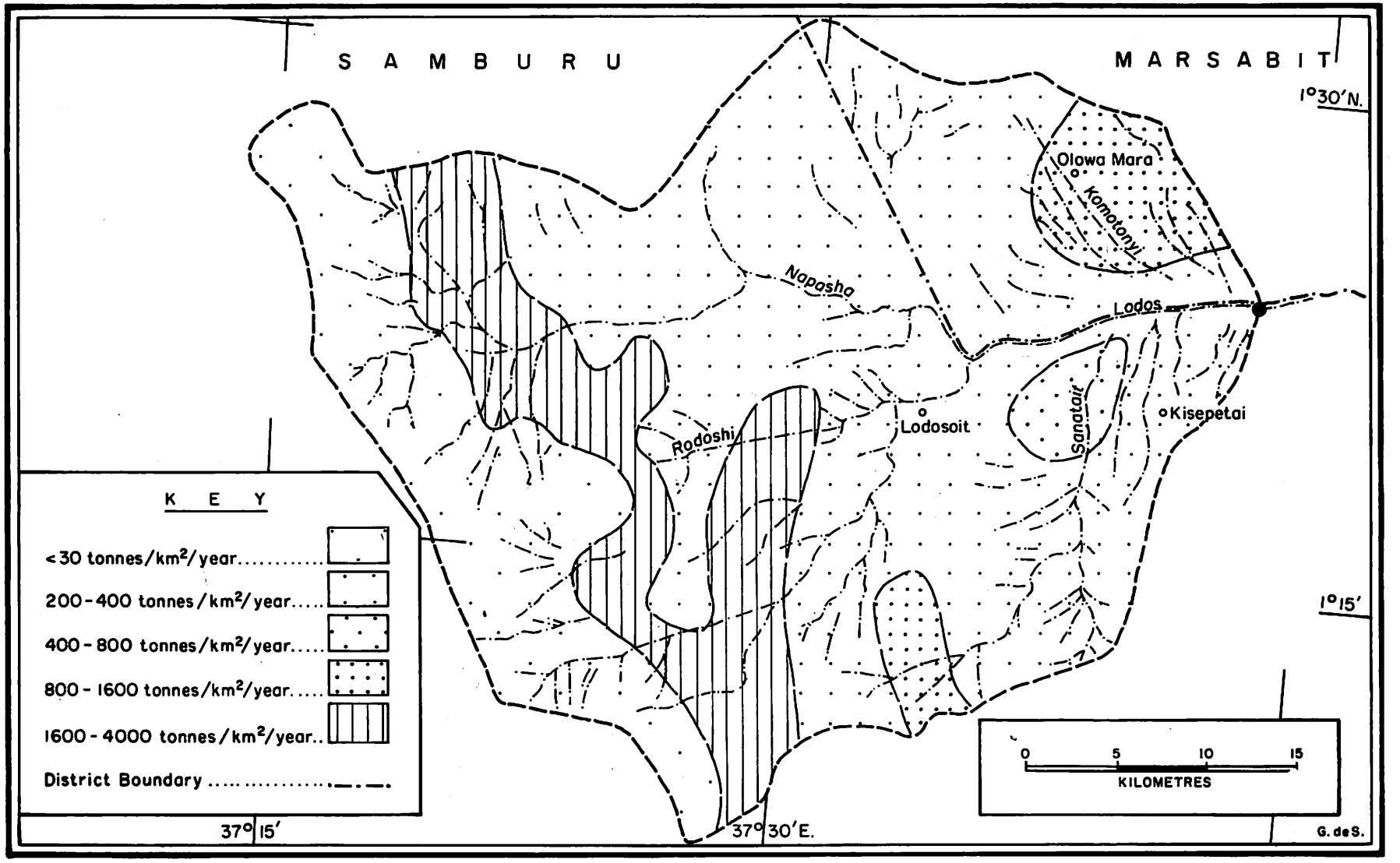


Figure 85. A preliminary sediment-production pattern for Ngurunit drainage basin.

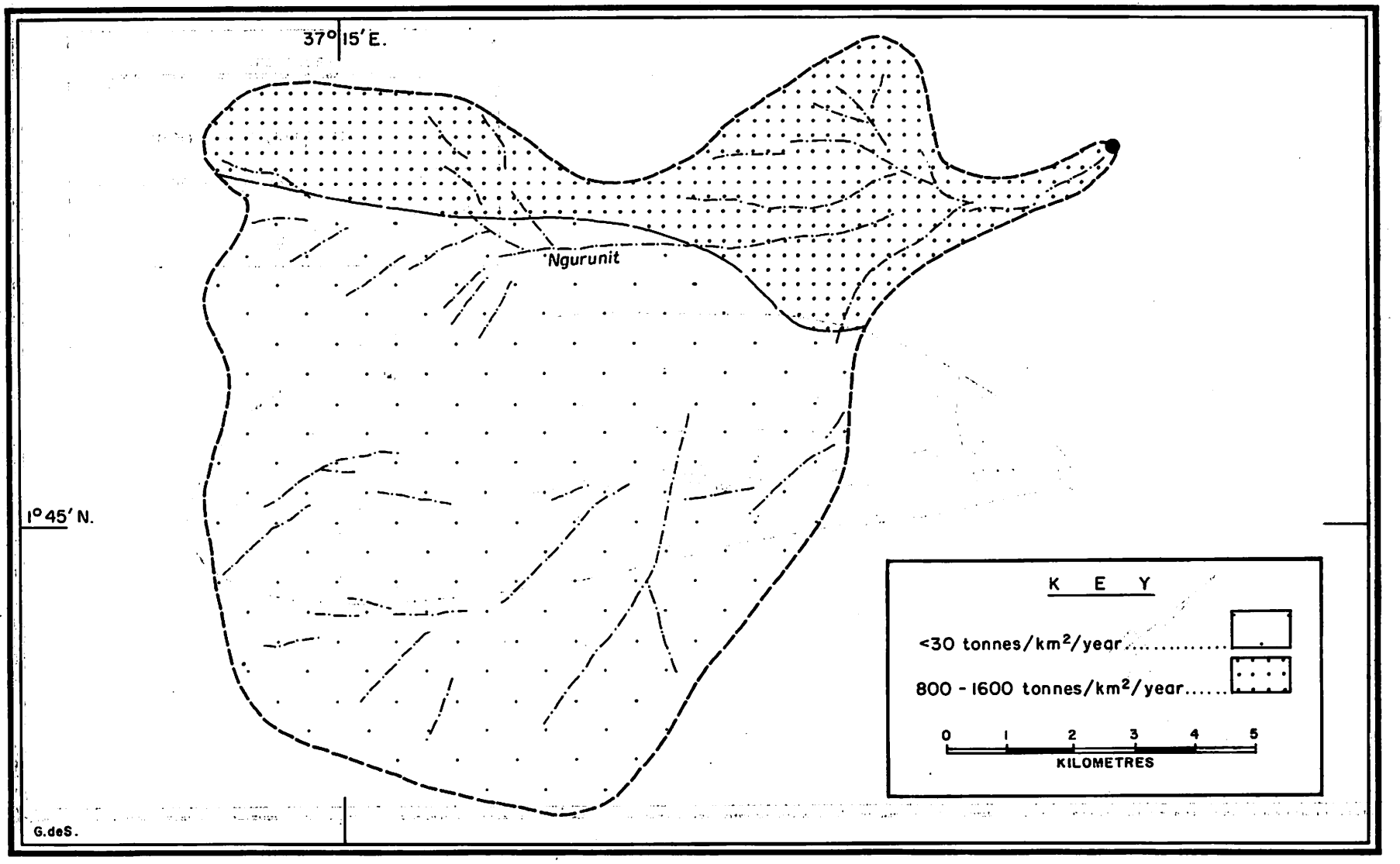


Figure 86. A preliminary sediment-production pattern for Bakuri drainage basin.

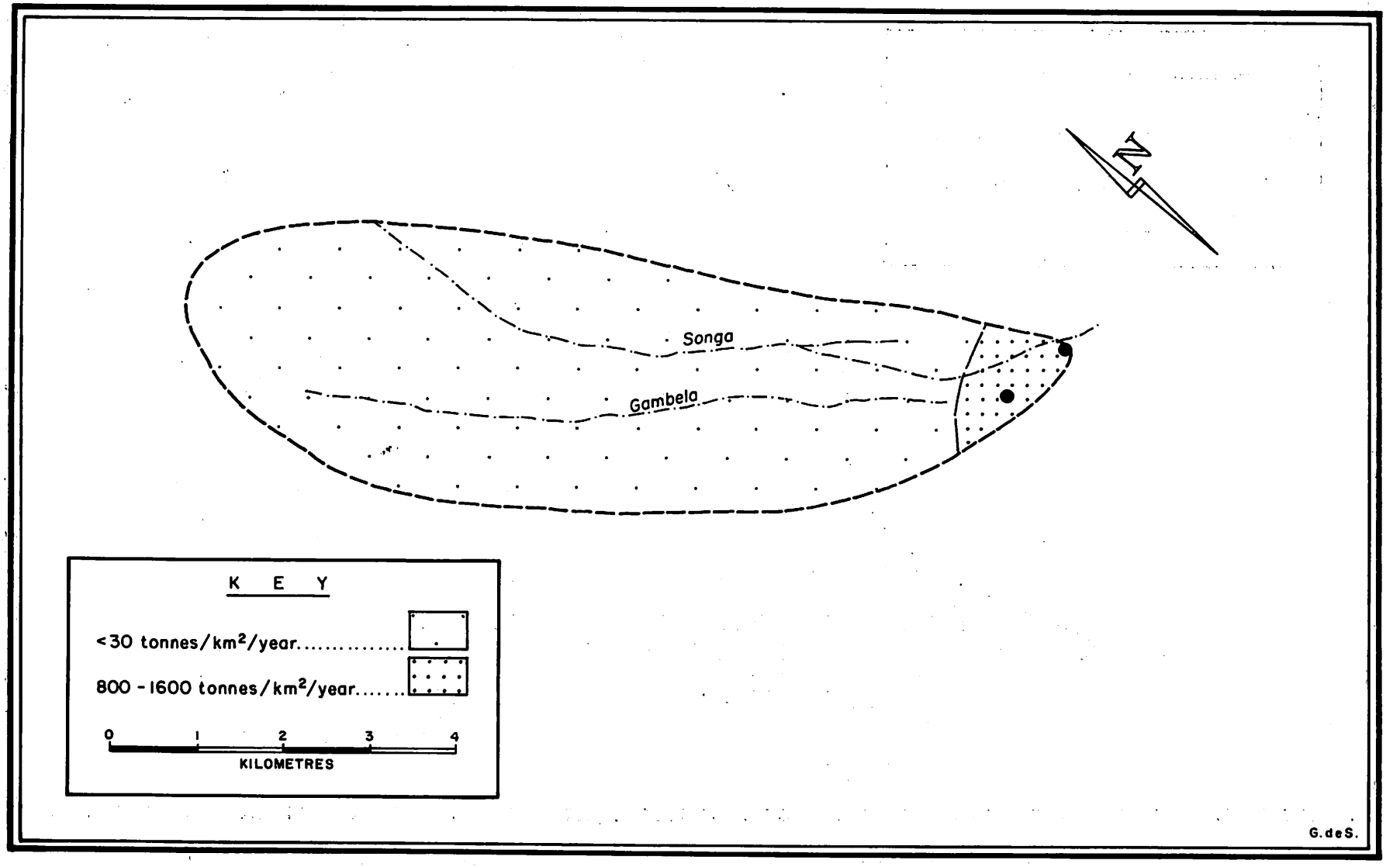


Figure 87. A preliminary sediment-production pattern for Balesa drainage basin.

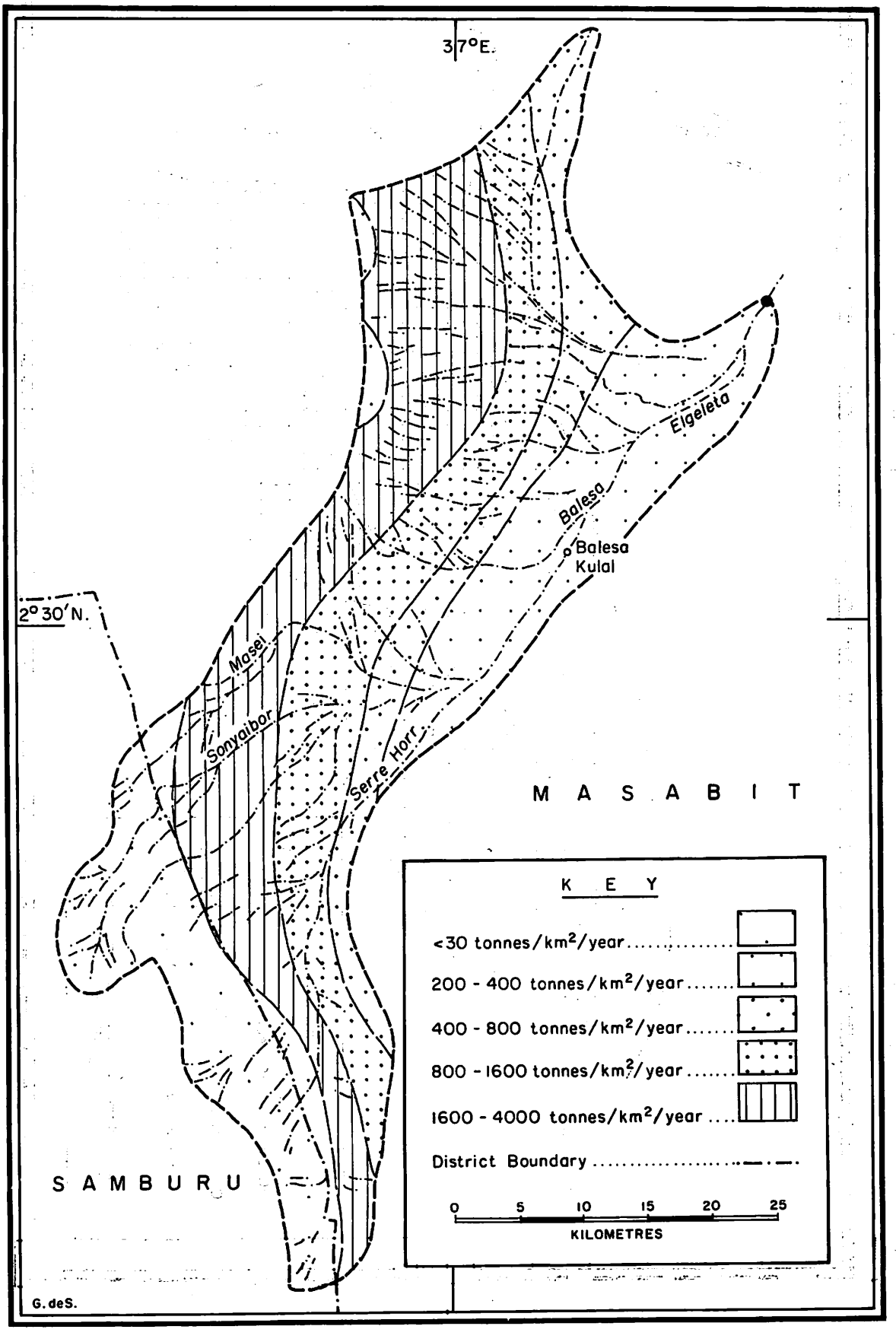


Figure 88. A preliminary sediment-production pattern for Morgut drainage basin.

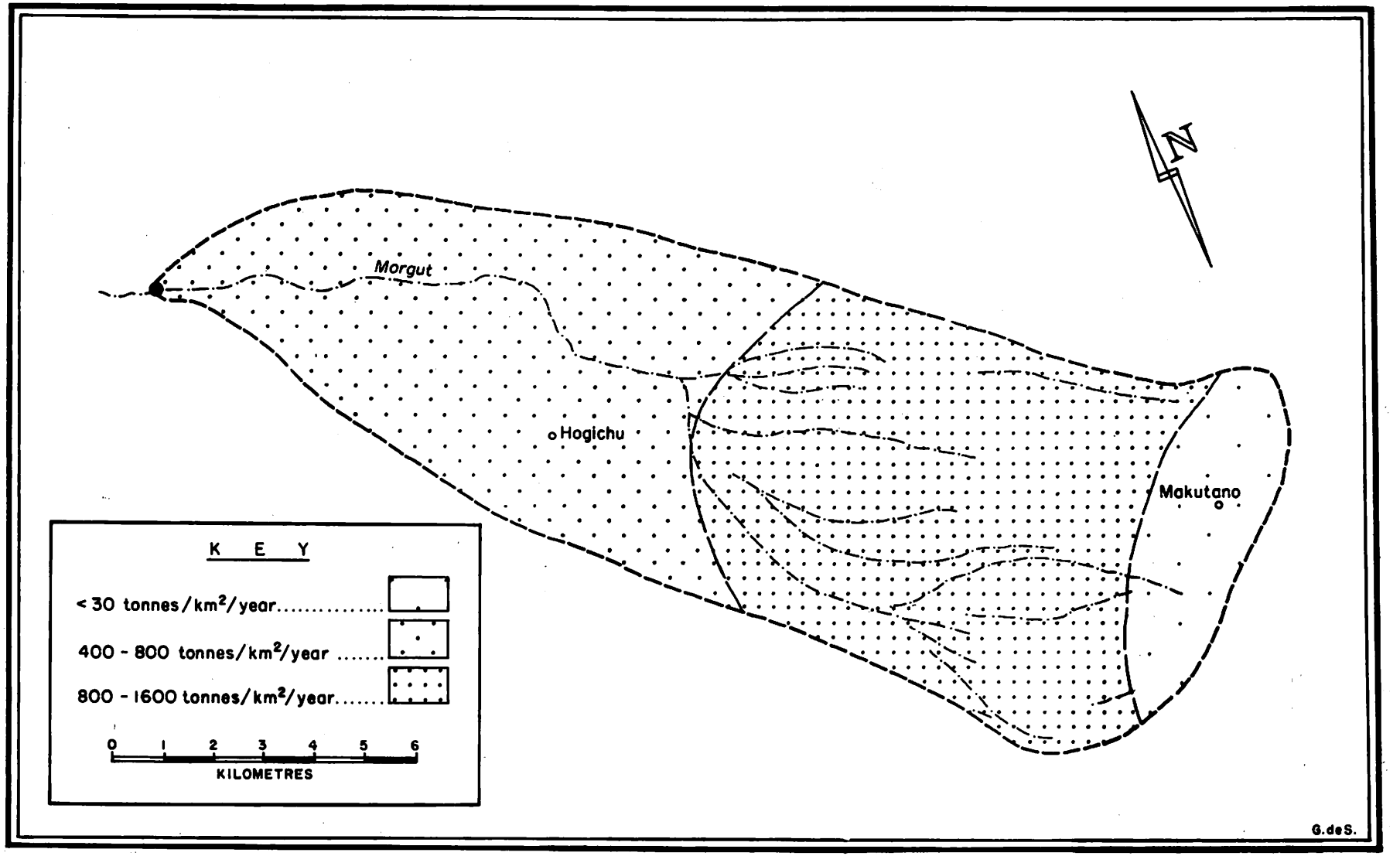


Figure 89. A preliminary sediment-production pattern for Halam drainage basin.

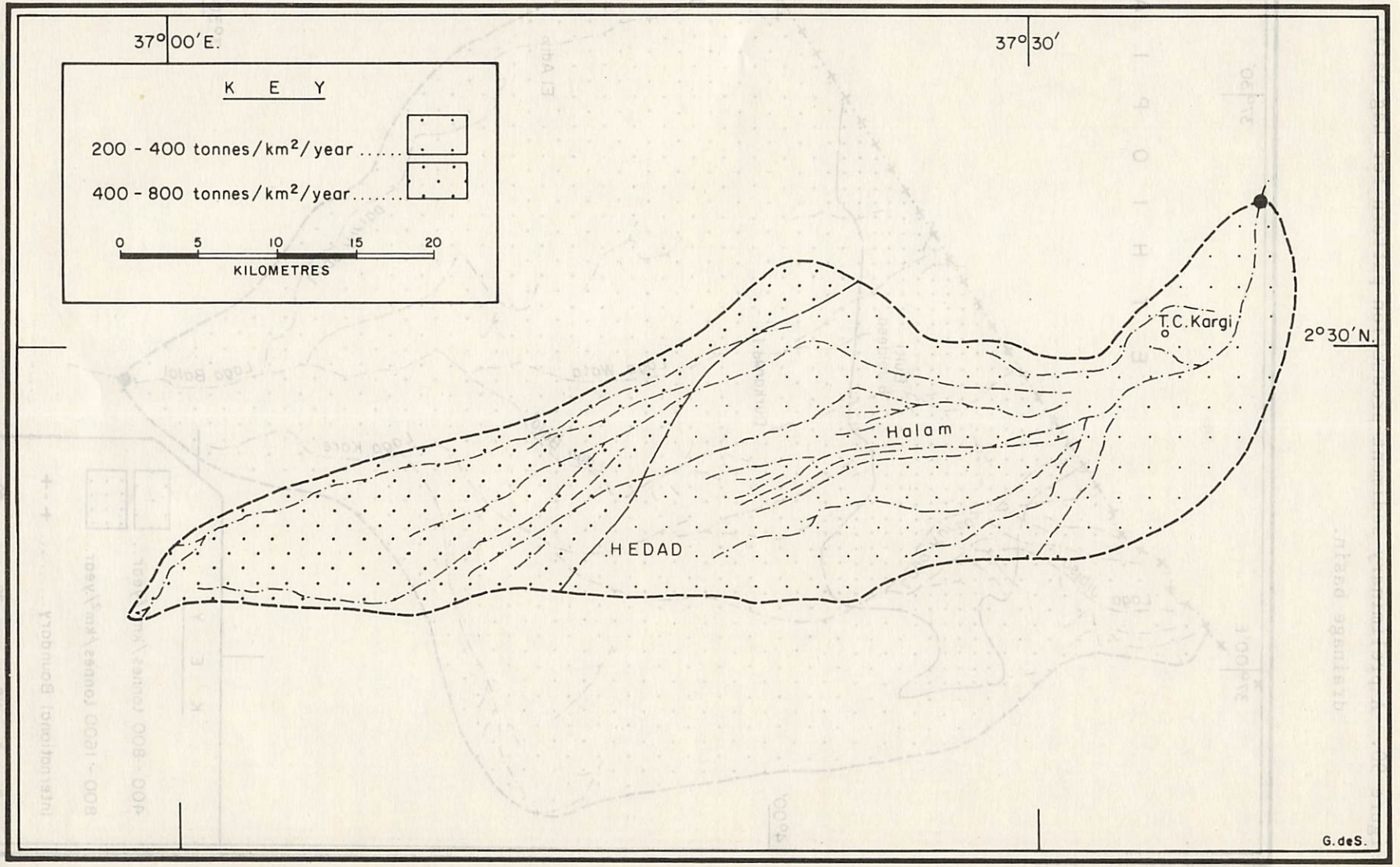


Figure 90. A preliminary sediment-production pattern for Lag Balal drainage basin.

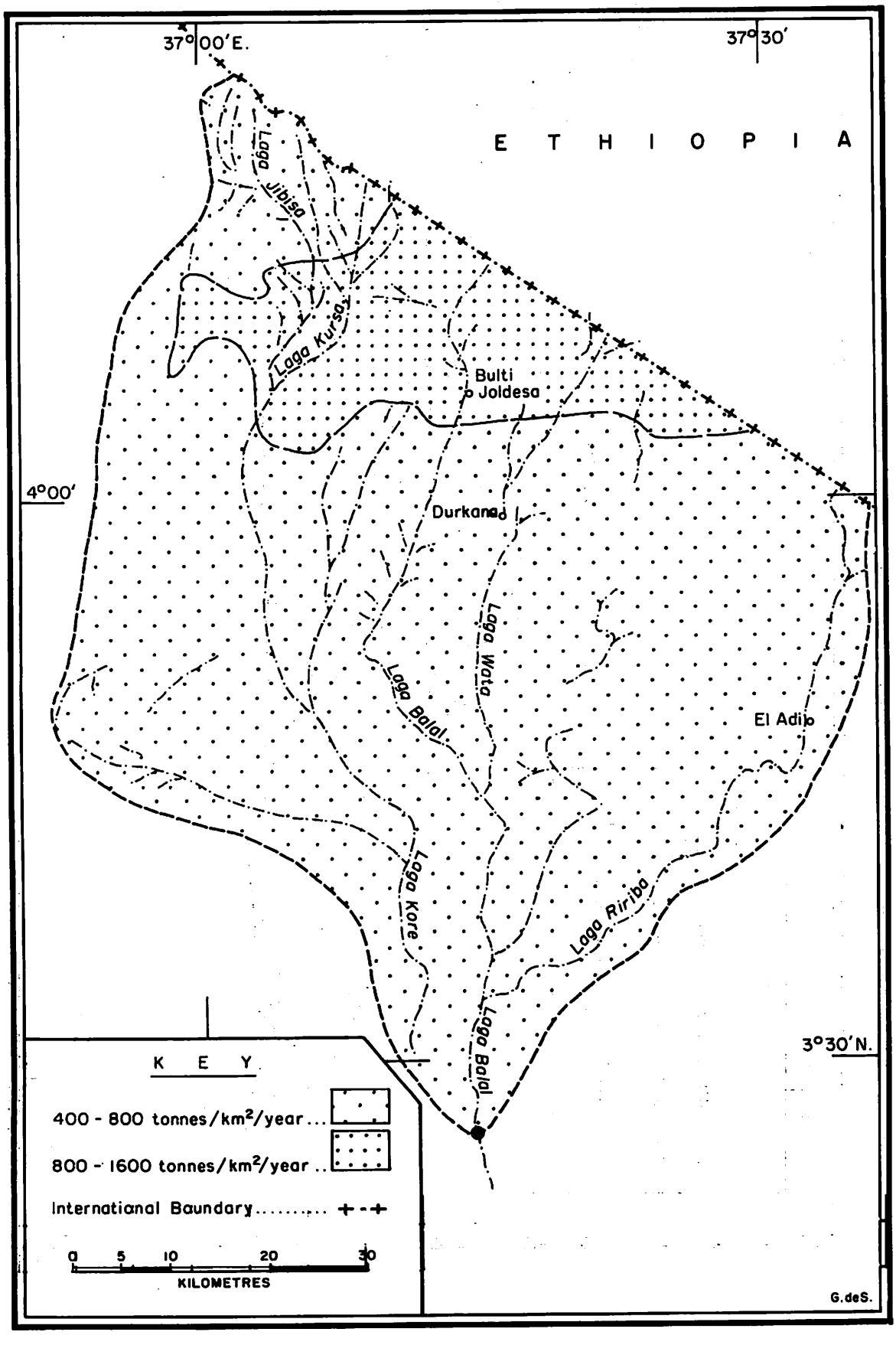


Table 4. Sediment yields in different basins

Basin	Area	Sediment yields	Sediment production
	km²	t/yr	t/km²/yr
Merille	1500	924,700	600
Malgis	9300	12,000,000	1300
Ngurunit	100	36,000	360
Bakuri	24	1,890	80
Halam	1000	444,000	440
Morgut	125	102,500	820
Lag Balal	4800	3,308,400	690
Balesa	1600	2,000,000	1200

Table 5. Seasonal (flow) variability of sediment yields

Basin	Area	High	Low
	km²	t/yr	t/yr
Merille	1500	1,800,000	365,000
Malgis	9300	14,600,000	11,000,000
Ngurunit	100	73,000	7,300
Bakuri	24	3,650	109
Halam	1000	912,500	14,600
Morgut	125	219,000	3,650
Lag Balal	4832	3,700,000	365,000

in northern Kenya', in 'Proceedings of a scientific seminar', IPAL Technical Report No. A3 (1980), 'Report on combating desertification and rehabilitating degraded production systems in Northern Kenya' (1981), and hydrological characteristics to be discussed in the next chapter. The highest figures of between 1600 and 4000 t/km²/yr of sediment are recorded in the steep, relatively well-watered areas where there is intense grazing and partial cultivation. Upper-lying slopes have sediment production of less than 1600 t/km²/yr and the lower-lying slopes have a sediment production rate of less than 800 t/km²/yr and the flat and semi-arid areas, where although rates of erosion may be high deposition takes place *in situ*, thereby recording figures of less than 400 t/km²/yr. Here wind erosion is dominant.

The observations above suggest that forests provide a very good productive cover for the soil thereby reducing rainsplash and sheet erosion. This further suggests that the forest cover has a great deal of influence not only in the geomorphic processes on hill slopes located within forested mountainous areas but also exerts considerable pressure on the hydrologic processes in these areas.

The interpretation emanating from the above discussion is that there is a strong influence of land use on sediment production as well as other ecological variables. In general, the sediment production rates tend to continue to increase progressively from the undisturbed forested areas to the partly grazed steep slopes and heavily grazed areas and again decrease to the stony arid regions of the basins. One should bear in mind that 5-20% of sediment is contributed by rural roads (see Figures 35 to 36) and this needs to be investigated.

BEDLOAD TRANSPORT

As stated earlier the bedload material within the respective catchments was not measured because of problems with instrumentation. These problems generally confront scholars of sediment transport (Gregory and Walling, 1973). However, as suggested by Hebbel (1964), empirical derivations of bedload transport can be achieved if the hydraulic geometry of a given stream and the character of the bed materiab are known (see Figures 57-67 and 68-73 and Table 3). This could be of the order of 5-10% of total sediment yields and in this case a figure of 10% has been accepted as reasonable (Ongweny, 1979; Gregory and Walling, 1973; Einstein, 1950, 1964). But this is an area requiring sufficient and adequate investigation.

CHEMICAL DENUDATION

Monitoring of the chemistry within the respective catchments as described in Chapter 4 enabled laboratory determination of the concentration of total dissolved solids of a given stream. This concentration varied with discharge. For a given discharge it was then possible to compute the solute transport rates in tonnes per day for dissolved-solids concentration. The acquired values facilitated determination of the solute transport rating curves (Figures 91-94). From the curves and the flow frequency analysis it was possible to compute the gross annual solute yields given in Table 6. These were done in the same manner as the computation of suspended-sediment yields documented earlier.

The annual solute yields shown in Table 6 are uncorrected because they are elevated above the true denudation rates by inputs of anions such as SO_4^{2-}, HCO_{3-}, CO_3^{2-} and Cl^- from the atmosphere and from biogenic sources within the soil profiles. These anion components should not be counted as denudations unless they are supplied by sedimentary rocks. In silicate rocks such as those in these basins there are no significant petrologic sources of these anions. Rainfall also imports cyclic salts from nearby Lake Turkana and the highly seasonal flooding of the Chalbi Desert should not be counted as channel denudation components. In such basins rainfall also adds to catchment salts that have originated as dust in other drainage basins. These last additions are conventionally treated as true chemical denudation (Janda, 1971) but it is difficult to separate them from cyclic oceanic or lake salts.

Janda assessed and underlined the importance of identifying denudational and non-denudational components. He has suggested that with silicate rocks the atmospheric and biogenic components should be removed from gross solute yields by dividing the latter by 1.5 to 2.5, the correction factors which vary with runoff. Dunne (1978) has carried out a study of chemical denudation of silicate rocks in various catchments in Kenya. He has demonstrated that in this country correction factors vary with mean annual runoff from 1.47 at 2000 mm to 2.55 at 100 mm. Therefore knowing the runoff of the sub-catchments under investigation it is possible to obtain a correction factor for these imports. After these corrections the true chemical denudation rates are reduced to the values shown in Table 7.

Figure 91. A Preliminary Total-Dissolved-Solids Transport-Rating Curve for the Halam River.

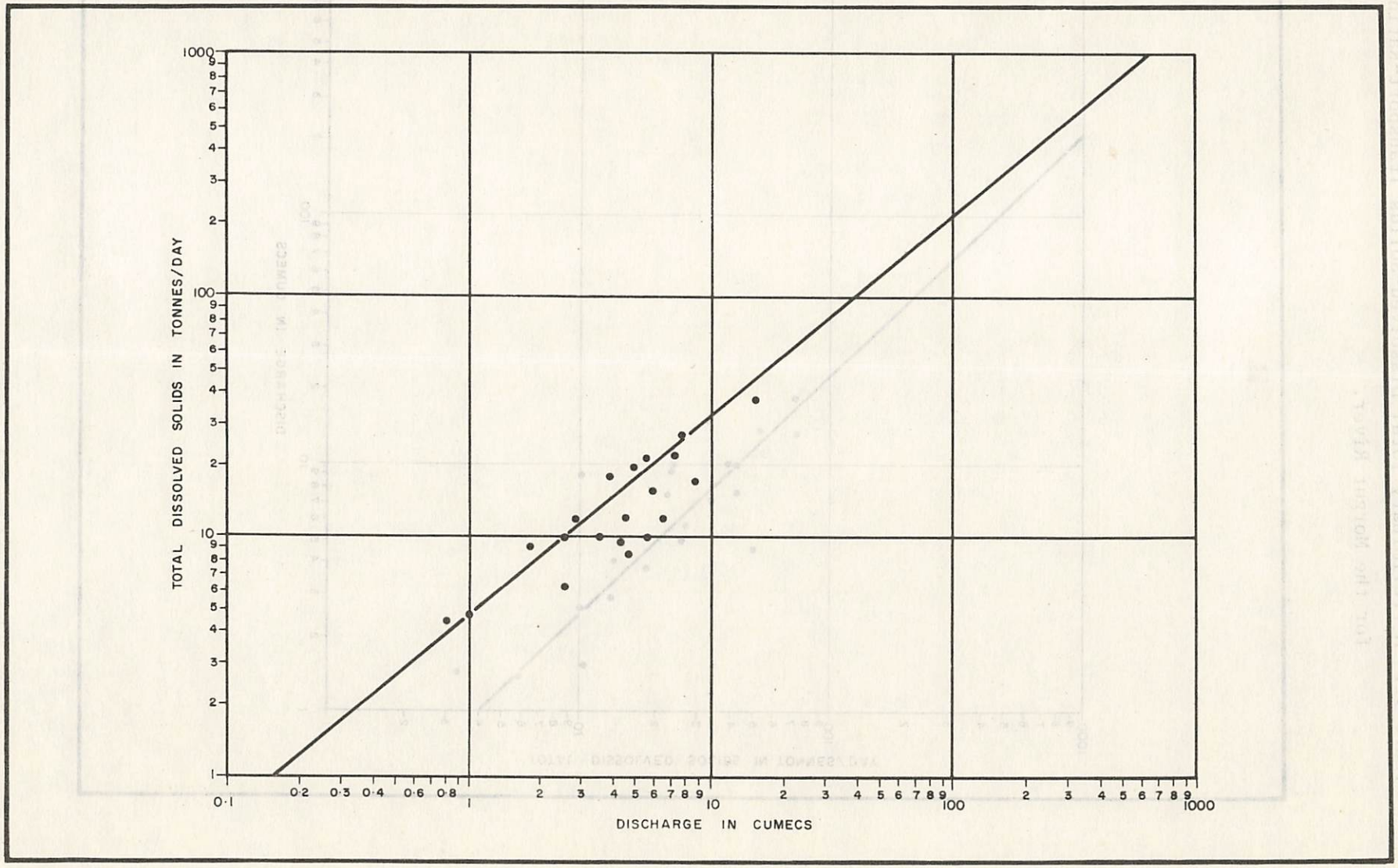


Figure 92. A Preliminary Total-Dissolved-Solids Transport-Rating Curve for the Morgut River.

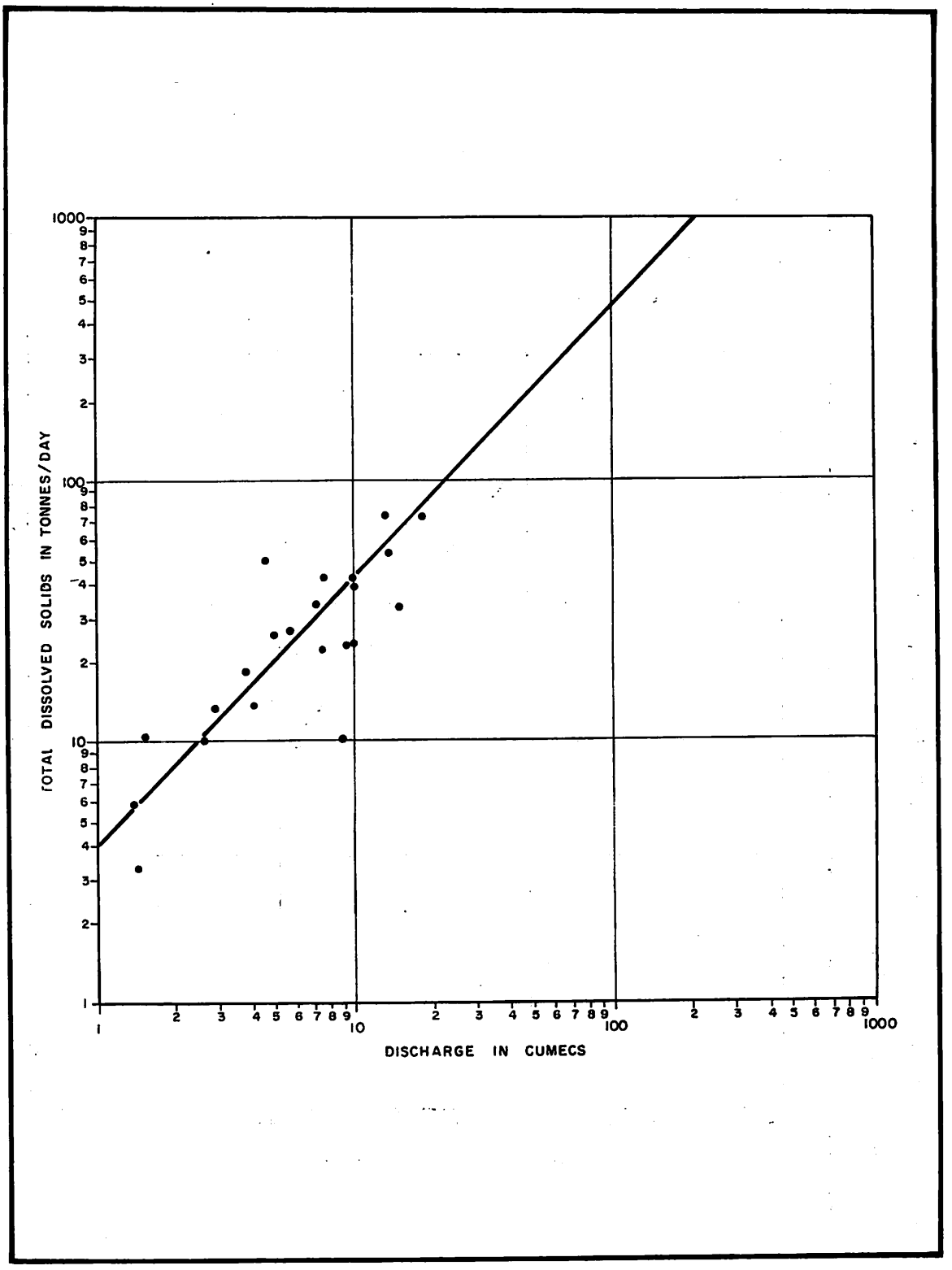


Figure 93. A Preliminary Total-Dissolved-Solids Transport-Rating Curve for the Malgis River.

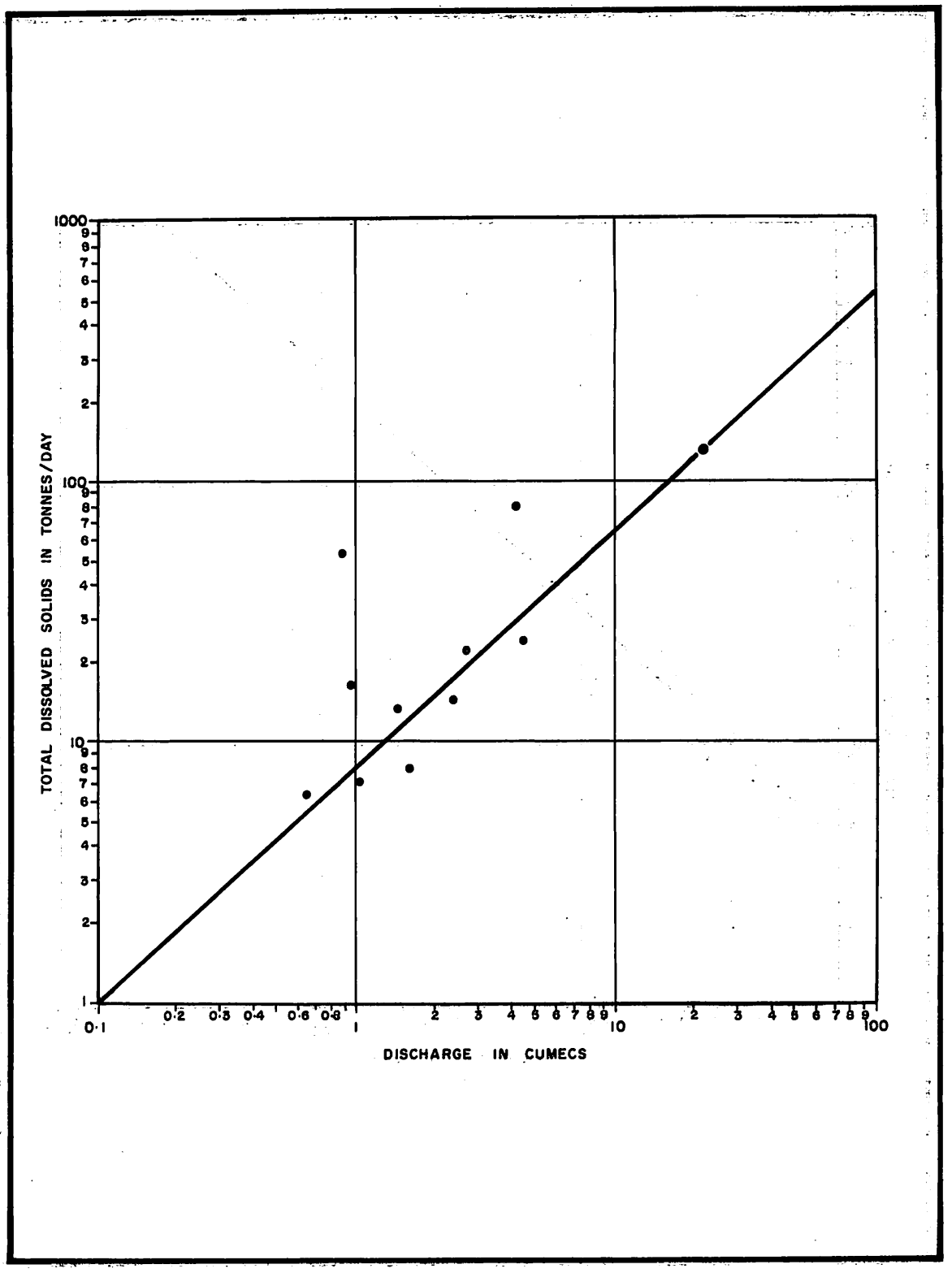


Figure 94. A Preliminary Total-Dissolved-Solids Transport-Rating Curve for the Ngurunit River.

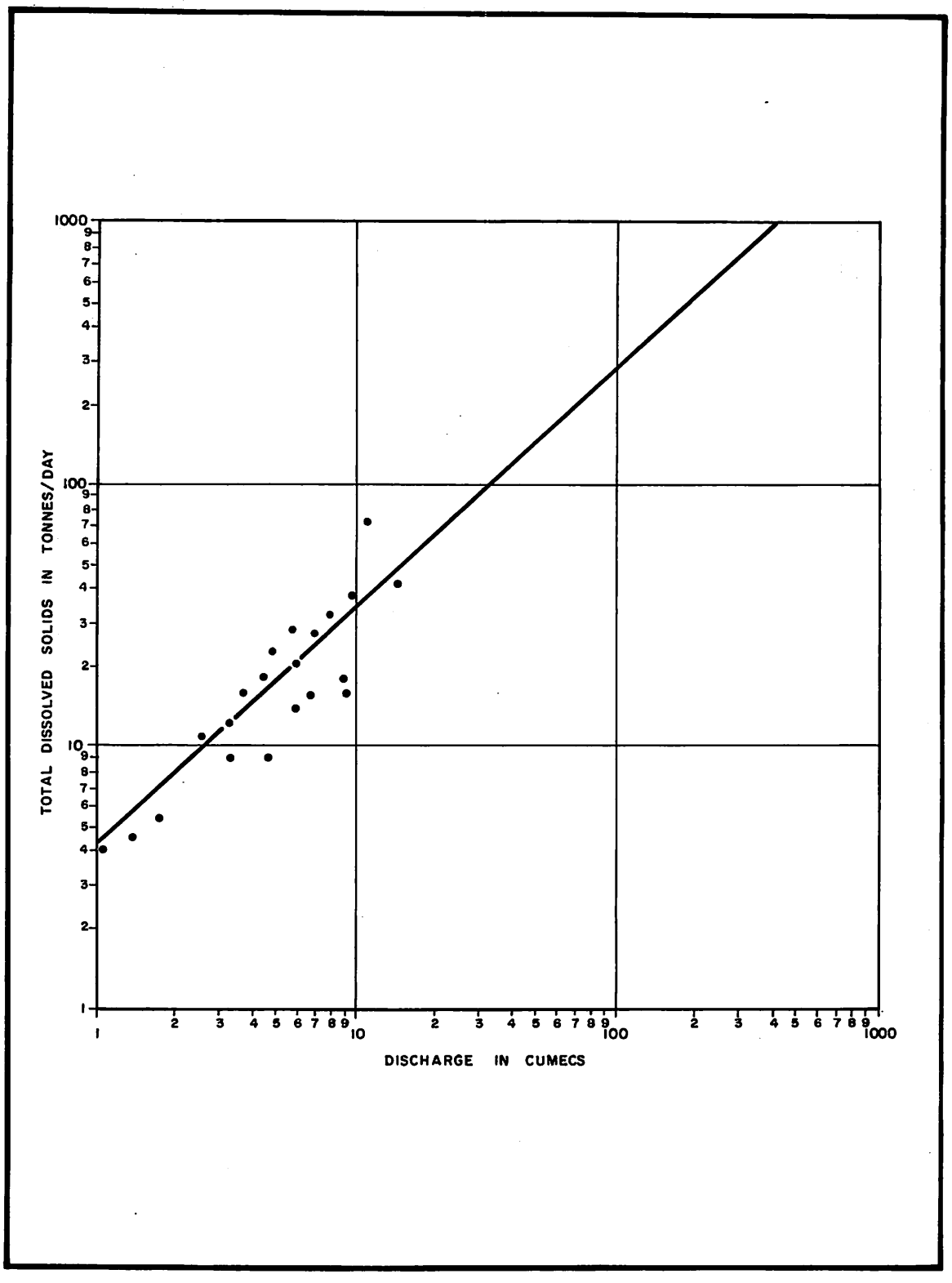


Figure 95. A Preliminary Total-Dissolved-Solids Transport-Rating Curve for the Bakuri River.

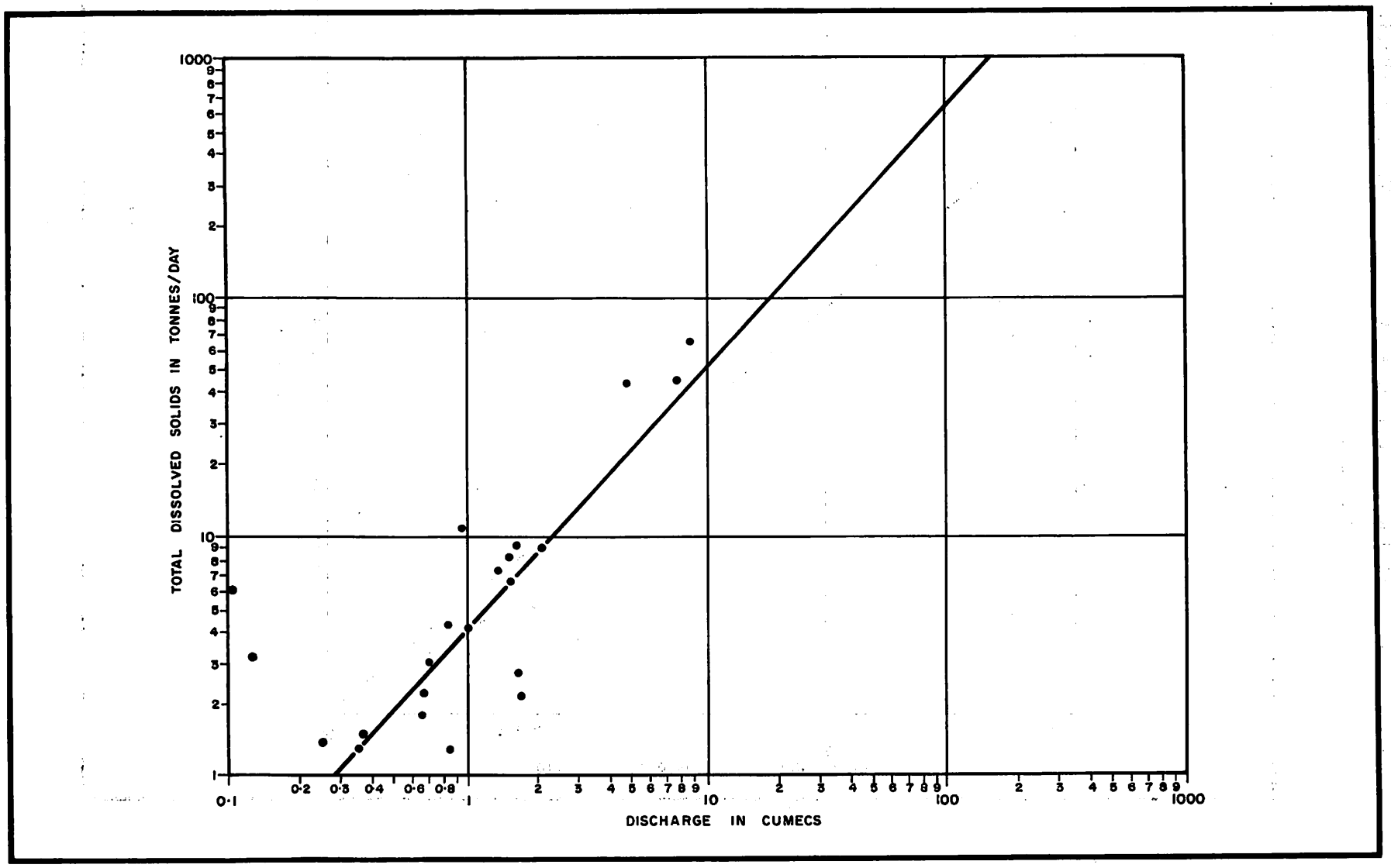


Figure 96. A Preliminary Total-Dissolved-Solids Transport-Rating Curve for the Merille River.

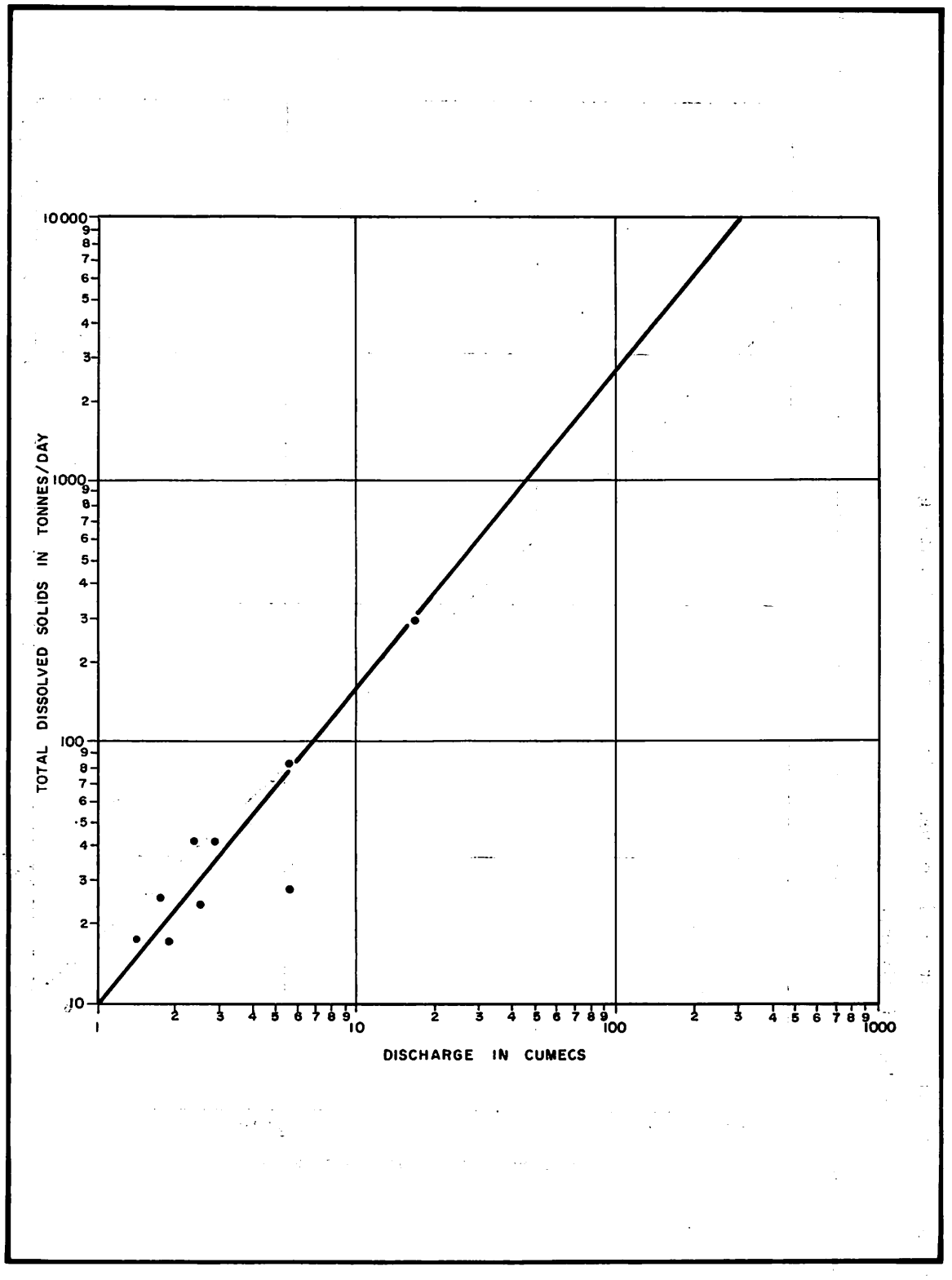


Table 6. Uncorrected total-dissolved-solids yields

Basin	Area	High	Lower	Average	Tonnes
	km^2	t/yr	t/yr	t/yr	$t/km^2/yr$
Merille	1500	14,600	7300	10,950	7.3
Malgis	9300	10,950	3650	7300	0.7849
Ngurunit	100	10,950	1825	6387.5	63.875
Bakuri	24	14,600	730	7665	319.375
Halam	1000	14,600	730	1095	1.095
Morgut	125	14,600	3650	9125	73

Table 7. Corrected total dissolved-solids yields for respective basins

Basin	Area	High	Lower	Average	Tonnes
	km^2	t/yr	t/yr	t/yr	$t/km^2/yr$
Merille	1500	8588	4294	6441	4.294
Malgis	9300	4761	1587	3174	0.341
Ngurunit	100	6083	1014	3549	35.49
Halam	1000	608	304	456	0.456
Bakuri	24	9125	456	4791	199.625
Morgut	125	9125	2281	5703	45.624

However, having corrected the solute production rates for the atmospheric and biogenic imports, one has still to correct these values for the precipitation imports of cations. Rainfall analyses carried in the present study indicate that rainfall does not contain any significant amount of silica.

The new values suggest that chemical denudation continues to increase with increasing runoff and it is highest in Mt. Marsabit Forest Reserve followed by Morgut and Ngurunit. These are zones that receive high rainfall containing high concentrations of carbonic acid (CO_2 in solution) and other acids of organic origin.

Chapter VI

SURFACE-WATER RESOURCES, THEIR CONSERVATION, DEVELOPMENT AND RECOMMENDATIONS

INTRODUCTION

The variables governing the drainage network and patterns in the respective drainage areas have already been discussed in earlier chapters. The methodology used to measure the quantity and quality of the water resources in the given basins has also been discussed in Chapter 4 of this study.

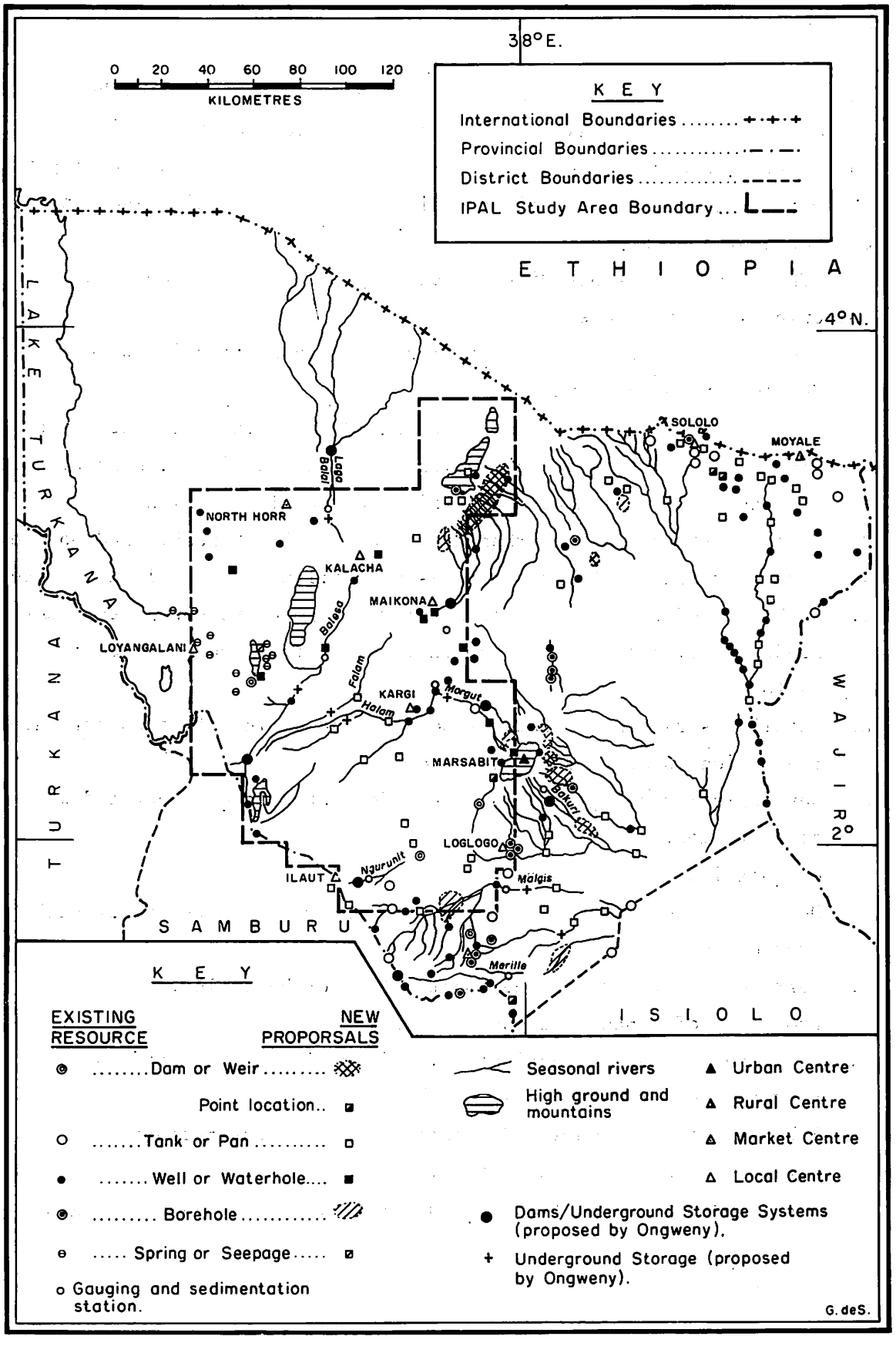
The 1979-83 Marsabit District Development Plan outlines the following water problems:

1. Lack of hydrological investigations to enable effective water development progamming.
2. Water facilities have been concentrated in certain clusters (see Figure 97) and this concentration of human and livestock populations has caused a problem of overgrazing on fragile rangeland.
3. Water shortages in the urban areas, especially Marsabit and Moyale.
4. Forty per cent of the district is not utilized due to lack of water.
5. Inability of the Ministry of Water Development to cope with water needs. They continue to list their objectives and proposed strategy as follows:

a. Detailed surveying of water resources and siting of works for water regulation, storage and extraction.
b. Developing hydrology models to use for water development and water conservation.
c. Calculation of water demand.
d. Designing and constructing dams, runoff improvements, river bank protections.
e. Carrying out tests and the construction of boreholes.
f. Provision of urban water-supply schemes.
g. Water harvesting projections, i.e. improving the runoff and therefore water catchments.
h. Rehabilitation of dams and existing water infrastructure.
i. Sewage systems in urban centres.
j. Water spreading activities in the drier areas to reduce overgrazing.

Figure 97. Topography, Drainage and Water-Development Network of parts of Marsabit District.

Source: Marsabit Development Plant 1979-1983.



They have outlined water development programmes which need not be reviewed here.

However, for the efficient development of water resources it is useful to know the total amount of water available for various uses. The variability of this amount is almost as important as its average value.

WATER RESOURCES

Quantity

The methodology of the measurement of water resources and its analysis was discussed in Chapter 4 of this report.

The computation of the discharge shown in Table 8 was mainly accomplished by discharge rating curves and modified by flow frequency analysis shown in Figures 40-45, while those for Lag Balal and Balessa were extrapolated from the Malgis figures in conjuction with the few current water gaugings carried out on site.

For Bakuri the low flow measured was of the order of 0.4 m^3 with a high flow of about 1.4 m^3. This would give an annual high and low flow of 35 and 13 million m^3 per year. Malgis, on the other hand, recorded high and low flows of 20 m^3 and 2 m^3 respectively representing 7884 million and 788 m^3 respectively. These and other recordings are shown in Table 9 and annual flows are given in Table 8.

The annual computed high flows shown in Table 8 are not realistic because most of these streams are highly seasonal and ephemeral in character and this is demonstrated very clearly when one computes the discharge in terms of the flows recorded from the discharge-rating curves shown in Table 8 in terms of drainage area in mm per year. The annual low-flow figures would tend to give a much better picture because, as Dunne and Leopold (1978) have shown, about 80% of the water is lost through evaporation in the open water bodies of parts of northern Kenya.

It must be understood that these figures represent the overall basin runoff because most of these streams obtain their waters from outside the IPAL study area. This is particularly true for Malgis, Merille, Balessa and Lag Balal. This means that the drainage basins studied, covering an area of close to 20,000 square kilometres, have a total discharge of close to 2 million cubic metres per year or a runoff of

about 1300 mm per year. This excludes the water resources on the various surface dams documented in Marsabit Development Plan 1979-83, also listed in Chapter 3 of this study which account for almost 700,000 m^3.

Quality

The water chemistry data for Malgis River shown in Table 10 indicate that the water is slightly alkaline and of acceptable hardness and mineralization. The water is, however, heavily loaded with mud with a turbidity of up to 50,000 JTU. This water should be filtered to reduce colour and turbidity. The coliform count indicated that there were 1800 *Escherichia coli* per 100 ml of water, which means that apart from the chemical pollution this water is bacteriologically polluted and is therefore unsatisfactory for drinking purposes unless it is further treated.

Water chemistry data given in Table 11 show that the water is slightly alkaline with average softness and mineralization, but as in the Malgis case it is heavily loaded with mud giving turbidity values of up to 15,000 JTU, an indication of sediment pollution. The bacteriological examination of this water reveals that the *E. coli* count is far above normal (10-25%). This water is therefore unsatisfactory for drinking purposes although it could be useful for other purposes, e.g. irrigation.

Ngurunit water chemistry data are given in Table 12. This shows that the water is soft and of acceptable alkalinity as well as being average in terms of mineral content. It is chemically suitable for human consumption and other multipurpose uses. The bacteriological examination of the water indicates that the coliform count lies well between 10 and 25 per 100 ml of water meaning that the water is of good bacteriological quality and therefore suitable for all purposes.

Like the Ngurunit water, the water-chemistry data for Bakuri given in Table 13 indicate that the water is neutral and moderately soft, of low mineral content and is as such chemically suitable for human consumption and other multipurpose uses. The *E. coli* (coliform) count lies between 10 and 25 per 100 ml of water and hence the water is quite suitable for multipurpose uses.

Table 8. Summary of water resources by basin.

Basin	Area km²	Million m³/yr		mm/yr per drainage area**		Average runoff mm/yr**
		high	low	high	low	
Malgis	9300	7884	788	847	850	470
Ngurunit	100	85	18	850	190	519
Morgut	125	221	19	1800	150	975
Merille	1500	1261	315	840	210	525
Halam	1000	284	32	283	31	157
Bakuri	24	35	13	1500	525	1000
*Lag Balal	4800	442	315	262	66	163
*Balesa	1600	5076	380	800	80	440
Total	18,500	15,300	1900	7000	1300	4250

*Estimated from Malgis and a few current-meter gaugings.

**Evaporation accounts for about 80% of water lost from open water bodies in northern Kenya (Leopold and Dunne, 1978).

Table 9. Recorded flows.

Stream	Low flow	High flow
	m^3	m^3
Bakuri	0.4	1.4
Morgut	0.6	7.0
Halam	1.0	9.0
Ngurunit	0.6	2.7
Malgis	2.0	20
Merille	10	40
Lag Balal	10	40
Balesa	4	40

Table 10. Water chemistry data for the Malgis River, 1981
(colour in Hazen units, turbidity in JTU, and all other ions in mg/l).

	7 May	18 May	19 May	7 May	21 May	11 May	9 May	22 May
Colour	3,000,000	50,000	60,000	40	20,000	600	60	120,000
Turbidity	1500	15000	45,000	9.7	3000	190	8.5	50,000
Deposition	Mud	Mud	Mud	Silt	Silt	Mud	Silt	Mud
pH	8.0	7.5	7.5	7.2	7.4	7.3	7.1	7.4
Free carbon dioxide	2	20	10	9	1	2.0	4	Nil
Free and saline ammonia as nitrogen (N)	Nil	0.164	0.656	0.118	Nil	0.26	0.722	0.213
Albuminoid ammonia as nitrogen (N)	2.985	0.082	1.148	0.079	0.131	0.80	0.308	11.874
Nitrates as nitrogen (N)	Nil	Nil	1.0	Nil	0.25	Nil	Nil	1.5
Nitrites as nitrogen (N)	Nil	0.001	Nil	Nil	0.01	Nil	Nil	Nil
Oxygen absorbed. Four hours at 27°C (O)	1.25	1.7	2.4	2.3	1.6	9.6	1.35	1.9
Alkalinity as $CaCO_3$ - phenolphthalein (carbonate)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	20
Methyl Orange (bicarbonate)	174	142	116	182	166	136	207	128
Carbonate hardness as calcium carbonate ($CaCO_3$)	160	146	120	176	140	120.0	172	134
Non-carbonate hardness as calcium carbonate ($CaCO_3$)	Nil	4	4	Nil	Nil	Nil	Nil	6
Chloride (Cl)	22	22	24	16	26	24.0	19	28
Sulphate (SO_4)	34.25	33.5	35.75	6.5	17	10.0	2	42
Silica (SiO_2)	20	30	5	30	20	30.0	20	200
Fluoride (F)	0.47	0.58	0.8	0.44	0.54	0.7	0.44	0.42
Potassium (K)	6.88	6.72	4.36	8.28	8.4	8.1	11.2	7.8
Sodium (Na)	20.8	20.7	23	10.4	41.4	17.1	30	19.7
Calcium (Ca)	49.6	46.2	36.8	44.8	42.4	37.6	54.4	38.4
Magnesium (Mg)	8.64	9.12	6.72	15.36	8.16	6.2	8.6	9.12
Manganese (Mn)	Nil	Nil	Nil	Nil	0.6	2.0	Nil	Nil
Iron (Fe)	1.4	0.16	0.12	0.04	15.6	32.0	Nil	Nil
Lead (Pb)	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	<0.001	0.001	0.001	0.06	0.12	0.01	0.34	0.01
Total dissolved solids, residue dried at 180°C	215	200	200	65	70	200	59	250

Table 11. Water chemistry data for the Merille River, 1981
(colour in Hazen units, turbidity in JTU and all other ions in mg/l).

	26 May	20 May	19 May	18 May	21 May	11 May
Colour	40000	6000	5000	6000	500	15
Turbidity	15000	1600	180	3250	30	37
Deposit	Mud	Silt	Silt	Silt	Silt	Silt
pH	8.2	7.9	7.4	8.1	7.5	7.1
Free carbon dioxide	Nil	5	2	1	2.0	7.0
Free and saline ammonia as nitrogen (N)	0.64	Nil	Nil	Nil	0.08	Nil
Albuminoid ammonia as nitrogen (N)	0.18	0.04	0.066	3.034	0.06	0.66
Nitrates as nitrogen (N)	0.50	1.25	0.625	Nil	Nil	0.5
Nitrites as nitrogen (N)	Nil	Nil	0.006	Nil	Nil	Nil
Oxygen absorbed. Four hours at 27°C	1.8	1.75	1.6	9.7	2.7	7.3
Alkalinity as $CaCO_3$-phenolphthalein (carbonate)	8.0	Nil	Nil	Nil	Nil	Nil
Methyl orange (bicarbonate)	126	118	112	104	110.0	100.0
Carbonate hardness as a calcium carbonate ($CaCO_3$)	120	114	100	102	102.0	110.0
Non-carbonate hardness as calcium carbonate ($CaCO_3$)	Nil	Nil	Nil	Nil	Nil	10.0
Chloride (Cl)	22	25	26	20	25.0	30.0
Sulphate (SO_4)	20	18	9	33.75	35.0	55.0
Silica (SiO_2)	10	20	10	20	25.0	40.0
Fluoride (F)	0.64	0.36	0.5	0.57	Nil	2.0
Potassium (K)	5.2	5.5	4.44	4.8	4.8	6.8
Sodium (Na)	21	31.2	24.2	24.8	26.4	28.5
Calcium (Ca)	35.2	32	28.8	30.4	25.6	36.8

Table 11 (contd)

	26 May	20 May	19 May	18 May	21 May	11 May
Magnesium (Mg)	7.68	8.16	6.72	6.24	29.1	4.3
Manganese (Mn)	Nil	Nil	0.41	1.2	Nil	Nil
Iron (Fe)	0.12	2.1	10	3.0	0.4	0.2
Lead (Pb)	<0.001	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	<0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	<0.001	0.01	0.009	0.01	0.01	0.01
Total dissolved solids residue dried at 180°C	200	210	60	175	165.0	220.0

Table 12. Water chemistry data for Ngurunit River, 1981
(colour in Hazen units, turbidity in JTU and all other ions in mg/l).

	26 June	12 July	5 July	18 July	3 July	15 July	10 July
Colour	5.0	20	15	20	15	15	10
Turbidity	2.6	12	4	15	3	5	4
Deposit	Silt	Debris	Debris	Debris	Debris	Debris	Debris
pH	8.4	-	6.83	8.3	8.2	8.2	7.9
Free carbon dioxide	Nil	9.0	6.0	Nil	Nil	Nil	5.0
Free and saline ammonia as nitrogen (N)	0.02	Nil	Nil	Nil	Nil	Nil	Nil
Albuminoid ammonia as nitrogen (N)	0.29	0.9	Nil	Nil	Nil	Nil	Nil
Nitrates as nitrogen (N)	0.13	Nil	Nil	Nil	Nil	Nil	Nil
Nitrites as nitrogen (N)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Oxygen absorbed. Four hours at 27 °C (O)	0.3	3.4	2.4	1.1	1.4	1.3	1.5
Alkalinity as $CaCO_3$- phenolphthalein carbonate	8.0	Nil	Nil	12.1	8.0	8.0	Nil
Methyl orange (bicarbonate)	60.0	68.0	72.0	58.0	58.0	56.0	78.0
Carbonate hardness as calcium carbonate ($CaCO_3$)	74.0	108.0	100.0	76.0	72.0	80.0	78.0
Non-carbonate hardness as calcium carbonate ($CaCO_3$)	14.0	40.0	28.0	14.0	14.0	24.0	Nil
Chloride (Cl)	36.0	16.0	16.0	16.0	16.0	20.0	14.0
Sulphate (SO_4)	6.0	67.0	40.0	30.0	30.0	30.0	33.0
Silica (SiO_2)	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Fluoride (F)	0.3	0.4	0.3	0.2	0.2	0.2	0.3
Potassium (K)	3.8	3.5	3.0	3.5	3.5	3.5	3.0
Sodium (Na)	15.0	20.7	19.2	17.4	17.8	17.4	19.6
Calcium (Ca)	16.0	28.0	20.8	14.4	16.0	13.5	16.0
Magnesium (Mg)	8.2	9.1	11.5	9.6	7.7	11.0	9.0
Manganese (Mn)	Nil	Nil	0.6	Nil	Nil	Nil	Nil
Iron (Fe)	Nil	0.1	0.1	Nil	0.6	0.4	0.1
Lead (Pb)	<0.001	0.001	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	<0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	< 0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total dissolved solids, residue dried at 180°C	200.0	200.0	170	150	150	150	150

Table 13. Water chemistry data for Bakuri River, 1981
(colour in Hazen units, turbidity in JTU, and all other ions in mg/l).

	27 June	23 June	18 May	18 May
Colour	<5	5	5	10
Turbidity	1.4	1.6	1.4	1.0
Deposit	Silt	Silt	Silt	Silt
pH	7.4	7.3	7.4	7.0
Free carbon dioxide	2	3.5	5	7.0
Free and saline ammonia as nitrogen	Nil	0.039	0.052	5.2
Albuminoid ammonia as nitrogen (N)	0.07	0.085	0.001	0.10
Nitrates as nitrogen (N)	Nil	0.25	0.375	Nil
Nitrites as nitrogen (N)	Nil	Nil	Nil	0.012
Oxygen absorbed. Four hours at 27°C(0)	0.55	0.70	0.9	0.6
Alkalinity as $CaCO_3$-phenolphthalein (carbonate)	Nil	Nil	Nil	Nil
Methyl orange (bicarbonate)	144	1.58	170	156.0
Carbonate hardness as calcium carbonate ($CaCO_3$)	142	154	150	140.0
Non-carbonate hardness as calcium carbonate ($CaCO_3$)	Nil	Nil	Nil	Nil
Chloride (Cl)	14	22	26	30.0
Sulphate (SO_4)	0.1	0.1	9.5	Nil
Silica (SiO_4)	40	30	5	5.0
Fluoride (F)	1.1	0.24	0.2	Nil
Potassium (K)	2.6	3.0	5.82	5.2
Sodium (Na)	15	3.7	15.9	9.5
Calcium (Ca)	18.4	31.2	25.6	22.4
Magnesium (Mg)	23.28	18.24	20.64	20.2
Manganese (Mn)	0.8	Nil	0.3	Nil
Iron (Fe)	0.25	0.8	2.8	0.02
Lead (Pb)	<0.001	0.001	0.001	0.001
Copper (Cu)	0.001	0.001	0.001	0.001
Zinc (Zn)	0.01	0.21	0.12	0.01
Total dissolved solids, residue dried at 180°C	55	57	56	200.0

Table 14. Water chemistry data for the Halam River
(colour in Hazen units, turbidity in JTU and all other ions in mg/l).

	20 May 1981	15 May 1981
Colour	4000	350
Turbidity	1200	250
Deposit	Silt	Mud
pH	8.3	7.0
Free carbon dioxide	Nil	3.0
Free and saline ammonia as nitrogen (N)	Nil	0.31
Albuminoid ammonia as nitrogen (N)	0.13	0.16
Nitrates as nitrogen (N)	0.625	0.25
Nitrites as nitrogen (N)	Nil	0.006
Oxygen absorbed. Four hours at 27°C (O)	2	2.1
Alkalinity as $CaCO_3$-phenolphthalein (carbonate)	16	Nil
Methyl orange (bicarbonate)	220	148.0
Carbonate hardness as calcium carbonate ($CaCO_3$)	140	54.0
Non-carbonate hardness as calcium carbonate ($CaCO_3$)	Nil	Nil
Chloride (Cl)	9	10.0
Sulphate (SO_4)	1	8.0
Silica (SO_4)	5	50.0
Fluoride (F)	0.14	0.2
Potassium (K)	10.4	14.0
Sodium (Na)	40	29.2
Calcium (Ca)	45.6	15.2
Magnesium (Mg)	6.24	3.8
Manganese (Mn)	Nil	0.2
Iron (Fe)	2.3	16.0
Lead (Pb)	<0.001	0.001
Copper (Cu)	<0.001	0.001
Zinc (Zn)	6	0.01
Total dissolved solids, residue dried at 180°C	260	45

Table 15. Water chemistry data for the Morgut River
(colour in Hazen units, turbidity in JTU and all other ions in mg/l).

	11 May 1981
Colour	5
Turbidity	37
Deposit	Silt
pH	7.5
Free carbon dioxide	23.0
Free and saline ammonia as nitrogen (N)	Nil
Albuminoid ammonia as nitrogen (N)	0.16
Nitrates as nitrogen (N)	0.13
Nitrites as nitrogen (N)	Nil
Oxygen absorbed. Four hours at 27°C (O)	1.0
Alkalinity as $CaCO_3$-phenolphthalein (carbonate)	Nil
Methyl orange (bicarbonate)	34.0
Carbonate hardness as calcium carbonate ($CaCO_3$)	30.0
Non-carbonate hardness as calcium carbonate ($CaCO_3$)	Nil
Chloride (Cl)	8.0
Sulphate (SO_4)	2.5
Silica (SiO_2)	20.0
Fluoride (F)	1.6
Potassium (K)	4.0
Sodium (Na)	4.6
Calcium (Ca)	9.6
Magnesium (Mg)	1.4
Manganese (Mn)	Nil
Iron (Fe)	0.4
Lead (Pb)	< 0.001
Copper (Cu)	< 0.001
Zinc (Zn)	< 0.01
Total dissolved solids, residue dried at 180°C	28.0

Table 16. A sample of water chemistry data for Lag Balal, 16 May 1981 (colour in Hazen Units, turbidity in JTU and all other ions in mg/l).

Colour	1500
Turbidity	200
Deposit	Silt
pH	7.1
Free carbon dioxide	2
Free and saline ammonia as nitrogen (N)	Nil
Albuminoid ammonia as nitrogen (N)	0.026
Nitrates as nitrogen (N)	1.25
Nitrites as nitrogen (N)	0.006
Oxygen absorbed. Four hours at 27°C (O)	1.4
Alkalinity as $CaCO_3$-phenolphthalein carbonate	Nil
Methyl orange (bicarbonate)	80
Carbonate hardness as calcium carbonate ($CaCO_3$)	50
Non-carbonate hardness as calcium carbonate ($CaCO_3$)	Nil
Chloride (Cl)	8
Sulphate (SO_4)	0.5
Fluoride (F)	0.48
Potassium (K)	3.68
Sodium (Na)	9.2
Silica (SiO_2)	10
Calcium (Ca)	14.4
Magnesium (Mg)	3.36
Manganese (Mn)	0.4
Iron (Fe)	9
Lead (Pb)	<0.001
Copper (Cu)	<0.001
Zinc (Zn)	<0.01
Total dissolved solids, residue dried at 180°C	30

Table 17. Water chemistry data for various dams in Marsabit District (colour in Hazen units, turbidity in JTU and all other ions in mg/l).

	Horo Boha 21 May 1981	Goff Jirime 21 May 1981	Arugosoba Dam 18 May 1981	Arugosoba Dam 18 May 1981	Harobotta Dam 21 May 1981	Arowilly Dam 18 May 1981	Moyale Dam 21 May 1981	Moyale Dam 22 May 1981	Arowilly Dam 18 May 1981	Goff Jirime Dam 21 May 1981
Colour	80,000	4000	200	300	1500	3500	10	160	4000	2000
Turbidity	250	200	80	130	200	240	1.5	220	2600	1200
Deposit	Silt	Mud	Silt	Silt	Mud	Mud	Silt	Silt	Mud	Mud
pH	6.5	6.7	8.0	7.9	7.4	6.4	7.9	8.6	7.1	7.3
Free carbon dioxide	6	4	Nil	2	5.0	3.0	1	Nil	1.0	1.0
Free and saline ammonia as nitrogen (N)	Nil	Nil	Nil	Nil	Nil	0.08	0.039	0.279	Nil	0.213
Albuminoid ammonia as nitrogen (N)	0.967	0.403	0.098	0.05	Nil	0.39	0.066	0.394	0.853	0.197
Nitrates as nitrogen (N)	Nil	Nil	0.75	1.25	Nil	Trace	0.375	0.375	Nil	Nil
Nitrites as nitrogen (N)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Oxygen absorbed. Four hours at 27°C (O)	3.0	4.4	1.6	1.7	1.2	6.0	1.5	3.3	2.8	2.8
Alkalinity as $CaCO_3$-phenolphthalein (carbonate)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Methyl orange (bicarbonate)	34	40	140	144	35.0	40	524	176	106	92
Carbonate hardness as calcium carbonate ($CaCO_3$)	20	30	124	126	4.0	44	488	156	28	18
Non-carbonate hardness as calcium carbonate ($CaCO_3$)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Chloride (Cl)	Nil	Nil	23	23	3.0	16	110	4	6	2.0
Sulphate (SO_4)	Nil	Nil	Nil	Nil	2.5	50	105	Nil	Nil	Nil
Silica (SiO_2)	Nil	Nil	10	10	20.0	30	20	Nil	10	5
Fluoride (F)	0.13	0.15	Nil	Nil	0.2	0.2	Nil	Nil	Nil	Nil
Potassium (K)	6.83	7.5	6.0	6.0	7.4	12.5	20.6	5.4	7.36	7.36
Sodium (Na)	1.3	1.0	15	16.0	1.3	2.1	203.2	17.4	2.3	1.0
Calcium (Ca)	2.4	3.2	34.4	35.2	1.6	8.0	64	34.4	4.8	3.2
Magnesium (Mg)	3.36	5.28	9.12	9.12	Nil	5.8	78.72	16.8	3.84	2.4
Manganese (Mn)	1.0	Nil	Nil	Nil	Nil	0.3	Nil	Nil	Nil	Nil
Iron (Fe)	40	50	0.1	0.1	32.0	94	0.1	Nil	45	35
Lead (Pb)	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	<0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.01	0.01	0.01
Total dissolved solids, residue dried at 180°C	33	45	180	180	31.5	30	220	180	50	15

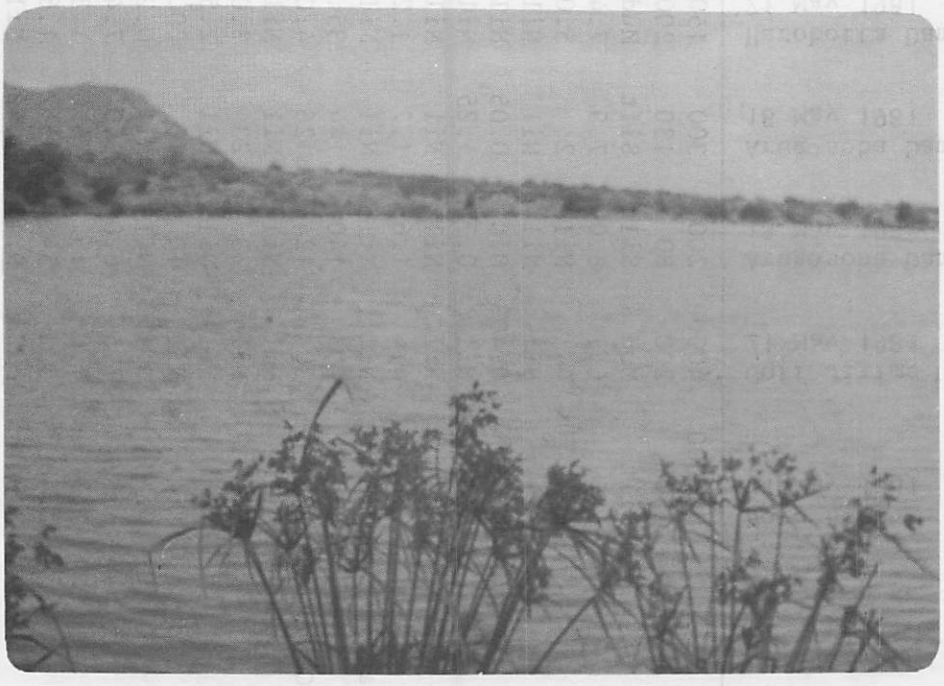


Figure 98. A well-protected dam in Sololo. The water is clear with little turbidity.

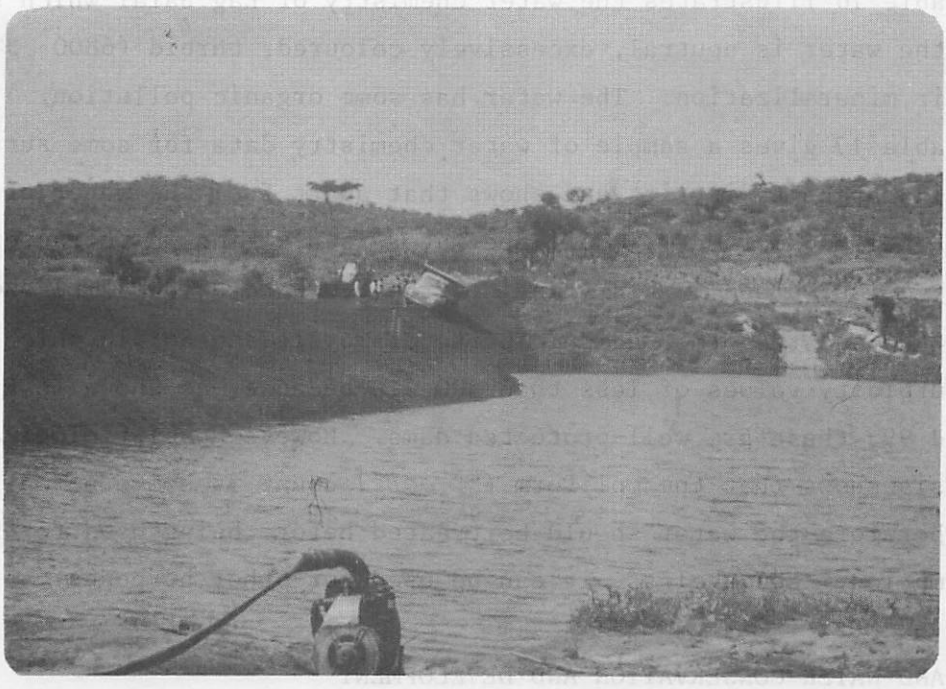


Figure 99. A well-protected Moyale dam with clear water.

Table 14 gives water chemistry data for Halam River which show that the water is alkaline, highly coloured and turbid with average mineralization. The colour is partly due to dissolved matter such as iron. Bacteriological examination for *E. coli* (coliforms) shows that the water is unsatisfactory for drinking purposes unless further treated, but could be easily used for other purposes.

The water chemistry data for Morgut given in Table 15 indicate that the water is of alkaline character with average mineral content and would be suitable for various purposes, although it is not bacteriologically suitable for drinking purposes.

Table 16 illustrates the water chemistry of Lag Balal which shows that the water is neutral, excessively coloured, turbid (6800 JTU), and of fair mineralization. The water has some organic pollution.

Table 17 gives a sample of water chemistry data for some surface dams in Marsabit District and shows that apart from the water of Horr Botta and Goff Jirime all the water is alkaline in character, highly coloured and turbid (ranging from 2,000 to 80,000 JTU) except for Arogosaba and the other dams in parts of Moyale and Sololo which show low turbidity values of less than 300 JTU because, as shown in Figures 98 and 99, these are well-protected dams. However bacteriological analysis shows that the coliform *(E. coli)* count is above normal levels and therefore the water should be treated before being used for human consumption. Nonetheless, it can be used for other purposes.

SOIL AND WATER CONSERVATION AND DEVELOPMENT

In Chapter 5 we recorded that the steep, highly grazed and partially cultivated areas can be major sources of sediment. It has also been indicated that vegetation cover is an important factor determining runoff and soil loss from grazed areas. The problem of water and soil conservation within the grazed areas is exacerbated by overgrazing and moisture deficiency which further deplete the vegetation.

Dunne (1976) has indicated in Kajiado District that the volume and intensity of sheetwash cannot be altered greatly by land management because they are mainly controlled by rainfall and soil properties. However, experiments in other rangelands have shown that on small plots improvement of vegetation cover increases the infiltration capacity of

the soil. He thought that similar results could be achieved by maintaining a thick grass cover. Nevertheless, Dunne concludes that the resulting decrease of runoff cannot be very large because of other related factors such as differences of soil texture, structure and antecedent moisture. He shows that increasing the groundcover to about 20% would greatly decrease erosion. He further shows that in order to improve the groundcover significantly massive destocking of domestic herds would be necessary. This, he says, could only be done at great cost to the current landowners or to any Government agency which subsidizes the destocking by replacing the flock which would be lost. As he rightly points out, any destocking measure should only be carried out after a prediction is made of the ecological changes that take place as a result of this erosion-reducing measure. He also indicates that trampling would be reduced as a by-product of destocking.

Dunne (1976) also suggests that in the Kajiado area massive destocking would be required before the changes in grass cover would be great enough to improve soil structure. Reduction in grazing pressure would improve soil structure and allow bush encroachment. Such development of vegetation would improve the ground, encourage the accumulation of organic matter in the topsoil, improve structure and probably reduce surface runoff and hence reduce erosion. We might also ask what benefits would be reaped from the longer lifespan of the soil thus achieved.

The quantification of the economic benefits and related social benefits of such measures is beyond the scope of the present study. According to the work of Berry and Townshed (1972), the human perception factor is much more important than many people realize. They have evaluated soil conservation policy in the semi-arid regions of Tanzania and have shown that some soil conservation measures failed because they gave no improvements in crop yields or land fertility. Obviously the cultural, social and economic status of the people must be taken into account in designing any soil and water conservation methods otherwise they are bound to fail.

The present field study observations indicate that the creation of grazing blocks such as those in Moyale and Sololo area tend to minimize problems of land degradation and pollution of surface dams.

The study further shows that there should be an indirect method of destocking by the creation of locally run livestock co-operative societies which could be supported by the appropriate government expertise and finance. This would improve the marketing situation considerably. This improvement can only be achieved by the improvement of the total infrastructure, e.g. roads, in the area.

RECOMMENDATIONS

1. Present soil-loss computations have been made using only a few measurements supported by checks from other developed methodologies. In addition to measurements of sediment transport within river channels, there is a need to study the distribution and nature of sediment sources within the catchments as they relate to the geomorphic and hydrologic processes. These processes must in turn be studied to define quantitatively their controlling factors such as rainfall, soil type, topography, vegetation cover and landuse. Only when all major sediment sources and erosive processes are identified can rational decisions be made about the kinds of soil conservation measures that will be effective. The present documentation is only a preliminary one.
2. Rural settlements, roads and footpaths have been identified as a major source of sediment. A methodology should be developed in order to measure this input.
3. Hill-slope plot experiments using artificial rainfall simulators should be developed in order to quantify the soil losses and relate these to those documented.
4. There is need to continue water-quality and sediment-monitoring operations with a view to obtaining quantitative information on all the available surface-water resources and sediment-production rates in the respective catchments.
5. The current river-gauging and sediment-monitoring network is inadequate and should be evaluated adding more stations at the inlets of these rivers.
6. Farmers and pastoralists should be educated formally and informally on the values of soil and water conservation in the area. This will only achieve the desired goals when the people in the drainage basin see the immediate benefits of such measures. Indiscriminate

destruction of vegetation for commercial charcoal burning should be minimized.

7. Because of the high evaporation and seepage losses, man-made underground storage reservoirs will have to be constructed at suitable sites along these river channels (see Figures 97 and 100).

   This will also mean that during the flood period people and livestock will have a permanent water supply to improve their pastures and quality of life. In such cases surface runoff (Figure 101) can be stored by ground catchments (Ongweny, 1978; UNEP, 1979). Because of the improvement of the pasture and watering points the accelerated soil erosion prevalent in these areas during flood will be greatly reduced. With the reduction of soil erosion, the silt load will be greatly reduced in the streams and will therefore improve the quality of the water. This will also reduce the rates of siltation of the sub-surface storage reservoirs at the appropriate channel sites which have been proposed in this report (see Figure 97). During drought conditions the sub-surface storage reservoirs, wells and boreholes will be used by the people, livestock, and small-scale irrigation.

8. In order to reduce problems of soil erosion associated with high stocking rates, the marketing arrangements should be improved through the formation of livestock co-operative societies to be run by the people in the District with the assistance of the appropriate Government agencies. This will help the destocking problems and also encourage other spheres of development through the co-operative societies.

9. The provision of permanent watering points *per se* will not rehabilitate the arid areas of the district, but an integrated approach to development, including the development of permanent watering points, schools, health centres and other infrastructure, is necessary and will also improve the security of the area which is in turn necessary for further development.

10. This preliminary hydrological and hydrogeological work which has been initiated by UNESCO under the IPAL Project should be supported and continued in the entire district.

11. Harvesting of water from runoffs should be encouraged and should supply adequate water for the major urban areas, e.g. Marsabit,



Figure 100. Underground storage reservoir under construction at Bobisa near Marsabit.



Figure 101. Surface runoff on the Marsabit-Kargi Road.

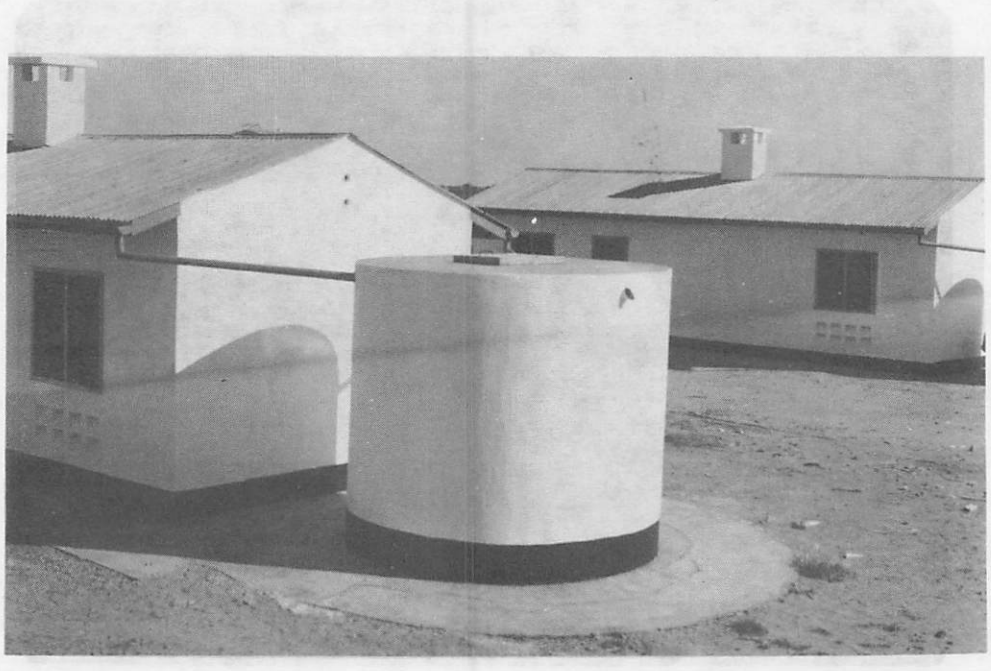


Figure 102. Harvesting of roof catchment water in North Horr. The water harvested is adequate to serve this station for the entire season.

Moyale, Logologo, etc. Such water can be reticulated in such a manner as to serve the adjoining areas and will greatly improve the water sanitation. Construction of houses using toxic asbestos material such as those of the Customs building at Moyale should be avoided. Ongweny (1978) and UNEP (1979) have shown that under average climatic conditions a 5000-litre storage tank can harvest enough water in 12 hours to last a family of six for 45 days (see Figure 102).

12. The current rapid siltation of Lake Turkana should be halted by introducing, as a matter of priority, immediate rural development centres, especially at the main sediment-source areas. Reclamation of the affected areas in order to alleviate environmental hazards that could be associated with destruction of fish and other related life within the lake should be given priority. Afforestation and reafforestation programmes should be encouraged because forests protect the quality and amount of water (see Figure 103).
13. Appropriate training of personnel in the relevant fields of water-resource management should receive the attention of IPAL and the relevant Kenya Government agencies.
14. Dam construction at suitable sites would help in flood control - water may be a source of power. Such plans should take into account problems of the environment, health and other social problems (see Figure 97).
15. The rivers should be fully utilized in order to provide water for various uses. In this regard the regulation on the flows before they get to the arid and semi-arid regions may be desirable (see Figure 97).
16. All development programmes should have a multipurpose outlook in order to ensure co-ordinated development and also promote good water quality.
17. The creation of rural development centres should be encouraged as a means of utilizing the limited water available.
18. Surface dams in parts of Moyale, Sololo and other parts of the IPAL study area should be investigated with a view to maintaining them and harnessing the water for multipurpose uses in this arid environment.
19. Wind erosion which has not been studied here should receive urgent attention in order to fully elucidate its role in land degradation and with a view to rehabilitating the environment.
20. Having harnessed the water, small-scale irrigation projects should be introduced. These include the growing of salt-tolerant crops in

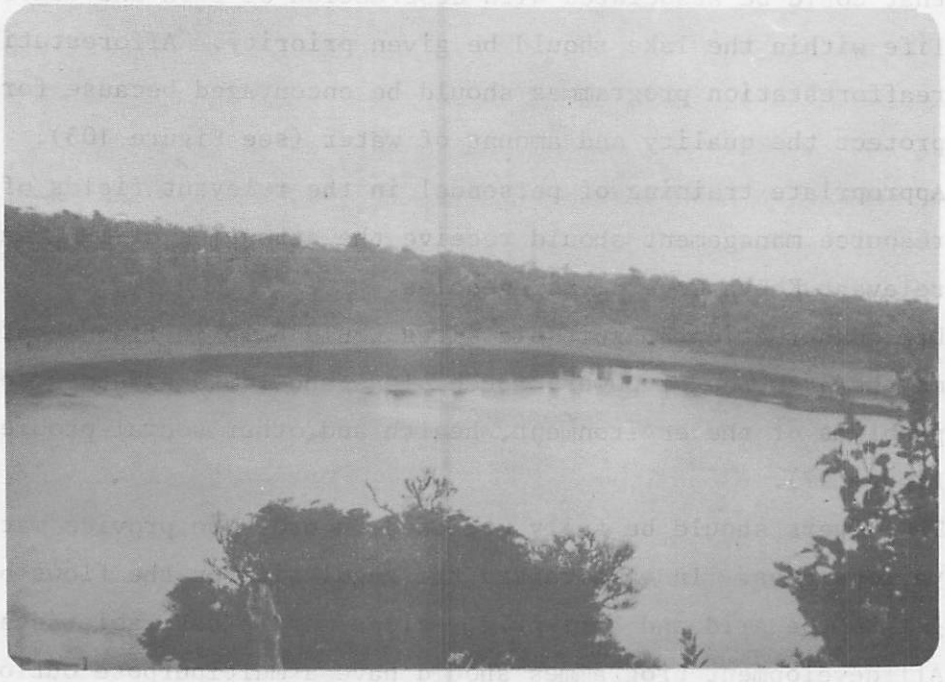


Figure 103. Lake Paradise within Marsabit Forest Reserve has very good quality water stored all the year round.

such areas as the fertile edges of the Chalbi Desert. This will improve the pasture and rehabilitate the area.

Our main point of emphasis here is that the time has come when Kenyans ought to stop thinking of the negative impacts of floods but rather generate appropriate technology in order to tame the flood water for multipurpose uses. Such technology is available but for it to be applied the necessary data must be obtained. Detailed hydrological investigations can only be achieved through the monitoring of both surface and ground water in the District. We believe that our scientific endeavours must now be directed to finding practical solutions to the conservation of water in the arid zones and the time may come when we must be prepared to utilize even the water of Lake Turkana for irrigation. We know that some salt-tolerant crops such as palms, mangoes, cotton, sorghum and others can be grown within the flood plains of these seasonal rivers. It is also known that with the improvement of pasture the area can be self-sufficient in meat production which could earn more foreign exchange for development.

Lastly, the development of this arid area can only be achieved by a co-ordinated catchment approach to development.

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REPORT OF A SHORT TERM CONSULTANCY ON WATER DEVELOPMENT IN SOME PARTS OF MARSABIT DISTRICT, NORTHERN KENYA

by

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SUMMARY

Ephemeral runoff on the surface of the ground, from rooftops, on bare rocky hillsides and in sand rivers is potentially an important source of water for human and livestock consumption in the IPAL study area. Some of this water may be utilized by constructing a wide range of structures to conserve water at the various sources. This report covers only runoff conservation in sand rivers in detail.

Types of structures that are appropriate to rivers in the IPAL area are wells, pans, subsurface dams and sand dams. Subsurface and sand dams store water underground, making it available for extraction by wells with handpumps. Diversion of water out of the rivers into adjacent pans is another important technique of conserving scarce river flow.

Ten sites for these structures were identified in three parts of the IPAL study area during a three-week fieldwork period. Simple feasibility studies and estimated costs of development are presented. Pans are much cheaper than dams per unit volume of water stored.

The general approach which should be adopted when planning the development of the water resources of the IPAL study area is outlined.

Chapter I

INTRODUCTION

1.1 The General Problem

The UNESCO Integrated Project in Arid Lands (IPAL) was established in 1976 in Marsabit District, northern Kenya (Figures 1 and 2) in order to study the natural arid and semi-arid ecosystem in its relation to human land use. Particular emphasis has been placed on analysing the factors which contribute to, and which may be used to combat, environmental degradation and desertification, a widespread and only partly natural phenomenon in semi-arid areas throughout the world.

The aim of IPAL is to produce a scientific basis for the future rational management and development of this and other similar areas in which pastoralism forms the dominant economic activity.

One of the major components of the development plan is likely to be water development. However, very little is known about the hydrology of the study area that can be used to plan the development of the water resources in a rational manner and to design structures. For example, important unknown factors may be listed as follows:

(a) amounts, effectiveness and reliability of temporally and spatially erratic rainfall;
(b) the relationship between rainfall amounts and the quantity and duration of ephemeral flash floods in the luggas (sand rivers);
(c) the distribution, amounts and duration of ponded runoff in natural depressions;
(e) the variability of all the above factors.

Equally important for planning purposes, very little is known of the spatial distribution and amount of water that is actually used by the nomadic population in the remoter areas. The question "How much more water is required and where?" is therefore very difficult to answer.

The spatial and temporal distribution and accessibility of water for human and livestock consumption has a great influence on the distribution and movement of people at any one time. At present many parts of the project area, amounting to 40% of the total of 22,500 km^2, are under-utilized, owing to a lack of either security or water, or both.

An improvement in security and in the distribution of water would, it is believed, relieve the grazing pressure in many over-utilized areas and enable the environment to be more fully and effectively used by the people.

The main problems facing the developers of the water resources of the area will be to conserve some of the ephemeral surface runoff as cheaply as possible and to make it available for consumption in under-utilized areas. This must be done without disrupting the traditional seasonal migration patterns and without having a degrading effect on the areas where the water points are installed.

1.2 Aims and Objectives of the Hydrological Consultancy

The aim of this report is to suggest the types of structures that might be appropriate to the IPAL study area and to find sites where such structures might be located. It does not address itself specifically to the problem of how to plan water development.

Fieldwork took place in only three parts of the study area. Three weeks were spent in the field. These areas were:

1. Balesa Kulal: 20-30 km upstream and downstream form Olturot Field Station;
2. the luggas crossing the Gatab-Ilaut road south-east of the Balesa Kulal;
3. the luggas crossing the Korr-Kargi road (Figure 2).

The objectives of the consultancy as defined by the terms of reference were:

1. to suggest appropriate means by which the ephemeral surface-water resources of the study area may be conserved and made available for human and livestock consumption;
2. to assess the potential for developing the surface water in each of the above three areas and to suggest the appropriate means of doing this;
3. to identify sites where use of natural structures and the installation of artificial structures would be possible for water storage;
4. to make feasibility studies of the sites identified and to give average costs of development.

Detailed designs are not considered in this report.

1.3 Methods

The fieldwork consisted virtually entirely of searching for sites for subsurface dams and sand dams and only occasionally for pans and diversion structures. Locating sites entailed driving along the courses of luggas and identifying places where the site criteria for pans and dams (see sections 2.3 and 2.4) were satisfied. Wherever a site appeared promising in topographical terms the nature of the sediments was checked at the dam-wall site for possible beds of clay, using a soil auger with extensions to 4 m. In practice, however, none of the augerings penetrated more than 3 m down, owing to the presence of beds of course gravel.

If present, the extent of a clay bed across the lugga at and upstream from the dam site was determined by further augerings. Quick topographic surveys were made using a Quick-Set level and staff in order to produce simple topographic maps from which the storage volumes of sediment and water could be calculated. Detailed site surveys were not possible owing to the large area which had to be covered in the short period available for fieldwork.

It is difficult to calculate accurately the storage volume of sand or water behind a subsurface dam. The existing river bed, the water-table, and the bed of impervious clay all have different and, for the latter two, unknown slopes. If the situation can be simplified by assuming that the clay bed has a slope parallel to the surface of the existing river bed and that the surface of the water-table is horizontal from the crest of the structure, then the volume of aquifer material V_A between two points with cross section areas A_1 and A_2 and separated by distance L containing water behind the structure may be calculated, using

$$V_A = \frac{A_1 + A_2}{2} L$$

In reality the slope of the water-table may extend far upstream and therefore the volume of sediment (which will be a potential source of water) in the reservoir will be grossly underestimated. However, the calculations do, to a limited degree allow a certain amount of comparison to be made when choosing between alternative sites for development.

The equation becomes more accurate and reliable when it is used to calculate the storage behind sand dams. The assumptions in this case are that the surface slope of the created sediment reservoir and the water-table are both horizontal and that the storage created is completely full.

Accurate individual maps of the three areas where fieldwork was undertaken, showing the dam sites identified, could not be drawn. The kilometre gauge on the author's vehicle was used to measure the distance from a landmark such as a road junction to the luggas in question. Unfortunately, the measured distances do not correlate with the positions of luggas on the 1:250,000 and the 1:100,000 maps of the area. As a result it was very difficult to determine to which luggas on the maps the identified sites should be assigned. For this reason the sites are mapped only very approximately, at a scale of 1: 1,250,000 (see chapter 7).

Samples of the river-bed sediments, particularly of those sediments containing silt and clay, were taken during the surveying of the dam sites identified. However, there was insufficient time in which to analyse the size distribution of these samples and, in any case, determination of whether these beds are impermeable or not is very difficult.

Chapter 2

APPROPRIATE TECHNOLOGY

2.1 Introduction

In selecting a particular type of structure or form of water development for a place the question "Who is going to pay for and repair the inevitable breakdowns and how?" must always be asked. The answer should determine what type of structures are built and the materials used. If a structure is not to remain useless for a long period following a breakdown, then it is essential that appropriate action is taken to ensure that the local people are able to cope with any repair work required. A large part of this can be accomplished at the outset by selecting the appropriate type of structure, design and materials, so that repair work does not require much skill or expertise. Undoubtedly, a certain amount of technical advice on repairs is often needed, but this can be kept to a minimum if a local person or group is trained to maintain the structure.

The following discussion is restricted mainly to those types of structures that are considered to be appropriate to the remote, lowland parts of the IPAL study area. The hydrology of these areas is characterized by very infrequent heavy storms, high evaporation rates (potentially in excess of 2.5 m per year) and rapid ephemeral runoff. Any given lugga may flow for only a few days or even hours each year. Therefore, particular emphasis must be put on conserving the water lost from the land in the episodic flash floods which generally follow heavy storms. Even though the rainfall may occur mainly in the upland areas, the water may flow long distances and can be utilized far away in the lowlands, thereby improving the distribution of water available for consumption.

2.2 Wells

There are basically two main types of well construction: shallow wells and deep wells. Shallow wells include hand-dug wells, driven tube wells, bored (augered) tube wells and jetted tube wells. Deep wells consist mainly of drilled boreholes. The relative merits and disadvantages of boreholes and hand-dug wells will now be considered and the suitability of both types for use in the IPAL study area assessed.

2.2.1 Boreholes

Although boreholes are widespread in rural Kenya, they have tended to be used most effectively on private ranches where there has been strict control on the usage of water. Access to large quantities of easily obtained water can often lead to the permanent concentration of large numbers of people and livestock around boreholes. This has occurred, for example, in the IPAL study area at Korr and Kargi. There are clear symptoms of overgrazing and environmental degradation in the vicinity of these settlements.

Boreholes are also very expensive to develop and run. The cost of drilling is very high and the pumps are usually dependant on diesel fuel. Moreover, boreholes require skilled maintenance, often beyond the capability of the local population. There is a relatively high risk of not obtaining water at a reasonable depth which is of acceptable quality. Water quality is particularly unpredictable in East Africa in the region of the Rift Valley, and large variations in salinity within only a few kilometres are not uncommon in Kenya.

For these reasons boreholes are considered by the author to be an unsuitable form of water development for the IPAL study area.

2.2.2 Shallow (hand-dug) wells

The advantages of dug wells are that they are cheap to construct and require only simple tools, largely unskilled labour, and relatively simple maintenance. They can be installed in low-yield aquifers since the well provides considerable storage that can be recharged over night. Furthermore, a dug well does not provide unlimited quantities of water. Work is necessary in order to obtain the water, whether a bucket and rope or a hand pump is used. Wastage of water is therefore small. Only a relatively limited number of people can obtain water for domestic and livestock usage each day, which should, to a certain extent, control the numbers of people using a well. This would also encourage the development of a locally established roster of water use, as already exists for many wells in the IPAL study area. In this way the failure of one well does not put a large population at risk.

For these reasons, hand-dug wells are a particularly appropriate form of water development for the IPAL study area.

The cost of a hand-dug well can vary enormously, depending upon whether it is constructed at commercial rates or just using local unskilled labour. The prices quoted below only include basic materials for a 5 m well. Labour is not accounted for, but up to 100 man-days may be required per well.

Materials		Price (KSh.)
Concrete:		
5 rings:	2.12 m^3	
Bottom slab:	0.19 m^3	
Top slab:	0.62 m^3	
Total:	2.93 m^3 at KSh. 1,400/m^3	4,102/-
Reinforcing rod:		
125 m of 0.01 m diameter		
(0.62 kg/m at KSh. 10/kg)		770/-
Ballast/filter material: 20 m^3 at KSh. 200/m^3		4,000/-
Hand pump and rods		6,000/-
Contingencies 10%		1,500/-
Total	KSh.	16,372/-

The disadvantages of hand-dug wells are that they are easily polluted unless properly designed, they can dry up during a dry season or drought (this may be an advantage in the IPAL study area), and they are not suitable for water-tables below 20 m.

2.3 Pans or Hafir Tanks

Pans (Hafir tanks) are water-storage structures which are commonly used in semi-arid areas for livestock watering. In contrast to subsurface and sand dams (see next section), water is stored in the form of a pond with an open water surface. Pans are therefore subject to losses by evaporation, but these losses may be reduced if the depth of water in the pan is appreciable (i.e. over 4 m deep).

Pans may be of two main types: a simple excavated pit in flat areas or in existing depressions, or an embankment pond. The excavated material, if it is sufficiently impervious to provide a water barrier, is placed surrounding the pond. This earth embankment is generally the easiest and least expensive ponding method for the amount of water stored and materials moved. The embankment design may be a zoned one (Figure 3, b-d) if the available material is not sufficiently impervious to retard seepage. However, the simplest condition is that the embankment is homogeneous and consists of silts and clays (Figure 3a).

Sources of water for both types of pan can be springs, surface runoff (if the soils are liable to cap during storms) and gully flow. In the IPAL study area ephemeral lugga flow is an important source of water that should be utilized. It is possible to divert part of the flood flow using a diversion weir and canal linking the lugga with a pan. The diversion of river flow will increase the probability that a pan will contain water. By virtue of the fact that most large luggas have their headwaters in the higher-rainfall mountainous areas and have relatively large catchments, more water can be expected to be diverted into a pan than if the pan relied on a small catchment area immediately upslope of it to supply surface runoff from lower annual rainfall totals with a higher spatial and temporal variability than in the highlands. Only a small fraction of the water in any flood will be required to fill a pan. Consequently it is important that every pan should have an adequate spillway. Figure 4 shows a typical layout for a pan sited adjacent to a lugga.

Pans may be excavated using either hand labour and donkey-drawn dam scoops or heavy earth-moving machinery. Consequently, costs may vary enormously, from very little to KShs. 40,000-200,000, depending on the capacity of the dam or how much fuel has been consumed. Average capacities for the costs quoted range from 12,000-20,000 m^3.

Pans are intended primarily for livestock watering, but may be safely used for domestic purposes if a hand-dug well is positioned adjacent to the pan with a graded sand and gravel filter linking it with the waterhole. The cost of installing a dug well and filter (see section 2.2) is negligible if the pan is excavated using machinery.

Figure 3. Types of embankments

Source: Wood and Richardson, 1975.

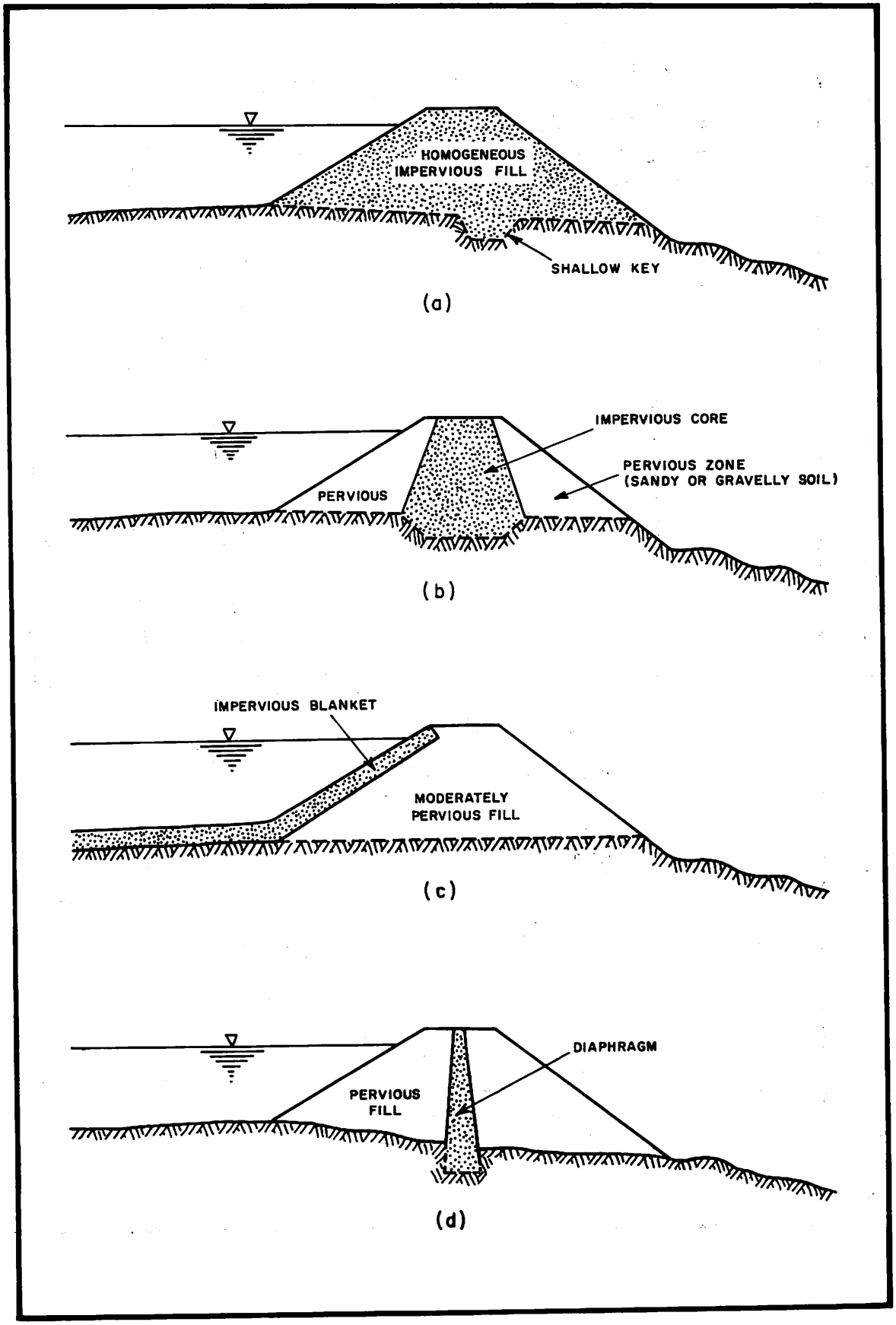
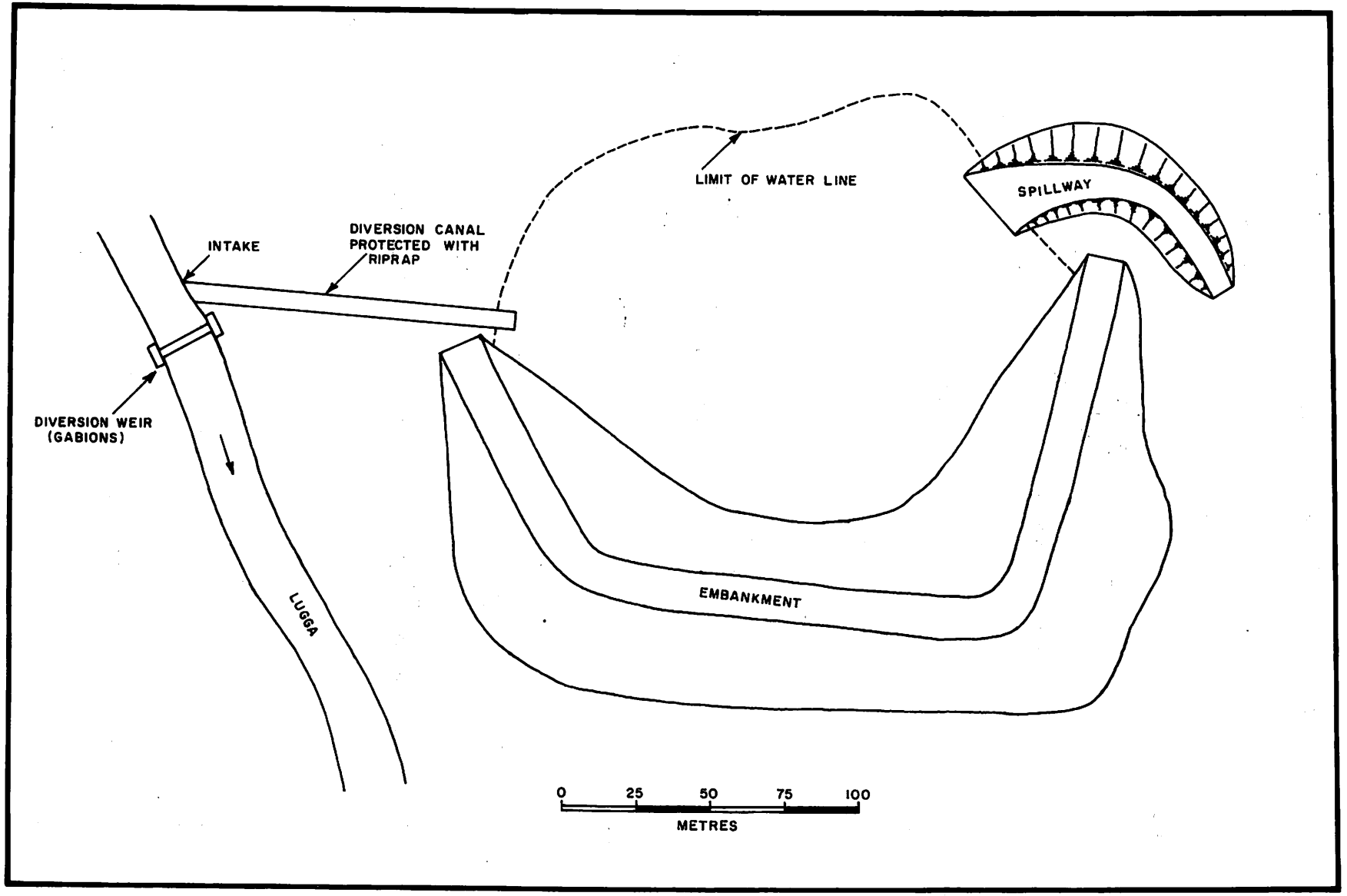


Figure 4. Sketch map of a pan located adjacent to a lugga with a diversion structure and canal



Adequate permeable diversion weirs can be readily constructed using 2 x 1 x 1 m gabion boxes filled with stones and placed across a lugga. Figure 5 shows the layout of a typical gabion diversion wier across a 10 m wide channel. A total of 41 gabions are used in this structure. At the time of writing the cost of one gabion is approximately KShs. 600/-. Therefore the total cost of this (relatively small) structure is KSh. 24,600/-.

The total cost of all four structures (pan, dug well, gabion wier and diversion canal) could therefore be in the range of KSh. 40,000/- (if hand labour is used to dig the canal and pan) to KSh. 80,000/- (if the pan is small and constructed using heavy machinery).

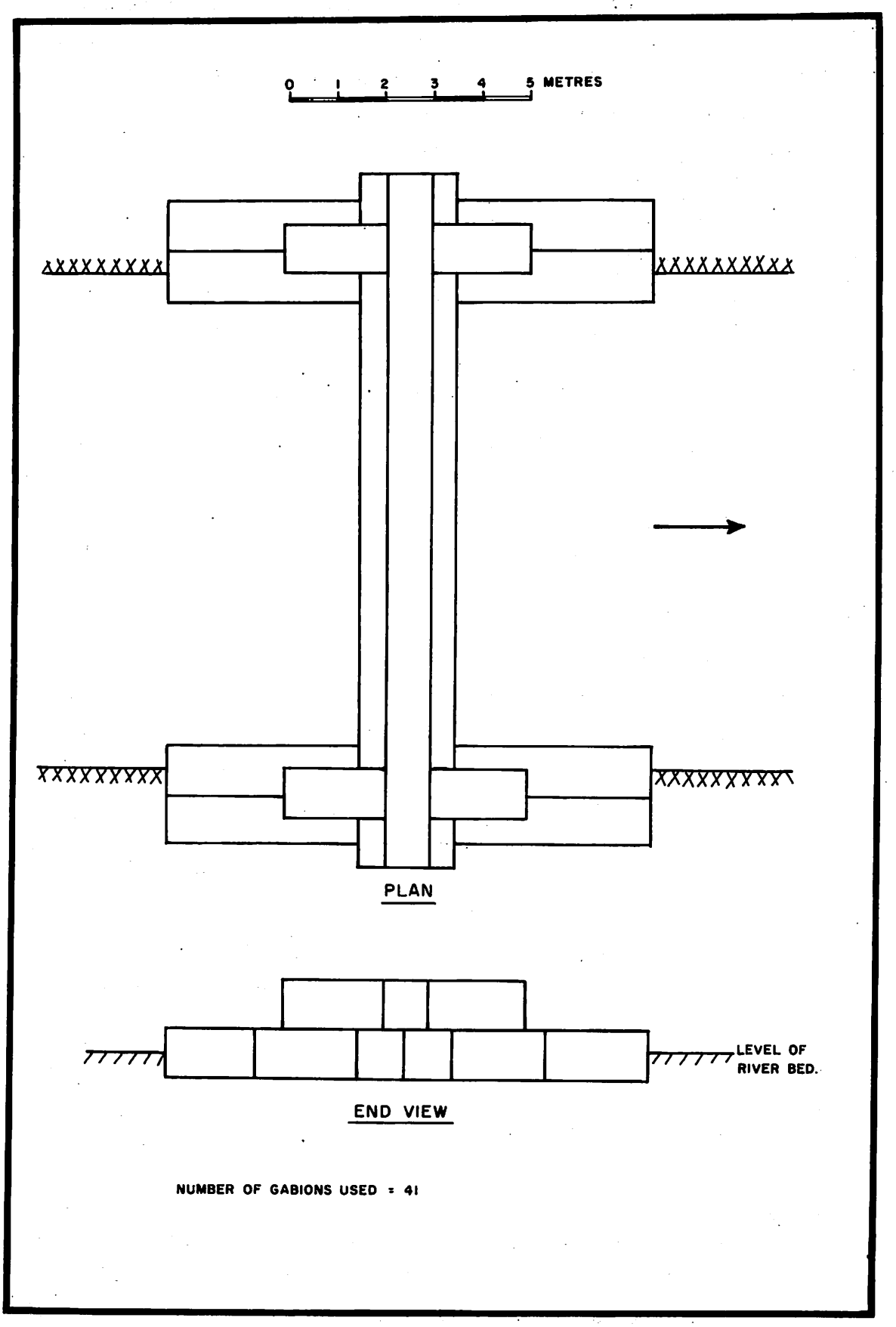
The site criteria for pans which must be satisfied when selecting sites are:

1. flat or gently sloping land or initial existing depression which can be further excavated adjacent to a lugga;
2. an impervious subsoil which will provide good water retention. If the initial depression appears well drained, then the site must be discarded unless there is a clay soil locally available which can be used to line the pan after excavation;
3. if the pan is to be constructed away from luggas then the site should have stony surface soils or soils which cap easily during storms. These types of soil usually create significant quantities of surface runoff during storms, which should enter the pan in small rills or gullies;
4. for the diversion structure, a relatively narrow stretch of main channel is required so that costs are minimized, the depth of flow in the lugga is substantial for diversion purposes, and the river is unable easily to change its course and flow down an alternative channel. A good supply of stones or transport to import them can then be a crucial factor in the choice of location of a pan.

2.4 Subsurface and Sand Dams

Water losses by evaporation from pans with open water surfaces are very high in semi-arid areas. An approach which reduces these losses almost to zero is to store water in the sediments which underlie the water sources. The sand retains the water for a relatively long period after surface flow in the river has ceased.

Figure 5. Typical layout of gabion diversion weir



Usually, a perched water-table forms above an impermeable layer such as bedrock or a bed of clay during a rainy season and slowly lowers during the ensuing dry season due to downstream subsurface flow. However, a water-table can be maintained near the surface of the river bed for a longer period by constructing a retaining, sealing structure (a masonry or concrete wall) across the width of the river with its foundations in the impermeable layer. The seal stops the groundwater flow, with the result that the water-table rises (initially) to the level of the upstream crest of the structure.

For a 'subsurface dam', the crest is sually buried 0.3 - 1.0 m below the existing river-bed level, in order to prevent damage to the structure by scour during floods.

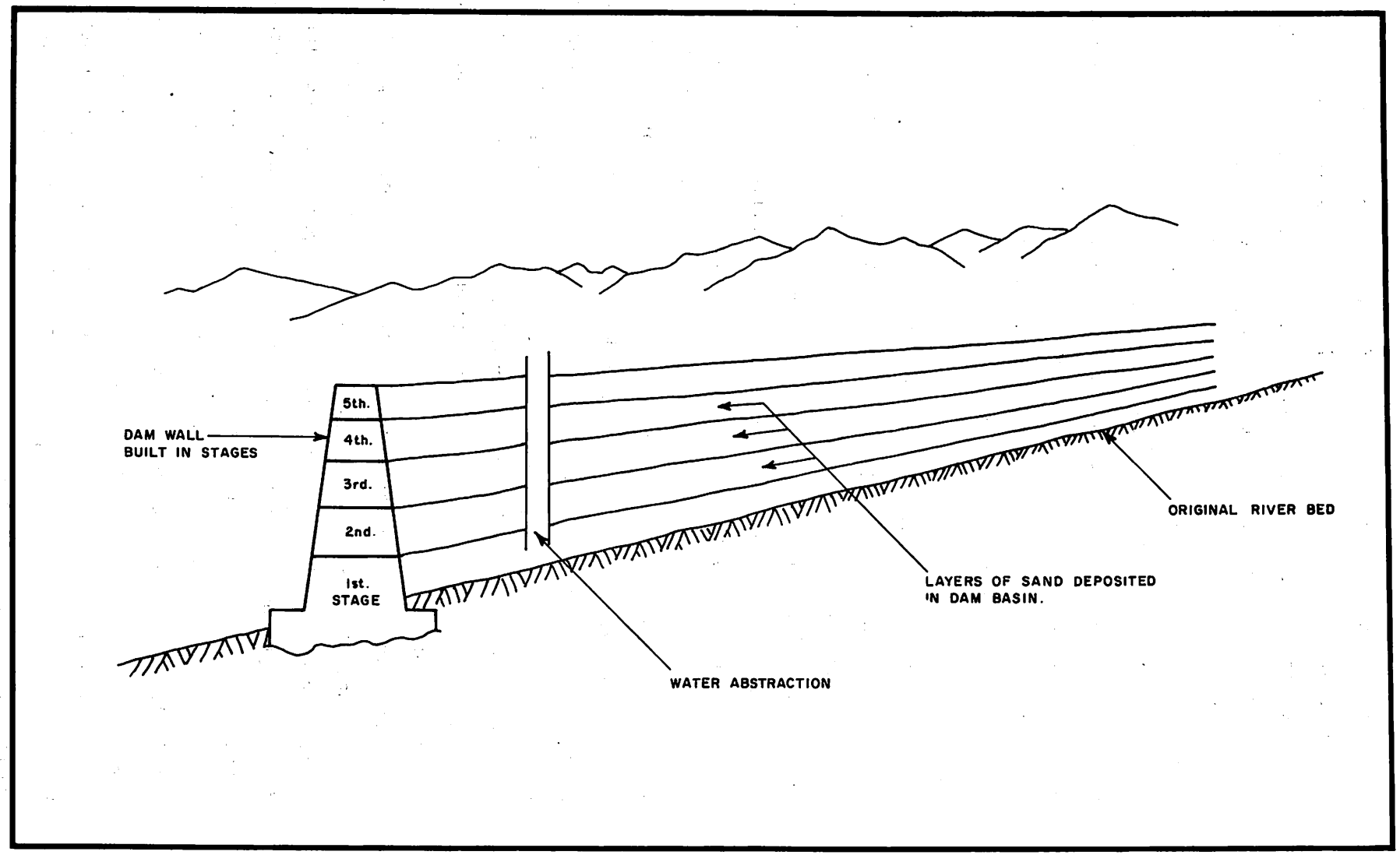
The crest of a 'sand-filled dam' extends above the original river-bed level to the height required to create the desired additional storage capacity. Deposition of sand and gravel occurs in the upstream basin where flow velocities are reduced behind the dam wall until the storage capacity behind the dam is completely filled.

The ideal deposits for water storage are fine gravel and coarse sand, but the sediment load of the river may include finer sands, silts and clays. Deposition of this finer material can be prevented by raising the heights of the retaining wall in stages (Figure 6) so that there is always an overflow along the crest during floods, carrying the majority of the finer sediments downstream. Wipplinger (1958) reports the success of this technique in Namibia. There, dams usually consist of four or five stages built over a period of ten years, during which 3-5 metres of sand is deposited.

Both types of dam largely eliminate the evaporation problem, while a sand dam, if constructed properly, also eliminates the siltation problem encountered with open reservoirs and pans. In addition, sand dams, through their energy-dissipating action and sediment-retaining function, reduce the overall sediment load of the river.

Details of average costs of subsurface dams and sand dams are difficult to relate. However, costs per cubic metre of dam wall are easier to estimate. If the structure is to be built entirely of concrete the average cost per m^3 of concrete is approximately KSh. 1,400/-. This price may be reduced by, say, 50% if 50% of the structure (by volume) consists of stones.

Figure 6. Construction principles of a sand-filled dam (taken from Burger and Beaumont, 1970)



Normally, a dug well is sited at a strategic point behind a subsurface or sand dam so that the water stored can be extracted.

The site criteria for subsurface and sand dams which should be satisfied when selecting a suitable site are:

1. a relatively narrow 'neck' in the channel where the costs of construction are minimized. Upstream, the channel should widen out with a low bed slope in order to maximize the storage volume;
2. the channel at the site of the proposed dam wall should preferably be incised into impermeable bedrock so that, again, the storage volume is maximized and the dam is built on strong foundations on the bottom and at the sides;
3. in the absence of rocky banks, sand dams may be feasible where there are high banks of clay-rich alluvium into which the wall must be 'keyed' by at least five metres at each end for protection against scouring by flood waters. This is a major risk criterion. If the banks are not high (less than 2 m) then only a subsurface dam is feasible. This structure will not interfere with the flow in the lugga and thus scour will be avoided;
4. in the absence of impermeable bedrock within 3 m of the river-bed surface, a bed of clay-rich alluvium (preferably pure clay) 0.5 m or more thick must be present across the width of the lugga at the dam site and it must extend upstream to underlie the sediment reservoir so that water loss by vertical percolation is minimized. The dam wall must have its foundations in the clay bed;
5. there should be either a supply of building stone near to the site or transport to import it and other building materials.

Chapter 3

THE BALESA KULAL

The Balesa Kulal is the largest sand river in the IPAL study area in terms of both the size of the channel and the size of the catchment area. The lugga has an average width in the lower 50 km of its course of 80-150 m. The Balesa rises in the mountainous Ol Doinyo Mara-Ol Doinyo Nyiru area and extends north past the eastern slopes of Mt. Kulal to the Chalbi desert. The channel exhibits many features characteristic of sand rivers. The river bed is made up of layers of sediment that are commonly discontinuous and which often form distinct individual lenses which dovetail together in the underlying deposits. This is due to the processes of scour and fill during periods of flow, when the flow conditions in any region of the channel are continually changing, causing the alternate erosion and deposition of the river bed. The banks usually consist of cohesionless sandy alluvium and may be vertical, 1-2 metres high, or virtually non-existent. In many places the main channel splits into a number of smaller, braided channels and identification of the main channel can be difficult. Indeed, there may be no single channel that is used all the time.

The Balesa rarely flows along its entire length because all but the largest floods are usually absorbed by the very deep deposits of sand gravel that underlie the lugga. Large quantities of water which are potentially exploitable are thought to be stored in the sediments in the form of a perched aquifer which is recharged during flood periods. Depths to bedrock determined by Borgeson (1981) range from 175 mm at the Gatab-Ilaut road crossing, possibly 245 m at 16 km north of the Olturot road crossing, and 30 m at Bobor, 32 km downstream from the Olturot road crossing (Figure 2). These depths of sediment make the concept of a subsurface dam founded on bedrock impossible. However, the possible existence of beds of clay and lava flows across the river which could support structures and perched water-tables was investigated.

Augerings were made in the river bed to a maximum depth of 3 m every kilometre for a distance of 30 km downstream from the Olturot road crossing to the seasonal wells at Bobor. The aim was to obtain an idea of the nature and variability of the sediments in the Balesa and also to assess the frequency of occurrence of clay beds. No extensive beds of clay were found, and therefore no possible sites for subsurface dams were located downstream from the Olturot crossing.

At the Olturot road crossing and at Balesa El Derc, near the edge of the Chalbi desert, there are traditional seasonal wells, similar to those at Bobor. They are dug in the river channel by the local people and intercept the perched water-table below the Balesa during the wet season. The wells are unlined and the walls are subject to frequent collapse. At the time of visiting the wells at Bobor the water-table lay at 3.0 m, 3.5 m and 4.8 m in three uncollapsed wells, all located within a downstream distance of 300 m. The variable depths to the water indicate the importance of highly local variations in porosity and permeability of the sediment in controlling the level of the water-table.

The Balesa was not inspected downstream of Bobor, but it is thought (Borgeson, 1981) that the perched water-table and the regional water-table both approach the ground surface towards the Chalbi desert. Thus it would appear that the ease with which groundwater may be tapped may increase towards the Chalbi desert.

It is recommended that a small number of the traditional wells (perhaps two at each location) should be improved with concrete rings or culverts and hand pumps. The culverts should be caissonned into the river bed in the middle of the main dry season (January-February) to a depth of 1.0-1.5 metres into the perched water-table. In this way the developed wells ought not to become perennial water points.

The cost of developing six wells each with a depth of, say, 6 m would be in the region of KSh. 98,000/- (see section 2.2). Sand for concrete is locally available, but ballast for filter material will have to be brought to the sites together with cement.

At two points across the Balesa Kulal (2-3 km downstream and 4 km upstream from the Olturot road crossing) outcrop and large rocks of lava mark the positions of lava flows which traverse the lugga. It is possible that they could form rock bars on which sand dams could be built, and it is conceived that the lava flows can act as natural subsurface dams. The problem is to know whether the lava overlies ancient sandy sediments or whether it extends down to the Basement complex. If the former were the case then it is likely that water would flow downstream under the lava and any kind of extra, artificial dam would not function. It is likely, however, that the lava flows themselves are not impermeable, since lava is normally highly fractured and jointed.

The absence of traditional wells at the lava flows suggests that they do not act as natural dams (the herdsmen usually know where water can be easily found). Augerings were made upstream of the lava flows, but the depth of penetration was low owing to the presence of rocks and, in any case, a perched water-table was not reached. A subsurface or sand dam cannot be recommended at these points until further intensive investigations using resistivity equipment are able to determine the suitability of the sites.

No further specific sites were found in the Balesa Kulal, even though the channel was inspected nearly all the way to South Horr. In the South Horr valley the channel is much narrower (20-30 m wide) and is incised, often with 2-3 m high, vertical banks consisting of sandy alluvium. However, this area is within the mountainous region and is relatively well watered. Hence no definite sites for development were sought and no places with rocky banks suitable for sand dams were found.

In general the great width and the low, cohesionless banks of alluvium of the Balesa Kulal prohibit the easy construction of relatively cheap and safe structures, even for flow diversion purposes. It is not recommended to try to divert the flow from only one part of the channel, as the lugga could easily change its course in its attempt to adjust itself to the presence of a structure.

Chapter 4

THE LUGGAS BETWEEN GATAB AND ILAUT

4.1 Introduction

There are eleven major luggas which cross the Gatab-Ilaut road. Table 1 gives their distances from the Gatab-Ilaut-South Horr-Kargi junction and from Ilaut to facilitate their location in future. These sandy luggas, and many smaller ones which were not inspected, rise on the Ol Doinyo Mara and in the Ndoto mountains near the south-western margins of the study area and flow north-east across the Hedad, a sandy alluvial plain (Figure 2). The Hedad is at present under-utilized by the nomadic population owing to a shortage of water and security. Provision of these factors is a prerequisite to the more extensive use of this area.

The luggas crossing the Hedad are narrower than the Balesa Kulal and most appear to have a layer of sandy, silty, clayey material at 1-2 below the river beds. These luggas therefore appear to be potentially more amenable to development than the Balesa Kulal. However, they retain many characteristics typical of sand rivers which prevent them from being easily exploited. These characteristics are: a relatively wide, often undefined, braided channel and banks consisting of cohesionless, easily erodable sediment.

Under these circumstances sand dams, which affect the flow conditions around them, are not feasible, since the flow would certainly erode around the ends of a dam and render it useless. Subsurface dams, however, are quite feasible providing the crests of the structures are buried by at least 0.3 m below the existing river-bed level. In this way there will be little danger of these structures inducing scour, assuming that the existing bed level is stable.

A significant problem, which is difficult to assess, is that excessive amounts of water may leak laterally from the sediment reservoirs and flow around the subsurface dams in the alluvial banks. In this case the water-table behind the structure would not remain high for very long. Experimentation with structures needs to be undertaken to assess the importance of this problem.

Table 1. Location of inspected luggas along the Gatab-Ilaut road

Lugga No.	Distance from Gatab-Kargi junction (km)	Distance from Ilaut (km)
1.	13	45
2.	19	39
3.	19	39
4.	21	37
5.	23	35
6.	30	28
7.	30	28
8.	36	22
9.	53	5
10.	55	3
11.	58	0

Given these uncertainties, possible sites for development do exist. These are treated here according to lugga number (Table 1). Where sites on luggas were not found, for the reasons stated above, these luggas are not mentioned.

4.2 Lugga No. 3 (Site No. G-1.3)

Approximately 1 km upstream from the road crossing is a site for a small subsurface dam with a relatively low storage capacity which might provide water for very short periods following floods. At the proposed dam site there is a bed of coarse sandy, silty clay at 1.3 m below the river-bed level and which is over 0.7 m thick. The bed extends upstream across the entire width of the channel and may form an impermeable barrier to percolating water despite its sand content (a perched water-table was not found at the time of inspection).

Figure 7 shows details of the site. The bulk storage volume of sand containing water was calculated to be 1,500 m^3, using the crude method outlined in section 2.5. Assuming an average specific yield (the extractable water expressed as a percentage of a unit bulk volume of aquifer material) for sand of 20%, then at least 300 m^3 of water will be available for extraction.

The approximate cost of constructing a dam at this site with a 3 m dug well is given in Table 2. This estimate does not include the cost of transport of materials or labour and it may be reduced by increasing the proportion of masonry relative to concrete. There is a rock outcrop 200-300 m downstream from the site which would be a source of building stone. There is also good access from the road.

Figure 7. Diagram of the proposed subsurface dam site G-1.3 on lugga No. 3

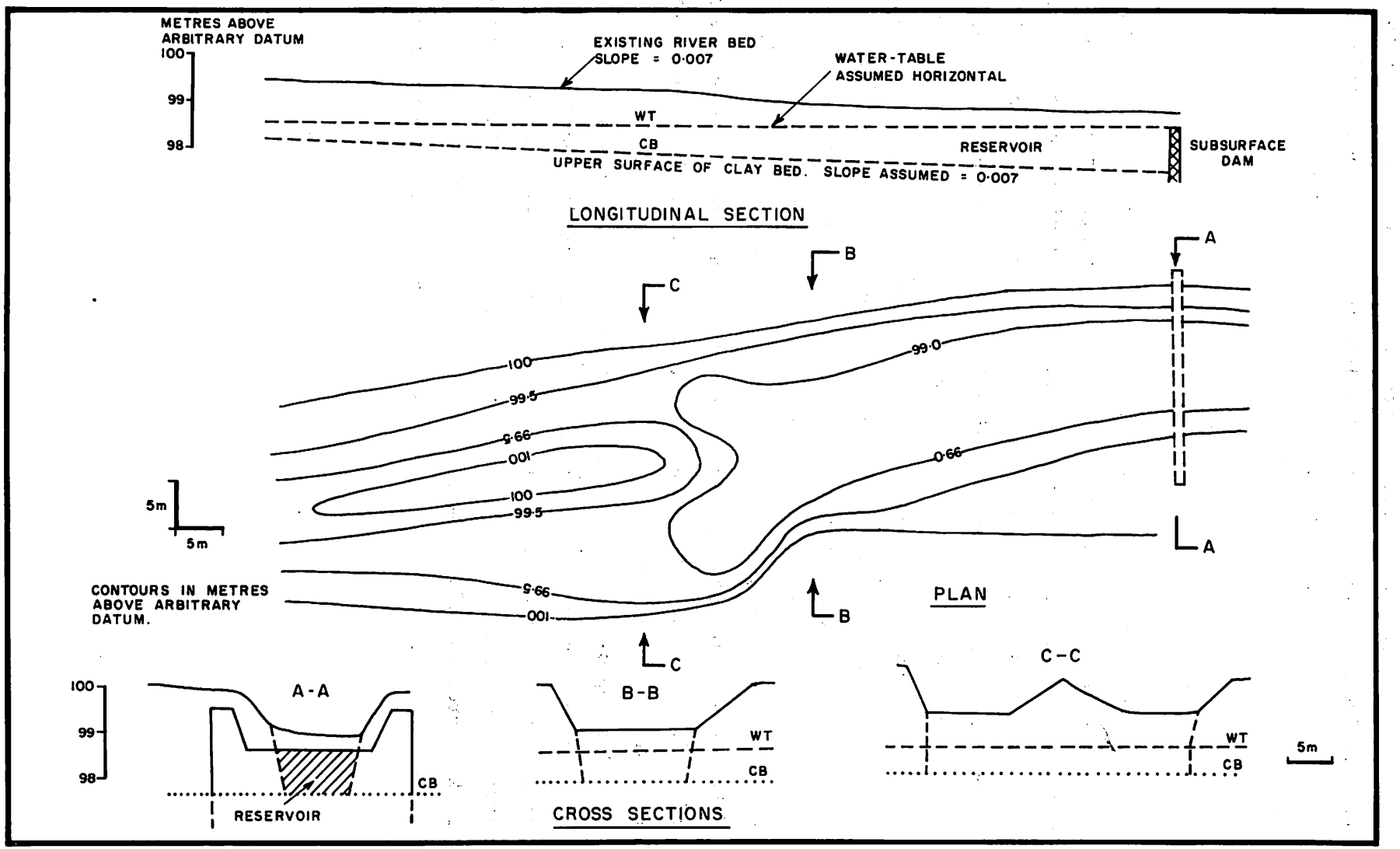


Table 2. Cost of constructing a subsurface dam and well at site G-1.3

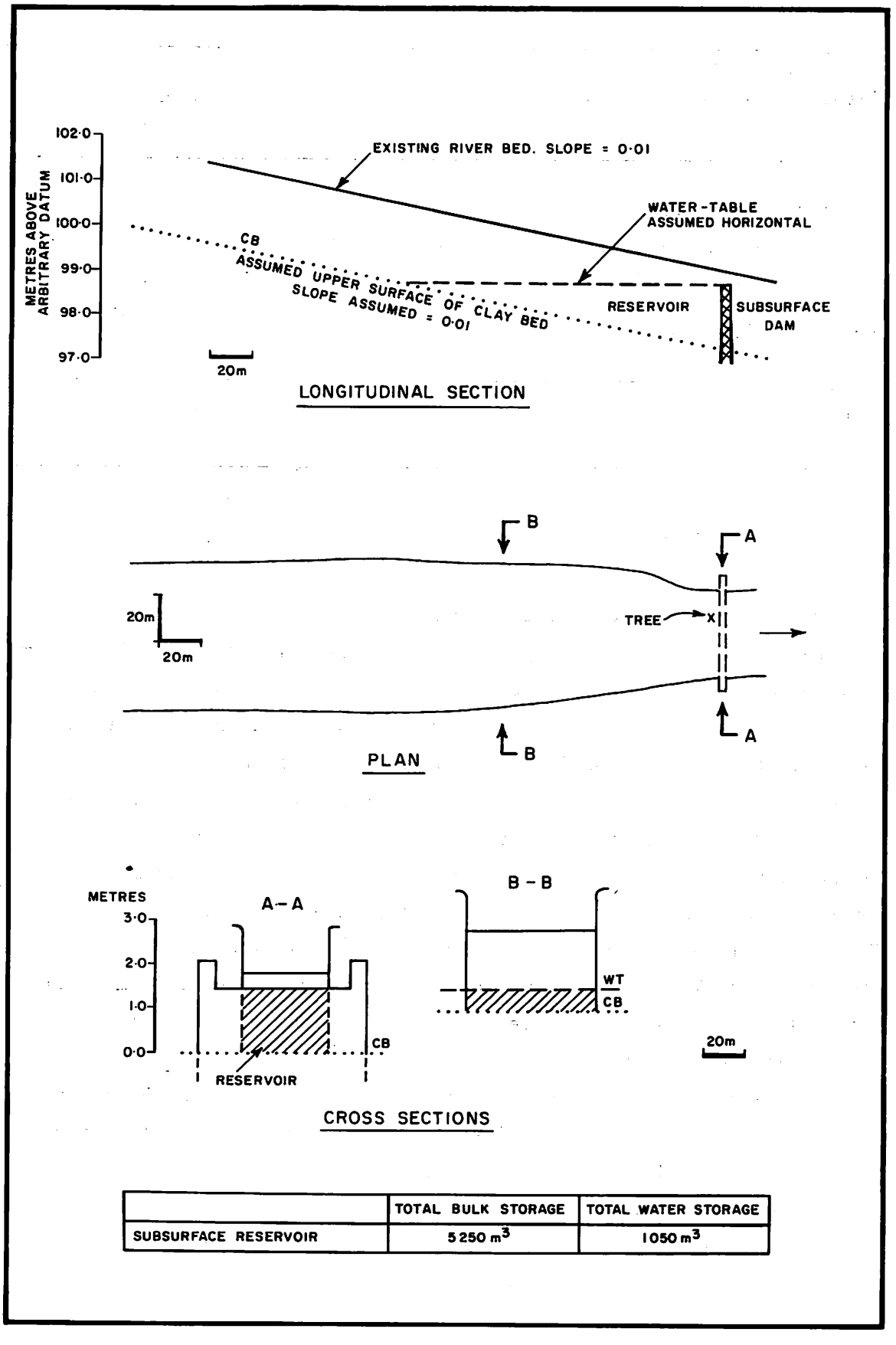
Structure and dimensions	Cost (KSh.)
Subsurface dam: 25 x 2 x 0.5 m, 25 m^3 volume built with ratio 1 masonry : 1 concrete (1 m^3 concrete = KSh. 1,400)	17,500/-
Dug well, 3.0 m deep	10,000/-
Total	27,500/-

4.3 Lugga No. 5 (Site No. G-1.5)

Approximately 0.5 km downstream from the road crossing there is a possible site for a 1.5 m high subsurface dam. The dam site is marked by a tree standing near the centre of the channel. The lugga is approximately 60 m wide upstream of the proposed dam site and then narrows to a width of 35-40 metres at the site of the dam axis (Figure 8). There is a bed of clay at 1.8 m depth which extends down to cover 2.2 m below the present river bed level. The banks are approximately 1.5 m high and consist of sandy deposits. There is therefore a risk of lateral leakage out of the sediment reservoir. The dam would be buried 0.3 m below the existing river bed so as to reduce the risk of floods damaging the structure. The minimum total created storage is approximately 5,250 m^3 and the minimum volume of extractable water would be 1,050 m^3

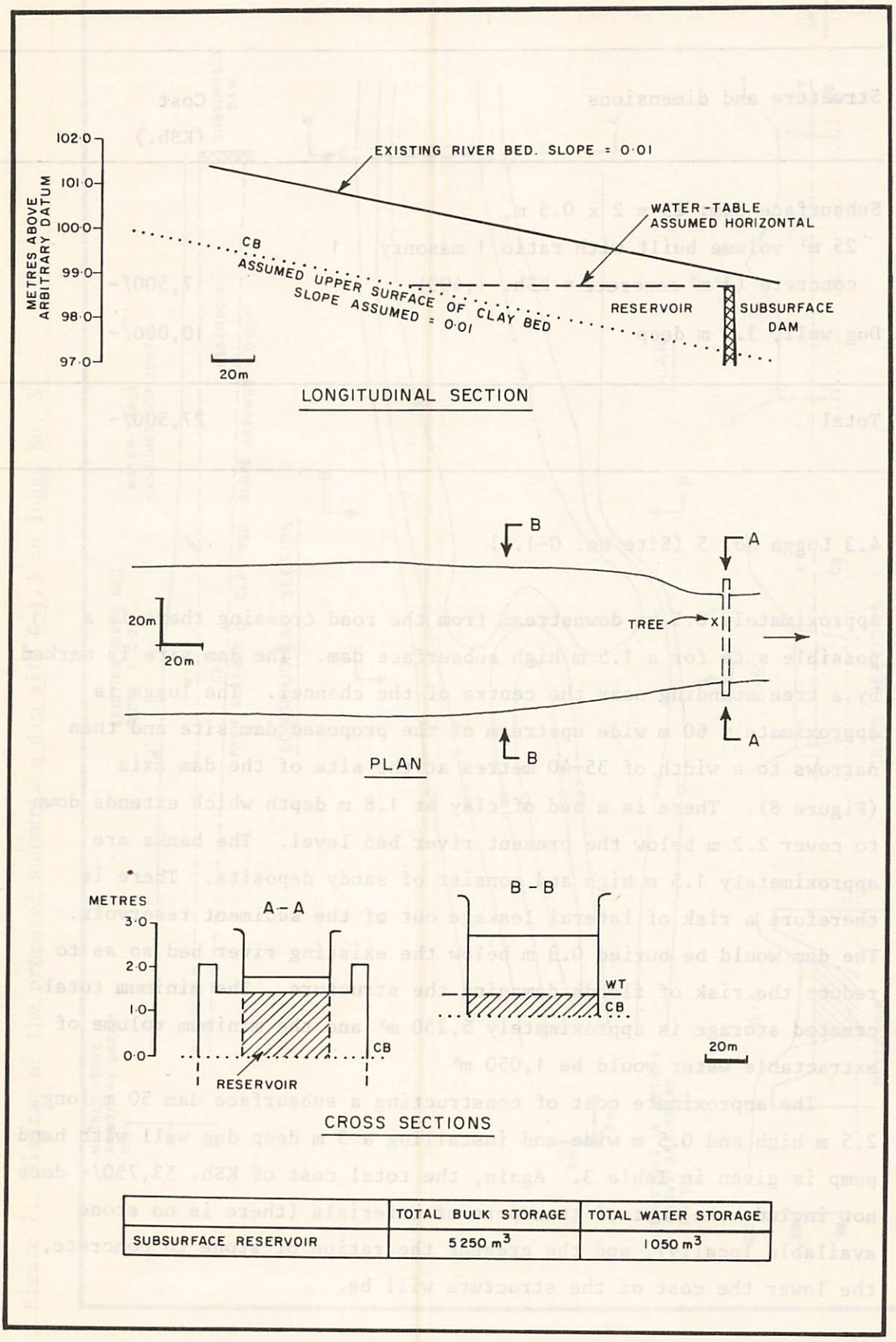
The approximate cost of constructing a subsurface dam 50 m long, 2.5 m high and 0.5 m wide and installing a 3 m deep dug well with hand pump is given in Table 3. Again, the total cost of KSh. 53,750/- does not include the cost of transport of materials (there is no stone available locally), and the greater the ration of stone to concrete, the lower the cost of the structure will be.

Figure 8. Sketch of proposed subsurface dam site G-1.5 on lugga No. 5



	TOTAL BULK STORAGE	TOTAL WATER STORAGE
SUBSURFACE RESERVOIR	5250 m^3	1050 m^3

Figure 8. Sketch of proposed subsurface dam site G-1.5 on lugga No. 5



	TOTAL BULK STORAGE	TOTAL WATER STORAGE
SUBSURFACE RESERVOIR	5250 m^3	1050 m^3

Table 3. Cost of constructing a subsurface dam and dug well at site No. 5

Structure and dimensions	Cost (KSh.)
Surface dam: 50 x 2.5 x 0.5 m, 65 m³ volume built with ratio 1 masonry : 1 concrete (1 m³ concrete = KSh. 1,400/-)	43,750/-
Dug well and hand pump, 3 m deep	10,000/-
Total	53,750/-

4.4 Lugga No. 6 (site No. G-1.6

At the road crossing this lugga is deeply incised to a depth of 3-4 m into stratified alluvium. Downstream, the lugga becomes increasingly less incised and therefore unamenable to development. Less than 1 km upstream from the road crossing the width of the incised lugga suddenly increases from 32 m to 95 m, with banks approximately 2.5 m high. The narrow 'neck' in the channel, behind which is a wide 'bowl', marks an ideal site for a sand dam with a large storage capacity. The site was not surveyed fully, but rough measurements were made and a scale sketch is shown in Figure 9.

A surface dam is not feasible because the layer of sandy, silty, clayey material which exists at the proposed dam site is at a depth of only 0.8 m (although it extends down to a depth below 1.7 m). Upstream, in the centre of the 'bowl', this bed lies at a depth of only 0.2 m. The lack of natural storage means that artificial storage capacity must be created. A 1.5 m high sand dam is therefore suggested as being appropriate to this situation. Calculations show that it would have a total storage capacity of 7,440 m³ and a volume of extractable water of 1,500 m³.

Figure 9. Sketch of proposed sand dam site G-1.6 on lugga No. 6

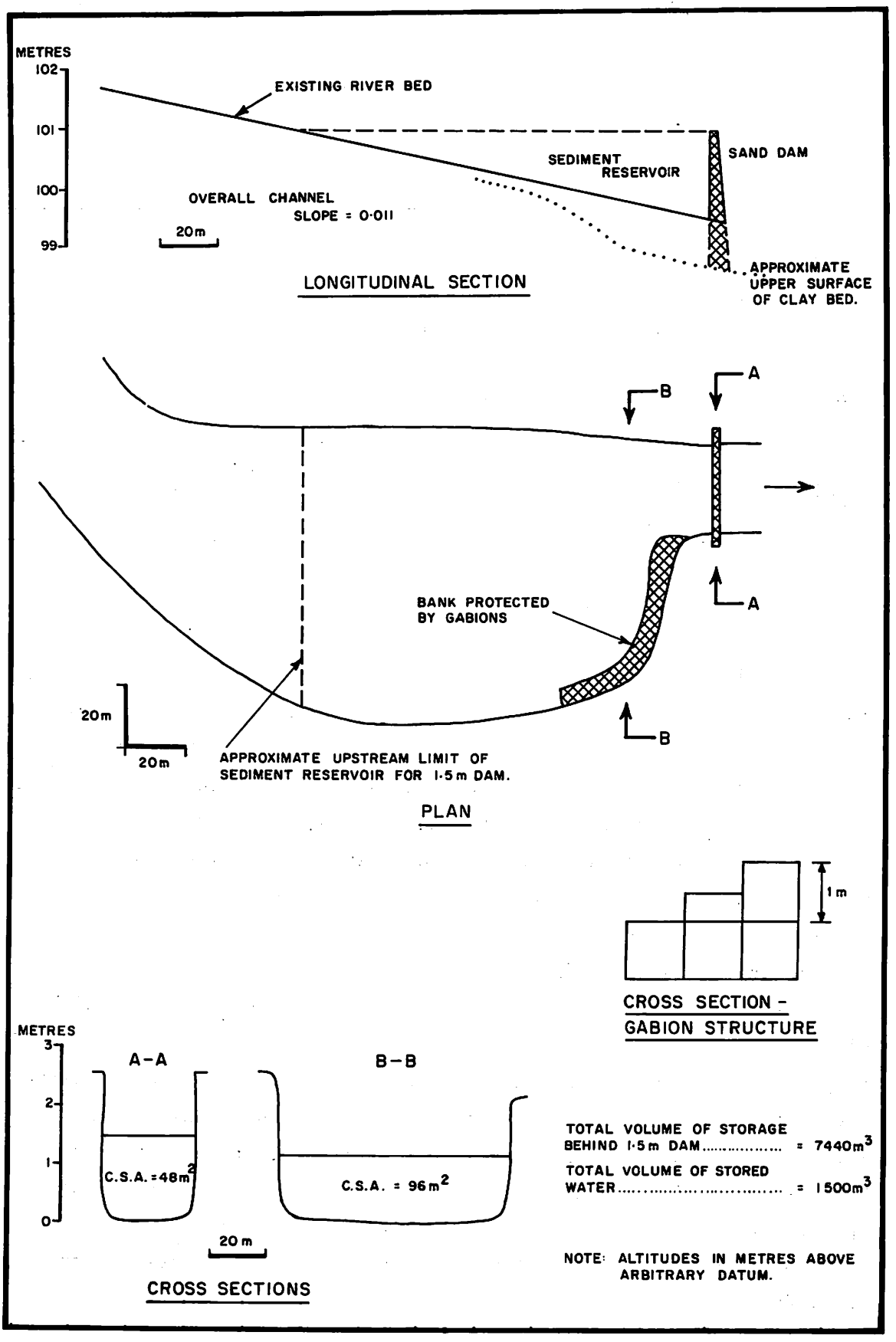


Table 4. Costs of constructing a sand dam and well at site No. G-1.6

Structure and dimensions	Cost (KSh.)
Sand dam: 20 x 2.5 x 1.0 m, 50 m³ volume built with ratio 1 masonry : 1 concrete	35,000/-
Dug well and hand pump, 3 m deep	10,000/-
Gabion protection structure: 250 gabions @ 600/-	150,000/-
Total	195,000/-

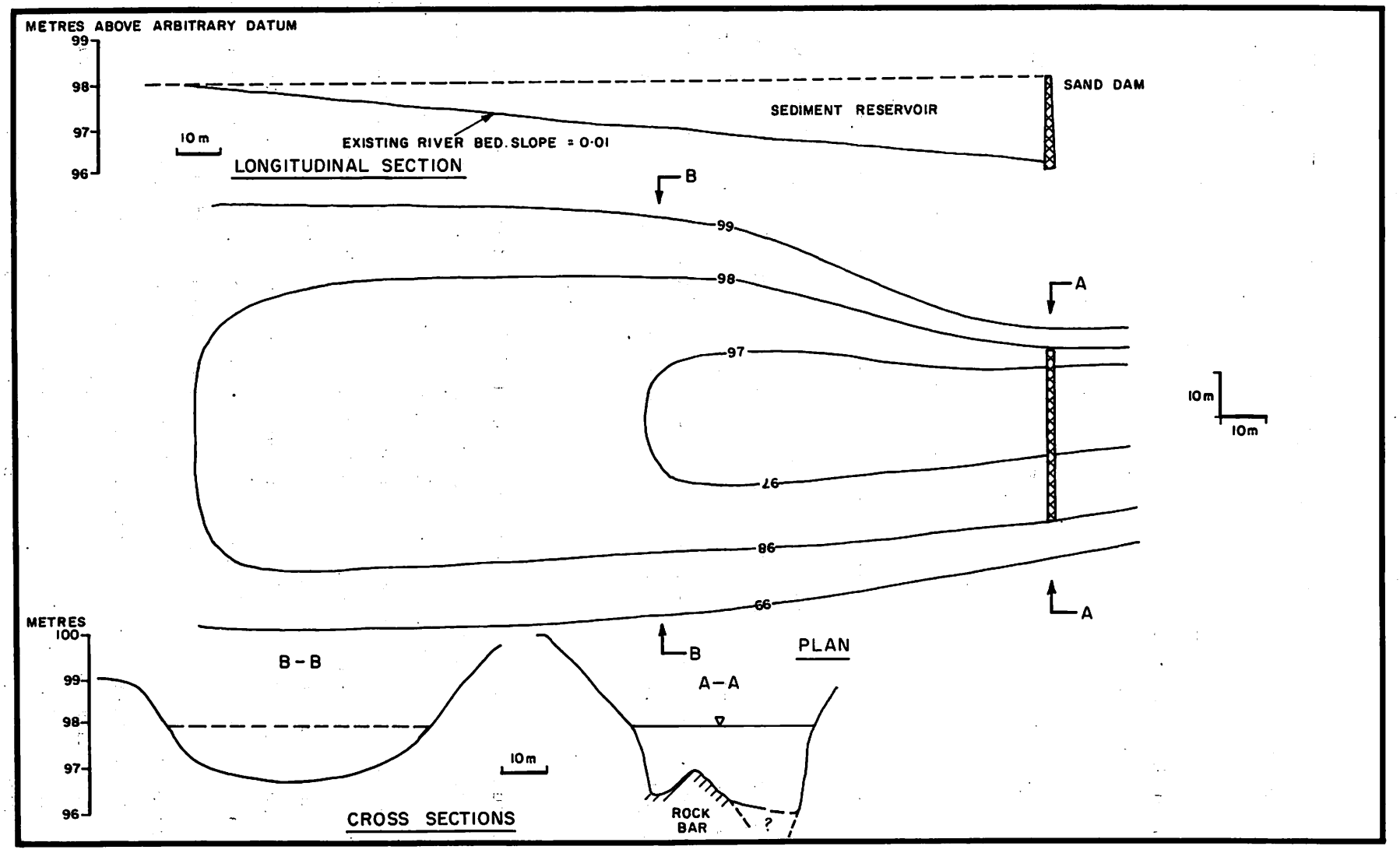
The dam wall must therefore be well keyed into the banks, which must in turn be protected by gabions. Table 4 gives the approximate cost of a sand dam and a well at this site and a bank protection structure 70 m long constructed of gabions, as shown in Figure 9. There is no local supply of stones, which would therefore have to be imported by lorry.

4.5 Lugga No. 11 (site No. G-1.11 - Ilaut Centre)

Ilaut is a permanent settlement located in the foothills of the Ndoto Mountains (Figure 2) adjacent to a large sandy lugga which is underlain by impermeable granitic rock. The lugga is traversed by a number of rock bars which are exposed across at least two-thirds of the width of the lugga. These bars, which are separated by 'pools' of deep coarse sand containing large quantities of water, offer potentially good sites for sand dams. At the time of inspection the lugga had flooded the previous day and had filled in the numerous traditional unlined wells with sand.

A potential site for a sand dam was identified on the main lugga opposite the large single *Acacia tortilis* situated on the central ridge between the main channel and a smaller, tributary lugga which was at one time the camp site for the IPAL range-survey team. Figure 10 shows the layout of the site. A 2 m high sand dam is suggested as appropriate here. The total bulk storage would be 6,605 m³, of which 1,321 m³ would be extractable water (excluding the natural storage). The main problem with this site is that the bedrock between the end

Figure 10. Diagram of the proposed sand dam site G-1.11 at Ilaut Centre



of the exposed rock bar and the left bank may be very deep (see cross section A-A, Figure 10). This was the case with an alternative site 150 m downstream and downslope from a single *duka* on the main road at the village. A local person alerted the author to the fact that this was a traditional well site and that the depth of the sand at the end of the rock bar was in excess of 6 m. It is therefore recommended that, in the dry season, a hole should be dug at the proposed site and the depth to bedrock determined. Augering at the time of inspection was impossible because the sand was completely saturated with water.

Elsewhere along this lugga there are numerous places where traditional wells can be improved with ease by installing concrete rings and hand pumps. For the time being, two dug wells supplementary to the well associated with the proposed dam are recommended for the centre as a whole. Table 5 presents the estimated costs of the structures.

Table 5. Costs of constructing a sand dam and three wells at site No. G-1.11 (Ilaut Centre)

Structure and dimensions	Cost (KSh.)
Sand dam: 40 x 2 x 1.0 m, 80 m^3 volume built with masonry : concrete ratio of 1 : 1	56,000/-
3 hand dug wells (one with sand dam) each 10 m deep	58,000/-
Total	114,000/-

4.6 General

No further sites for subsurface or sand dams were found. Moreover, no definite sites for flow diversion and pan construction were identified, since the emphasis was placed by the author on finding sites for subsurface

and sand dams and inspection was confined to the river beds. However, there are many places (generally upstream of the road crossing) where the channels are sufficiently narrow to make the diversion of their flows a viable and economic proposition. Costs of constructing one diversion weir, say, 30 m in length and using gabions arranged as in Figure 5 would be in the region of KSh. 40,000.

It was noted that the banks of the luggas often consist partly of beds of silt-size material at depths of 1-2 m below the tops of the banks. Assuming that these beds extend laterally away from the river channel, the possibility exists of storing diverted water in pans excavated adjacent to the luggas and lined with silty material, particularly along luggas 4, 5 and 9.

Enquiries were made from the local population regarding the location of water sources in the luggas. The invariable answer was that water was found in the river sediments only within the mountainous area and was exploited mainly during the dry season. Away from the mountains the only water available was that standing in rainwater pools. There are no places where the people dig wells and obtain water from these luggas, except at and around Ilaut, which is located in the foothills of the granitic Ndoto Mountains.

Owing to the possibility of problems associated with vertical and lateral leakage from the sediment reservoirs of the proposed dams, it may be appropriate to experiment with the smallest, cheapest site (lugga No. 3) before embarking on the larger sites.

Chapter 5

THE LUGGAS BETWEEN KORR AND KARGI

5.1 Introduction

The nature of the luggas crossing the Korr-Kargi road (Figure 2) is very different from that of those crossing the Hedad. The Korr luggas are steep and rocky in their upper reaches on the Korr plateau and, occasionally, are incised into bedrock. In general the bedrock is very near the surface of the lugga beds and outcrops are common. The depth of the sand is highly variable, but is generally shallow. There is little or no natural storage capacity in the sand. Storage, therefore, has to be created by choosing sites where the channel is incised with steep rocky banks. Where this situation occurs there are excellent opportunities for constructing sand dams. As the luggas flow north-west off the plateau and converge into a single lugga flowing north along the edge of the Marsabit lava, the width of the luggas increases and the banks become less rocky and steep. Therefore, opportunities for constructing sand dams become fewer towards the north.

Inspection of the luggas was restricted to those within 12 km of Korr, owing to wet weather and poor driving conditions in a flat marshy area called Balah, 12 km north of Korr. This area could not be crossed but, as far as the author is aware, there is only one lugga of significant size between Balah and Kargi which was not inspected.

Table 6 gives the distances from Korr of the luggas crossed by the road so that they may be located in future.

Table 6. Numbered luggas and their distances north of Korr

Lugga number	Distance (km)
1	2
2	3
3	6
4 (Balah lugga)	11

Lugga No. 1 was not inspected owing to its proximity (2 km) to Korr, which has a large number of dug wells and boreholes supplying a settled and rapidly expanding population.

5.2 Lugga No. 2 (site No. K.2)

Upstream from the road crossing there are no sites for development. However, 1.5-2.0 km downstream of the crossing, there is a possible site for a sand dam. Figure 11 shows the details of this site. The total bulk volume of storage created behind a 2 m high dam is approximately 1,800 m^3 and the total volume of water that would be available for extraction is 360 m^3

It is likely that there will be no problems associated with this site in terms of lateral or vertical leakage from the sediment reservoir; the banks are mostly rocky and the sediment in the existing river bed contained water at a depth of 0.3 m at the time of inspection. The cost of constructing a sand dam and well is given in Table 7. There is a good supply of building stone and there is easy access from the road.

Downstream, this lugga passes not far from the Korr Mission and lugga No. 1 joins it. Initially the lugga is incised into alluvium and the width gradually increases. However, the incised section does not have rock outcrops. Therefore the lugga becomes increasingly less well incised and eventually divides into a large number of braided channels. The lugga was not inspected further.

Figure 11. Diagram of proposed sand dam site K.2 on lugga No. 2, north of Korr

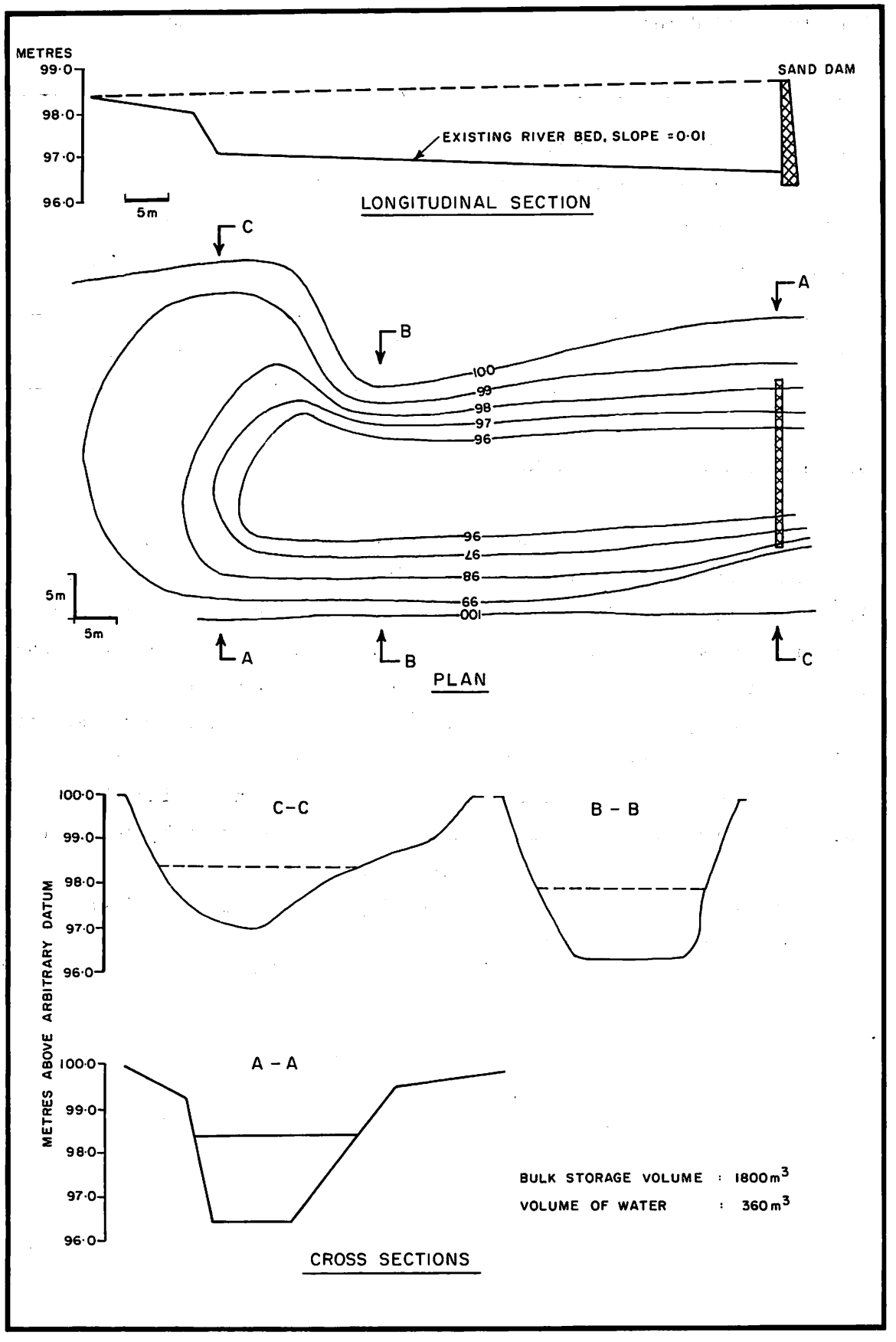


Table 7. Cost of constructing a sand dam and well at site K.2

Structure and dimensions	Cost (KSh)
Sand dam: 19 x 3.0 x 1.0 m, 57.0 m^3 volume built with ratio 1 masonry : 1 concrete	40,000/-
Dug well, 3 m deep	10,000/-
Total	50,000/-

5.3 Lugga No. 3 (site No. K.3)

A good site for a sand dam was identified on lugga No. 3, approximately 1 km upstream (west) of the road crossing. Figure 12 shows the general layout of the site. Very steep rocky banks will enable a 3.5 m high dam to be constructed with relative ease. It may be possible to raise the dam wall later to 4.0 m. The sediment reservoir volume is calculated to be 8,000 m^3, of which 1,600 m^3 will be water available for abstraction. Existing sand depths are shallow, but were observed to contain water at a depth of 0.2 m below the existing river bed, indicating that the underlying geology is impermeable. A good supply of building stone is available and there is easy access from the road.

Estimates of the cost of constructing the sand dam and installing a well are given in Table 8.

Figure 12. Diagram of proposed K.3 sand dam site on lugga No. 3, north of Korr

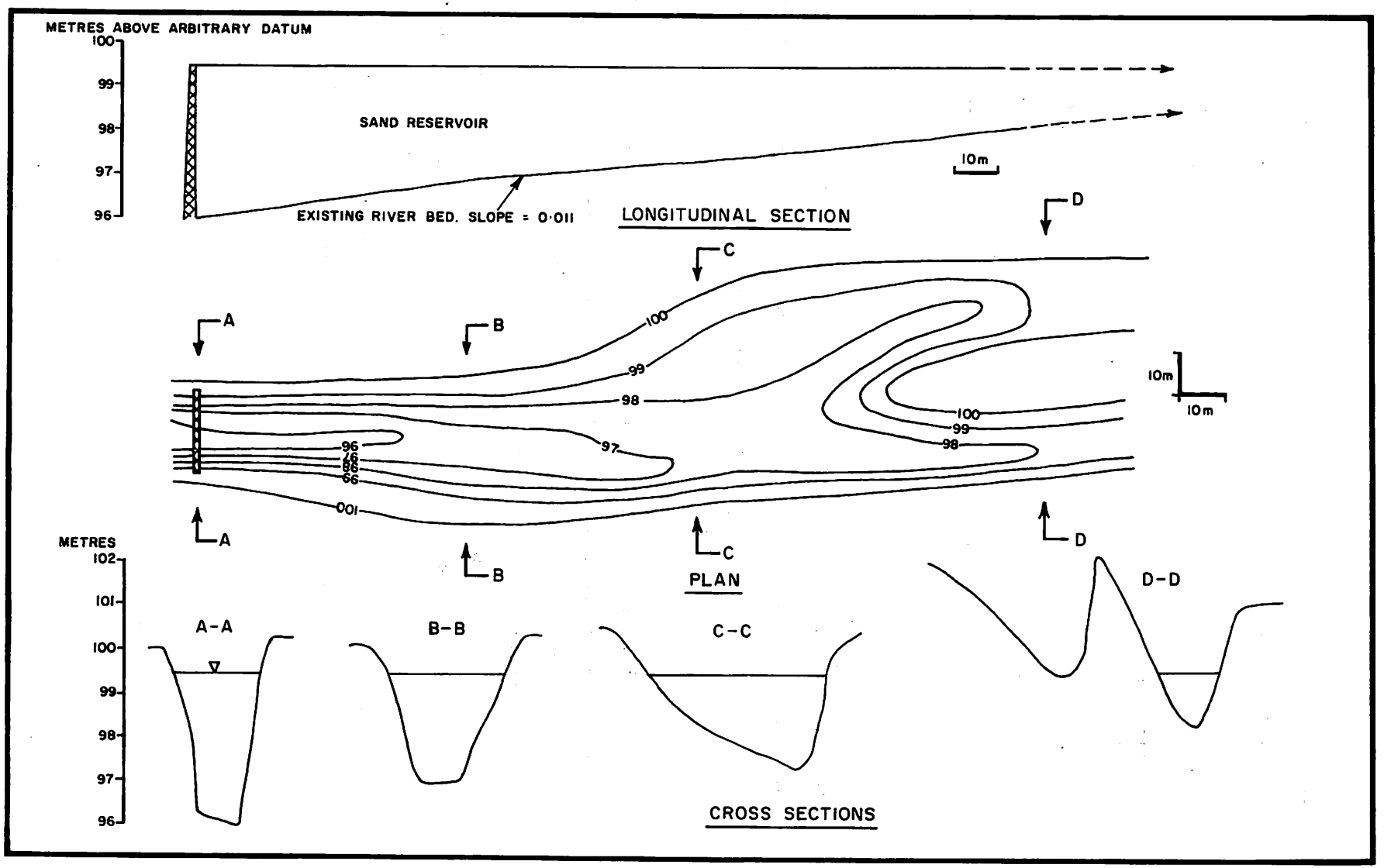


Table 8. Cost of constructing a sand dam and well at site K.3

Structure and dimension	Cost (KSh.)
Sand dam: 20 x 4.0 x 1.5 m, 120 m^3 volume built with ratio 1 masonry : 1 concrete	84,000/-
Dug well, 5 m deep	16,000/-

5.4 Lugga No. 4 (Balah Lugga)

Balah lugga is a sandy-bedded lugga, approximately 15 m wide, which flows across Balah, a flat marshy area, approximately 12 km north of Korr. The soils of Balah are deep, very poorly drained, and contain significant amounts of clay. They are therefore highly suited to pan construction.

Although a specific site for a pan was not located, the general observation was made that it would be relatively easy to divert the ephemeral lugga flow into a pan excavated adjacent to the channel, using a structure similar to that illustrated in Figure 5. The cost of a diversion weir following this design in Balah lugga would be approximately KSh. 29,000. Assuming that the pan is excavated using heavy machinery and that it has a capacity of 12,000 m^3, then the cost of excavation would be approximately KSh. 40,000. The total cost, including a 5 m deep dug well, would be approximately KSh. 85,000.

Figure 13. The study area: Soils suitable for pan construction

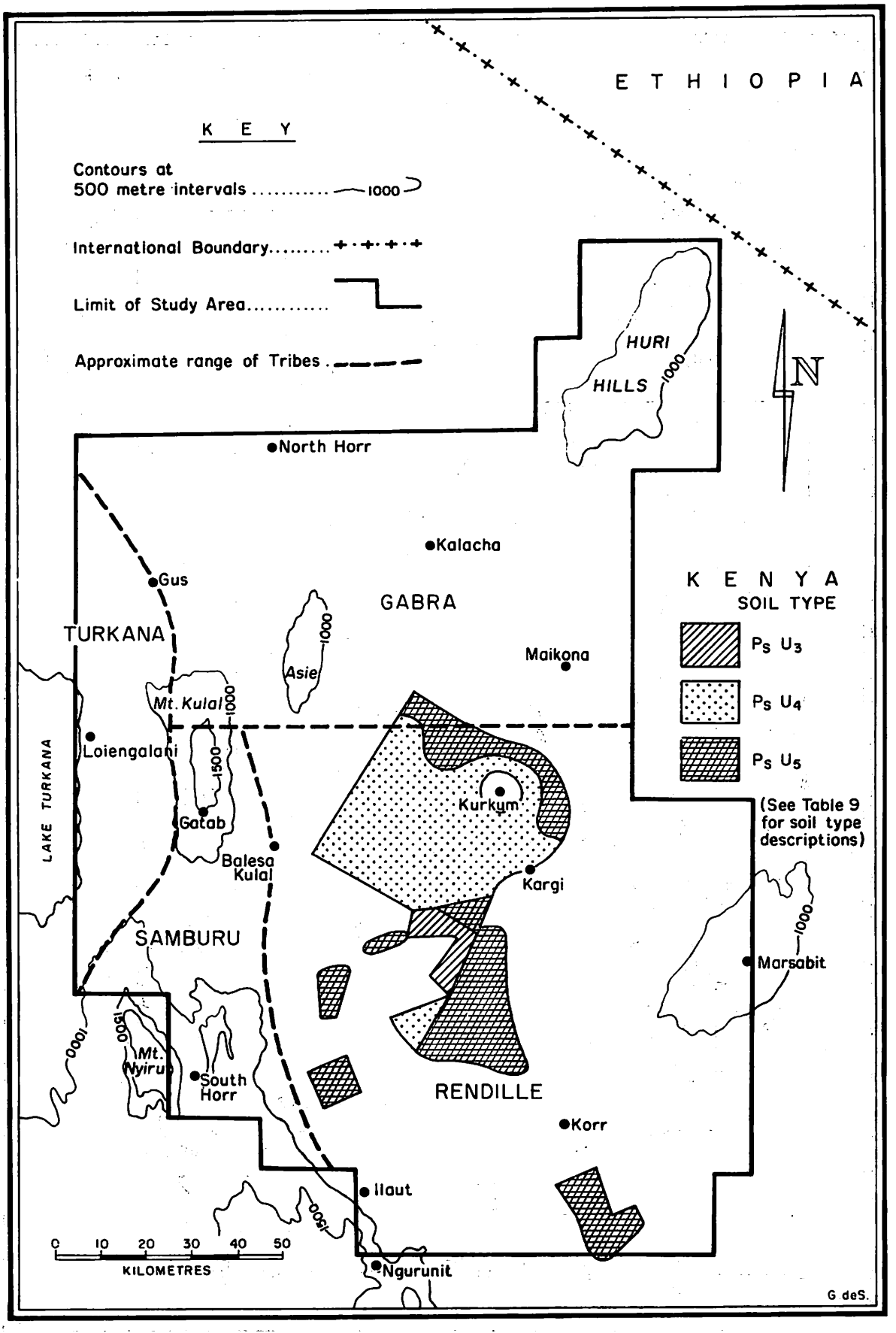
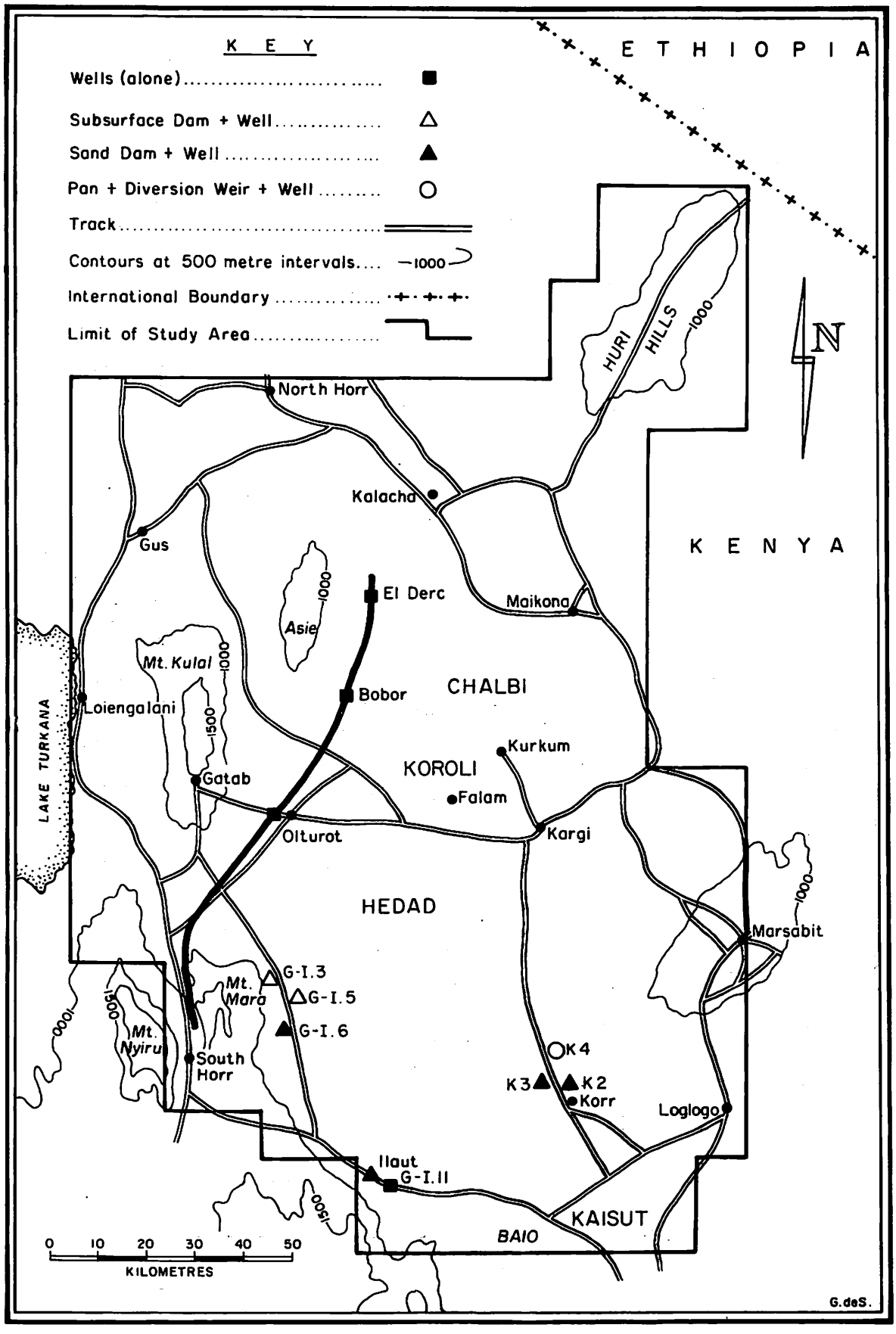


Figure 14. The study area: Distribution of potential sites for water development



Chapter 6

PANS: GENERAL AREAS FOR CONSTRUCTION

The location of pan sites during the three weeks fieldwork has, perhaps, not received sufficient attention relative to the importance of pans in semi-arid areas. However, good sites in the sandy area bordering the Balesa Kulal and adjacent to the luggas crossing the Gatab-Ilaut road are relatively uncommon and require considerable time to locate and verify. The best (clay-containing) soils are not found in the areas inspected (with the exception of those of Balah). Discussions with Mr. A.J. van Kekem, the IPAL soil scientist, resulted in the identification of three types of soil which are particularly suitable for pan construction. Figure 13 shows the approximate distribution of these soil types over the project area and Table 9 gives detailed descriptions of the soils. For a more accurate map of the distribution of these soil types, see the soil map of the IPAL study area (van Kekem, in preparation).

The soils identified are all developed in sediments derived from the Basement complex. The topsoils are mostly loamy sands (80% sandy, maximum 8% clay) to sandy loams (60% sand, 10-15% clay). These textures do not promote surface runoff. However, in many places the topsoil is eroded and the underlying B horizons are exposed. Where this has occurred surface runoff is a commoner phenomenon.

The B horizons are commonly sandy clay loams (60% sand, 20-25% clay) to sandy clays (50-60% sand, 30-35% clay) and become virtually impermeable when saturated. For example, standing water has been observed after rain between small sand dunes in areas covered by soil type P_s U_5.

Specific sites in these and other areas should be determined by field inspection and trial soil pits and, finally, topographic surveys. Pans should be sited near luggas wherever possible, since they are a more reliable source of water than surface runoff.

Table 9. Description of soils suitable for pan construction (N.B. P_sU = soils developed on sediments derived from undifferentiated Basement rocks. Relief intensity is less than 5 m with slopes 0-2%.)

Soil code	Description
P_sU_3	Well drained to moderately well drained, very deep, dark reddish brown, friable, slightly to moderately saline, strongly sodic sandy clay loam to sandy clay, often with a topsoil (15-20) of loam to clay or with a topsoil of loamy sand to sandy loam (orthic solonetz, saline phase).
P_sU_4	Well drained to moderately well drained, very deep, reddish brown to dark reddish brown, friable, slightly to strongly saline, strongly sodic, sandyclay loam to sandy clay, abruptly underlying a topsoil of loamy sand to sandy loam (orthic solonetz, saline phase).
P_sU_5	Well drained to imperfectly drained, very deep, red to reddish brown, friable, strongly calcareous, slightly to strongly saline, strongly sodic, sandy clay loam to sandy clay, abruptly underlying 10-40 cm sand, in places truncated or buried (orthic solonetz, saline phase).

Chapter 7

DISCUSSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter is mainly concerned with outlining a number of aspects of water development that have not yet been treated in this report, but which are vital to the water-development component of any project. Firstly, the sites identified during the fieldwork are briefly discussed. There follows a discussion of a number of methods of water conservation which are appropriate to the IPAL study area in addition to pans and subsurface and sand dams. These are rock catchments and roof-top rainwater harvesting, water harvesting using micro-catchments and catchment protection work, which is an activity closely related to water development. The suitability of these techniques to the IPAL study area in general is briefly assessed. By employing as wide a range of water-conservation measures as possible an increasing proportion of the water that is at present lost may be used to good effect and for a wide range of purposes. Thirdly, some aspects of water-development planning and implementation are outlined. These are considered to be essential to the success of the development programme.

7.2 The Sites Identified

Figure 14 shows the approximate distribution of the sites identified. It was not possible to map the areas and locations of the sites accurately, for the reasons given in section 1.3. The sites are mostly located around the margins of the Hedad. It is not necessarily the case that the sites are in the best locations in terms of spreading the movement of livestock as widely as possible over this area. The core of the Hedad, which is the main waterless region of the study area during the wet season, has still to be properly surveyed for possible water points. Factors which must be taken into account besides satisfying the site criteria (see Chapter 2) are treated in section 7.4.2.

Table 10. Summary of the sites identified for water development.

Site	Structure	Cost (KSh.)	Water storage (m^3)	Unit cost (KSh./m^3)
Balesa Kulal	6 wells	98,000/-		-
G-1.3	S.S.D. + well	27,500/-	300	92/-
G-1.5	S.S.D. + well	53,750/-	1,050	51/-
G-1.6	S.D. + well	195,000/-	1,500	130/-
G-1.11	S.D. + well	75,000/-	1,321	57/-
	2 wells	39,000/-	-	-
K.2	S.D. + well	50,000/-	360	139/-
K.3	S.D. + well	100,000/-	1,600	62/50
K.4	Div. W + pan + well	85,000/-	12,000	7/-

Note: S.S.D. = Subsurface Dam; S.D. = Sand Dam; Div. W = Diversion weir.

So far only the estimated costs of development of individual sites have been given. The relative costs of pans and dams may be compared if the cost is expressed in terms of shillings per cubic metre of water stored. Table 10 gives a summary of storage capacities and costs of the structures. Colum 5 shows that although only one pan has been proposed, the estimated unit cost is only KSh 7/- as compared with the costs of dams, which range from KSh. 30/- to KSh. 139/- per unit volume of water stored. This suggests that, of the three main types of structures, pans should be the main form of water development used in the rangelands of the IPAL study area. Indeed, the chances that a pan will function successfully appear to be greater than those of a subsurface or sand dam, given the uncertainties concerning vertical and lateral leakage from the sediment reservoirs. Moreover, the cost of pans may be reduced by using donkey or camel-drawn dam scoops and hand labour rather than the earth-moving plant which the above figures assume.

The availability of stone or the transport to import it will also affect the type of structure used. In general, gabion diversion weirs will require larger quantities of stone than subsurface or sand dams. In the Hedad, stone is extremely rare except at the western, southern and eastern margins. With the exception of the luggas north of Korr, most of the sites identified will require transport to import stones and other building materials. The construction costs will rise according to the distance to be travelled and the quantity of material required.

The availability of labour for construction and maintenance is another important factor which must be considered. During the period of fieldwork the author was struck by how few people there were, particularly near the Balesa Kulal and in the area along the Gatab-Ilaut road. Although information on work rates is not available, it must be assumed in the planning process that any type of structure will require at least three hundred man-days to complete, providing there are no delays in the arrival of building materials and so forth. Special arrangements may be necessary in order to get a reasonable workforce; most of the people's time appeared to be taken up with

looking after their livestock. Nevertheless, the participation of the local population is essential if a sense of ownership and responsibility for the waterpoints is to develop. This aspect is discussed further in section 7.4.2.

7.3 Other Forms of Water Development and Related Activities

7.3.1 Rock catchments

Where there are hillsides of bare impermeable Basement System rocks, nearly all the rain runs off and is rapidly lost in the sandy pediment surrounding the hills. Small masonry walls 25-30 cm high can be built along hillsides to guide the runoff into either a masonry storage tank or a small storage reservoir. The reservoir may be created by constructing a masonry weir at a suitable site in a natural depression in a rocky valley.

Opportunities for this form of water development exist mainly in the mountainous area around Ilaut and Ngurunit and at isolated rock outcrops such as Baio Mountain (Figure 2). In these areas there are huge rock faces which could yield large quantities of good quality water if fully developed.

7.3.2 Roof-top rainwater harvesting

Roof-top rainwater harvesting is viable and to be encouraged wherever there are buildings with impermeable roofs. Roofs consisting of corrugated metal sheeting are found in most of the more permanent settlements in the IPAL study area. Again, nearly all the rain will run off the roof and may be channelled, using guttering, into a small tank. Providing the tank is kept covered the water will be of relatively high quality and should be used for domestic purposes. The tank may consist of anything from a fuel drum to a large jar constructed using a wooded lattice framework plastered with morter. The areas of roof-tops in the settlements and the low, unreliable rainfall will not be sufficient to provide water for more than a short time after the end of a rainy season. However, at least the domestic water situation will be improved a little. The scattered pattern of building in the settlements will probably mean that this form of development will have to take place on a private basis, but with technical advice provided for the people.

7.3.3 Water harvesting using micro-catchments

Micro-catchment systems for collecting and using surface runoff before it reaches a stream channel are becoming an increasingly important component in the rehabilitation and development of semi-arid areas. The principle of runoff harvesting involves slowing the velocity of surface runoff and allowing the water time in which to infiltrate the ground. This is achieved by constructing bunds or ridges of stone or earth at successive, limited vertical intervals so that volumes of runoff generated between them are small and non-destructive.

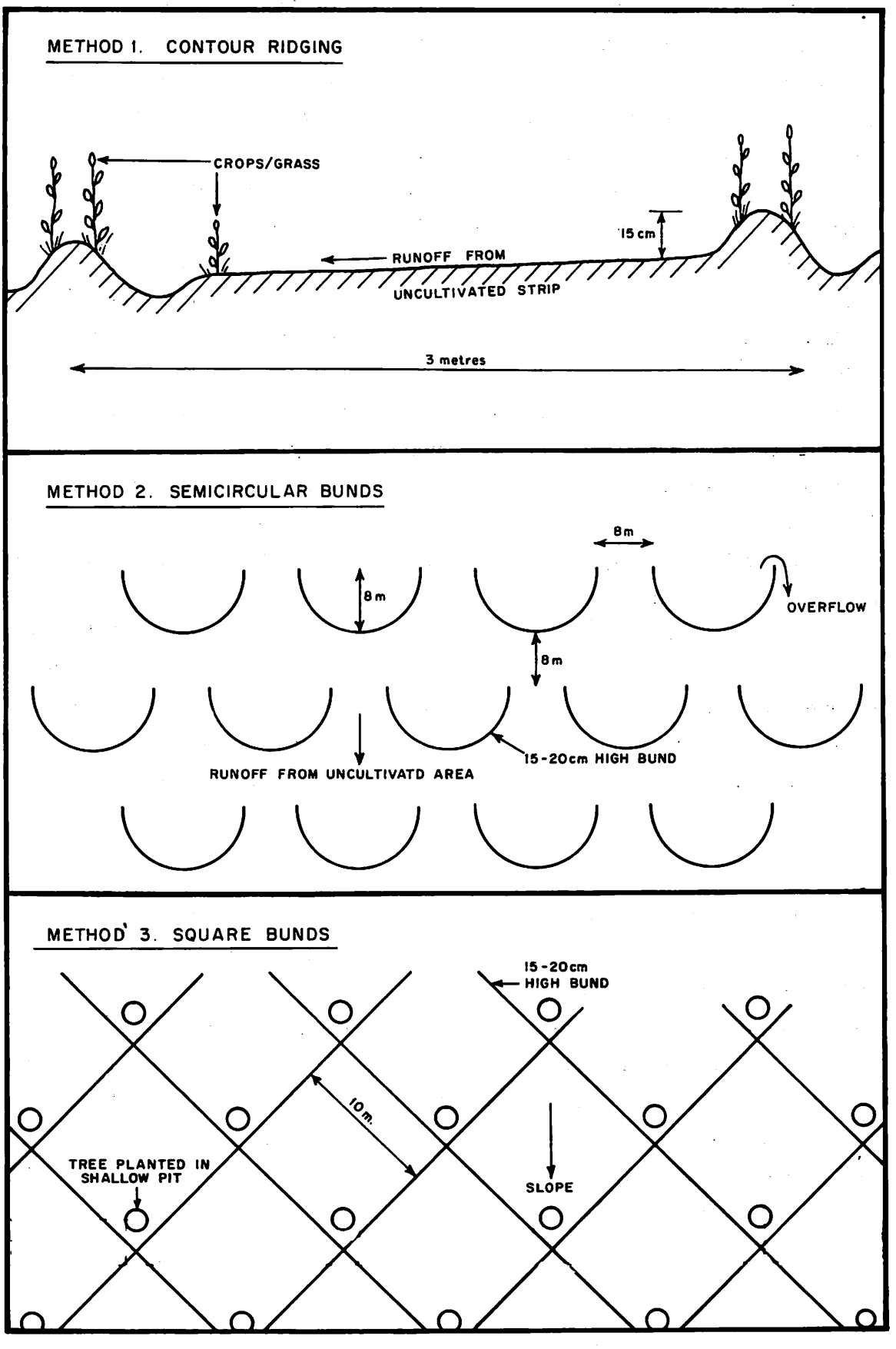
Various designs exist for micro-catchments. For example, they may be simple ridges running parallel to the contours on steeper slopes, or loops (Smith and Critchley, in press) or squares with one corner pointing downslope (Figure 15) (Shanan and Tadmore, 1979). In each case the effect is the same: The runoff is concentrated, it is allowed to infiltrate, and more water becomes available for plant growth. Such systems can be used to increase grass cover, to grow trees, and to increase the yield of crops.

Runoff-harvesting techniques could be most effective and successful around the permanent settlements where the vegetation has been almost completely removed for a radius of several kilometres. The establishment of runoff-harvesting systems will be an essential part of any rehabilitation schemes that are initiated around the settlements. The techniques and tools required are well within the capability of the population, provided that an adequate environmental education programme is run.

7.3.4 Catchment protection

Catchment protection involves activities which are undertaken mainly in the upper reaches of stream networks in order to preserve the natural hydrological characteristics of the catchments. At the same time soil loss from the catchment is reduced and the vegetation cover is maintained or increased. Typical activities involve: working in a downstream direction, and constructing heaped stone check dams in small, headwater gullies at intervals of, say, 30 m, gabion weirs in channels of over 4 m width at intervals of about 100-200 m, and gabion dams on the larger stream channels of up to 30 m width.

Figure 15. Three runoff harvesting methods (after Smith and Critchley (in press) and Shanan and Tadmore (1979))



The purpose of the structures is basically to reduce the sediment yield in the rivers by slowing the velocity of the water, inducing deposition of sediment and infiltration of the flood waters into the river beds. More water is thus made available for use by vegetation and for recharge of regional or perched aquifers. If the vegetation cover can be increased the amount of water used will also increase, thereby reducing the volume of flood flows. The duration of flow in the ephemeral streams can be prolonged if more water is initially retained in the soil and sediment is then released more slowly. In this way the magnitude of flood peaks can be reduced and flooding in general will become less destructive. To be effective. catchment-protection works must be intensive and widespread. Soil-conservation activities on slopes should be integrated with the work in the stream channels.

A large proportion of the IPAL study area consists of sandy plains of very low slope. Catchment degradation and gully-network development are comparatively rare in these areas. These factors, together with the very low population densities, do not justify catchment-protection works on a large scale. However, such work is vital in the upland areas of Mt. Kulal, the Hurri Hills, Marsabit and the Ndoto Mountains, where many of the river systems have their head-waters. The condition of the soils and vegetation of these areas controls, to a large extent, the hydrology of the catchments as a whole,

Protection works should begin with badly degraded catchments and the areas around settlements where gully networks are forming (the programme should be integrated with water harvesting and rehabilitation schemes), particularly near roads. A fully developed catchment-protection programme would help the people understand and conserve their environment better than at present and would improve their dry-season grazing resources.

7.4 Planning and Implementation of the Water-Conservation Programme

7.4.1 General procedures

The following, much of which is taken from Trojanow (1982), is an outline of the procedures followed by the Government in planning and implementing the water-conservation programme in semi-arid parts of Kenya.

Not all such areas, Marsabit included, are covered by the programme, owing to limited funds and manpower However, there are plans to expand the programme's activities to the District. These sections are included to aid the setting up of the water-development component of IPAL in the future.

The water-conservation programme is co-ordinated and implemented by the Agricultural Services Division in the Ministry of Water Development. The overall planning takes place at the headquarters in co-operation with the District Development Committee and District Administration.

Planning begins at the sub-locational and locational level with meetings between Chiefs, Sub-Chiefs, Councillors and the elders of the location. A list is made of sites where the people think they need water points. The lists for each location are then presented at the District Development Committee meetings chaired by the District Commissioner and attended by the departmental heads in the district, Chiefs, Councillors and other local leaders. At this stage there is little critical selection of priority sites for development and little thought is given to analysing how the proposals fit into the District Development Plan as a whole.

The proposals are passed on to the Ministry of Water Development's district staff and planning staff at headquarters. Feasibility surveys are made of the proposed sites and, where necessary, alternative suggestions are made. Detailed designs of structures are made at the headquarters and the construction is finally implemented by direct labour units or contractors.

The labour units consist of dam-construction units, of which there are five in the country, and smaller water-conservation teams. Each dam-construction unit consists of earth-moving plant, vehicles, workshops and miscellaneous small machinery. The units are involved mainly in the construction of earth dams and pans. The water-conservation teams are engaged in the construction of subsurface dams, weirs, rock catchments and catchment-protection measures.

The only significant contribution from the local people has been the provision of casual labour for construction. The role of self-help or harambee groups is limited at the moment to implementing some of the smaller water-conservation work. Moreover, experience so far has shown that the involvement of the people on this basis has been rather modest.

7.4.2 Improved planning methods

7.4.2.1 Introduction

In this section, ways in which the planning process may be improved are suggested. Improved planning of water development in Marsabit District is necessary for several reasons. Firstly, current planning procedures (see section 7.4.1) do not take sufficiently into account the possible adverse effect of the waterpoints on the environment, on both regional and local scales. Secondly, there is an enormous need, if water development is to be planned on a rational basis, to integrate it with the development plans for the district as a whole. Thirdly, greater involvement of the people right from the start in the planning and implementation phases is vital. This will ensure the programme a greater chance of success in terms of the life span and sound management of the structure provided.

7.4.2.2 Planning for the environment

The siting and nature of water points will need careful planning so that traditional grazing patterns are maintained and adverse effects on the grazing exosystems in general, and in the vicinity of the water-points in particular, are minimized. Some method of controlling the availability of water will be necessary in order to maintain seasonal movements. The environmental degradation which has occurred at Korr and Kargi (see section 2.2.1) has demonstrated the importance of this. The simplest and most ethically convenient method of controlling the use of water is to instal seasonal water points. Such structures would tap or store only limited quantities of water which would become naturally exhausted during the dry season. Examples are wells sunk into only the top metre or so of a perched water-table, pans having a capacity of not more than 12,000 m^3 (to allow for losses) and subsurface or sand dams with a storage capacity of not more than 3,000 m^3

It is probable that even seasonal waterpoints will have a deleterious effect on the vegetation around them. Some method must therefore be found to minimize the effect of grazing pressure over the study area, which will increase if more water becomes available. Overgrazing in the immediate vicinity of waterpoints must also be controlled. Various

ill-defined methods have been suggested by IPAL workers, e.g. Field (1979). The methods include:

(i) provision of more waterpoints;
(ii) provision of security in areas of intertribal conflicts;
(iii) strict rules governing who should water;
(iv) some method of controlling the amount of water used (e.g. payment);
(v) prevention of all grazing within a 2-km radius of the waterpoint;
(vi) provision of a more efficient marketing system to encourage the selling of stock.

Provision of more waterpoints and security are undoubtedly necessary to spread the grazing more widely. Grazing pressure will also be reduced if the offtake of livestock by selling can be increased. Points (iii) to (v) are possible courses of action but, alone, will be insufficient. The location of more waterpoints needs more careful consideration.

Lewis (1977) has suggested that the location of water-points should be related to the carrying capacity of the environment. This would minimize the pressure on the better-quality grazing areas and would exercise a certain amount of control over the use of water. Waterpoints should be located in areas of relatively low carrying capacity with radii of 3-5 km. Degradation of the vegetation within these areas would be inevitable but not irreversible, and may result in the preservation of higher grazing potential in areas further away. The seasonality of the water supply together with the absence of good grazing surrounding the water-point would also discourage the excessive use of a few water-points by livestock owners, providing there is an adequate distribution of waterpoints over the grazing area. In this situation the overgrazed area would not increase rapidly in size and could be controlled by small rehabilitation schemes associated with each waterpoint.

The implementation of points (iii) to (v) could be organized at a later stage if it was felt that more careful control was needed over the amount of water being used and the grazing in the vicinity of the waterpoint. This would involve the policing of waterpoints by either employed personnel or self-help groups. This could be combined with the establishment of environmental monitoring and rehabilitation schemes at the waterpoints. Careful environmental planning procedures, together

with close monitoring of water use and vegetation changes, will provide information invaluable for future planning purposes.

7.4.2.3 Planning for the district

Seasonal grazing patterns and physical environmental criteria alone should not determine the sites for water development. A gamut of factors - social and economic as well as physical - affect the location and types of waterpoints in reality. Examples are missions, schools, settlement patterns and growth centres. It is not intended to discuss the role of these factors, but rather only to point out that they are extremely important and should be taken into consideration when planning integrated water development in the study area. This spatial approach to planning is the rational method of planning for a balanced development of the area's water resources. It will be of enormous benefit to the district as a whole in the future.

7.4.2.4 General recommendations

In order to be able to plan adequately, IPAL should establish a Water Development Unit at the earliest possible opportunity. The Unit should consist of a combination of project and Government personnel and should be based both in the district and at the headquarters of the Ministry of Water Development. In the early planning stages the aim of the Unit should be to collate as much detailed information as possible on the spatial distribution of water needs and requirements in the study area. The other components of IPAL should collaborate in this.

The role of the Government should be to provide technical expertise and equipment in the planning, design and implementation phases, which is beyond the capabilities of the people. However, the people should be expected to make a significant contribution in terms of self-help labour teams and also financial contributions towards the cost of structures. This will provide them with a sense of ownership of the waterpoints.

The involvement phase is essential. The setting up of village water committees should be encouraged. These groups should be given the responsibility for identifying their own water needs and should

be closely guided in this by the extension staff of the Water Development Unit. This may lead to the formation of self-help groups for activities other than water development.

Close liaison and communication between the Unit and the people will lead to a better understanding and overall appreciation of water development, the role of the Government, and what contribution is expected from the people. The Unit will also benefit from this. The confidence and co-operation of the people will be obtained, making both planning and implementation much easier and more effective. Above all, the needs of the people will stand a better chance of being satisfied.

The sites identified by the village water committees and the unit should than be discussed by the District Development Committee, with a view to integrating the proposals with the District Development Plan. Detailed surveys of the sites approved by the District Development Committee would then be undertaken by the staff of the Water Development Unit and designs would be made at the Ministry of Water Development headquarters.

7.4.3 Improved implementation

The local people should be involved as much as possible in the implementation phase. The formation of self-help labour units should be encouraged wherever possible. This will be greatly aided by deeply involving the people in the planning stages, during which confidence in themselves and in the Government will be gained. The employment of people on casual-labour terms is not to be discouraged, since this will help introduce a money-based economy into the area.

Local pan-construction units using donkey or camel-drawn dam scoops should be created. They should perform the desilting of pans as well as construction. The involvement of the people in planning and implementing the construction of waterpoints, particularly in the form of self-help groups, will lead to the establishment of local maintenance teams. Such groups are essential for maintaining the life span of a waterpoint. Not all maintenance will be able to be carried out by the local people, but much preventive work can be done. For example, where there are pans, the people can construct fences, plant grass on the embankment, and protect the inlet canal and livestock access ramp from

erosion by laying down riprap (broken stones). Less frequent desilting will then be required. If the strict control of water use is necessary, the group can perform this duty by collecting watering fees (which may be used as revenue for maintenance purposes) and perhaps controlling who waters at the point. For the former activity to succeed (if it is included in the plans for water development) the community must be able to trust the dam revenue collectors, otherwise the system will collapse. The community must also understand the need for the collection of watering fees.

Financial problems are often faced in the implementation phase. These problems are commonly connected with the procedure for disbursing funds from headquarters to the Government labour units for the purchase of fuel and materials. It is essential that possible bottlenecks in the system are identified early on and that steps are taken to iron them out as far as possible. The smooth flow of funds and the continuation of work are of vital importance in maintaining the confidence and co-operation of the people.

7.4.4. The role of non-government organizations

Non-government organizations such as missions and mission-based development projects will be involved with water development in some capacity. Therefore they should be fully involved and incorporated into all phases of the water-development component of IPAL. These projects, which will probably cover more restricted areas than IPAL, will be a source of manpower, expertise and funds. The close co-ordination and co-operation between IPAL and non-governmental organizations in all activities (not just water development) will result in the more efficient utilization of the resources of both parties, and this can only be of benefit to the district.

7.4.5 Further work required immediately

Before the planning of the water-development component can begin properly, much more knowledge is required of, firstly, the district's surface and subsurface water resources and, secondly, the feasibility of different types of water-conservation structures in different parts of the project area.

It is therefore recommended that intensive groundwater surveys using resistivity equipment are carried out in both the wet and dry seasons. These should take into account the extensive baseline surveys undertaken by Borgeson and Ndombi in the wet and dry seasons respectively. Employment of a full-time hydrologist is necessary in order to collect sufficient information on the surface-water resources of the area which can be used in the planning of water development. (The terms of reference for a full-time hydrologist are given in Appendix 1.)

Further field surveys should be carried out in all parts of the study area to assess the feasibility of different forms of water development for each locality. A record of possible sites identified can be kept until the planning phase of the water-development component begins in earnest, at which point the people will be involved in the selection of the sites.

Chapter 8

CONCLUSIONS

1. The potential for the development of the ephemeral surface-water resources has been assessed for the Balesa Kulal, the lugga between Gatab and Ilaut and the luggas immediately north of Kargi. Suitable forms of water development have been identified. There are lined hand-dug wells located alone and in association with subsurface and sand dams and pans. Pans should be located adjacent to luggas and the ephemeral flood flow should be diverted into then using gabion diversion structures.
2. A total of ten sites for development has been identified and preliminary estimates of the cost of materials have been presented. Unit costs of storing 1 m^3 of water vary from KShs. 7/- for a pan to KShs. 139/- for a sand dam.
3. Additional appropriate forms of water development are rock catchments, rooftop rainwater harvesting, water harvesting using micro-catchment systems and catchment protection works. Surveys of the feasibility of all these in different parts of the study area are required.
4. The problem of how to tap the considereble reserves of water below the Balesa Kulal at a reasonable cost remains unsolved. Intensive investigations should be undertaken using resistivity equipment to determine the depth of the perched water table along the channel to locate well sites in addition to the two wells recommended at each of the traditional well sites at Olturot, Bobor and El Derc. The location of clay beds at shallow depth and the determination of the nature of the lava flows are also priority needs. The large size of the Balesa Kulal will make any form of water development very expensive.
5. The luggas crossing the Gatab-Ilaut road may be amenable to the construction of subsurface dams owing to a widespread subsurface layer of sandy, silty, clay material. Four sites have been identified on these luggas. However, problems may be encountered with lateral and vertical leakage from the sediment reservoirs.

It is recommended that a small site is developed first as an experiment. Further away from the Ndoto Mountains the general texture of the soils of the Hedad and the bed material of the luggas becomes finer, thereby increasing the suitability of pans. The main problem that will be encountered will be transporting adequate quantities of building stone to the sites and the high cost of constructing weirs across wide luggas.

6. The luggas north of Korr are mainly amenable to the construction of sand dams. The incised nature of these luggas provides some good sites for increased sediment storage. Two sites for sand dams have been identified. A pan and a diversion weir are also recommended on a lugga in an area of clay-rich soil between Korr and Kargi.
7. It is recommended that careful spatial planning of the location of seasonal and non-seasonal waterpoints is undertaken, taking account of the carrying capacity of environmental and social and economic forces operating in the district. This is in order to minimize the adverse effects that are often caused by artificial waterpoints on the environment. Water will also be provided in a rational way to cater for the needs of the district. Close monitoring of changes in the vegetation around water points should be undertaken.
8. We repeat that the local population must be fully involved in the planning and implementation stages of the water-development programme. This will cultivate an awareness of the importance of correct usage and maintenance of the water supply.

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APPENDIX 1

Terms of reference for a full-time hydrologist

The hydrologist will investigate in detail the components of the hydrological cycle which are of direct importance to the planning and implementation phases of the water-development component of the project. These investigations will be related to the spatial variation of physical attributes of the study area such as the geomorphology, soils and vegetation. The effect of man and his activities on the various components of the hydrological cycle will be evaluated. The results of the field investigations and comparisons with the results of work performed elsewhere will provide criteria with which structures can be designed. The duration of the study will be three years.

The hydrologist will be required to:

1. continue the collection, quality control and analysis of meteorological and stream-flow data at the already established stations and expand the hydrometric network into areas not already covered;
2. attempt to determine and map the reliability of rainfall over the study area;
3. using a portable rainfall simulator establish relationships between rainfall characteristics, infiltration and surface runoff generation on different soil types, vegetation covers and slopes;
4. determine the water-retention characteristics of the different soil types found in the study area;
5. using the representative/experimental catchment approach establish the relationship between rainfall characteristics, the physical condition of the catchment and stream-flow response under different land-use management practices (different stocking rates);
6. relate the findings of (5) to the rainfall and runoff records of larger, monitored catchments;
7. attempt to define general relationships between rainfall and runoff and and between runoff and catchment area on annual and seasonal time scales;

8. extend existing knowledge of the relationship between discharge and sediment transport on the monitored rivers and attempt to determine the relationships between annual runoff and sediment yield and between sediment yield and catchment area and extrapolate these relationships to ungauged areas;
9. determine the relationship between sand dam height and the quantity and texture of sediment deposited behind dams during construction phases. This relationship should be explained in terms of the physical nature of the catchment area, the channel and the flow regime;
10. help in the planning of water development. The identification of sites for development, in particular, will be one such duty.

A PRELIMINARY ANALYSIS OF GROUND-WATER DATA FROM THE MARSABIT DISTRICT OF NORTHERN KENYA

by

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INTRODUCTION

In the Chalbi basin, like most regions in the world, ground water can be found at some depth, but its quantity and quality and the energy required to raise it to the surface may preclude development. This study has the main general objective of determining where suitable water can be found for reasonable use by humans and livestock in the context of range management plans. Micro-irrigation of gardens and/or trees may have significance in relation to improving the health of the people and in halting and reversing the degradation of the environment.

The specific objectives of the field work were to determine:

- the quantity, quality and movement of the ground water
- the depth to the ground water
- the possible well capacities of existing and projected wells.

The limited time precluded a detailed study of any of the areas. The main body of this report is an area-by-area description of the ground-water situation based on the limited data available.

Ideally there should have been a geological study of the area by a trained geologist before a hydrological study was attempted. Such a geological study is being undertaken by the Kenya Government, along with others, but the data will not be available for this report.

The different areas are arranged in more or less the order in which they were visited because of the effects of the weather. The field work began during the April rainy season which was very heavy this year in most of the areas. Therefore shallow ground-water levels, measured or estimated, may reflect recent seasonal infiltration from the surface.

AREA DESCRIPTIONS

Ngurunit area

Since the basement rock is close to the surface in most of the Ngurunit area there may be only sporadic pockets of ground water, the water-hole near the old airport being one example. An electrical resistivity measurement about 1-2 km SE of the water-hole also showed water from eight metres depth to the top of the bedrock at about 24 metres. If management plans call for more water, or more watering points, other shallow aquifers can be

found, but in estimating the volume of water available in these aquifers during the dry season much more geophysical work will have to be done. There is also a need to improve on the hand dug wells or water-holes which the people are able to dig each year as they are able to utilize only the very top part of the aquifers (see section on *Appropriate technology).*

Ngurunit to Korr

This area has a surface drainage south towards the Milgis River and east towards the Kaisut Desert. Since the bedrock is close to the surface in at least part of the area the ground water would tend to move in the same direction. However, the area directly between Ilaut and Korr (Elgosa area) was not visited due to bad roads in April so this area can not now be factually described. By inference from data from the south and north of this area it may be assumed that this could be a good ground-water area. The lava beds north of Ilaut may be a major recharge area for the ground water flowing eastward over bedrock, at moderate depths, which dips towards the east. This area shows many volcanic extrusions which may affect the ground water depths and directions of flow.

It is possible that the basement complex apparent at Korr extends westward towards the lava beds north of Ilaut as basement rock outliers and small inselbergs are located in or near the lava beds. This basement complex may act as a ground-water divide between the Chalbi and Milgis basins.

Korr

The area around Korr may be a basement complex outlier, with some more recent pluvial (lacustrine limestone) and volcanic deposits superimposed and intruded in it. The underground extension of this complex to the east and west has not been fully explored to determine definitely whether or not it is an impermeable barrier to the southward movement of the ground water out of the Chalbi basin. It has been definitely determined that the basement complex is at a lower elevation to the south and to the north of Korr.

Fortunately, the basement complex is fractured and metamorphosed, so considerable amounts of water have been found in it. The yields from the wells are low and chemical tests of the water indicate moderately high chloride and carbonates but low sodium adsorption ratio (SAR). Six or seven wells have been drilled in the general area but only one hand pump was working as of April 1981 (MOWD No. E4071, 2 km NW of town). Well logs indicate specific capacities of 2.08 and 3.9 litres per minute per metre of drawdown for wells No. 4108 and 4071 respectively. Electrical conductivity measurements of four samples of water from three different wells indicate roughly the same spatial and temporal quality.

Korr to Kargi

An electrical resistivity measurement (15, see numbered measurement points Map 2 and Table 1) indicates a gradual increase in depth to bedrock towards the north without much change in depth to water. However, the depth to ground-water probably would change somewhat as the dry season progresses.

Kargi

The Kargi well logs indicate a layer of basaltic rock over the basement complex which may begin at a depth of about 72 metres, with the water surface at about 13 metres.

An electrical resistivity measurement (10) taken near the MOWD well No. 3960, correlates quite well with the well log, although the water level was much higher (at a depth of 4 metres). This is due to the fact that the resistivity measurement was taken in April right after the heavy rains while the well log indicated a pumping test in October, probably after several dry months.

The resistivity measurement may be interpreted to show that the layer of basalt is rather porous, but hand dug wells dug into the basalt near the town of Kargi indicate that it may not be very permeable as water can be found in the hand dug wells late in the dry season even though the water surface elevations in these wells are 15 to 25 metres higher than the drilled well about one kilometre away.

Map 2. The study area showing resistivity measurement points.

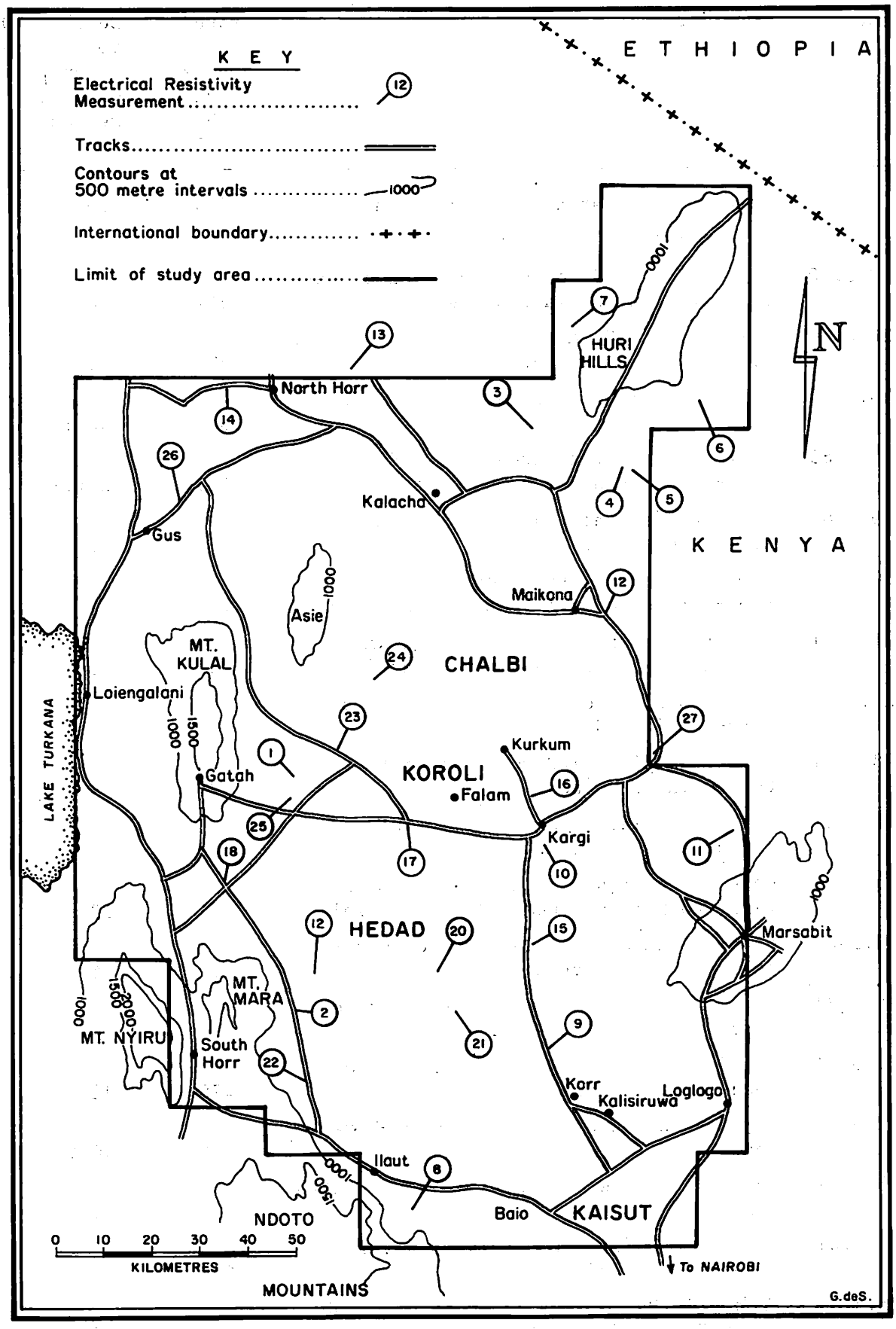

Table 1. Electrical resistivity measurements

No.	Date	Location	Ground surface approx. elevation m above sea level	Depth to ground water in metres	Depth to bed rock in metres
1.	21.8.80	*Balessa Kulal* area: 1,000 m North of UNESCO IPAL well at Olturot	569	70	-
2.	23.8.80	*Hedad* 27.7 km S of Rd. junction of Kargi-S. Horr & Gatab Ilaut-Roads	667	4	45
3.	26.8.80	*Hurri Hills* 10 km N of Afgab Mt. near site of *SA* 84, Logologo area	628	160+	-
4.	16.6.80	*Hurri Hills:* Arano area, 15 km E of Hurri Hills-Farole Road	671	40(?)	-
5.	28.8.80	*Hurri Hills:* Arano area, 18 km E of H.H.-Farole Road, 3 km E of # 4	615	125(?)	-
6.	29.8.80	*Hurri Hills:* Jaldessa area, 15 km E of H.H. Farole Road	805	30(?)	-
7.	30.8.80	*Hurri Hills*: Kalessa area, 16 km NW of H.H.-Farole Road, N 15°E, 32 km Afgab	785	47(?)	285(?)
8.	21.4.81	*Ngurunit:* along road to Korr, 4 km E of Ngurunit, ½ km off end new airstrip	727	8	24
9.	23.4.81	*Korr:* 13 km N of Korr, near creek along Korr-Kargi Road	525	5	35
10.	28.4.81	*Kargi:* S. 85°E, 120 metres from B.H. C-3960 in creek near Kargi	428	4	?
11.	14.5.81	*Segel:* SW side of old Segel airstrip on Marsabit-Kargi Road	657	-	250(?)
12.	15.5.81	*Maikona* on Marsabit-Kalacha Road near forks to Maikona, near old SA 112 well	501	33	?
13.	18.5.81	*Balal:* ½ km W of Balal Road on upper Kalacha-North Horr Road	401	6	130
14.	19.5.81	*North Horr:* 10 km W of North Horr, on old airstrip, on Loyangalani Road	421	37	-
15.	21.5.81	*Kargi*: 25 km S of Kargi on Kargi-Korr Road (Surusi area)	478	12(?)	32
16.	22.8.81	*Kargi:* 8 km NW of Kargi on Kargi-Kurkum Road	?	10(?)&40(?)	-
17.	23.5.81	*Falama:* 19 km W of Kargi on Kargi Gatab Road	481	?	?
18.	25.5.81	*Balessa Kulal:* in the Balessa River at Gatab-Ilaut Road crossing	658	11	175
19.	25.5.81	*Hedad:* in Hedad area 13 km NE of Gatab-Ilaut Road and from # 2 measurement	595	15	105
20.	26.5.81	*Hedad:* 35 km downstream on 2nd big river North of Ilaut lava beds.	564	11	120

Table 1. (contd)

21.	27.5.81	*Hedad:* Near NE tip of Ilaut lava beds N of creek, about 20 km NW of Korr	550	4(?)	59
22.	28.5.81	*Korante:* In Korante Plains just W of rock outcrop, 1 km W Ilaut-Gatab Road about 46 Km S. of Balessa	736	10	20
23.	30.5.81	*Balessa* river bed (in), 16 km North of Olturot Road. Cross at Kargi-Gus road	499	4	245(?)
24.	1.6.81	In *Balessa River* bed 1 km below Kargi-Olturot Road Crossing	567	3	?
26.	25.6.81	Near Creek, 8 km NE *Gus*, 1 km off road	455	20	150?
27.	26.6.81	*Korante-Boro* area 1 km W Marsabit-Kalacha-Kargi Road Junction	501	-	?

Kargi to Kurkum

A resistivity measurement between Kargi and Kurkum (16) showed no regional ground-water table (but maybe a perched water table or damp ground at 8-18 metres) and no bedrock to a depth of 250 metres, with a possible layer of basalt from 18 to 32 metres.

Kurkum

The Kurkum area is a mixture of basement complex with overlying basalt, as at Kargi, but with surface exposures of the basement complex. The four hand-dug water holes and wells are dug into basaltic gravel and rock; the basement complex cannot be very far down, however. The quality of water varies from fairly good (E.C. = 1325 and 1608 micromhos/cm at 25°C) in the shallow water holes near the creek by the existing building, to salty and very salty (E.C. 3223 and 11,577) in the old British well and the newer UNESCO well with the hand pump. In June 1981, the depths to water were about one metre in the shallow wells and 5.5 and 4 metres in the British and UNESCO wells respectively. The water in the British well had dropped about 1.2 metres between 21 May 1981 and 22 June 1981.

Pumping tests were tried on three of the 'wells' at Kurkum. Since the jet pump used could not be regulated to a low rate without stopping, the wells were not pumped to points of stabilization. Therefore the specific capacities could not be computed. However, from past experience with well tests, it can be estimated that these wells may have a specific capacity between 10 and 20 litres per minute per metre drawdown. Later in the dry season the shallower wells would have much lower capacity and may even dry up and the other wells would have somewhat lower capacity because the aquifers are not homogeneous.

Kargi to Olturot

A resistivity measurement (17) along the road 25 km west of Kargi was inconclusive due to the extreme conductiveness of the soil. Generally, as one approaches the Chalbi Desert from the south, the conductivity of the soils increases (resistivity decreases). See Appendix *Accuracy and precision of study - Resistivity).*

Undoubtedly, the ground-water flow from south to north towards the Chalbi Desert is affected to a great extent by the volcanic and basement rock extrusions and intrusions of Kurkum, Garanyel, Kalama, Kobatel and others unnamed. It is difficult to predict the depths and directions of the flow of the ground water in this area without more field data which is difficult to obtain due to the heavy thorny bush and highly conductive soils in these areas. However, the regional ground water probably is not over 150 metres deep as the surface elevations are only that much above the Chalbi Desert. The quality of ground water may be very poor except for perched water along seasonal rivers or in the rocks near the surface.

Kargi to Kalacha (via eastern track over the lava)

Resistivity measurements were taken near the Kargi road junction with the Marsabit-Kalacha road (27), on the Segel airstrip (11), and near the Marsabit road junction with the Maikona road (12).

The two former measurements indicated no water or bedrock within the depth limits of the instrument and electrode array (theoretically 300 metres). It is possible that there could be water somewhere in the sandstone that may be under the lava in these areas, but the top of the sandstone is 60 to 200 metres below the ground (lava) surface. Further north, where the lava is thin or non-existent above the sandstone, water may be found at depths of 100 metres or less in the sandstone (i.e. east of Koronli, Mayidate and Barcho Barcho springs and in the Ramatrobi areas), but the quality is unknown.

The electrical resistivity measurement near Maikona (12) at the old drilled well SA 112 (1941) correlated quite well with the well log (water surface at 41 metres in April 1941) as the measurement indicated water at 33 to 48 metres. Unfortunately, the measurement was inconclusive for depths beyond about 95 metres so the depth of the sandstone cannot be determined.

Hurri Hills

Other reports by the FAO and UNESCO/IPAL for this area give good outlines of the ground-water possibilities of this area. The resistivity measurements (3), (4), (5), (6), and (7), taken at the base of the Hurri

Hills in August 1980 indicate possible water at depths of 30 to 160 metres, with the greater depths to the south-west and south-east and the smaller depths further north on both sides on the hills. Due to the very high resistance of the surface soils and the upper layers of basalt the plotted curves of the resistivity measurements do not give a precise definition of a ground-water surface except for the one (3) at Logologo near the well site of SA 84 (drilled in 1941). Therefore, before any drilling is done in these areas more geophysical work should be done to confirm or reject the present interpretations, i.e. whether or not there really is water at these four locations at the depths indicated. The well site for SA 113 (1941) was found along the road on top of Hurri Hills and the log indicates no water to a depth of 61 metres. Another well, SA 85, drilled to a depth of 104 metres further south at a lower elevation (site not found) also reached no water. Both of these wells were drilled largely in volcanic ash, while the one at Logologo was drilled primarily in lava. This latter site may be near a fault zone as both the electrical resistivity measurements (taken in 1978 and 1980) and magnetometric measurements taken in 1981 indicate a strong anomaly in this area. Also, a geological map of Ethiopia shows a major fault with a strike in the direction of this area. However, the anomaly may also be due to a local fissure or fracture from which lava has been intruded beneath the upper layers of basalt.

Kalacha

There are many springs and wells in and near Kalacha. The springs and some of the wells are near the edge of the Chalbi Desert and other wells are one or two kilometres back from the edge of the Desert nearer the lava escarpment. The water in the wells near the desert is at, or near, the ground surface while the water surface in the wells near the airstrip is at 8 to 10 metres depth, depending on the season. The water surface rose 2.15 metres in the UNESCO well at Kalacha between 15 May 1981 and 26 June 1981 reflecting the recharge from the heavy rainy season with a lag of approximately one month.

The water in the wells is relatively low in chlorides but moderately high in alkalinity. Electrical conductivity measurements indicate that the well water is above the threshold concentration but below the

limiting concentration for irrigation uses. See Appendix *Water quality, Table 2.*

Hand bailing methods (estimated at 20 to 30 litres per minute) were said to empty the wells at the AIC station but not the one near the UNESCO house.

Kalacha to North Horr

It is obvious that there is much ground water coming from under the basalt into the Chalbi Desert between the Kalacha and the Balal rivers. Between the Balal River and North Horr it is not so obvious. An electrical resistivity measurement (13) taken immediately to the west of the Balal River indicated water to a depth of about 6 metres (18 May 1981) with the rock (basement or basalt) at about 100 metres. More resistivity measurements along with the drilling of test and observation wells would be helpful in determining the quality and quantity of the ground water in this area. This one place where very limited irrigation might be possible if the aquifer proved reasonably permeable.

North Horr

The North Horr area is unique because it has a good quality of ground water perched over a very poor quality of ground water. See Table 2 *Water quality analysis.* This anomaly is probably due to a hard layer of old lacustrian limestone or other lake bed sediments which separate the two layers of water. The upper layer is recharged each year by surface and shallow subsurface flow from the north and north-west. The lower layer is part of the Chalbi basin regional ground-water table. The Chalbi basin had an outlet to the west at one time but it was blocked by volcanic and tective activity at the end of the Middle Pleistocene epoch and by wind-blown sediment off the Chalbi in more recent times. Therefore the Chalbi Desert acts as a sink for the whole basin and the salts in the ground water underlying the Chalbi basin continue to increase. It is possible, however, that some ground water still escapes to the west as the ground-water table may slope downwards towards the west in the dry season. Further dry-season study will be required to confirm or refute this assumption.

Gus Area

The Gus area south-west of North Horr and the similar area north west of North-Horr lies in a former lake bed area which was transformed by volcanic and tectonic events. Lava was extruded through fissures trending in a north-south direction and faulting occurred parallel to the main rift valley faults near Lake Turkana. The effect of this action was the blocking of the hydraulic connection between the Chalbi basin and Lake Turkana.

Whether the series of springs, starting with Gus and extending to the north-west, are a result of this blocking or whether they are merely seepages from the porous basalt can be determined with a more careful geological study. The quality of the spring water suggests that it has moved a considerable distance through material with a high chloride content and is not locally recharged.

Although the quality of water in the individual springs varies considerably it is all near the upper limit of concentration of salts recommended for livestock. Since it is obviously used to a great extent by livestock and to some extent by humans it would be interesting to know if the poor quality causes any ill effects.

Balessa Kulal

The Balessa Kulal River is one of the major rivers draining into the Chalbi Desert. Although the runoff period lasts only a short time there is a fairly large perched water table under the river bed which remains for a long time, possibly throughout the dry seasons. The nomad and semi-nomadic tribesmen dig wells in the bottom of the river each year after the rains, especially in the Olturot area and at a point 30 km downstream. Late in the dry season the water surface drops to a level of 7 to 8 metres beyond which the herdsmen cannot dig due to the danger of collapse of the sandy well walls.

Resistivity measurements (18), (23), 24 and (25) taken shortly after the rains indicate a perched aquifer of considerable thickness with the water-table surface at 1 to 11 metres and the bottom at 30 to 70 m. It may merge with the regional water table which is at about 70 metres in the Olturot area, and probably at less depth further downstream. Often in this type of river there is not much lateral flow out of the perched

water table but there may be some longitudinal flow down the river. In any case, it is a large source of good quality water if a low cost method of extracting it can be devised.

Hedad

The Hedad area is much like the area under and around the Balessa Kulal River, except that the streams are much shorter and have smaller drainage basins. In the upper reaches of the Hedad, at the foot of Ol Donyo Mara, the basement rock is close to the surface but it is at greater depths in the lower reaches to the east.

The resistivity measurements (10), (19), (20), and (21) in this area were all taken beside the rivers. (Most of the Balessa Kulal measurements were taken in the river beds.) Therefore depths to the water may indicate the regional water table while those in the Balessa Kulal river bed may indicate a perched water table. The Hedad measurements indicate water fairly close to the surface at 10 to 30 metres, but it must be remembered that the measurements were taken shortly (1 month) after the heavy rains.

The minimum resistivity values indicate that the ground water is fairly good in the headwaters area (near the Mara Hills) but is of lower quality further east.

AQUIFER CHARACTERISTICS

Depths of aquifers

The depth to water is a determining factor in what type of drilling/digging and water pumping is appropriate in any area. It is especially important in planning sustainable projects in the Chalbi study area. In this study the depths to the water surface in many existing shallow wells were measured, the well logs of the Ministry of Water Development wells were examined, and resistivity measurements were taken in areas where no wells exist.

The depths to water varied from zero in springs and river beds to about 160 m in the lava at the foot of the Hurri Hills. In some places no ground water was indicated by the resistivity measurements, e.g. near Segal airstrip and along Marsabit/Kargi road (measurements 11 and 27)

and between Kargi and Olturot (17). Some well logs also indicated no water (e.g. on and near the Hurri Hills - wells SA 113 and SA 84).

Since most of the volcanic rocks in the area are moderately porous and permeable, the ground water is often associated with the basement rocks as in the Ngurunit Plain and Korante Plain areas or in the metamorphic or weathered basement rock complex in the Korr area and the sandstone plains east of Maikona. Because of this association attempts were made to determine the depths to bedrock.

Other material such as layers of clay or non-permeable basaltic rock can support perched water above the basement rocks. Where possible, it is useful to differentiate between the smaller perched water table and the general regional water tables. In areas where impermeable basement rock is close to the ground surface, say one to 30 metres, a regional water table may not exist, but sporadic pockets of ground water may be found in depressions and low places in the basement rock, e.g. Ngurunit area. These pockets of water and the perched water tables are more difficult to delineate since they are sporadic both in time and space, i.e. they may dry up every dry season, or in an exceedingly dry season; or sometimes they can be pumped dry. However, if they can be found, they may be more easily utilized than the regional water table. For example, after the April 1981 rainy season there has been a perched water table under the Balessa Kulal River 30-70 metres thick with the surface of the water table only a few metres down. The dry season regional table is estimated (August 1980) to be at a depth of about 70 metres near Olturot. It is obvious that the perched table may leak into the regional water table and therefore could be considered a recharge area. Closer to the Chalbi Desert the two water tables may coincide and could only be differentiated by water samples obtained from both aquifers.

Permeability and direction of flow

In situ permeability is usually determined by pump tests (see *Limitations, accuracy and precision of study - pump tests)*. However, proper pump tests were not possible for this study due to the limited time and budget. Neither could a flow net be constructed due to the insufficient number of precise ground-water measurements. A flow net would be useful in comparing the permeability and directions of flow in the different areas.

One area where the comparison of the two permeabilities and directions of flow can be made is in the Korr area. The difference between the ground water surface elevations 11.5 kilometres south and 10.5 and 30 kilometres north of Korr indicate that the area north of Korr is 90 to 100 times more permeable than the area immediately south of Korr and the direction of the flow is away from Korr in both directions (north and south). This fits the surface geological evidence that the basement rock complex in the Korr area acts as a ground-water divide between the Chalbi basin and the Milgis river basin.

Another area of interest is the North Horr area. It appears that the ground water may flow towards North Horr from west to east during the rainy season and away from North Horr from east to west during the dry season. Another interpretation could be made that fresh water in an aquifer flows towards North Horr from west to east and brackish water in a deeper aquifer flows away from North Horr from east to west. It is known that an aquifer of fresh water lies over a more brackish aquifer in and near the town of North Horr (see Table 2). Further study is needed to delineate the extent of the more useable fresh water aquifers.

Table 2. Water quality analyses

Sample date	Location	E.C. micromhos per cm	Meq x 10^2 by calcul.	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	pH	Alkalinity mg/l $CaCo_3$	Hardness mg/l $CaCO_3$	Chloride mg/l Cl^-	Sulfate mg/l Na_2SO_4	Flouride mg/l	SAR by Calcul.
	Ngurunit													
-9-77	Water hole near old airstrip *			985	16.5	96.1	127.5	8.5					1.55	
-9-77	Source of piped water*			1175	71.0	151.0	140.0	8.9					1.27	
	Korr													
-12-79	Village handpump	1838						7.5						
-12-79	2 km W main village	1874						8.5						
-12-79	Handpump near AIM station	1862						7.8-8.1						
28-4-81	B.H. C-4071 Handpump (under windmill)	1849	1655					8.3	222	440	301	340	1.0	3.70
-9-77	SW Korr, 6-7 km*		2579	277.5	26.0	81.0	128.3	8.4					1.45	3.72
	Kargi													
21-12-79	Well near exclosure	2631						8.5						
24-4-81	Hand dug well 500 m South of town	1698	998					9.0	32	444	216	306		0.53
22-4-81	B.H. # C-3960 town pumped water	2971	2635					8.0	862	68	233	240	1.0	30.3
-9-77	Korole Spring NE of Kargi*		13,841	3000	300	0.6	5.8	9.8					4.17	
-9-77	Korole Springs NE of Kargi*		3,502	800	9.2	-	-	9.6					2.3	
-9-77	*Maikona* *(1)		16,449	2,800	250	420.9	35.8	8.35					2.4	28.53

Table 2. (contd)

Sample date	Location	E.C micromhos per cm	Meq x 10^2 by calcul.	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	pH	Alkalinity mg/l $CaCO_3$	Hardness mg/l $CaCO_3$	Chloride mg/l Cl^-	Sulfate mg/l Na_2SO_4	Fluoride mg/l	SAR by Calcul.
-9-77	*Maikona* *(2)		30,258	5.600	520	550.9	9.6	9.2						50.90
-9-77	*Maikona* *(3)		2,908	560	20	37.0	23.6	8.48					2.2	16.76
-9-77	*Maikona* *(4)		3,168	425	130	87.1	44.4	9.02						8.53
-9-77	*Maikona* *(5)		1,726	270	30	48.3	15.7	9.0						7.61
-9-77	Near doum palms* W of Maikona (1)		1,409	190	20	52.3	20.4	9.02					2.4	5.06
-9-77	Near doum palms W of Maikona (2)		2,158	240	25	52.3	9.2	9.5					2.6	6.76
	Kurkum													
21-5-81	Well upstream house	1,325						7.6	168	-	173			
21-5-81	Well downstream house	1,608						7.2	412	448	210			
21-5-81	Old British well	3,323	2,891					8.3	256	544	644	528		7.74
5-6-81	UNESCO well handpump	11,577						8.4	174	528	>1700			
	Kalacha													
-9-77	A.I.C. well #1							7.9	306	70(?)	124			
14-6-80	A.I.C. well #2	1244												
16-5-81	UNESCO well	1269												
-9-77	Upper Kalacha*		1,733	270	30	53.0	8.2	9.55					3.2	7.56
-9-77	Kalacha town (?)*		2,130	300	50	69.2	25.8	9.2					3.2	6.98
-9-77	Kalacha town (2)*		5,844	1,200	180	14.5	9.2	9.5					1.56	57.44
16-5-81	Hand dug well near town with handpump	1841	1,765					7.7	378	344	196	432	0.4	5.82
16-5-81	Artesian well B.H. C-4825	1300	1,312					8.4	318	292	133	284		7.68

Table 2. (contd)

Sample date	Location	E.C. micromhos per cm	Meq x 10^2 by calcul.	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	pH	Alkalinity mg/l $CaCO_3$	Hardness mg/l $CaCO_3$	Chloride mg/l Cl^-	Sulfate mg/l Na_2SO_4	Fluoride mg/l	SAR by calcul.
5-6-81	Burka Springs near Kalacha	1512												
	North Horr													
-9-77	? (1)*		1,873	375	30	11.4	14.4	8.58					12.4	17.89
-9-77	? (2)*		11,700	2,600	150	0.1	4.6	10.2					58.0	
-9-77	? (3)*		1,482	320	20	2.1	4.6	10.15					7.0	31.1
19-5-81	Town supply (sweet)	1146	1,243					8.5	412	112	82	178	1.4	9.63
19-5-81	Mission supply (brackish)	12,435						8.5	944	116	669			
25-6-81	Cattle W.H. in Chalbi	4,288						7.5	1,726	144	179			
	Gus													
-9-77	? (1)*		3090	640	20	21.7	15.7	8.16					11.6	
-9-77	? (2)*		3420	720	20	20.0	16.7	8.4					10.4	
-9-77	? (3)*		3200	660	23	22.5	16.7	8.05					10.8	
-9-77	? (4)*		4200	860	40	28.7	24.3	8.3					13.2	
-9-77	? (5)*		3460	780	15	1.2	4.6	8.6					16.0	
25-6-81	Easterly spring (brown)	17,688						8.9			3,985		0.6	
25-6-81	Central spring (red)	75,040						9.6						
25-6-81	SW spring (grey)	5,411						8.6			1,390			
	Balessa Kulal													
2-6-81	Olturot well handpump	1,386	1,568					7.5	520	128	136	136	0.8	11.60
2-6-81	Well in river near road crossing	793						8.2	290	332	23			

Table 2. (contd)

Sample date	Location	E.C. micromhos per cm	Meq x 10^2 by calcul.	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	pH	Alkalinity mg/l $CaCO_3$	Hardness mg/l $CaCO_3$	Chloride mg/l Cl^-	Sulfate mg/l Na_2SO_4	Fluoride mg/l	SAR by calcul.
	Other areas													
30-6-81	*Bubisa* borehole	3,430						7.9	582	504	596			
19-7-78	*Soriadi* borehole	3,150	3,271					8.4	352	130	522	1,032	0.6	26.48
17.5.78	*Gudas* borehole	1,000						7.9	426	124				
-9-77	Logologo borehole*		4,105	600	80	146.3	19.5	10.1					2.0	10.19
-9-77	Loyangalani*		3,179	715	17	2.5	1.1	9.8					12.0	8.63
-9-77	Dukana*		390	24	6.8	15.2	30	8.5					2.4	.86
-9-77	Hurran Hurra* springs		2,230	460	10	20.6	4.6	9.42					8.4	20.9

*Samples taken by Dr. H.J. Schwartz in September 1977. Analysed by laboratories of the University of Nairobi and the National Agricultural Laboratories (Kenya).

E.C. = Electrical conductivity measured in micromhos per cm at 25°C

SAR = sodium adsorption ratio = $\frac{Na}{\sqrt{(Ca + Mg)/2}}$ Concentrations expressed in milliequivalents.

WATER QUALITY

Table 3 shows the results of water samples taken from the Chalbi basin springs and wells by various people at various times. The samples were tested in the author's laboratory unless otherwise indicated. Standard methods of testing were used but some of the reagents were not checked by standards. (See Appendix: *Limitations, accuracy and precision of study - Water quality.)*

Some samples are included from areas not really within the Chalbi basin but adjacent to it. These samples reflect qualities of ground water which may be moving towards or away from the basin. Map 1 shows the locations of most of the sample areas.

It is important to note that there is a considerable temporal as well as spatial change in quality. Further sampling (including test wells in areas where there are no springs or wells) and testing is necessary to quantify and explain the seasonal changes and the spatial differences due to depth, the non-homogeneity of the soil and rocks, and the length of time the water remains in the different aquifers. However, some preliminary observations have been made, and are mentioned in the description of the different areas. A comparison of water sample tests with the appended standards (Tables 3 to 10) gives an idea of the potential usefulness of the ground water. The standards given are only a partial list as more recent analyses give more specific details of the effects of water quality on potential uses, especially with regard to the elements or compounds occurring in very small or 'trace' quantities.

In areas where there are no wells or springs the resistivity measurements may give some indication of what quality of water might be expected if wells were drilled or dug. The apparent resistivity values of the different layers of materials in the soil and the level of the minimum resistivity gives an idea of the dissolved minerals in the ground water.

In general the quality of the ground water in the seasonal perched water tables and the re-charged areas is better than the water in the deep regional water tables. Most of the recharged areas have basaltic surface or subsurface layers which are quite permeable. The Ngurunit and the Mara Hills are of basement complex, however. There is evidence that the ground water picks up salts in relatively short distances while flowing through the more non-basaltic rocks and sediments (e.g. Hedad,

Table 3. Tentative guide for evaluating the quality of water used by livestock

Quality factor	Threshold (a) concentration	Limiting (b) concentration
Total dissolved solids (TDS), mg/l	2500	5000**
Cadmium, mg/l	5	-
Calcium, mg/l	500	1000
Magnesium, mg/l	250	500*
Sodium, mg/l	1000	2000*
Arsenic, mg/l	1	-
Bicarbonate, mg/l	500	500
Chloride, mg/l	1500	3000
Fluoride, mg/l	1	6
Nitrate, mg/l	200	400
Nitrite, mg/l	none	none
Sulphate mg/l	500	1000*
Range of pH	6.0-8.5	5.6-9.0

(a) Threshold values represent concentrations at which poultry or sensitive animals might show slight effects from prolonged use of such water. Lower concentrations are of little or no concern.

(b) Limiting concentrations based on interim criteria, South Africa. Animals in lactation or production might show definite adverse reactions.

* Total magnesium compounds plus sodium sulphate should not exceed 50 per cent of the total dissolved solids.

** Indications are that the maximum concentrations of salts that can be tolerated by domestic animals without danger of injury by osmotic effect lies between 15,000 and 17,000 mg/litre. However, a value of 10,000 mg/l is more realistic for sheep and perhaps 7000 mg/l for milk cows in production. For more desert seasoned livestock see Table 5.

Source: McCauhey, 1966.

Table 4. Chemical standards of drinking water

Quality factor	Recommended maximum limits (a) (milligrams per litre)		Maximum permissible concentrations (i.e. which constitute grounds for rejection of supply) (milligrams per litre)	
	1946	1961 Revision	1946	1961 Revision
Alkylbenzenesulfonate (detergent)	-	0.5		
Arsenic	-	0.01	0.05	0.05
Barium			-	1
Cadmium			-	0.01
Carbon chloroform extract (exotic organic chemicals)	-	0.2		
Chloride	250	250.		
Chromium			0.05	0.05
Copper	3	1.0		
Cyanide	-	0.01	-	0.02
Fluoride	-	1.7(b)	-	2.2(b)
Iron manganese	0.3	-		
Iron	-	0.3		
Lead			0.1	0.05
Manganese	-	0.05		
Nitrate	-	45.		
Phenols	0.001	0.001		
Selenium			0.15	0.01
Silver			-	0.05
Sulphate	250	250.		
Total dissolved solids (TDS)	500	500.		
Zinc	15	5.		

(a) Concentrations in water should not be in excess of these limits when more suitable supplies can be made available.

(b) For fluoride temperature concentration relationships see Table 6.

Source: McCauhey, 1966.

Table 5. Salt tolerance of desert livestock

Camels	1850 mmol/litre	(65,600 mg/1 Cl^-)
Fat tailed sheep	220 mmol/litre	(7800 mg/1 Cl^-)
Turkana goats	257 mmol/litre	(9110 mg/1 Cl^-)

Source: Maloiy, 1972.

Table 6. Recommended fluoride ranges
(US Public Health Service Drinking Water Standards, 1968)

Annual average of maximum daily air temperatures* °C	Limit mg/litre
10-12.1	1.7
12.1-14.6	1.5
14.7-17.6	1.3
17.7-21.4	1.2
21.5-26.1	1.0
26.2-32.5	0.8

*Based on temperature data obtained for a minimum of five years.
Source: American Water Works Association. National Technical Advisory Committee Report, 1968.

Table 7. Alkalinity and hardness

	Suggested limits for public supplies mg/litres as $CaCO_3$
Alkalinity	500
Hardness	500

Source: As Table 6.

Table 8. Tentative guides for evaluating the quality of water used for irrigation

Quality factor	Threshold (a) concentration	Limiting (b) concentration
Coliform organisms, MPN/100 ml	1000*	(c)
Total dissolved solids (TDS) mg/l	500*	1500
Electricity conductivity, micromhos/cm	750*	2250*
Range of pH	7.0-8.5	6.0-9.0
Sodium adsorption ratio (SAR)	6.0*	15
Residual sodium carbonate (RSC), µg/l	1.25	2.5
Arsenic, mg/l	1.0	5.0
Boron, mg/l	0.5*	2.0
Chloride, mg/l	100*	350
Sulphate, mg/l	200*	1000
Copper, mg/l	0.1*	1.0

(a) Threshold values at which irrigator might become concerned about water quality and might consider using additional water for leaching. Below these values water should be satisfactory for almost all crops and almost any arable soil.

(b) Limiting values at which the yield of high crops might be reduced drastically, or at which an irrigator might be forced to grow less valuable crops.

(c) Aside from fruits and vegetables which are likely to be eaten raw, no limits can be specified. For such crops, the threshold concentration would be limiting.

* Values not to be exceeded more than 20% of any 20 consecutive samples, nor in any 3 consecutive samples. The frequency of sampling should be specified.

Source: McCauhey, 1966.

Table 9. Significance of SAR

SAR	Water class
10	Excellent
10-18	Good
18-26	Fair
26	Poor

Source: American Water Works Association. National Technical Advisory Committee Report, 1968.

Table 10. Significance of salinity

Salinity EC, micromohs/cm at 25 °C	Crop responses
0-2,000	Salinity effects mostly negligible
2,000-4,000	Yields of very sensitive crops may be restricted
4,000-8,000	Yields of many crops restricted
8,000-16,000	Only tolerant crops yield satisfactorily
above 16,000	Only very few tolerant crops yield satisfactorily

Source: McCauhey, 1966.

Ngurunit, Korr, Kargi, Kurkum areas) and that the water may flow long distances through the basaltic material without becoming highly mineralized (e.g. Hurri Hills, Kalacha and Maikona areas).

The electrical conductivity (EC) of the water is closely related to the total dissolved solids. TDS x 1.56 $\simeq$ EC (EC is stated in micromhos per centimetre at 25°C and TDS is stated in milligrams per litre). The EC can give a quick measure of the quality of a particular water. Practically all of the water tested was found to be suitable for livestock. Some exceptions are: (1) some of the pools at Gus, (2) Koroli spring water, (3) UNESCO well at Kurkum, (4) brackish water at North Horr. However, according to Maloiy, camels could drink even these waters (Maloiy, 1972). Humans would take longer to adapt to the high concentrations of salts. In some areas where the water contains excessive chloride and/or fluoride it might be desirable to install solar distilleries to provide a better quality of water for the people. Table 10 gives the possible crop response with regard to salinity as measured by EC.

The type of salts found in the ground water is important because for irrigation the bad effects from sodium in the water are to some extent negated by the calcium. A measure of this is the sodium absorbtion ration (SAR). $SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$. Concentrations are expressed in milliequivalents per litre. Table 9 gives a water classification according to SAR.

It is apparent then, from a review of Table 2 showing the results of the water testing, that some of the water coming from under the basalt in the Kalacha area and in the Maikona area is of a quality good enough for irrigation. Also, the ground water at Korr is of good quality due to the fairly high calcium concentration. It is evident that the ground water at Korr has not moved very far through the basement complex and the lacustrian limestone in the area contributes a considerable amount of calcium to the water.

LIMITATIONS, ACCURACY AND PRECISION OF STUDY

Electrical resistivity

Since much of the study of the area where there are no wells or springs is based on electrical resistivity measurements the accuracy and limitations of these measurements must be understood. Textbooks are available to describe the theory and practice of resistivity measurements, so this discussion will be limited to the problems encountered in the Chalbi basin study.

The main problems were: (1) extremely high conductivity (low resistance) of the soil in some areas; (2) insufficient power of the instrument used, (3) insufficient time to take enough measurements to make a detailed analysis of any one area, and to check measurements which might give ambiguous results.

The data obtained by resistivity measurements must be used with caution, especially the ones showing shallow water. Most of the measurements were taken in May directly after a very heavy rainy season, so the shallow depths indicated may change later in the dry season. Also, it is not advisable to base a deep-well drilling programme on relatively few measurements. Before drilling, several more resistivity sounding measurements should be taken in any specific area and resistivity profiling should be done if the area has complex geological structures.

In some areas it was found that the resistance was higher in the river beds than in the surrounding area where measurements were impossible due to high conductivity. But measurements taken in the river beds often indicate perched water tables which are of value, but also tend to interfere with determination of the regional water table. The depths to water or rock are often only an approximation due to the variable relationships between electrode spacing and depth of penetration of the electrical current. However, at the worst, poor resistivity measurements are of value in that they may indicate where more work should be done and where drilling or digging is a big gamble. At best they can indicate the depth to water within a few metres, what type of material can be expected while drilling and to some extent the quality of water, i.e. conductivity of the water. Both poor and good measurements were taken in the current study.

Graphical analysis of the curves in which apparent resistivity is plotted against electrode spacing is helpful in some cases in order to delineate more accurately the depths to the different layers of material and to the water table. This analysis is based on fitting the plotted field curves to families of plotted theoretical curves. This analysis was done for many of the curves giving depths, thickness, and apparent resistivity of the several layers.

Magnetometric measurements

The magnetometre is used to measure the vertical component of the earth's magnetism. It has been found that fault zones cause an anomaly in the local vertical magnetism. A fault zone will affect the ground-water movements, sometimes causing the water to move closer to the surface, sometimes causing it to move downwards, and often the fault zone is more permeable than surrounding areas, especially in rock formations.

A systematic magnetometric survey of an area may be useful in finding fault zones. The Chalbi basin is too large an area to survey in any detail in the short time available but some measurements were taken where faults or fractures were thought to exist.

Although no major fault zones were identified some useful information was obtained.

1. The areas over the basement rock have much more constant vertical magnetism than those over basalt. In fact, the edge of an underground basalt layer can be identified by the change from a constant magnetism to a more erratic magnetism.
2. Sometimes the relative proximity of the basement rock to the surface can be discerned for adjacent areas by comparing the relative magnetism.
3. In basaltic areas, extreme point magnetic anomalies exist, which have no surface manifestation. However, further study may show that these point anomalies are associated with more linear fractures or faults.
4. Magnetic anomalies often affect the electrical resistivity measurements, causing the plotted curves to show distinctive breaks, i.e. unsmoothness (Griffiths and King, 1965 ;Van Nostrand and Cook, 1966).

There are undoubtedly some fracture or fissure zones in the Chalbi basin where the basalt has been extruded, but faults showing tectonic movements are mainly confined to the extreme north-west part of the study area, with the possible exception of the western foot of the Hurri Hills. It has not been possible to determine whether or not the Chalbi Desert (sump) has been directly caused or changed by faulting, except as mentioned earlier in the description of the Gus and North Horr areas.

Pump tests

As mentioned in the area description for the Kurkum area the pump tests attempted were not very satisfactory. A satisfactory pump test is one in which the water surface elevation stabilizes for a certain pumping rate. Often in the case of a perched water table the water surface will continue to drop at a very slow rate (10 mm or less per hour) which may indicate mining of the aquifer, i.e. the aquifer is not being recharged at the rate it is pumped. A more useful pump test is possible when an observation well is located within the area of influence of the test well. With measurements of the drawdown in the two wells and the pumping rate the permeability of the aquifer can be determined.

Elevations

In order to determine the ground water flow gradients and directions of flow it is necessary to get accurate elevations at all wells, springs and points where resistivity measurements were taken. Since the time did not allow running accurate levels to all these places, barometric altimeters were used to obtain elevations. There are a few points where the Kenya Surveys Department have established elevations, but these are mainly on the periphery of the Chalbi basin and on the tops of hills and mountains.

Fortunately, a fairly precise altimeter was loaned for use for our third and final field trip. By checking in at known elevations and recording the time of day a curve was drawn to correct the indicated elevations for the diurnal fluctuations as much as possible. Of course, the diurnal fluctuation changes from day to day. The best way to reduce

the error due to this change is to have a stationary barometer or altimeter at a known elevation and have it read every hour or so, but we did not have the equipment or the personnel to do this. The fluctuations may be different in different parts of the basin, and there are not enough points with accurately known elevations for a base while working in each area.

It is estimated that most of our elevations are within ± ten metres, but it is known that a few might have a larger error. This probability or error and the insufficient number of measurements precludes the drawing of a useful flow net.

Water surface fluctuations

Although some fluctuations in well and spring water surface elevations were observed and measured, not enough time elapsed to give any definitive information. Also, the fluctuations should be related to the thickness of the water table and the depth to the water table to give useful relationships, i.e. safe and useable yields at reasonable depths. The depths to water and bedrock that were measured or estimated are too sparsely separated and imprecise to make anything but a very general analysis.

Water quality

The results of the water testing shown in Table 2 are fairly reliable except possibly for the fluoride. At least these analyses give a good picture of the range of quality and what could be expected with further ground-water development. It also indicates that the shallower water may be of better quality. However, by no means should it be assumed that all the good quality water has been found.

APPROPRIATE TECHNOLOGY

Shallow ground water at depths of one to 30 metres could be more fully utilized in many areas of the Chalbi basin. There are many opportunities for improving livestock production while at the same time protecting and improving the environment not only for the animals but for the people themselves.

It is obvious that the capital and operating costs of shallow water development are much less than for deeper ground water. It would be much easier for the local people to develop and manage these resources in the near future, but there are some limitations and problems:

1. The development of water supplies must be integrated with a definite management plan to insure against overgrazing. At the same time it should provide for an improvement of the environment for the more sedentary life which is going to occur for at least some of the local people.
2. The present necessity to dig wells in the bottom of the lagas every dry season to a maximum (for safety reasons) of seven or eight metres must be improved on for better utilization of even the shallow aquifers.
3. A cheap reliable way of extracting the water in the context of this remote area must be perfected.

It is beyond the scope and purpose of this report to analyse in detail how to approach, much less surmount, these problems and limitations. However, it may be worthwhile to elaborate further three aspects of the problems.

Integrated development

The main livelihood of the Chalbi basin people will be livestock for many years. They will continue to settle in more or less permanent villages and consequently degrade the environment unless changes are made soon. The ground-water supplies, therefore, should be used soon, for at least two main purposes: (1) to provide the opportunity to disperse the herds into areas which are not now fully utilized, e.g. Hedad, Korante plains, etc., (2) to provide water for starting and growing trees and other plants in the villages which are already in degraded areas, e.g. Korr, Kargi, Kalacha, North Horr. An indirect

method would be to irrigate small gardens in each village so livestock would not have to be kept in such close proximity to the village as the day-to-day food supply for the few people who live there. Perhaps fodder could be grown for the minimum livestock required, without destroying the grass and shrubs necessary to prevent desertification.

Already experiments at Kalacha and North Horr prove that limited irrigation is possible.

Well development

Since the cost of drilling wells is about Ksh. 200,000 for mobilizing the equipment and about Ksh. 1,300 per metre for drilling, it is advisable to develop the available shallow water first. Also it may be possible to either improve on the present methods of hand digging or provide a low cost method of mechanical drilling.

The main improvement in hand digging would be to: (1) provide concrete casing rings so the wells could be dug to deeper depths without the danger of collapsing walls, (2) provide some way of sealing the wells during the flood runoff periods so they do not have to be re-dug each dry season.

It may very well be impossible to perfectly seal a concrete lined well with a diameter of 1.5 metres situated in a river bottom. In some places a well beside the river may not silt up. But wells beside the river in desert areas have often been found to have water at a much lower elevation than the perched water table in the river. However, careful study may find places where this is practicable.

An alternative is to put 6" or 8" steel casing in the hund-dug well with an airtight cap being fitted at the end of the dry season to prevent the silt-laden flood flows from entering. The water would be bailed out by hand with an elongated bail made of 5" or 7" plastic pipe with an inlet valve at the bottom. A weighted bail could be used to remove a limited amount of silt or sand.

One of the main disadvantages of hand-dug wells is the fact that they usually do not penetrate the aquifer far enough to utilize more than a very small amount of the water in the aquifer. Therefore the well has to be deepened when a dry year comes along and the total daily yield is severely restricted to that available for only one or two metres drawdown.

The only alternatives to these restrictions are to dig more wells or to drill well by mechanical means. It is possible to construct, or buy, low cost drilling equipment which can overcome these problems without going to the higher cost drilling machines.

Pumping equipment

As mentioned above, the first improvement on the bucket, can, gourd, or hide scoops which are presently used by the people to lift water out of the wells, might be a bail made out of plastic pipe with a one way (check) valve in the bottom. The next improvement would be a hand pump. However, with each step of improvement, capital and operating costs go up, and for a self-sustaining local economy the local people would have to decide what level of improvement they are willing to support.

With any of these intermediate technological water lifting devices the human limit of power in this environment is reached at about 1/6 HP and 50% efficiency. This 1/6 HP at 50% efficiency can lift water eight metres at a rate of 48 litres per minute or 30 metres at about 13 litres per minute. The daily requirement of water is about 25 litres/day/cow, 3 litres/day/sheep or goat or 7 litres/day/camel (FAO, 1971). It can be seen that there is a definite number of animals which can be watered per day from a shallow well utilizing human energy, assuming there are enough men and/or women to 'spell' each other and enough water in the well.

Animal, wind and sun powered pumps are the next step in increased power sources.

CONCLUSION

It has not been possible in three months to attain all the objectives of the study. A few areas were not visited at all, insufficient resistivity measurements were taken, and the pumping tests were not satisfactory. It is not possible to construct a flow net of any of the basin area.

However, a considerable amount of useful information was obtained. The depths to water and bedrock have been determined for many areas for the first time. A large amount of data about the quality of the ground water throughout the basin are available and will be helpful in determining the best places for further development. The approximate directions of flow of the ground water is known for several areas and the relative permeabilities for a few areas are known. Areas where the ground water is very deep as well as where it is very shallow are now known.

Further ground water studies should concentrate on, among other things, better well testing for both existing and newly drilled test and observation wells. The recently drilled well at Kalacha could be pumped with a high rate pump and the nearby hand-dug well would be used as an observation well to obtain much useful information on permeability and quality of water in an area of rather high potential.

More resistivity measurements should be taken in unvisited areas and in areas where more detailed and precise information is required, at least enough to plot a flow net.

Better elevations should be obtained by use of a good quality roving and base altimeter throughout the basin and by running spirit levels to areas of special interest.

Seasonal water surface fluctuation in wells and springs should be measured. The seasonal water levels in other areas could be checked with resistivity measurements.

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Water analyses

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REPORT ON FEASIBILITY STUDIES FOR GROUNDWATER DEVELOPMENT IN THE UNESCO/IPAL STUDY AREA, MARSABIT, NORTHERN KENYA

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SUMMARY

Groundwater is the most important resource for the human and livestock populations in the IPAL study area in Marsabit District of northern Kenya. Rangeland management plans for this area are dependent on the availability of adequate water supplies. This report presents the results of a feasibility study made in an effort to identify and evaluate the groundwater resources of the study area. The sites having the greatest exploitable groundwater potential within the study area are delineated. Recommendations for the optimum development of the available groundwater resources at those sites are presented.

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4. The Permanent Secretary, Ministry of Energy, Kenya Government for lending us a resistivity meter for this work.

1. Introduction

1.1 General

The UNESCO/IPAL project area, hereafter referred to as the study area, lies in Marsabit District of northern Kenya. It is a semi-arid to arid region under threat of desertification. The UNESCO/IPAL Project was set up to carry out relevant studies to identify the causes of the rapid desertification processes currently occurring in this area, to formulate range management plans suitable for eliminating or retarding or reversing the desertification processes, and to assist in the implementation of those range management plans.

Pastoralism is the most important economic activity in the study area. Desertification in the area is mainly due to the over-use of land by the increasing human and livestock populations. The availability and distribution of water is the greatest influence on the distribution and movement of livestock and consequently on land use. Some parts of the area are overgrazed while other parts have not been utilized for grazing for long periods. The redistribution of water resources will help ease the grazing pressure on many over-utilized areas by inducing livestock movement into previously under-utilized areas.

The most important water resource in the area is groundwater. Ephemeral surface runoff occurs for only a few days or even hours during the March-May and October-November rainy seasons along the various laggas (sand rivers) in the area. Most of this runoff sinks into the laggas and forms shallow perched groundwater aquifers. Water from these aquifers can be extracted by means of shallow wells. Depending on the geological structure and rock types present, part of the remaining runoff sinks deeper into the ground and eventually constitutes a deep regional groundwater aquifer. Water from this aquifer can be extracted by means of boreholes.

In this study hydrogeological investigations were made to delineate the shallow groundwater aquifers at specific places within the study area. The selected sites occur mainly along various laggas. For those sites which occur away from the laggas and at which no shallow groundwater aquifers were delineated efforts were made to delineate the depth to the deep regional groundwater aquifer. A total of fifty-four

electrical resistivity soundings were carried out at the preselected sites within the area. The results of these soundings have been interpreted in terms of the groundwater aquifers at each site. These results, along with the available geological and hydrogeological data, have been used to evaluate the groundwater potential in various parts of the area.

The development and utilization of groundwater resources in the study area must be planned with the aim of protecting the environment and improving livestock production and the welfare of the people. Efforts are to be made to supply as much water as possible and as cheaply as possible throughout the area, but with emphasis on under-utilized areas such as the Hedad desert. The implementation of groundwater resources development plans will depend on the availability of funds and the local people's response to the plans, in view of their traditional seasonal migration patterns, their change towards a money-based economy, and their security.

1.2 Objectives of the hydrogeological consultancy

The objectives of the consultancy as defined by the terms of reference were:

1. To carry out hydrogeological investigations for shallow groundwater layers at specific areas within the study area.
2. To carry out resistivity measurements at specific places for groundwater level and depth to bedrock (the sites for resistivity measurements were the same as those at which the hydrogeological investigations of (1) above were to be carried out).
3. To carry out capacity and charging tests in specific preselected boreholes and wells.
4. To take samples of water for water-quality tests from various wells in the study area. These samples were to be forwarded to the UNESCO/IPAL laboratory for analysis. No analysis or discussion of water chemistry was to be made by the consultant.
5. To carry out a short study of costs of drilling new boreholes and wells in the Hedad. This was to include the costs of pipeline and distribution places.
6. To make a recommendation, based on this study and a previous study by Borgeson, on the optimal utilization of groundwater resources in the study area.

The consultancy was carried out over a period of three months. The field work took place over a period of about two months between 14 August and 15 October 1982. The field data interpretation and analysis and report preparation took place over a period of one month between 15 October and 15 November 1982.

1.3 Previous hydrogeological studies in the study area

Previous hydrogeological studies in the area were carried out in 1981 by Borgeson (1981). Borgeson's field work was carried out during the March-May rainy seasons when there were extremely heavy falls in most of the study area. A total of twenty-seven resistivity soundings were carried out by Borgeson from which interpretations of the depths to the groundwater and/or bedrock were made. Borgeson also obtained data on the water chemistry of the groundwater throughout the study area.

The work of this consultancy is an extension of the work of Borgeson. Of the fifty-four electrical soundings carried out during this consultancy twenty-seven soundings were made at or close to those sites at which Borgeson's soundings were made. The period during which the field work under this consultancy was done represents the driest months of the year in the study area. During this time the shallow groundwater levels in the wells are at their lowest and the shallow well yields are at their minimum. An examination of the geoelectrical results from this consultancy and those of Borgeson's work reveals the seasonal fluctuation in the shallow water table in various parts of the study area.

2 Physiography

2.1 Location of study area

The study area lies in the western part of Marsabit District and covers an area of about 22,500 km² approximately between latitudes 1½°N and 4°N and longitudes 36½°E and 38°E (Figure 1). It is basically a major north-south trending geological basin over 100 km wide which lies on the eastern flanks of the East African Rift Valley.

2.2 Topography

The study area is a region of contrasting topography, with low-lying plains in the central regions surrounded almost everywhere by hills. The larger part of the area consists of the extensive plains of Kaisut in the south and Korante in the south-west, the Hedad and Koroli desert plains in the central area, and the Chalbi desert salt plains in the north. The plains are interrupted by occasional low-lying volcanic hills in the central region and Basement inselbergs in the southern region. The topographic highs are constituted by Mt. Kulal and the Oldoinyo Mara mountains in the west, the Hurri Hills in the north-east, Marsabit mountain in the east, and the Ngurunit and Ndoto hills in the south.

2.3 Drainage

All the rivers in the study area are seasonal and carry flowing water for only a few days during the rainy seasons of March-April, and October-November. It is convenient to describe the drainage pattern in relation to the controlling source highlands rather than use the conventional method of describing drainage patterns in relation to the existing rivers. The drainage pattern in the area (Figure 2) therefore embraces the following: the Hurri Hills drainage system, the Marsabit mountain drainage system, the Ndoto and Ngurunit hills drainage system, and the Mt. Kulal drainage system.

Rivers originating in the Hurri Hills and the surrounding areas flow southwards into the Chalbi desert. The north-south trending central ridge of Mt. Kulal forms a drainage divide, with rivers flowing westwards into Lake Turkana and others flowing eastwards into the Chalbi desert. The Balesa Kulal and its numerous tributaries constitute the main drainage channels off the eastern sides of Mt. Kulal into the Chalbi desert. Rivers originating from the Ndoto and Ngurunit hills flow either north-eastwards into the Korante plains and eventually into the Hedad desert, or eastwards into the Kaisut desert. Of these, the Milgis and its tributaries are the most prominent drainage channels. In the Marsabit region the river flow is either in a north-westerly or south-easterly direction away from Marsabit mountain. The north-westerly flow is towards the Chalbi desert, while the south-easterly flow is towards the eastern part of the Kaisut plains outside the study area.

3 Geology

No detailed published geological mapping reports are available for the study area, since field geological mapping is only currently being undertaken by the Mines and Geology Department of the Kenya Government. However, detailed geological studies have been made in the areas surrounding the study area which give an indication of the geological set-up within the area. These include studies in the Laisamis area (Randel, 1970) to the south, the Baragoi area (Baker, 1963) and South Horr (Dodson, 1963) to the south-west of the study area. In the absence of detailed geological studies efforts have been made to obtain a generalized geological picture of the area from field observations, aerial photographs, satellite images and any other data from relevant studies within and around the area. This, together with a regional geological map (Figure 3), constitutes the regional geology of the study area. Emphasis is laid on the effect of the regional geology on the hydrogeological conditions within the area.

The surface geology within the study area is represented by three distinct geological units: the metamorphic rocks of the Basement System, the volcanic lavas, and the weathering derivatives of the two, comprising sands and soils. In addition to the above there are intrusive rocks within the Basement System rocks.

The oldest rocks in the study area are the metamorphic rocks of the Basement System. These are the local representatives of the extensive Precambrian Mozambiquean belt which covers most of eastern Africa. The rocks consist of biotite-hornblende gneisses, biotite-muscovite schists, quartzo-feldspathic granullites and bands of crystalline limestone. They are commonly intruded by basic, ultrabasic and acid igneous rocks composed of amphibolites, pyroxenites, serpentinites, granites and quartz veins.

The Basement rocks are exposed in the south-western parts of the area, in the Ngurunit and Ndoto mountains. Other exposures are seen as the resistant inselbergs of Baio and Illim, and as large pegamatite outliers in the hills around Korr. The presence of Basement rocks is indicated in most of the southern areas by the occurrence of quartz detritus and micaceous sands on the surface. In general, the Basement has a north-south strike, a dip of foliation of approximately 60°E, and a low-angle plunge northwards.

Figure 2. Drainage pattern IPAL study area, Marsabit

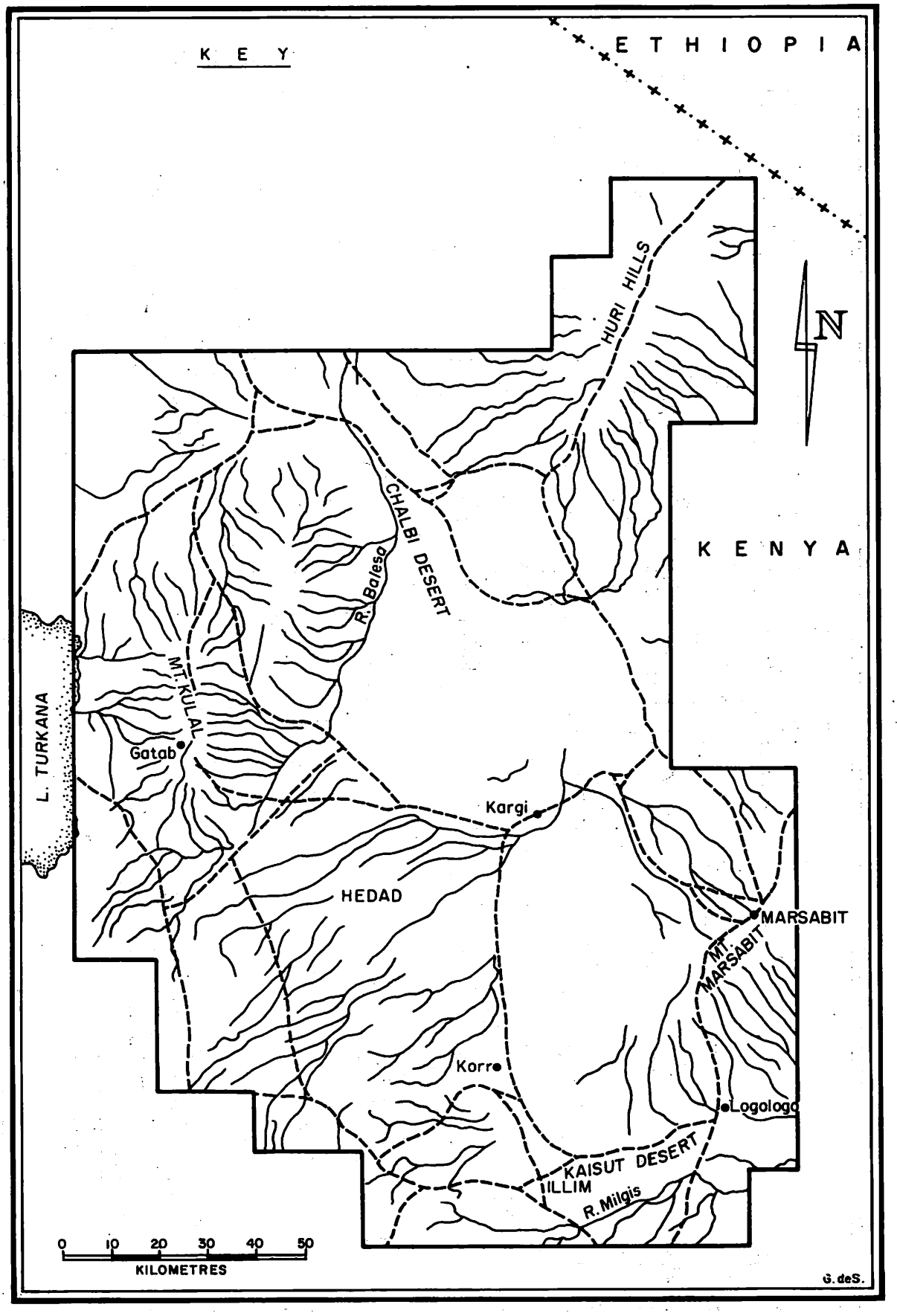
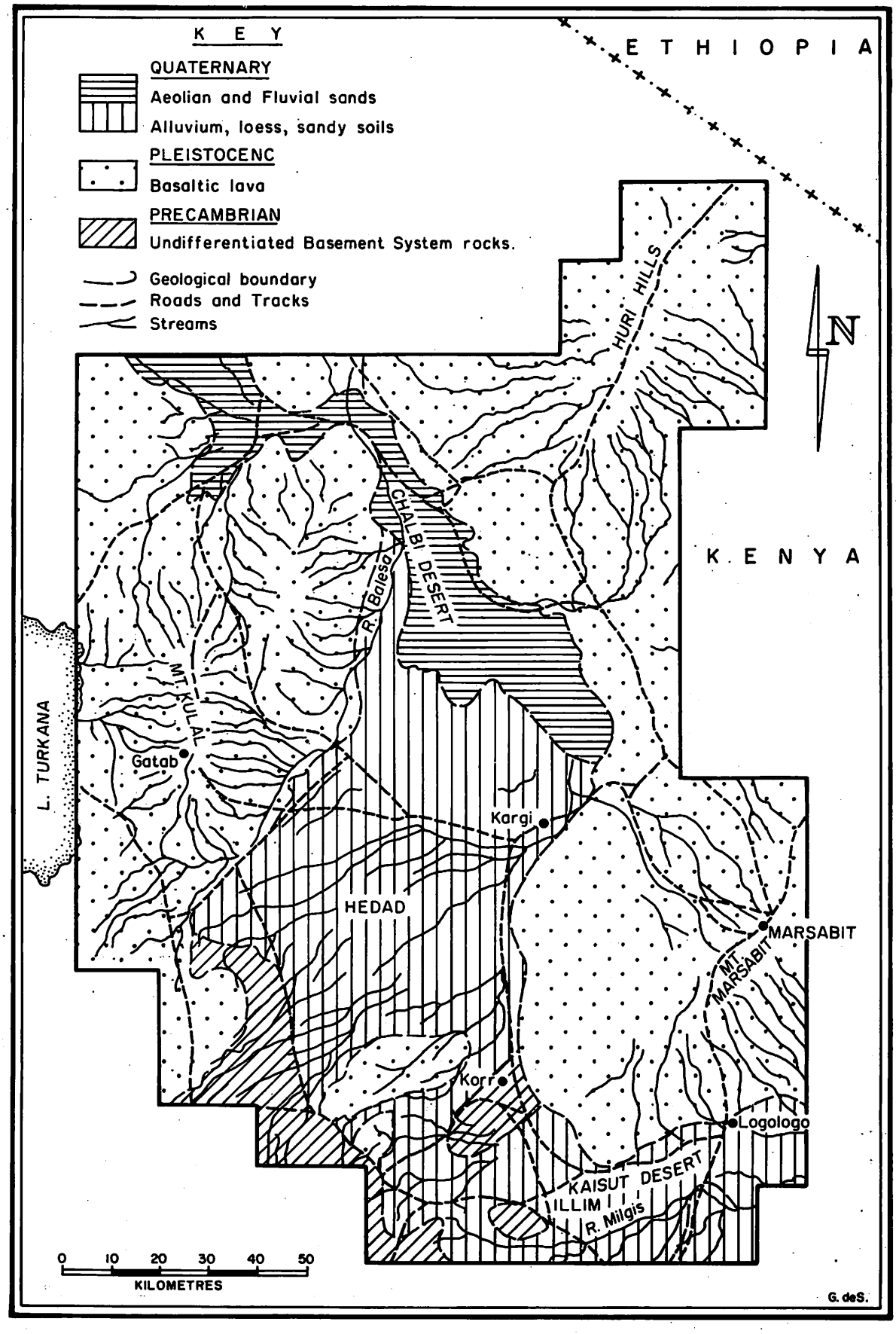


Figure 3. Regional geological map
IPAL study area, Marsabit



Over a long time span, the Basement System was subjected to erosion, the products of which constitute the Tertiary sediments. These Tertiary sediments were deposited in valleys and geosynclinal basins in the Basement System. They are coarse gritty conglomerates made up of pebbles of quarts and feldspars and less commonly gneiss pebbles, which alternate with fine-grained reddish sand beds. The Hedad most likely represents one such geosynclinal basin in which these sediments were deposited.

A large part of the study area is covered by volcanic lavas which sometimes have a thin soil cover. Three episodes of volcanism have been recognized (Dodson, 1963; Randel, 1970; Baker, 1963). The first of these, which occurred during the Middle and Upper Pleistocene, gave rise to an extensive flow of olivine basalt lava, 3 to 6 m in thickness, which immediately overlies the Tertiary erosion sediments. This lava had as its origin a series of separate fissure eruptions. The second volcanic eruption episode, during the Upper Pleistocene, resulted in a broad flow of olivine augite basalt in the western region and small flows of analcime basalt over all of the olivine basalt plateaus mentioned above. The analcime basalt flows are distinguished by the absence of surface soil cover. These lavas rise up to 15 m above the olivine basalt plateau and vary greatly in extent. Some are merely small isolated ridges up to 1 kilometre long, while others cover extensive areas. Outcrops of these lavas consist of angular vesicular blocks. The third and final volcanic episode resulted in the formation of small vents and lava flows of limited extent, and the formation of small explosion craters with widespread emission of volcanic ash. From the well preserved character of these structures it is concluded that they are Recent in age. Reddish-brown sands are common and form an extensive blanket over most of the southern and central parts of the study area. Large deposits occur in the region around North Horr and extend over the Chalbi desert. The sands contain fragments of quarts, feldspars, hornblende and biotite, which indicates that they are derived entirely from the metamorphic Basement rocks. The mode of deposition was initially fluvial but in later stages aerial (inland) transport mechanisms played an important part, giving rise to aeolian sand dunes, for example, at North Horr and in the Chalbi. Alluvium and sandy soils which are contemporaneous with these sands cover most of the southern region, including the Hedad. Other superficial deposits

include small patches of secondary limestone (Kunkar) which commonly occurs in small fragments scattered about the surface as in the region west of Kargi. The presence of Kunkar limestone is characteristic of areas with limited rainfall. It owes its origin to capillary action, which draws lime-rich water to the surface so that upon evaporation, a calcareous deposit is formed.

From the available data, the following simplified geological succession for the study area is proposed:

Geological sequence		Approximate thickness	Age
(v)	Superficial deposits (volcanic ash, alluvium, sands and calcareous deposits)	Variable	Recent
(iv)	Olivine-augite basalt	15 m	Upper Pleistocene
(iii)	Olivine basalt	3-6 m	Middle to Upper Pleistocene
(ii)	Tertiary sediments	30 m	Tertiary
(i)	Basement rocks	-	Precambrian

Faulting in the study area is essentially in a north-south direction and follows the general trend of faults in areas adjacent to the East African Rift Valley system (Figure 3). Faulting is most prominent in the Basement System rocks of the Ndoto, Nyiro and Oldoinyo Mara mountains in the southern parts of the area. The faults continue northwards to the western parts of the area and on towards the Bura Galadi hills outside the study area. In the Mt. Kulal area the faults are concealed under the young volcanic lavas which were extruded through fissures along the faults. Faulting is less prominent in the central parts of the area. This is mainly because the areas have thick sedimentary deposits which cover older faults that may be present. However, the presence and alignment of volcanic rock outcrops implies some faulting in these areas. In the eastern parts of the area faulting is inferred from the linear arrangement of explosion vents and craters such as those in the Kaisut volcanic plateau. These volcanic centres occur along a system of faults extending from the Laisamis area in the south to beyond the Hurri Hills in the north.

4. Hydrogeology

4.1 General characteristics

The nature and occurrence of groundwater is dependent upon the geological formations present and the hydraulic properties of the rocks through which the water flows. Before presenting and analysing the available hydrogeological data from the study area it is first important to discuss the aquifer characteristics of the existing rocks in the area.

The geology of the area changes from the old Precambrian Basement metamorphic rocks and their weathering derivatives in the southern parts to Tertiary and Quaternary volcanics and sediments in the rest of the area. The average annual rainfall is between 160 mm and 820 mm and occurs in two distinct seasons. The long rains occur between October and December.

The groundwater potential in a given area will depend on the porosity, permeability and orientation of the geological formations present, the amount of available rainfall, and the existing drainage pattern.

Uncemented sediments constitute good groundwater aquifers in any situation where groundwater recharge occurs. The groundwater resource within a sedimentary sequence therefore depends on the amount of rainfall present and the existing drainage pattern.

Metamorphic rocks are generally impermeable and therefore equicludes. However, upper layers of metamorphic Basement System rocks are usually weathered, giving rise to sands and sometimes clays. These weathering derivatives are possible aquifers and the result is the occurrence of perched groundwater aquifers in the synclines of folded Basement System rocks. Experience elsewhere has shown that groundwater can be found at depths of up to 20 m into Basement rocks, this being the extent of weathering into overburden-covered Basement rocks. The extent of weathering into exposed Basement rocks, where the weathering products are washed away by surface runoff, is much less. Interconnected joints and fractures in Basement System rocks act as water channels and commonly give rise to springs. This is the case, for example, in the Ngurunit hills in the study area.

Volcanic rocks may be impermeable and therefore equicludes or porous and permeable and thus potentially good aquifers if they occur in the correct environment. The occurrence of porous and permeable volcanic rocks in high-altitude recharge areas favours the flow of groundwater through them to lower altitudes.

The hydrogeology of the study area may be considered under several geographic zones as follows.

4.1.1 The Ngurunit - Koronte plains area

This extends from the Oldoinyo Mara and Ndoto mountain areas up to the Hedad and the Kaisut desert. It includes the Korante plains, and the Ilaut and Ngurunit areas.

The surface geology of the area consists of Basement System rocks to the south and west. The Oldoinyo Mara and Ndoto mountains are the result of a series of folds and overfolds in the Basement System rocks. Subsequent weathering processes have resulted in thick deposits of sand and soils, giving rise to thick vegetation on the limbs of the folds. The faulted axes of the overfolds give rise to a series of springs in Ngurunit and Lependera. The surface geology in the north and east of this area consists of gravels and sands that are weathering derivatives of the Basement System rocks. These are overlain by thick sedimentary deposits consisting of alluvial sands and silts that occur in broad flood plains which have been developed by the existing drainage systems. The vegetation here consists mainly of shrubs and dense bush.

This area receives an average annual rainfall ranging from 200 mm to 665 mm. In the higher grounds of the south and west the Basement occurs at the surface or at shallow depths and forms an impermeable barrier to the percolation of water into the ground. Because of the existing topography, the surface runoff is quickly drained by laggas (drainage channels) which run in a north-easterly direction into drainage valleys. The drainage valley floors consist of alluvial sand and silts which overlie the weathered zone of Basement rocks. Whereas most of the surface runoff is carried downstream by the laggas, some water percolates downwards through the alluvial sands and under favourable conditions, such as impermeable rock or clay layers at the bottom of the laggas, constitutes shallow groundwater aquifers within the laggas. This water may be harvested by means of shallow wells sunk into the laggas. The remaining surface runoff that percolates into the ground either in the existing laggas or elsewhere sinks further downwards into the

weathered portion of the Basement and forms perched groundwater aquifers in synclines in the Basement System. In order to harvest this groundwater wells must penetrate the sediments consisting of the weathered portion of the Basement. Determination of the depth to the Basement provides the necessary information on how deep this aquifer extends.

Hydrogeological records indicate that this area has no boreholes at all; field observations during the study reveal that several springs and wells are found in the area. Springs originating from joints in the Basement System rocks occur in Lependera. However, these produce a very limited amount of water. In the Ngurunit area, springs produce plenty of water from joints in the Basement System rocks of the Ndoto mountains. A well 2.3 m deep with a water-rest level at 1.75 m was observed at Ngurunit in a lagga. At Ilaut several wells with water-rest levels varying from 2.0 m to 5.0 m were observed in the laggas. No wells were observed in the various laggas in the Korante plains. The main reason for this is that there are no people (or livestock) in the area to require and therefore construct wells there. However, several good potential sites for wells were identified in the area (see section 7.2).

4.1.2 The Hedad desert

The Hedad desert lies in the middle part of the study area. It is bordered by the Korante plains and the Balesa Kulal to the west, the Chalbi desert to the north, the Marsabit mountain area and the Kaisut plateau to the east and the Kaisut desert region in the south. The ground surface of the Hedad consist of fine to coarse sands, silts and soils which are covered with a vegetation consisting mainly of shrubs and dense bush. It is the least populated region in the central and southern parts of the study area and therefore the least utilized for livestock grazing. The area is thus most important for future range-management plans in terms of spreading the movement of livestock as widely as possible and directing it from over-utilized to under-utilized areas. Being the most waterless region in the area, the Hedad must receive top priority in the delineation and development of potential groundwater resources. It is for this reason that the present groundwater studies were concentrated in this region.

The Hedad is generally a flat, low-lying region which receives a low annual rainfall of between 180 mm and 220 mm. The physiographical

features around the Hedad make it a natural hydrogeological sink. Numerous laggas originate in the adjoining mountainous recharge areas to the south and west and drain surface runoff into it in a north-easterly direction (Figure 2).

The prevailing geological conditions also favour the north-eastward flow of groundwater into the Hedad. The impermeable Basement System rocksoccur at higher elevations but at or near the surface to the south and west of the Hedad. These are sometimes covered with sands and silts that are the weathering derivatives of the Basement System rocks, or by sands, silts and soils that are alluvial deposits in flood plains developed by the existing drainage channels. Towards the north, within the Hedad, the Basement System rocks are deeper, being covered by Tertiary sediments overlain by the younger Quaternary deposits. Groundwater from the recharge areas in the south and west of the Hedad eventually constitutes a deep regional groundwater aquifer which flows in a north-easterly direction along the interface of the Basement and the overburden.

At Korr the exposed Basement rock, which is further intruded by a pyroxenite and quatz-core-pegmatite body, forms a hydrogeological barrier to the deep regional groundwater movement above. This results in the rise of groundwater to shallower depths. Groundwater abstraction from areas around Korr is from boreholes (see section 4.1.7) penetrating the resulting shallow groundwater aquifers.

North of Korr and towards Kargi the groundwater, on reaching the contact of the Hedad and the plateau volcanics, changes course and moves towards the north along the faults/fractures at this contact. Thus the contact of the Hedad and the plateau volcanics is a high-potential groundwater area.

Hydrogeological records show that only one borehole, No. C4080 (Figure 4) was sunk in the middle of the Hedad. This borehole, the log for which is given in Appendix 1C, was drilled to a depth of 200 m but was found to be dry.

Two boreholes have been drilled in the north-east part of the Hedad at Kargi. Borehole C3962 was drilled through lavas to a depth of 32 m and abandoned before striking any water; reasons are given for the abandonment. Borehole C3960 was drilled to a depth of 95.7 m;

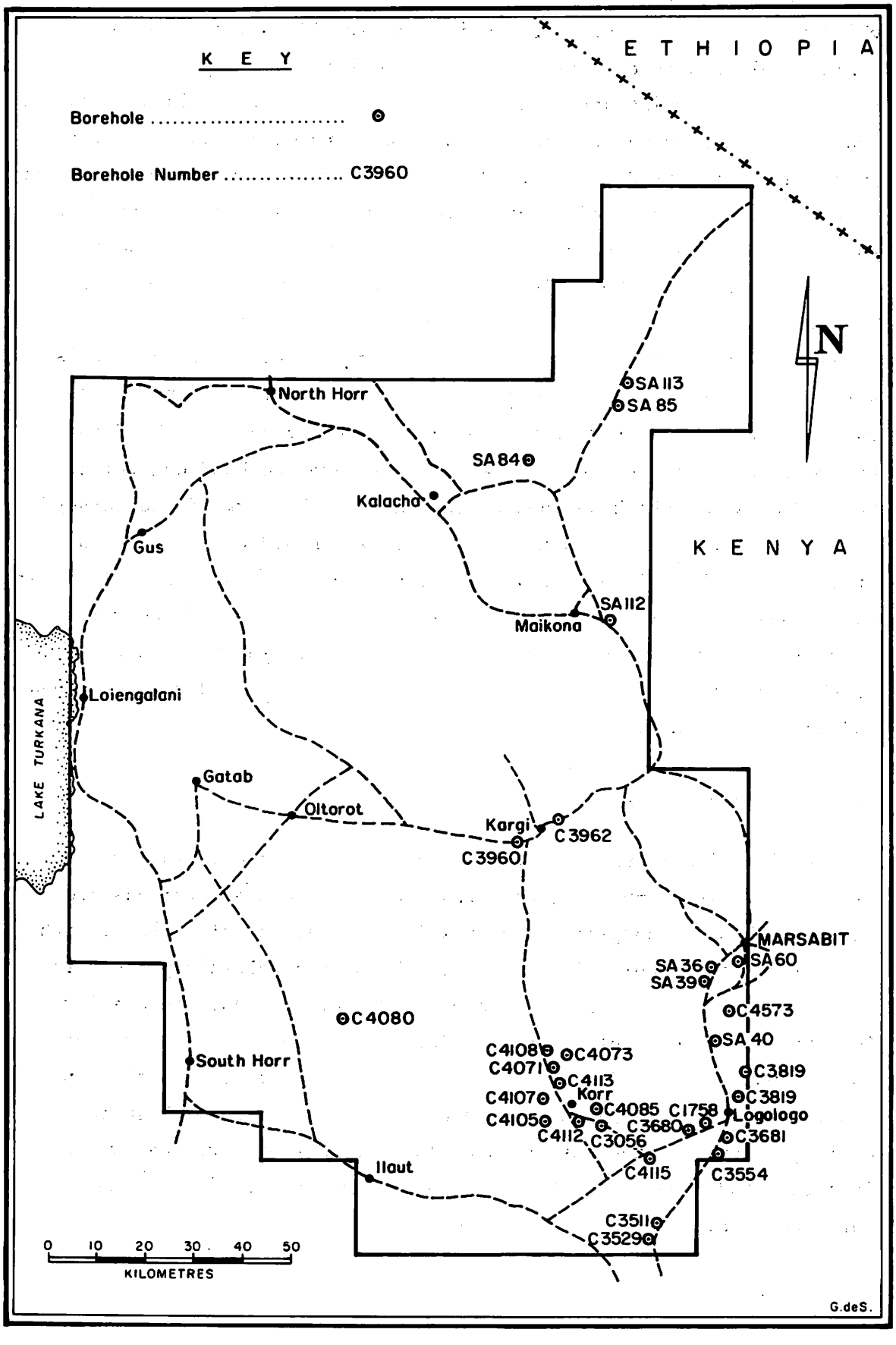
some groundwater was struck at a depth of 18 m in volcanics but the main aquifer is at a depth of 72 m within a sequence of sandstone. The hydrogeological data for this borehole are given in Appendix 1 A, while the geological log is given in Appendix 1C. This borehole has a high yield and an exceptionally high specific capacity. The detailed test pumping data are given in Appendix 1B. It is unfortunate that the test pumping of this borehole was carried out using a small pump and the reported yield of 10.9 m^3/hr is merely the maximum capacity of the pump that was used. Had a bigger pump been used the original specific capacity indicates that a higher tested yield could have been obtained. This borehole is apparently very highly productive.

Various wells were noted in laggas in the middle parts of the Hedad. However, all the existing wells were dry at the time of this survey, indicating that the depth to the water table (if one exists) in the laggas is greater than about 4.0 m, the average depth of the hand-dug wells in the area. At Kargi there are two hand-dug wells, the UNESCO well, which was non-operational at the time of the survey, and a second well about 50 m away from it which had water at a depth of 4.5 m. Both wells are very productive and lie along a fault/fracture zone. Several wells occur to the east of Kargi. Some of the wells occur in laggas and contained a limited amount of water. Others occur at the edge of the volcanics that mark the eastern boundary of the Hedad and contained plenty of groundwater.

4.1.3 Mt. Kulal-Balesa Kulal region

This region lies in the western part of the study area. The area has highly contrasting physiographic features. These are, from east to west, the broad floodplain through which the Balesa Kulal flows, with elevations mostly below 600 m a.s.l., the barren volcanic plateau in the Gus area at an elevation of about 600 m a.s.l., and the heavily forested volcanic highlands of Mt. Kulal, which reach an altitude of about 2300 m a.s.l. The Mt. Kulal area receives heavy rainfall, up to 820 mm annually. Its axis forms a hydrological divide with surface drainage either to the west towards lake Turkana or north-eastwards into the study area. The Balesa Kulal is the main drainage channel into the area.

Figure 4. Location of boreholes
IPAL area, Marsabit



Mt. Kulal lies in a region of major Rift Valley faulting and is itself the product of volcanism along the Rift Valley faults. It is in turn also highly faulted. The faults in Mt. Kulal control the movement of groundwater, which is the result of percolation of rainfall through porous volcanic lavas on the slopes of the mountain. The result is the occurrence of several springs on the eastern edges of this mountain.

The Balesa Kulal and its numerous tributaries are the main drainage channels for surface runoff from Mt. Kulal and the surrounding areas. The laggas consist of sandy, silty and clayey material and flow towards the Chalbi desert. Upstream the Balesa Kulal lagga is narrow, with well defined vertical banks 1 m or more high. As the lagga continues downstream it becomes very broad, 30-50 m wide, and its banks become less and less definable until the lagga merges into the surrounding floodplain.

Some of the surface runoff along the Balesa Kulal and its tributaries percolates through the sands and silts in the laggas. If an impermeable layer of clay or volcanic lava of appropriate configuration occurs at the bottom of the lagga, this water forms a perched groundwater aquifer along the course of the lagga. Otherwise the groundwater movement is deeper down towards a deep regional groundwater aquifer. Groundwater from the rest of the recharge area in this region also percolates towards a deeper regional groundwater aquifer.

Several wells with depths ranging from 3 m to 4 m were noted near the point where the Kargi-Olturot road crosses the Balesa Kulal lagga. Each of them contained very little water at the time of this survey. At Olturot a UNESCO well has been sunk immediately outside the Balesa Kulal lagga. This well is about 9.2 m deep and contained plenty of water at the time of these studies.

4.1.4 The Chalbi desert region

The Chalbi desert region is located in the northern part of the study area. It is a flat low-lying region at an elevation of less than 500 m a.s.l., surrounded almost everywhere, except to the south, by volcanic plateaus and hills. These include the volcanic plateau of the Hurri Hills region to the north and east, Mt. Kulal and the Bura Galadi volcanic hills to the west. The Hedad forms its southern boundary.

The ground surface of the Chalbi consists mainly of sedimentary deposits of sands, soils, clays and secondary limestone deposits which constitute salt flats. The region receives an average rainfall of less than 250 mm a year, and this, combined with the salty nature of the ground surface, hinders vegetation growth. In fact, most of the salt flats have hardly any vegetation cover.

The Chalbi desert region appears to be the ultimate groundwater sink of the study area; most of the laggas in the area run towards it. Although most of the laggas disappear before reaching the Chalbi, it can be extrapolated that the ephemeral runoff in these laggas sinks into the subsurface and proceeds towards the Chalbi desert region. Thus a regional groundwater table is to be expected beneath this region. Along the eastern boundary of the Chalbi desert, between Maikona and Kalacha, the incoming groundwater from the plateau volcanics, to the east, culminates in springs at the contact of the lava escarpment and the Chalbi desert. Thus, many shallow wells and springs occur between Maikona and Kalacha.

Lagga Bulal is the main drainage channel into the Chalbi desert region. This lagga flows southwards into the Chalbi. Some groundwater exists in shallow perched aquifers along its course.

There are no boreholes in the Chalbi desert region, but several wells were noted at the eastern edges. At Maikona several wells are operating. The water-rest levels in these wells vary from 1.0 to 2.0 m at the immediate edge of the Chalbi desert to 3.0 to 6.0 m at Maikona shopping centre about 1 km away from the desert edge, just before the lava escarpment. These wells provide water for the population and their livestock within several tens of kilometres of Maikona. Several wells also occur at Kalacha, but there the depth to the water-rest level is greater. For example, in the UNESCO well the depth to the water level was measured at 8.15 m below ground level. Some wells are said to be located and in use about 15 km before the Bulal lagga along the upper Kalacha-North Horr road, but these were not visited during this study. Some wells are known to exist along the Bulal lagga but because of their distance from the Kalacha-North Horr road crossing none were visited. At North Horr several wells occur. The main well, which supplies North Horr with water, is 5 m deep and had a water-rest level at 1.2 m below ground level and a specific capacity of 0.75 $m^3/hr/m$ (Appendix 1B). This well is fault controlled and draws its water from the contact of sandstone and limestone rocks.

4.1.5 Hurri Hills region

The Hurri Hills region lies in the extreme north-eastern part of the study area. It comprises the Hurri volcanic hills and the lava plateau surrounding them. The Hurri Hills region varies in altitude from approximately 600 m a.s.l. to over 1,200 m a.s.l. The Hurri Hills volcanics were extruded along north-south-trending faults extending from the study area into Ethiopia. The plateau volcanics are fairly thick and represent a young sequence of lavas of fissure origin. The volcanics overlie a sequence of Tertiary sediment resulting from the weathering of the old land surface of the Basement System. As elsewhere in the region, the Basement System forms the basal layer.

The Hurri Hills receive an average annual rainfall of between 300 and 500 mm a year, the highest fall occurring towards the axis of the hills. The volcanic plateau receives an average annual rainfall of 200 to 300 mm. Due to the nature of the topography and the existence of porous volcanic rocks in this area most of the rainwater percolates into the ground and drains away from the region towards either the south-west or the south-east. Several laggas originate from the Hurri Hills and these carry the surface runoff also either south-west or south-east away from the region. The Hurri Hills region is therefore a recharge region whose axis forms a hydrological divide for the area.

To date, four boreholes have been drilled in the Hurri Hills region, (Figure 4). Boreholes SA84, SA85, and SA113 were drilled through a succession of lavas and volcanic ash to various depths (Appendix 1C), but all were found to be dry. Borehole SA112 near Maikona was drilled to a depth of 49.4 m and struck water at 42.7 m. However, its yield (Appendix 1A) of 0.23 m^3/hr was poor.

No wells were noted in the Hurri Hills region during our studies. This may imply the absence of shallow perched groundwater aquifers in the laggas in the region.

4.1.6 Marsabit mountain region

The Marsabit mountain region includes Marsabit mountain and the surrounding country. This is a high-altitude region in the east of the project area with an elevation that rises from about 900 m a.s.l. to

1,430 m a.s.l. The area receives a high rainfall of 400 mm to 750 mm annually. It forms a hydrological divide for surface and groundwater flow towards the north-west into the project area and south-west out of the project area. However, few laggas cut through the volcanics. The alignment of volcanic hills and craters suggests a narrow zone of north-south-trending faults/fractures. The porous nature of the volcanic rocks in the area allows for most of the groundwater to percolate downwards towards the faults and fractures. This water then flows southwards towards the Kaisut plateau or north-westwards towards the north-eastern end of the Hedad beyond Kargi.

There are five boreholes in the Marsabit mountain region (Figure 4), but only one, C4573, is productive (Appendix 1A). This productive borehole is located on a fault and taps 8.1 m^3/hr of water from a fractured and brecciated fault zone. The others have been drilled through a series of lavas and ashes to various depths, the deepest reaching 109 m. It is concluded that if a regional groundwater aquifer occurs in this region it is at a depth greater than 109 m and groundwater is obtainable at depths less than 109 m only where it is nearer the surface due to faulting. A few wells occur in the Marsabit mountain region. The groundwater in these wells is also fault controlled.

4.1.7 Kaisut plateau and Kaisut desert region

This region lies in the south-eastern part of the study area. It extends from Loglogo in the north to Laisamis in the south, and from Korr in the west to the south-eastern boundary of the study area. The northern part of the region consists of volcanic lavas of the Kaisut plateau, while the southern part consists mainly of the sedimentary deposits of the Kaisut desert, which are occasionally interrupted by Basement rock outliers. The region receives a low rainfall of 200 to 300 mm annually. The surface drainage is in an easterly direction via laggas from the Ndoto mountains towards the Kaisut desert, and southwards from Marsabit mountain through the Kaisut plateau to join the Milgis lagga.

Several boreholes have been drilled in the Kaisut plateau around Loglogo. Two of these, C1758 and C3681 (Appendix 1A), were drilled along faults and tap large quantities of water. All other boreholes are

either dry or give low yields. The productive boreholes are recharged from the high-altitude and high-rainfall Marsabit region by way of the north-south-trending faults that occur in the area.

A large number of boreholes have been drilled in the Kaisut desert area, which includes the Halisurwa and Korr areas, mostly by Catholic missionaries. The common feature of most of the boreholes is that they tap water from the Basement System rocks or from intrusives in the Basement System. Borehole C4071 was drilled to a depth of 27 m in the pyroxenite intrusion and gives the relatively high yield of 3.6 m^3/hr and a high specific capacity (Appendix 1A). Those boreholes drilled to the east of the intrusion, e.g. C4073, have low yields while those drilled immediately to the west of the intrusion, e.g. C4103, have higher yields. This is in agreement with the hypothesis that the intrusives form a barrier to the eastward movement of the deep regional groundwater originating in the Ndoto and Oldoinyo Mara mountain recharge areas (see Section 4.1.1). Generally the boreholes tap water from the fructured and weathered upper zone of Basement rocks at depths between 22 and 38 m. The yield is poor, ranging from nil to 0.6 m^3/hr. Yields greater than 3.6 m^3/hr occur under special conditions such as those discussed above.

Several wells occur in the Korr area. These are of a maximum depth of 4.5 m. They tap water from perched groundwater aquifers in the sand rivers. The Basement System forms an impermeable layer at the bottom of the sand rivers confining the groundwater to the various shallow aquifers.

4.2 Capacity and charging tests

One of the terms of reference of this consultancy was to carry out "capacity and charging tests" in specific wells and boreholes. Three wells and one borehole were specified in the annex and these are discussed in the first parts of this section. To arrive at a value for specific capacity and an estimate of the recharge into a well or borehole it is necessary to carry out a test-pumping operation. This involves pumping out water from the borehole/well at a uniform rate and measuring the changes in the water level. When the rate of pumping from the well (discharge) is equal to the amount of water coming into the well from the water-supplying aquifer (recharge), the water level in

the borehole/well will remain at a constant value called the "pumping (or dynamic) water level". The difference between this level and the water level in the borehole/well before pumping started ("water-rest level") is termed the "drawdown" for that particular discharge. The specific capacity is defined as the yield (or discharge) per unit of drawdown. The results of test-pumping operations carried out in the study area presented in Appendix 1B. These results are discussed below.

4.2.1 Olturot and Balesa Kulal wells

The well at Olturot is equipped with a hand pump and the outlet is a small tap near the well. During the test, the pump was run at an approximately uniform rate while the drop in the water level in the well was measured by use of an electric dipper. The discharge was measured with a 20-litre jerrycan and a stop watch. The results of the test are presented in Appendix 1B.

The Balesa Kulal well was found to have very little water during the survey. This well was 3.7 m deep and only the bottom 0.1 had water. It was therefore not practical to carry out a pump test in this well.

4.2.2 North Horr well

At North Horr, the well is equipped with a diesel-engine-driven reciprocating pump. All the water is pumped directly into a tank about ½ km from the well for distribution to the town. For this well the fall in the water level after pumping started was measured and recorded. The discharge was calculated from measurements of the water levels in the tank before and after the pumping and measurements of the tank's diameter. The results of this test are presented in Appendix 1B.

4.2.3 Borehole C3960 at Kargi and other boreholes in the study area

This borehole was found to be equipped with a submersible pump and the well head completely sealed with a cover plate. In the presence of a cover plate, it was not possible to measure the changes in the water levels inside the borehole using the equipment available to us. The equipment required for a comprehensive test-pumping operation is listed in section 4.2.5. A record of the test-pump report for this borehole was obtained from the files of the Ministry of Water Development and

is reproduced in Appendix 1B, together with the records for other boreholes in the study area.

4.2.4 Results and limitations

The test-pumping results for the two wells tested indicate that the wells have very low yields and extremely low recharge rates. In view of the large diameters of the wells and the low recharge, it is apparent that the storage capacity of the wells masks the contribution of the respective groundwater aquifers. It is also noted that pumping quickly empties the wells and a "pumping water level", as explained earlier, is not achieved. It is therefore not possible to calculate the specific capacity of these wells and only a value of apparent specific capacity, which is of very limited value, can be assigned to each one.

The test-pumping report for borehole No. C3960 at Kargi (Appendix 1B) shows that the borehole is highly productive. The extremely high value of specific capacity of 4.3 m^3/hr implies that a yield far in excess of 10 m^3/hr could be obtained from this borehole. To obtain a value of safe yield, a test-pumping operation should be carried out using a pump with a capacity of 20 m^3/hr at a minimum head of 100 metres.

The records of test-pumping reports for four other boreholes in the study area are also presented in Appendix 1B. It is to be noted that the levels of water in boreholes neighbouring the tested one were not monitored. Values of yields and specific capacities have been assigned to boreholes in isolation and do not reflect the respective aquifer characteristics. The values may therefore be misleading and we suggest that the boreholes be retested while monitoring the water levels in neighbouring boreholes. A value for safe yield can then be assigned to each borehole with respect to other boreholes in the area.

4.2.5 Test-pumping equipment

The following is a list of the equipment required by a hydrogeologist for a comprehensive test-pumping operation to determine the practical capacities of wells and boreholes and the aquifer characteristics in the study area:

1. One submersible electric pump capable of discharging 20 m^3/hr from a depth of 100 m below ground level.

2. One diesel-engine-driven generator of sufficient power rating to drive the pump motor.
3. One 8 m height derrick, preferably mounted on a truck fitted with a motor-driven pulley system for installation and removal of the pump and riser pipes in the borehole.
4. Four electric dippers to measure water levels, one to be inserted in the borehole being tested and the other three in neighbouring boreholes.
5. One 200-litre container for measuring discharge.
6. One stop watch.
7. Twenty pieces of 6 m length 3" G.I. riser pipes.

Test-pumping is normally carried out by a drilling contractor working under the supervision of a hydrogeologist who records all the relevant data. This may be carried out in the study area under a special contract.

5. Electrical resistivity

5.1 General

The electrical resistivity method permits shallow subsurface exploration by means of electrical measurements taken at the surface of the earth. In this method an electrical current is introduced into the ground via a pair of electrodes (referred to as current, or transmitter, or source electrodes). This current flows through the subsurface and sets up different potentials at different points in the subsurface half space. Another pair of electrodes (referred to as potential, receiver, or voltage electrodes) measures the potential difference between any two points on the ground surface.

The potential difference that is measured by the potential electrodes will depend on the conductive properties of the subsurface through which the current has flowed. The conductivity of rocks is dependent on the content of water or moisture and dissolved salts. Thus massive rock formations, dry gravels, sands, etc. show high resistivities because they contain little or no moisture. Gravels, sands and other geological strata containing relatively fresh water have intermediate resistivities, while moist clays and other geological strata containing water and dissolved salts have low resistivities. On this basis rock

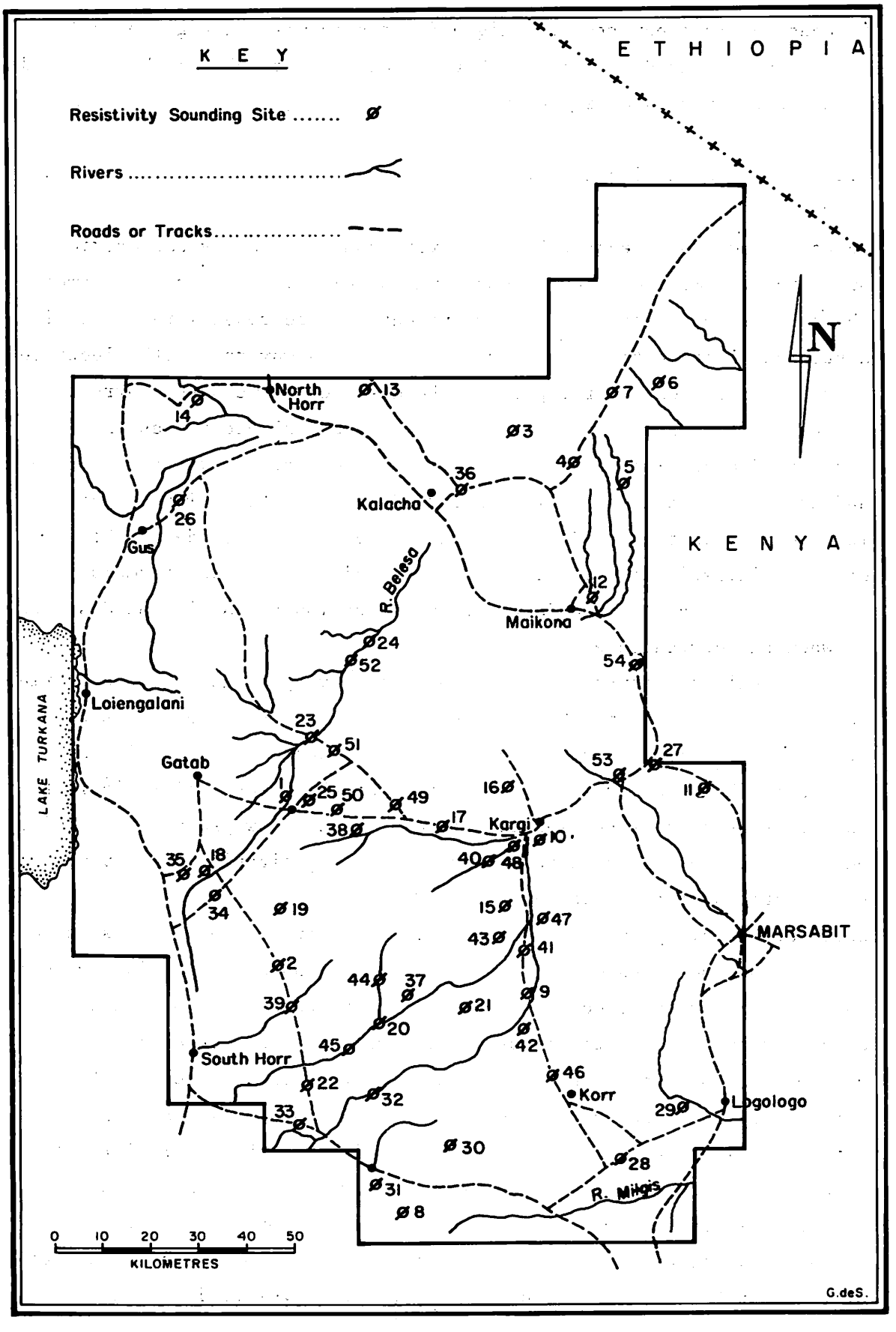
formations containing water and dissolved minerals can be distinguished from dry strata. The resistivity method for subsurface exploration is thus the most powerful technique for distinguishing a geological formation that is dry from one that contains relatively fresh water and from one that contains saline water.

5.2 Field resistivity survey

In this study the electrical resistivity-sounding survey was carried out using the Schlumberger electrode arrangement. In this arrangement the two current electrodes and two potential electrodes were placed in a straight line on the ground surface in such a way that both electrode pairs had a common central point. The distance between the current electrodes (AB) and that between the two potential electrodes (MN) was varied along the same straight line so long as the distance AB $\geq$ 5 MN and the same central point is maintained. The depth of investigation is dependent on the distance between the current electrodes. The depth of investigation is related to this distance by the formula $z = 0.4AB$, where z is the depth of investigation and AB is the distance between the current electrodes.

A total of fifty-four electrical resistivity soundings were carried out at sites preselected by the UNESCO/IPAL consultant for abiotic studies (Dr. Bake). Most of the sites were located in the existing laggas in the study area. The objective of the electrical resistivity soundings at these sites was to determine if shallow groundwater aquifers occur along the laggas at the sites of the investigation. However, some stations were located away from laggas for the purpose of delineating any groundwater aquifers in those areas where laggas do not exist. The locations of the resistivity stations are shown in Figure 5. The maximum current electrode separation (AB) used at each site was dependent on the sensitivity of the instrument (see section 5.2.1 below) and on the expected depth to the groundwater aquifers at each site. Within the laggas perched groundwater aquifers are expected to be within a few metres of the surface. In this case shallow resistivity soundings, with AB $\leq$ 50 m, were used. In areas away from laggas the groundwater aquifers are expected to be much deeper and therefore resistivity soundings were made with the aim of probing the subsurface up to a depth of 150 m providing the practical sensitivity of the instrument was not exceeded.

Figure 5. Location of resistivity sounding stations



5.2.1 Instrumentation: limitations and problems encountered

Two electrical resistivity measuring instruments were used in this survey. The first instrument was a Bison model 2350, which contains both the receiver and transmitter under one box. When the steady state is achieved this instrument gives a digital dial reading which, when multiplied by an appropriate scale multiplier, gives a "correct reading" which is the value of 2π V/I, where V is the potential difference between potential electrodes, and I is the current input via the current electrodes. The value 2π V/I, when multiplied by an appropriate constant dependent on the current electrode separation (AB) and the potential electrode seperation (MN), gives the apparent electrical resistivity.

The Bison instrument was used during the first month of the investigation. Towards the end of this period the power output of the batteries in this instrument fell, thus rendering the instrument incapable of measuring the required resistivities. This instrument uses four Eveready No. 490 and three Maloy TR 234R type batteries none of which were available in this country to replace the exhausted ones. The alternative was to use a different resistivity measuring instrument.

An Abem Terrameter SAS 300 was borrowed from the Ministry of Energy, Kenya Government, at the request of the UNESCO/IPAL Project Co-ordinator, Dr. Lusigi. This instrument was used for the second month of the field work in the Project area.

The Abem Terrameter SAS 300 also has the transmitter and receiver circuits in one container. The instrument can be used for deep-penetration resistivity probing with current electrode separations of up to 2,000 m during fair probing conditions. During each electrical resistivity sounding the instrument gives digital readouts of four values of V/I which are repeatedly displayed on a screen. V is the voltage measured by the potential electrodes and I is the current injected into the current electrodes. Normally the four values of V/I are numerically close to each other and an average value is used in calculating the apparent resistivities. If the four values of V/I vary greatly, then the instrument is set to give sixteen or even sixty-four values of V/I until the last several readings for each set are close to each other.

The main limitation during the execution of the electrical resistivity surveys in the study area was the fact that the ground surface consisted either of very dry sand or very hard volcanics. In the case of the dry sand the contact resistance at the electrode positions was so high that insufficient current was injected into the ground. With the hard volcanics surfaces it was not possible to make the electrodes penetrate the surface as required and this added to the high contact resistances. It was therefore not possible to inject the required current into the ground. The resulting potential difference between the potential electrodes was very small and therefore not accurately measurable by the instruments. Thus inconsistent resistivities were obtained at some of the survey stations and deep probing was not possible.

5.3 Resistivity results

At each electrical resistivity station the values of the apparent resistivity were obtained for increasing values of current-electrode separation (AB). The field data are to be presented to UNESCO/IPAL under separate cover. For each station the apparent resistivity was plotted against the current-electrode separation (AB) on logarithmic (log-log) graph paper with a scale of 62.5 mm per cycle. This scale assists in the interpretation of the electrical resistivity sounding curves using resistivity master curves.

5.4 Interpretation of resistivity results

The electrical resistivity sounding results were interpreted in a quantitative way in an attempt to determine the depth to the water table and, wherever possible, to the bedrock. Interpretation was by use of the curve-matching method which uses master curves (Orellana and Mooney, 1966) to produce simplified models of the subsurface.

Appendix 2 gives a summary of the interpretation of the fifty-four electrical resistivity soundings carried out in the study area during this consultancy. It must be pointed out that while the consultant tried as much as possible to carry out the first twenty-seven electrical resistivity measurements (stations Nos. 1-27) as close as possible to the sites surveyed by Borgeson (Borgeson, 1981), it was not always

possible to do so. Due to the rough terrain in some parts of the study area the consultant and his crew were occasionally unable to reach certain sites for fear of being stranded while having no backup support. In this case sites within several kilometres of Borgeson's sites were surveyed.

The interpretations of the electrical resistivity sounding for each hydrogeological region (Section 4.1) are discussed below. Figure 6 shows the depths to the groundwater table at resistivity sounding sites.

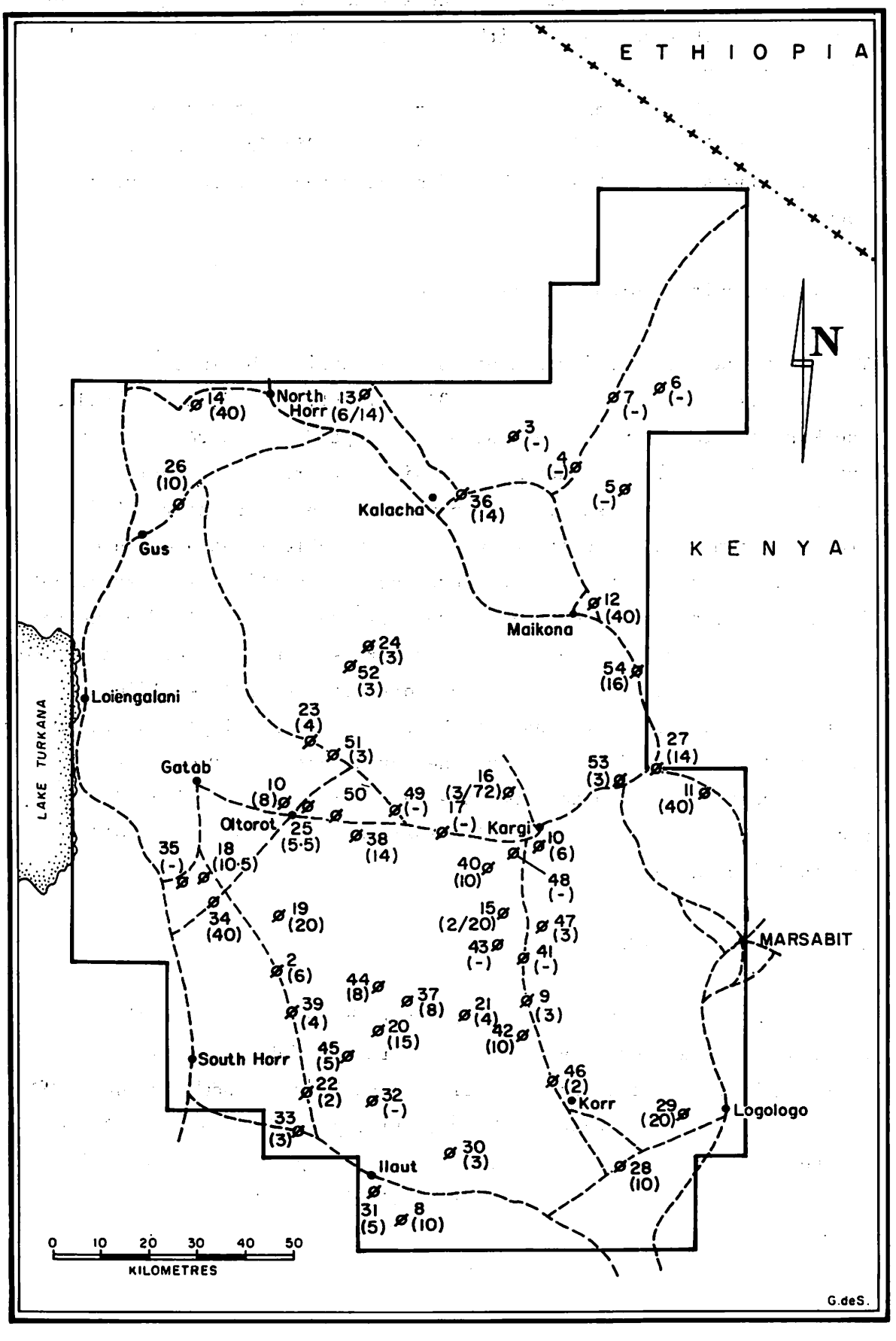
5.4.1 Ngurunit - Korante plains region

The electrical resistivity soundings were carried out in the region at stations numbers 8 at Ngurunit, 31 at Ilaut, and 33, 22, 39 and 2 in the Korante plains. All the stations, except No. 8, were surveyed out across laggas. In general the resistivity results reveal that all the laggas have a shallow groundwater table at depths ranging from 2 to 6 m. At Ngurunit the groundwater table is at a depth of 10 m and the groundwater aquifer here must be contained in a syncline in the Basement System rocks. The resistivity results also delineate the depth to bedrock (Basement). This varies from 10 m below the lagga at Ilaut to 45 m at station 2 in the north of the Korante plains. Whereas the results prove that the Basement is generally to be found at greater depths towards the north, the variations in the depth to the Basement from south to north are in reality too complicated to predict from a few spot resistivity measurements, due to the folding and faulting in the area.

5.4.2 The Hedad region

The region received top priority during the electrical resistivity surveys. Several resistivity surveys were carried out across the existing laggas in the area to delineate shallow groundwater aquifers in these laggas. The rest of the resistivity surveys were carried out in the middle of the Hedad at sites where no laggas exist, for the purpose of determining the regional groundwater table.

Figure 6. Depth to groundwater at each resistivity measurement station IPAL study area Marsabit



In general the resistivity results show that the occurrence of and depth to shallow groundwater aquifers in the laggas flowing towards the middle parts of the Hedad is variable. For example, station No. 22 shows groundwater at a depth of 2 m, station 45 shows groundwater at a depth of 5 m, while station 20 shows groundwater at a depth of 15 m. All the above stations occur along the same lagga and the results imply a rapid increase in the depth to the shallow groundwater table as the lagga proceeds towards the middle of the desert. The resistivity results on some of the laggas, for example the one on which station 32 is located, reveal no groundwater aquifer along the lagga. Further north along the Olturot-Kargi road the resistivity results show that the groundwater is at greater depths. For example, at station 38 and 49 the groundwater is at 28 m and 40 m respectively.

At several stations, for example stations 34, 17, 41 and 43, the resistivity results do not delineate any groundwater table. This implies that no groundwater exists in those parts of the Hedad above the maximum probing depth of 150 m.

At Kargi and to the east of it, stations 10 and 53, the groundwater is shallow, 6 m and 3 m respectively. Station 53 is located at the edge of the Hedad and the lava escarpment to the east. Wells close to the two sites produce plenty of groundwater.

5.4.3 The Mt. Kulal-Balesa Kulal region

Most of the electrical resistivity soundings in this area were carried out along the Balesa Kulal. These include stations 18, 23, 24, 25, 51 and 52. The resistivity results show that the Balesa Kulal contains some shallow groundwater aquifers all along its course. Although the depth to the shallow groundwater table in this lagga fluctuates from point to point along its course there is a general decrease in the depth to the groundwater table downstream. The groundwater table decreases from a depth of 10.5 m at the location of station 18, upstream, to 3.0 m at the locations of stations 52 and 24, downstream. It was not possible to determine the depth to the bedrock at most of the sites surveyed in this area because the limitations in the sensitivity of the instruments prevented deeper soundings.

5.4.4 The Chalbi desert region

No electrical resistivities soundings were carried out inside the Chalbi desert. Stations 36 at Kalacha, 13 along the Bulal lagga, and 14 at an airstrip 10 km west of North Horr were located near the margins of the desert. Station 36, next to the UNESCO well at Kalacha, delineated a shallow groundwater aquifer at a depth of 14 km and bedrock at 80 m. The UNESCO well at Kalacha had a water-rest level at a depth of 8.1 m during this survey. Thus at Kalacha there appears to be a confined shallow groundwater aquifer which feeds this well. Along Bulal lagga the resistivity results delineated a shallow groundwater aquifer along the lagga at a depth of 6.0 m. At station 14 west of North Horr a groundwater aquifer was delineated at 40 m but no bedrock was delineated. The aquifer is perhaps a regional groundwater aquifer which underlies the surface volcanics in the area.

5.4.5 Hurri Hills region

Electrical resistivity soundings were carried out at stations 3, 4, 5, 6 and 7 in the Hurri Hills and at station 12 in the lower Hurri Hills plateau to the east of Maikona. None of the resistivity soundings in the Hurri Hills delineate any shallow groundwater aquifers. The bedrock is at a depth greater than 150 m, the maximum depth of probing obtainable by the resistivity method used in this study. At Maikona a groundwater aquifer is delineated at a depth of 40 m. This is consistent with the borehole data results (see section 4.1.5).

5.4.6 Marsabit mountain region

This area received low priority in terms of electrical resistivity measurements during this study in accordance with the contract terms of reference (see Section 1.2). Three resistivity surveys were carried out to the north of the Marsabit mountain region. These are stations 11, 27 and 54. The stations reveal decreasing depth to the groundwater table and bedrock from the high-altitude area (station 11) towards the lower areas (stations 27 and 54).

5.4.7 The Kaisut plateau and Kaisut desert region

Electrical resistivity measurements were carried out in the Kaisut desert area and around Korr. These include stations 29, 28, 30 in the Kaisut desert and stations 42 and 46 at Korr. At stations 42 and 46 resistivity results reveal groundwater aquifers in laggas at shallow depths of 2-3 m and bedrock at depths less than 20 m. Shallow wells adjacent to these sites are used for groundwater abstraction. The bedrock is exposed in this area. At stations 28, 29 and 30 the groundwater aquifers are at greater depths — 10 m, 20 m and 10.5 m respectively. The bedrock was not delineated at these sites in this survey.

6. Water quality

Under the contract terms of reference, the consultant was to collect water samples from the study area for water-quality analysis. However, he was not to carry out the analysis of the samples collected nor to discuss the chemical data obtained from the analysis.

A total of thirteen water samples were collected from wells and boreholes in various parts of the study area. Figure 7 shows the location of sites from which the water samples were collected. The samples were collected in one-litre plastic bottles which were then capped and thereafter submitted to UNESCO/IPAL for analysis.

7. Development and utilization of groundwater

Groundwater in the study area is at present available from wells, boreholes and springs, but is potentially also available from subsurface dams, pans, rock catchments and other forms of storage. Groundwater development in the study area should aim at improving the present water supplies as well as developing new ones at suitable sites. The development of new groundwater supplies at given sites depends on the presence of a suitable aquifer, the water demand, and of course on the quality of the water. The utilization of groundwater in the study area is by human and livestock populations whose distribution or planned redistribution in accordance with range management plans is an important consideration in siting new groundwater supplies. In this investigation

Figure 7. Water sampling locations IPAL study area Marsabit

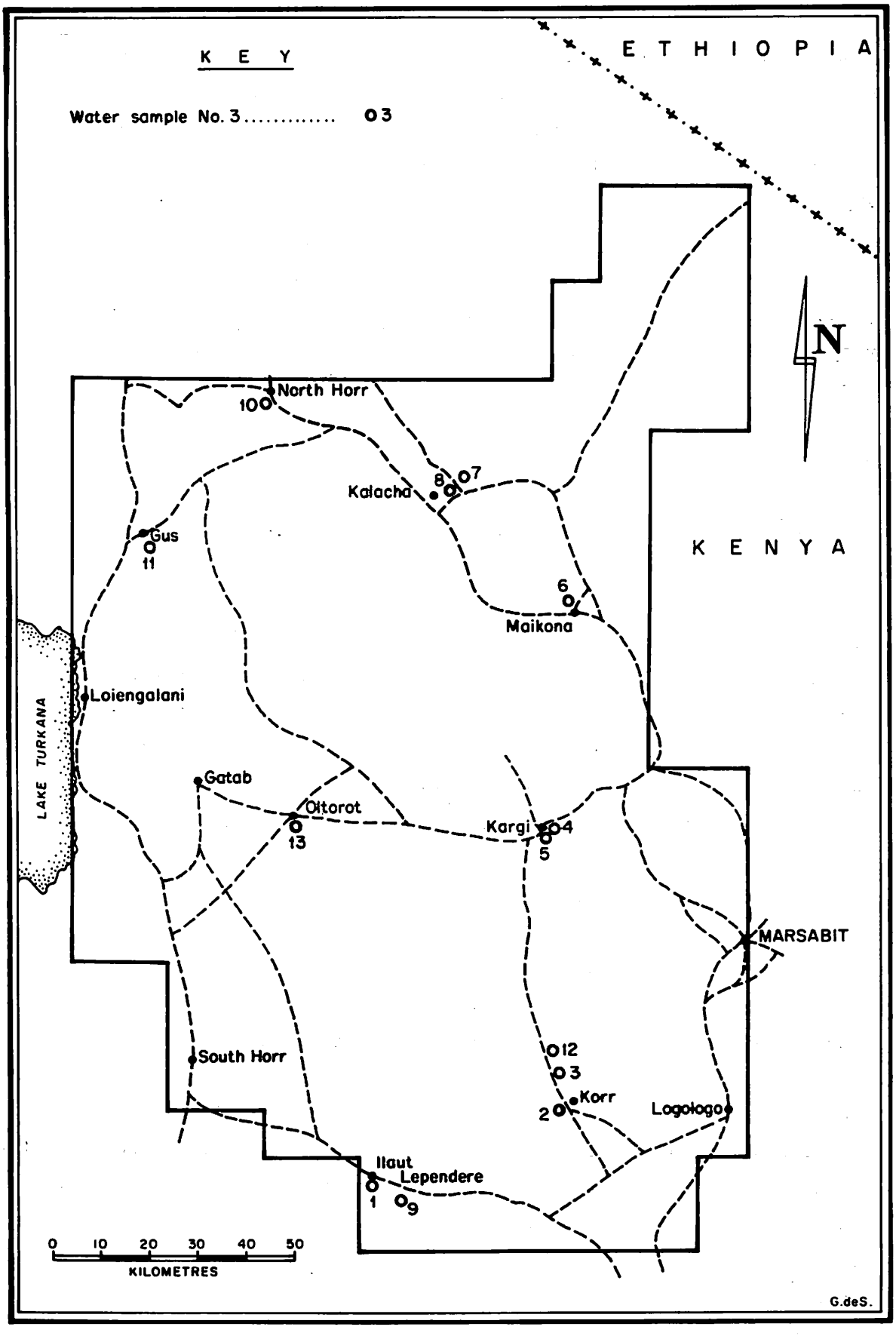
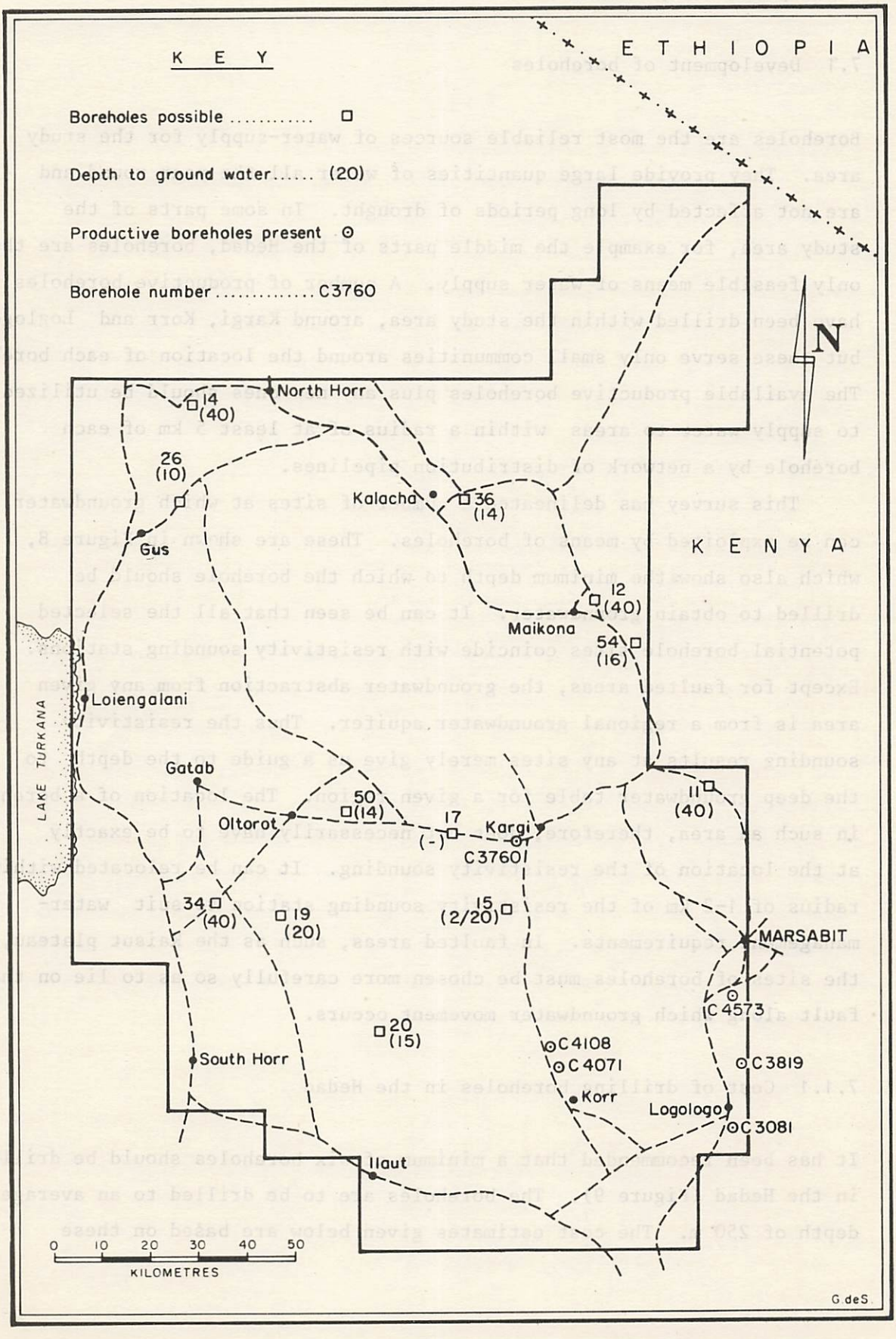


Figure 8 Possible borehole sites
IPAL study area, Marsabit



more emphasis has been laid on improving groundwater availability in the grazing areas of the Rendille, that is, the central and southern parts of the study area. The following recommendations on groundwater development are presented.

7.1 Development of boreholes

Boreholes are the most reliable sources of water-supply for the study area. They provide large quantities of water all the year round and are not affected by long periods of drought. In some parts of the study area, for example the middle parts of the Hedad, boreholes are the only feasible means of water supply. A number of productive boreholes have been drilled within the study area, around Kargi, Korr and Loglogo, but these serve only small communities around the location of each borehole. The available productive boreholes plus any new ones should be utilized to supply water to areas within a radius of at least 5 km of each borehole by a network of distribution pipelines.

This survey has delineated a number of sites at which groundwater can be exploited by means of boreholes. These are shown in Figure 8, which also shows the minimum depth to which the borehole should be drilled to obtain groundwater. It can be seen that all the selected potential borehole sites coincide with resistivity sounding stations. Except for faulted areas, the groundwater abstraction from any given area is from a regional groundwater aquifer. Thus the resistivity sounding results at any sites merely give us a guide to the depth to the deep groundwater table for a given region. The location of a borehole in such an area, therefore, does not necessarily have to be exactly at the location of the resistivity sounding. It can be relocated within a radius of 1-2 km of the resistivity sounding station to suit water-management requirements. In faulted areas, such as the Kaisut plateau, the sites of boreholes must be chosen more carefully so as to lie on the fault along which groundwater movement occurs.

7.1.1 Cost of drilling boreholes in the Hedad

It has been recommended that a minimum of six boreholes should be drilled in the Hedad (Figure 9). The boreholes are to be drilled to an average depth of 250 m. The cost estimates given below are based on these

recommendations. The cost of some of the work is shared out between the boreholes and the cost per borehole will therefore vary with the number to be drilled.

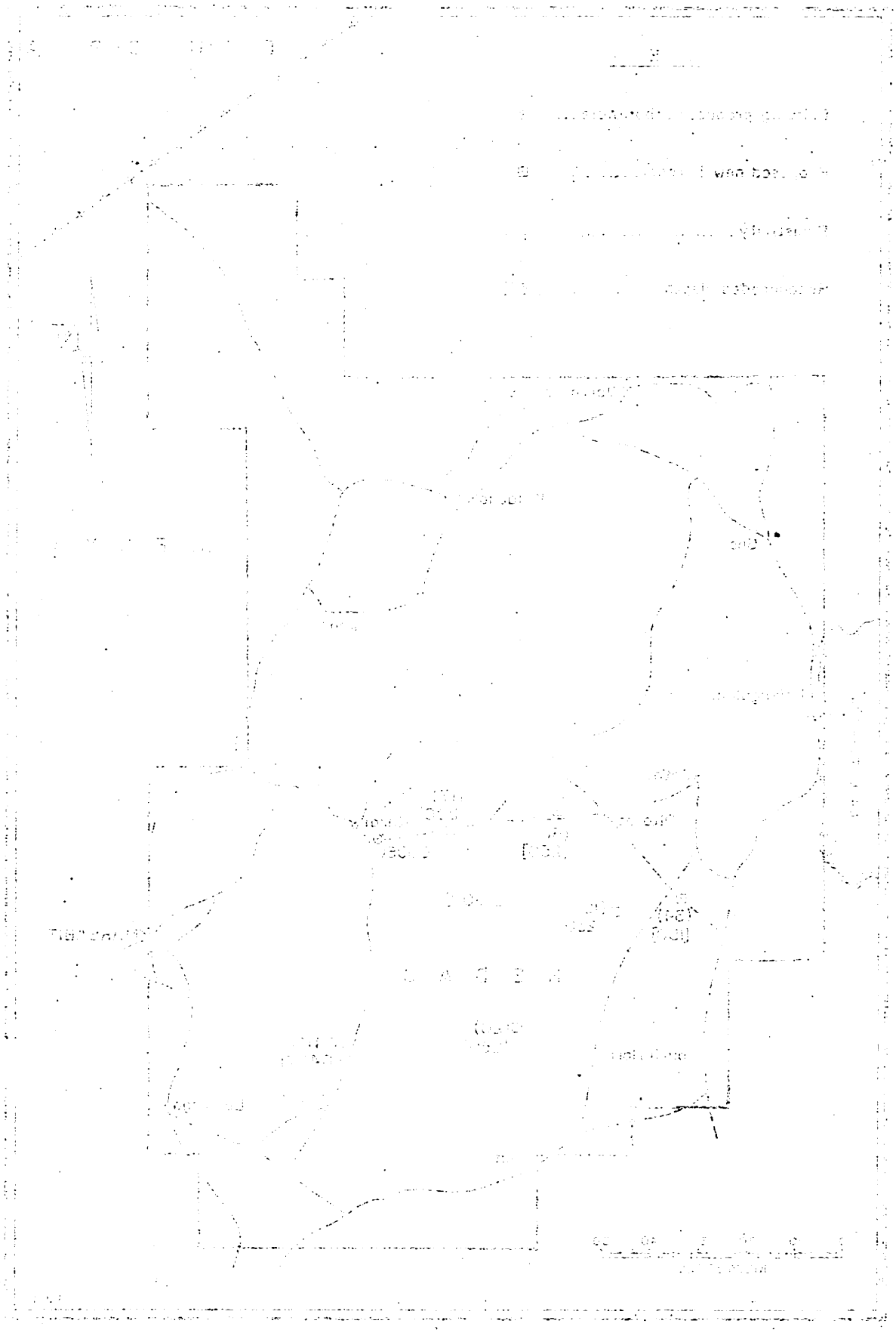
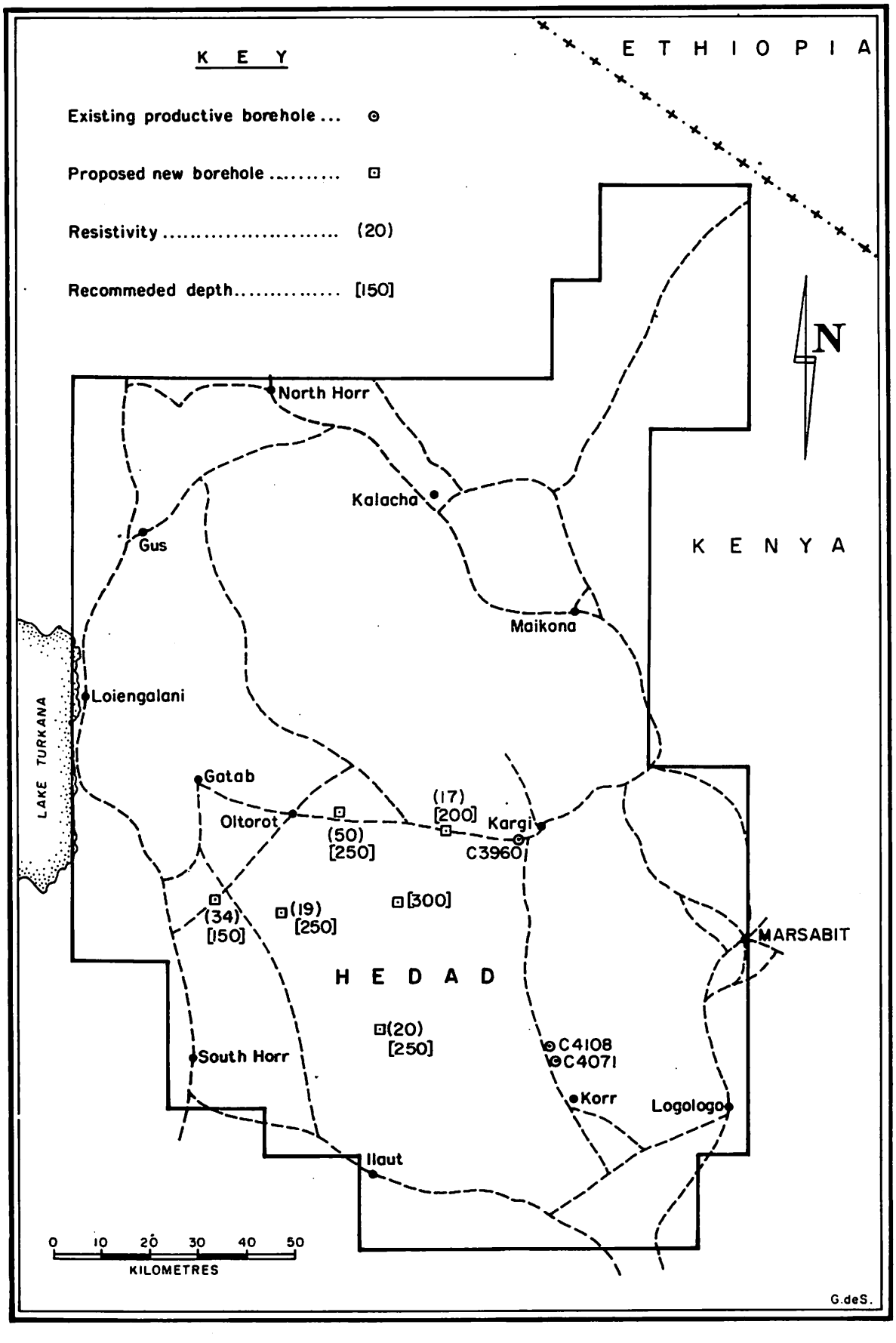


Figure 9. Proposed borehole sites in the Hedad IPAL study area, Marsabit

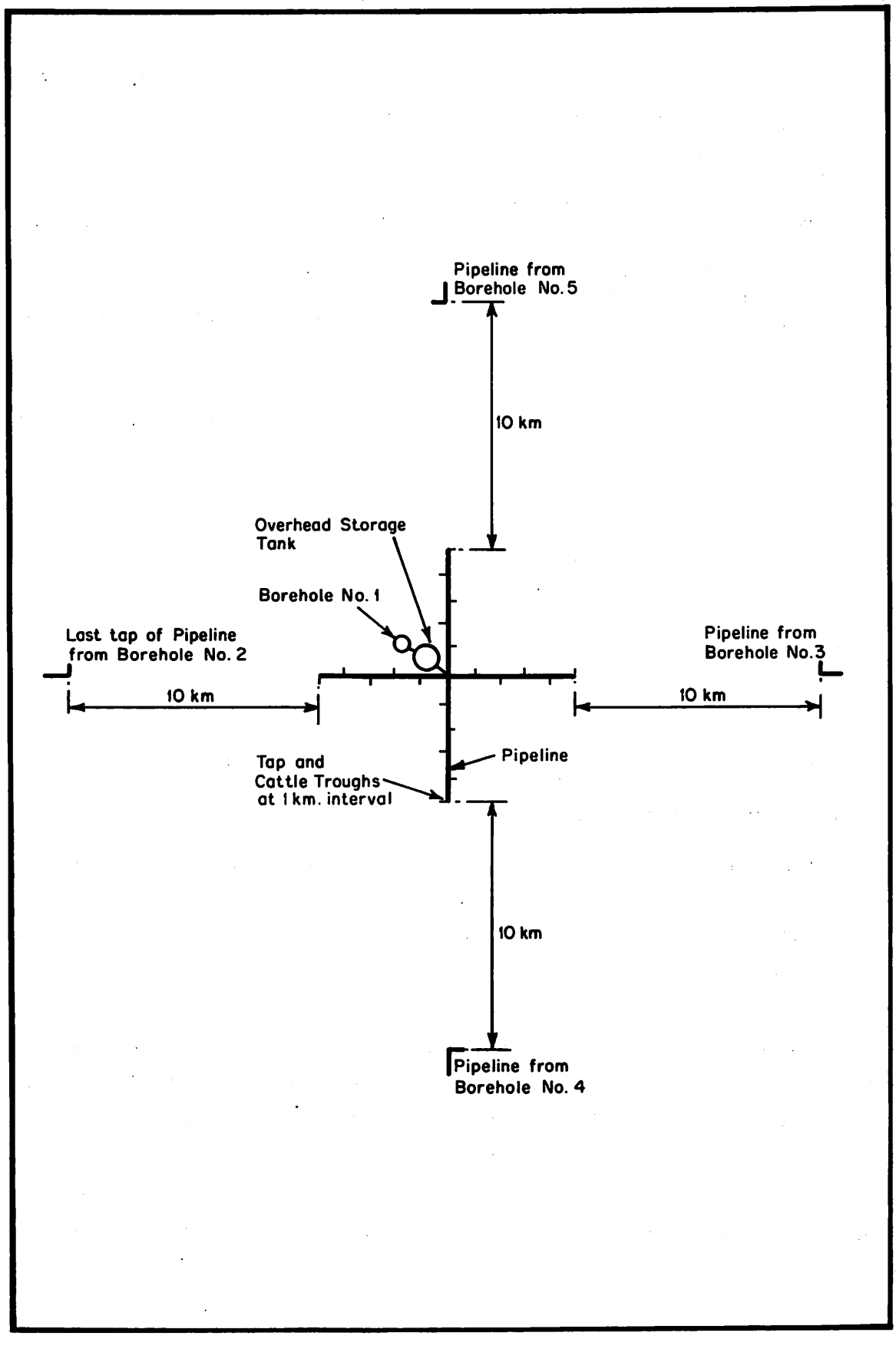


Cost estimates for drilling 6 boreholes in the Hedad

Item	Description of work	Qty.	Unit	Rate	Amount
1.	Mobilization and demobilization of drilling rig, equipment and personnel to and from site (drilling contractor based in Nairobi)	1,000	km	75	75,000.00
2.	Setting up and dismantling the rig at each boring position	6	No.	10,000	60,000.00
3.	Drilling 203 mm borehole to a depth of 250 m for each borehole	1,500	M	9,000	1,350,000.00
4.	Casing entire length of each borehole with plain and slotted, 152 mm diameter steel pipes (cost of transportation from Nairobi included)	1,500	M	9,000	1,350,000.00
5.	Test-pumping, including inserting and withdrawing of test pump	6	No.	15,000	90,000.00
6.	Developing, reaming, surging, grouting, etc.	6	No.	20,000	120,000.00
7.	Supply and installation of submersible pumps complete with engine and generator	6	No.	200,000	1,200,000.00
	Total estimated cost				4,245,000.00

Figure 10 shows a sketch of a suitable reticulation system around each of the proposed boreholes in the Hedad. The details of such a reticulation system will of course vary according to the land surface across which the water-carrying pipes will pass, the water-management requirements, etc. It is assumed that the flow of water from the storage tank to the user points is by gravity. The approximate cost of storage facilities and piping required for each reticulation system is given below.

Figure 10 Reticulation around each borehole in the Hedad IPAL study area, Marsabit



		Amount (KShs.)
Piping: 20 km of 1" pipes @ KShs. 24/m around each borehole		624,000.00
Fittings		2,080.00
Storage facilities:	Cost of installation of an overhead storage tank of 13.5 m^3 capacity	40,000.00
Total		666,080.00

The total cost for the six new proposed boreholes is thus KShs. 3,996,480/=.

The hydrogeological data (Appendix 1A and 1B) shows that the borehole at Kargi (No. C3960) can yield much more water than is at present being obtained from it. In order to optimize the yield of this borehole it is recommended that a bigger pump be installed. It is also recommended that the water from this borehole and those at Korr (Nos. C4108 and C4081) should be reticulated to the surrounding areas as proposed for the new boreholes above.

7.2 Development of wells

A considerable amount of groundwater exists at shallow depths, mostly along the laggas, in the study area. It was noted during this survey that this shallow groundwater is currently being exploited by means of shallow hand-dug wells at various locations. The extent of exploitation of this water is in most cases limited by the depth to which the inhabitants can safely dig into the sand without risking the collapse of the wells. However, in a number of cases the limiting factor is the hardness of the rock through which the inhabitants have to dig.

Electrical resistivity soundings at various sites across laggas have shown that shallow groundwater aquifers usually exist along the laggas. Abstraction by means of shallow wells sunk at appropriate sites in these laggas is an important component of groundwater development in the area. On the basis of resistivity sounding results a number of potential well sites have been selected (Figure 11). In contrast to

borehole sites, the potential well sites are localized and should be sited at the exact location chosen. This is because the shallow groundwater table along the laggas fluctuates widely over very short distances.

7.2.1 Cost of drilling wells in the Hedad

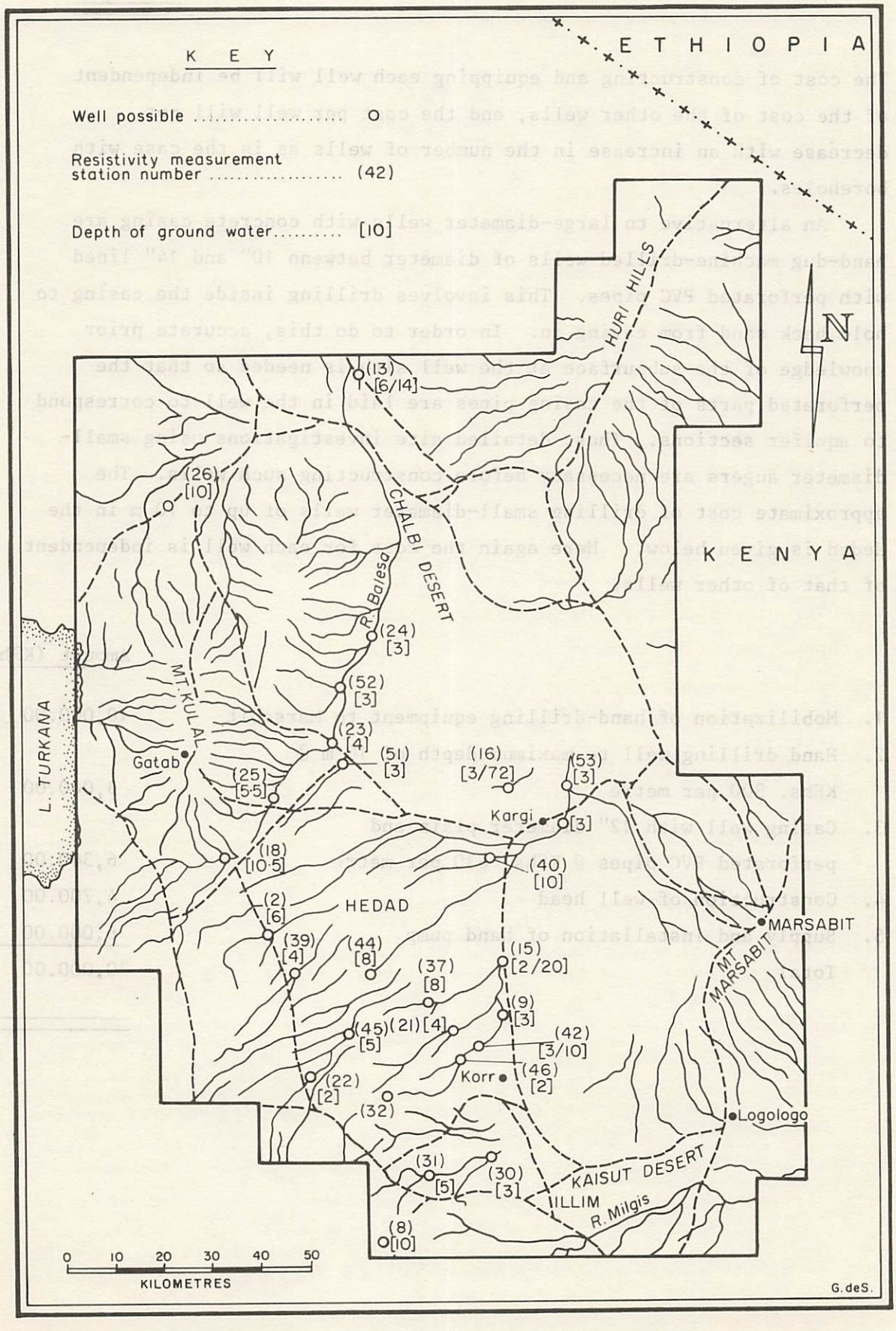
Figure 11 shows the proposed locations of wells in the Hedad. The sites are chosen on the basis of resistivity results and to provide as many parts of the Hedad as possible with some water supply. However, before beginning to develop all the proposed sites detailed surveys should be carried out at some of the selected sites to ascertain the productivity of the proposed wells. This should include a site investigation using small-diameter augers and the test pumping of each augered hole so that low-yield sites may be discarded. This survey should aim at selecting those sites with the thickest aquifer, highest yield, and appropriate impermeable underlying strata. Depending upon the results of such a survey, it is possible that many more wells could be sited in the Hedad. For example, the Balesa Kulal may have a shallow aquifer which could be exploited all along its course.

It is necessary to use a simple and cheap design for drilling and equipping the wells so that many of them can be developed. In particular, the material used to line the wells should be selected with care.

Large-diameter hand-dug wells are the cheapest to construct, if the lining is excluded. However, such wells are short lived, for floods easily destroy them by filling them with sand during the rainy seasons. Large-diameter wells must therefore be lined with concrete rings. These are relatively heavy structures and expensive to transport. The cost of a hand-dug well lined with concrete rings depends on the depth of the well. An approximate cost for drilling one well to a depth of 10 m in the Hedad is given below:

		Amount (KShs.)
Materials:	10 concrete culverts plus top and bottom slab of volume approximately 5.0 m^3 @ KShs. 2,500/m^3	12,500.00
	Hand pump and rods	6,000.00
Transport:	Transporting concrete culverts from Nairobi to the Hedad @ KShs. 10 per km @ 1,000 km each trip (3 trips)	30,000.00

Figure 11. Location of possible wells
IPAL study area, Marsabit



Manpower:	Well construction @ approximately KShs. 800 per metre for labour and supervision	8,000.00
Total		56,500.00

The cost of constructing and equipping each well will be independent of the cost of the other wells, and the cost per well will not decrease with an increase in the number of wells as is the case with boreholes.

An alternative to large-diameter wells with concrete casing are hand-dug machine-drilled wells of diameter betwenn 10" and 14" lined with perforated PVC pipes. This involves drilling inside the casing to hold back sand from caving in. In order to do this, accurate prior knowledge of the subsurface at the well site is needed so that the perforated parts of the casing pipes are laid in the well to correspond to aquifer sections. Thus, detailed site investigations using small-diameter augers are necessary before constructing such wells. The approximate cost of drilling small-diameter wells of up to 10 m in the Hedad is given below. Here again the cost for each well is independent of that of other wells.

		Amount (KShs.)
1.	Mobilization of hand-drilling equipment to Marsabit	10,000.00
2.	Hand drilling well to maximum depth of 10 m @ KShs. 300 per metre	3,000.00
3.	Casing well with 12" diameter plain and perforated PVC pipes @ KShs. 630 per metre	6,300.00
4.	Construction of well head	4,700.00
5.	Supply and installation of hand pump	6,000.00
	Total	30,000.00

7.3 Other sources of groundwater

7.3.1 Springs

Springs occur where a groundwater aquifer outcrops at the surface directly or indirectly. Direct occurrence may be observed where a valley has cut down into the aquifer, while indirect occurrence is through joints, fissures or faults. The springs found in the study area are of the second type. Several springs found in the study area are of the second type. Several springs occur in the Ndoto mountains near Ngurunit. The water issues from joints, fissures and faults in the Basement rocks. The second series of springs is found in the Mt. Kulal area along faults in the volcanic lavas. This consultancy did not require an investigation of springs in the area but the following suggestions are made.

The development of springs is dependent on the quantity of water from each spring or from a group of adjacent springs. Water from a number of springs in the Mt. Kulal area could be tapped into one or more storage tanks constructed near the springs. Thereafter the water could be reticulated to the low-lying areas on the eastern slopes of Mt. Kulal, which include the Olturot region, by gravity flow. Determining the feasibility of such a project will require an investigation to determine an accurate value for the quantity of water available from the springs. The survey should also determine the length of pipeline required. The cost of water storage and reticulation can be deduced from values given in section 7.2.1.

The water from the springs in the Ndoto mountains is now being utilized at Ngurunit. Investigations should be carried out in this area to determine the maximum potential yield of the springs and whether they can be used to supply wider areas near Ngurunit than is at present being done.

7.3.2 Subsurface dams

A subsurface dam is an impervious barrier across a water channel which is founded on an impermeable subsurface such as a massive rock or a layer of clay. Upstream the banks of the channel should also be impermeable, to prevent lateral percolation of water away from the channel. At the dam site the banks of the channel should have solid rock shoulders on which the dam may be founded to prevent it from being washed away during

floods. After the construction of the barrier wall, river sediments are deposited behind it and eventually rise to the level of the retaining wall. Water is held in these sediments and can be obtained by scooping to shallow depths into the sediments. The sediments also reduce the loss of water by evaporation. This investigation did not require an investigation for suitable subsurface dam sites, but the following suggestions, which would require further investigation, are presented.

Suitable sites for subsurface dams in the study area are limited, since most of the laggas have shallow banks consisting of permeable sands, silts, and soils which run across sedimentary floodplains. These make the laggas unsuitable for subsurface dam siting. Subsurface dams are only really suitable on the eastern slopes of the Oldoinyo Mara mountains in the western part of the Korante plains, in the Ilaut-Ngurunit area, and around Korr. In these areas laggas cut through Basement System rocks and therefore have impermeable banks and foundations. Barrier walls located at suitable locations across the relevant laggas could provide the required subsurface dams. A detailed investigation along the laggas in these areas would provide information on the best sites on these laggas.

7.3.3 Rock catchment

The region between Korr and Ngurunit, and particularly the Ndoto mountain region, have large expanses of Basement rocks exposed on the surface. These rocks are inclined to the ground surface at places such as Lependera, as a result of folding and other tectonic movements. These huge slabs of Basement rock can be used to trap surface-water runoff if suitable structures are built. Only one site for rock catchment was investigated during the survey, at Lependera. It was noted that the Basement rock face is composed of massive undifferentiated gneiss, which is only broken in a few places. It is proposed that the broken parts of the rock face be sealed with cement grout to prevent leakage. It is further recommended that a small concrete wall about 50 cm high be built at the edges of the rock face to guide water to a storage tank at ground level. The water should then be pumped by a small pump into an overhead tank from which it can be distributed to the southern parts of the Hedad.

The following cost estimates are based on a rock catchment of area 100 x 50 m, which with a mean annual rainfall of 300 mm is capable of collecting 1,500 m³ of water each year.

		Amount (KShs.)
1.	Construction of 15-50 cm concrete wall, including grouting of broken portions of the rock face. Concrete blocks manufactured at site	50,000.00
2.	Construction of 34.5 m³ storage tank to be placed at ground level to collect water from the rockface (Tank 1)	50,000.00
3.	Overhead G.I. storage tank to enable gravity flow for distribution (Tank 2)	9,000.00
4.	Cost of a small pump to raise water from tank 1 to tank 2	30,000.00
	Total	139,000.00

(NB. Reticulation costs are as given in section 7.2.1.)

8. Conclusions

From the foregoing feasibility studies it has been possible to establish the groundwater potential in the different parts of the study area. Two types of groundwater aquifers have been delineated from electrical resistivity soundings and hydrogeological investigations.

Shallow groundwater exists within the various laggas in the study area. This groundwater is contained in perched aquifers and can be obtained by means of shallow wells constructed at various sites identified in this survey. The cost of developing each well has been given.

A deep regional groundwater aquifer has been established in the study area. The depth to this aquifer in various parts of the study area has been established and several potential borehole sites have been identified. Six new borehole sites are recommended for groundwater development in the Hedad. The costs for this development are presented. Groundwater in the Hedad can also be obtained by distribution of water obtainable from the productive boreholes at Kargi and Korr. The costs for the distribution networks are also given.

Additional appropriate sources of groundwater are springs, subsurface dams and rock catchments. Feasibility surveys are needed to assess the practicality and cost of using these methods in the study area. One suitable rock catchment site has been identified in the Lependera area and cost estimates for developing the site are presented.

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Appendix 1A

Schedule of boreholes - IPAL study area, Marsabit

B/H No.	Location	Total depth (m)	Water struck level (m)	Water rest level (m)	Dynamic water level (m)	Tested yield (m^3/hr)	Specific capacity (m^3/hr/m)	Quality
C1758	Loglogo	85.4	69.8	62.8	84.8	6.63	0.30	
C3056	Halisurwa	100.6		66.5	97.6	2.3	0.07	
C3511	Laisamis	118.6	Dry					
C3429	Laisamis		Dry					
C3554	Loglogo	140	89.9	114.9		negligible		
C3680	Loglogo	Borehole abandoned due to floods						
C3681	Loglogo	122.9		90.9		12.6		V. good
C3682	Loglogo		Dry					
C3819	Gudas	125.6	106.4		86	8.1		Good
C3960	Kargi No. 2	95.7	18, 72	13.5	16.0	10.9	4.36	Salty
C3962	Kargi No. 1	32.0	Abandoned					
C4071	Korr	27.0	11, 14	9.7, 9.5	24.7	3.6	0.24	
C4073	Korr	96.9	38, 78	29, 27	91	0.5	0.008	Salty
C4080	Hedad	200	Dry					
C4085	Korr	33.5	Dry					
C4105	Korr	80,7	Dry					
C4107	Korr	58	25, 45	6.0	54.0	0.6	0.01	
C4108	Korr	45	30	11.5	42	3.8	0.12	
C4112	Korr	120	61	43	112	0.6	0.009	V. salty
C4113	Korr	70	22	14	54	0.3	0.007	V. salty
C4115	Kaisut	96	Dry					
C4573	Marsabit	130	76	72.5	73.44	8.1	8.62	Good
SA36	Marsabit	108.8	Dry					
SA39	Marsabit	71	Dry					
SA40	Marsabit	86.6	Dry					
SA60	Marsabit	74.4	Dry					
SA84	Kalacha	25.6	Dry					
SA85	Hurri Hills	103.6	Dry					
SA112	Maikona	49.4	42.7	41.1		0.22		
SA113	Hurri Hills	61.0	Dry					

Appendix 1B

Test pumping data

1. Borehole No. C1758 (Loglogo)

Pumping			Recovery rate	
Time (minutes)	Depth to water (m)	Discharge (m/hr)	Time (minutes)	Depth to water (m)
1	62.8	7.3	1	81.7
2	64.2	"	2	79.6
3	65.4	"	3	77.7
4	66.5	"	4	76.2
5	67.4	"	5	74.7
6	68.3	"	6	73.5
7	69.2	"	7	72.3
8	70.1	"	8	71.0
9	70.9	"	9	70.1
10	71.6	"	10	69.2
12	73.2	"	12	67.7
14	74.7	"	14	66.2
16	76.6	"	16	64.9
18	77.7	"	18	63.7
20	79.0	"	20	62.8
25	81.7	"	22	62.0
30	83.2	7.2	25	61.7
35	83.4	"	28	61.6
40	83.5	7.1	30	61.6
45	83.7	"	35	61.6
50	83.7	7.0	40	61.4
60 (1 hr)	84.0	6.9	45	61.4
70	84.1	"	50	61.4
80	84.3	"	60	61.3
90	84.3	6.8	70	61.3
100	84.6	"	80	61.3
120 (2 hrs)	84.8	6.6	90	61.3
150	84.8	"		
180 (3 hrs)	84.8			
Pump stopped				

Summary of test-pumping record

Total depth of borehole:	85.4 m
Maximum capacity of pump:	10 m^3/hr
Water-rest level (WRL):	62.8 m
Pumping water level (PWL):	84.8 m
Drawdown (= PWL - WRL):	22.0 m
Sustained yield:	6.6 m^3/hr
Specific capacity:	0.3 m^3/hr/m

(Appendix 1B contd.)

2. Borehole No. C3960 - Kargi No. 2

Depth to water level (m)	Time (minutes)	Discharge (m^3/hr)
13.50	5	10.9
14.00	10	10.9
14.65	15	10.9=
15.00	20	10.9
15.75	25	10.9
16.00	30	10.9
16.00	35	10.9
16.00	40	10.9
16.00	45	10.9
16.00	50	10.9
16.00	60 (1 hr)	10.9
16.00	120 (2 hrs)	10.9
16.00	180 (3 hrs)	10.9
16.00	240 (4 hrs)	10.9
16.00	300 (5 hrs)	10.9
16.00	360 (6 hrs)	10.9
Constant yield continued for the next 30 hrs		

Summary of test-pumping data

Total depth of borehole:	95.7 m
Water-rest level (WRL):	13.50 m
Pumping water level (PWL):	16.00 m
Drawdown (= PWL - WRL):	2.50 m
Discharge:	10.9 m^3/hr
Maximum capacity of pump:	10.9 m^3/hr
Specific capacity:	4.36 m^3/hr/m (or m^3/hr)

(Appendix 1B contd.)

3. Borehole No. C4071 (at Kargi)

Pumping			Recovery rate	
Time since pump started (minutes)	Depth to water level (m)	Discharge (m^3/hr)	Time since pump stopped (minutes)	Depth to water level (m)
5	10.85	9.60	5	18.80
10	12.15	8.28	10	16.25
15	13.10	"	15	16.02
20	15.95	"	20	15.88
25	15.95	"	25	15.15
30	16.20	"	30	13.70
45	16.65	8.00	35	12.9
50	18.65	"	40	12.25
60 (1 hr)	19.65	"	45	12.00
70	22.60	"	50	11.97
90	24.70	"	55	11.94
120 (2 hrs)	"	7.00	60	11.90
180 (3 hrs)	"	5.50	120	10.70
210	"	5.18	180	10.00
240 (4 hrs)	"	"		
300 (5 hrs)	"	4.80		
360 (6 hrs)	"	4.30		
420 (7 hrs)	"	4.24		
480 (8 hrs)	"	3.90		
720 (12 hrs)	"	"		
840 (14 hrs)	"	"		
960 (16 hrs)	"	3.80		
1080 (18 hrs	"	"		
1200 (20 hrs)	"	3.60		
1320 (22 hrs)	"	"		
1440 (24 hrs)	"	"		

Summary of data

Borehole total depth:	27 m
Date of test-pump:	23.9.74
Pump intake:	24.7 m
Pump output (maximum):	9.6 m^3/hr
SWL:	9.45 m
PWL:	24.7 m
Sustained yield:	3.6 m^3/hr
Specific capacity:	0.2 m^3/hr/m

(Appendix 1B contd.)

Borehole No. C4073 - Korr

Pumping			Recovery rate	
Time since pump started (minutes)	Depth to water level (m)	Discharge (m^3/hr)	Time since pump stopped (minutes)	Depth to water level (m)
1	26.0	3.0	2	91.0
5	51.0	3.0	5	89.0
10	75.5	3.0	10	86.0
15	91.0	1.0	15	85.0
20	91.0	1.0	25	81.5
25	91.0	0.9	30	79.0
35	91.0	0.9	40	78.0
45	91.0	0.8	45	76.0
60 (1 hr)	91.0	0.8	50	74.0
120 (2 hrs)	91.0	0.7	55	72.0
180 (3 hrs)	91.0	0.6	60	71.0
240 (4 hrs)	91.0	0.6	70	69.5
300 (5 hrs)	91.0	0.6	After 6 hrs, water level was 27 m.	

Summary of test-pumping record

Total depth of borehole:	96.9 m
Pump intake during test:	91.0 m
Maximum pump capacity:	3.0 m^3/hr
Water-rest level:	27 m
Pumping water level:	91.0 m
Drawdown:	64.0 m
Sustained yield:	0.6 m^3/hr
Specific capacity:	0.009 m^3/hr/m

(Appendix 1B contd.)

5. Borehole No. C4107 - Korr

Pumping			Recovery rate	
Time since pump started (minutes)	Depth of water level (m)	Discharge (m^3/hr)	Time since pump stopped (minutes)	Depth to water level (m)
0	5.8	9.00	1	53.5
1	18.8	"	2	52.5
2	27.8	"	3	51.5
3	33.3	"	4	50.5
4	34.3	"	5	49.5
5	36.8	"	6	48.5
6	37.8	"	7	47.0
7	37.8	"	8	46.25
8	37.8	"	9	45.75
9	37.8	"	10	45.5
10	45.5	6.00	12	43.8
11	54.0	1.80	14	42.3
12	54.0	1.80	16	40.9
13	54.0	1.80	18	39.4
14	54.0	1.70	20	39.0
15	54.0	1.65	25	38.80
16	54.0	1.65	30	38.43
17	54.0	1.60	35	38.25
18	54.0	1.60	40	37.90
19	54.0	1.60	45	37.40
20	54.0	1.50	50	36.50
25	"	1.40	55	35.20
30	54.00	1.30	60 (1 hr)	34.00
35	"	1.30	90	30.5
40	"	1.10	120 (2 hrs)	26.0
45	"	1.00	150	22.4
50	"	1.00	180 (3 hrs)	19.8
55	"	1.00	210	16.9
60 (1 hr)	"	0.96	240 (4 hrs)	14.0
120 (2 hrs)	"	0.96	300 (5 hrs)	10.7
180 (3 hrs)	"	0.60	360 (6 hrs)	8.5
			420 (7 hrs)	6.8
			480 (8 hrs)	6.0

Summary of test-pumping record

Total depth of borehole:	58 m
Pump intake during test:	54 m
Maximum capacity of pump:	9.0 m^3/hr
Water-rest level:	5.8 m
Pumping water level:	54.0 m
Drawdown:	48 m
Sustained yield:	0.6
Specific capacity:	0.01

(Appendic 1B contd.)

6. Borehole No C4112 - Korr

Pumping			Recovery rate	
Time since pump started (minutes)	Depth of water level (m)	Discharge (m^3/hr)	Time since pump stopped (minutes)	Depth to water level (m)
1	52	4.0	0	112
2	54	4.0	60 min	110
3	56	3.0	24 hrs	56 m
4	67	2.0	Very low recovery rate	
5	69	1.5		
6	72	1.5		
7	82	1.5		
8	95	1.5		
9	102	1.0		
10	112	0.8		
20	112	0.7		
40	112	0.65		
45	112	0.65		
60	112	0.60		

Summary of test-pumping record

Total depth of borehole: 120 m
Pump intake during test: 112 m
Maximum capacity of pump used: 4.0 m^3/hr
Water-rest level: 43.0 m
Pumping water level: 112.0 m
Drawdown: 69.0 m
Sustained yield: 0.6 m^3/hr
Specific capacity: 0.009 m^3/hr/m

(Appendix 1B contd.)

7. North Horr well

Time since pump started (minutes)	Depth to water (level (m)	Discharge (m^3/hr)
1	0.43	1.60
2	0.53	"
3	0.68	"
4	0.78	"
5	0.93	"
6	1.03	"
7	1.18	"
8	1.33	"
9	1.43	"
10	1.54	"
12	1.78	"
14	2.03	"
16	2.14	"
18	2.14	"
20	2.37	"
22	2.88	"
24	3.08	"
26	3.24	"
28	3.41	"
30	3.57	"
32	3.77	"
34	3.98	"
Pump stopped		

Summary of test-pumping data

Total depth of well:	3.98 m
Water rest level:	0.33 m
Pumping water level:	3.98 m (water is exhausted)
Drawdown:	3.65 m
Discharge:	1.60 m^3/hr
Apparent specific capacity:	0.44 m^3/hr/m

(Appendix 1B contd.)

8. Olturot - UNESCO well

Time since pumping started (minutes)	Depth to water level (m)	Discharge (m^3/hr)
0	8.35	0.8
12	8.49	"
15	8.52	"
20	8.55	"
25	8.59	"
30	8.61	"
35	8.64	"

Summary of test-pumping data

Total depth of well:	9.20 m
Water-rest level:	8.20 m
Drawdown:	0.44 m
Discharge:	0.80 m^3/hr
Apparent specific capacity:	1.07 m^3/hr/m

Appendix 1C

Borehole logs, IPAL study area, Marsabit

1. Borehole No C1758 (Loglogo)

From (m)	To (m)	
0.0	1.0	Red soil
1.0	11.6	Lava boulders
11.6	12.2	Tuffaceous clay
12.2	20.7	Basaltic lava
20.7	29.0	Clay and sand
29.0	55.8	Lava
55.8	57.0	Decomposed lava
57.0	65.9	Old land surface (unconformity)
65.9	72.0	Decomposed lava
72.0	74.7	Lava
74.7	81.7	Old land surface (unconformity)
81.7	85.4	Solid rock (Basement System)

2. Borehole No. C3056 (Halisirwa)

From (m)	To (m)	
0.0	3.0	Ferruginous sands
3.0	9.8	Fine lava gravel
9.8	21.3	Dark-brown lava
21.3	39.6	Brown sandy clay
39.6	45.7	Quartz and feldspar sand
45.7	51.8	Sand
51.8	76.8	Sandy clay
76.8	101	Basement System rocks

3. Borehole No. C3511 (Laisamis)

From (m)	To (m)	
0.0	3.4	Red soil
3.4	9.8	Alluvial sands
9.8	19.5	Red clay with quartz debris
19.5	25.9	Medium and fine sands
25.0	43.6	Ditto with clay horizons

(Appendix 1C contd.)

43.6	51.2	Medium to fine sands with Basement detritus
51.2	59.5	Fine sand with clays
59.5	71.3	Medium sand with Basement detritus
71.3	74.4	Coarse sands with clay horizons
74.4	93.0	Fine sands with biotite mica
93.0	96.0	Ditto with more biotite
96.0	100.0	Ditto between fractured bedrock
100.0	117.7	Fractured Basement rocks
117.7	118.6	Very hard bedrock

4. Borehole No. C3554 (Loglogo in Milgis River valley)

From (M)	To (m)	
0.0	0.6	Fine sandy soil
0.6	28.0	Coarse sand with biotite mica
		Old land surface
28.0	135.1	Vesicular olivine basalt
135.1	136.0	Weathered olivine basalt
136.0	140.0	Coarse yellow sand with large quartz crystals

5. Borehole No. C3680 (Loglogo in Milgis River valley)

From (m)	To (m)	
0.0	32.9	Sandy clay
32.9	53.3	Veined lava
53.3	57.0	Clay with calcareous rock
57.0	89.0	Compact lava

6. Borehole No. C3681 (Loglogo)

From (m)	To (m)	
0.0	8.8	Sandy clay
8.8	38.1	Hard lava
38.1	48.8	Crystalline rocks with lava
48.8	71.6	Lava
71.6	85.4	Lava
85.4	96.0	Compact sand
96.0	103.6	Lava with quartz fraction

(Appendix 1C contd.)

103.6	114.3	Fractured lava with loose sand
114.3	119.8	Fractured lava with clay
119.8	122.9	Compact clay

7. Borehole No. C3960 (Kargi No. 2)

From (m)	To (m)	
0.0	5.0	Brown grey volcanic gravel
5.0	6.7	Grey gravel
6.7	71.9	Hard dark rock (lava)
71.9	95.7	Sandstone

8. Borehole No. C3962 (Kargi No. 1)

From (m)	To (m)	
0.0	1.52	Grey lava
11.52	32.0	Hard black lava

9. Borehole No. C4071 (Korr)

Form (m)	To (m)	
0.0	2.0	Reddish-brown soil
2.0	4.0	Sandstone
4.0	6.0	Weathered pyroxenite
6.0	8.0	Pyroxenite
8.0	10.0	Fractured and slightly weathered pyroxenite
10.0	24.0	Fresh pyroxenite
24.0	27.0	Basement gneiss

10. Borehole No. C4073 (Korr)

From (m)	To (m)	
0.0	2.0	Reddish-brown clayey soil
2.0	4.0	Weathered olivine basalt
4.0	8.0	Olivine basalt
8.0	9.0	Altered sand
9.0	10.0	Silty sand
10.0	14.0	Sand

(Appendix 1C contd.)

14.0	16.0	Sand
16.0	22.0	Sandy silt
22.0	28.0	Silt
28.0	32.0	Weathered Basement
32.0	96.9	Fractured Basement System rocks

11. Borehole No. C4080 (Hedad)

Form (m)	To (m)	
0.0	2.0	Silty sand
2.0	6.0	Coarse sand
6.0	19.0	Fine conglomerate with clay cement
19.0	21.0	Basaltic lava
21.0	24.0	Fine conglomerate
24.0	26.0	Silty sand
26.0	28.0	Weathered basalt
28.0	92.0	Clayey sand
92.0	200.0	Very coarse sand without clay

12. Borehole No. C4085

From (m)	To (m)	
0.0	4.0	Weathered Basement rocks
4.0	8.0	Weathered, fractured Basement rocks
8.0	33.5	Compact Basement rocks

13. Borehole No. C4105 (Korr)

From (m)	To (m)	
0.0	4.0	Soil
4.0	16.0	Weathered, fractured gneiss
16.0	26.0	Fractured gneiss
26.0	28.0	Quartzite
28.0	34.0	Fractured gneiss
34.0	36.0	Fractured quartzite
36.0	50.0	Compact gneiss
50.0	54.0	Fractured gneiss
54.0	80.0	Hard gneiss

(Appendix 1C contd.)

14. Borehole No. C4108 (Korr)

From (m)	To (m)	
0.0	2.0	Detrital material
2.0	4.0	Deeply weathered Basement
4.0	44.0	Fractured and weathered Basement
44.0	45.0	Compact Basement

15. Borehole No. C4112 (Korr)

From (m)	To (m)	
0.0	2.0	Reddish-brown sandy soil
2.0	4.0	Fine gravel
4.0	110.0	Fractured Basement
110.0	120.0	Compact Basement

16. Borehole No. C4113 (Korr)

From (m)	To (m)	
0.0	4.0	Reddish-brown sandy soil
4.0	56.0	Fractured Basement
56.0	70.0	Compact Basement

17. Borehole No. C4115 (Kaisut desert)

From (m)	To (m)	
0.0	2.0	Soil
2.0	52.0	Basalt
52.0	94.0	Coarse sand and gravel
94.0	96.0	Clay

18. Borehole No. SA36 (7 miles south of Marsabit)

From (m)	To (m)	
0	1.0	Soil
1.0	5.5	Lava boulders
5.5	25.3	Solid lava
25.3	74.4	Decomposed lava
74.4	994.2	Solid lava
994.2	108.2	Volcanic ash

(Appendix 1C contd.)

108.2	108.8	Solid lava

19. Borehole No. SA39 (7 miles south of Marsabit)

From (m)	To (m)	
0.0	10.4	Lava boulders
10.4	71.0	Volcanic ash

20. Borehole No. SA40 (5.4 miles up Marsabit escarpment)

From (m)	To (m)	
0.0	17.7	Lava boulders
17.7	22.0	Lava
22.0	64.6	Volcanic ash
64.6	86.6	Compact lava

21. Borehole No. SA60 (foot of Marsabit escarpment)

From (m)	To (m)	
0.0	11.3	Lava boulders
11.3	25.3	Solid lava
25.3	36.0	Volcanic ash
36.0	64.6	Solid lava
64.6	69.2	Sand and clay
69.2	74.4	Sand clay and gravel

22. Borehole No. SA84 (Kalacha)

From (m)	To (m)	
0.0	11.0	Lava boulders
11.0	25.6	Lava

23. Borehole No. SA85

From (m)	To (m)	
0.0	4.0	Soil
4.0	7.9	Volcanic boulders
7.9	12.5	Lava
12.5	15.5	Clay
15.5	103.6	Volcanic ash

(Appendix 1C contd.)

24. Borehole No. SA112 (Maikona)

From (m)	To (m)	
0.0	0.6	Sand
0.6	2.0	Boulders
2.0	49.4	Sandstone conglomerate

25. Borehole No. SA113 (Hurri Hills)

From (m)	To (m)	
0.0	5.0	Soil
5.0	7.9	Lava
7.9	59.1	Volcanic ash
59.1	61.0	Solid lava

Appendix 2. Summary of electrical resistivity results

Resistivity station No.	Location			Depth to groundwater (m)	Depth to bedrock (m)
	Map sheet No.	Grid reference	Locality		
1	42	52E, 82N	Olturot airstrip next to UNESCO camp	10	40
2	54	53E, 54N	Across lagga in Korante plains	6	45
3	29	3E, 62N	10 km north of Afgab mountain	-	>150
4	29	17E, 56N	Hurri hills, 12 km north of Marsabit-Kalacha road junction	-	>150
5	29	33E, 50N	Eastern slopes of Hurri hills	-	>150
6	29	39E, 70N	Eastern slopes of Hurri hills	-	>150
7	29	24E, 70N	25 km north of Marsabit-Kalacha road junction	-	>150
8	66	11E, 93N	Along Ngurunit airstrip 4 km along Ngurunit-Korr road	10	20
9	55	01E, 36N	15 km north of Korr on Korr-Kargi road	3	20
10	43	08E, 77N	Kargi next to borehole No. C3962	6	-
11	43	50E, 80N	Segel airstrip, 25 km north of Marsabit	40	184
12	43	21E, 21N	500 m south of Marsabit-Maikona road junction	40	-
13	28	72E, 70N	Next to Bulal Lagga on upper Kalacha-North Horr road	6	140
14	27		10 km west of North Horr along North Horr-Loiengalani road next to Horr airstrip	40	-
15	54	99E, 55N	20 km south of Kargi-Korr road	2, 20	-
16	43	03E, 83N	8 km NW of Kargi on Kargi-Kurkum road	3	72
17	42	8E, 77N	Falama, 19 km west of Kargi	-	-
18	53	40E, 71N	Across Balesa-Kulal lagga at Gatab-Ilaut crossing	10.5	-
19	54	62E, 60N	10 km NE of station No. 2	20	105
20	54	70E, 35N	Hafarin, 18 km down lagga from Ilaut-Gatab road crossing	15	20
21	54	86E, 36N	Tip of lava north of Rorr	4	15
22	54	59E, 25N	Korante plains, 15 km north of Ilaut-South Horr-Gatab road crossing	2	20
23	42	65E, 94N	In Balesa lagga, 22 km NW of new Olturot-Kargi-Gus road junction	4	8
24	42		20 km down lagga from Kargi-Gus road crossing	3	4
25	42	53E, 81N	Olturot where Balesa crosses Kargi-Olturot road	5.5	-
26	27		8 km NE of Gus	10	56
27	43	32E, 93N	At Marsabit-Maikona-Kargi road junction	14	80
28	67	44E, 03N	Illim, 1 km west of rock outcrop	10	-
29	67	68E, 18N	15 km west of Loglogo	20	80

(Appendix 2 contd.)

30	66	24E, 9N	24 km from Ngurunit on Ngurunit-Korr road	10.5	-
31	66	06E, 06N	½ km east of Ilaut along Ilaut-Korr road	5	10
32	66	05E, 20N	Hedad east of Korr	-	-
33	66	90E, 19N	7 km north of Ilaut-South Horr-Olturot road junction	3	30
34	53	41E, 67N	15 km east of South Horr-Loiengalani-Kargi road junction	40	-
35	53	36E, 71N	Across Balesa lagga	-	-
36	28	91E, 45N	Kalacha, along airstrip	14	80
37	54	77E, 42N	Hedad	8	28
38	42	71E, 77N	15 km east of Olturot-South Horr-Kargi road junction	-	20
39	54	57E, 47N	27 km south of Olturot along Ilaut road	4	-
40	54	95E, 71N	15 km west of Kargi on Kargi-Olturot road	10	30
41	54	99E, 48N	21 km north of Korr on Korr-Kargi road	-	-
42	54	96E, 31N	10 km NW of Korr	3,10	20
43	54	93E, 50N	10 km west of station 43	-	56
44	54	69E, 47N	Across lagga	8	-
45	54	67E, 31N	Hafarin, 500 m west of volcanic hills	5	-
46	55	03E, 25N	2.5 km from Korr along Korr-Kargi road	2	5
47	55	02E, 49N	28 km north of Korr on Korr-Kargi road	3	-
48	55	05E, 73N	1½ km south of Kargi	4	20
49	42	78E, 81N	4 km NW of new Olturot-Kargi-Gus road junction	40	-
50	42	65E, 80N	9 km east of Kargi-Olturot-South Horr road junction	14	56
51	42	70E, 89N	16 km NW of new Olturot-Kargi-Gus road junction	3	40
52	42	69E, 09N	In Balesa lagga, 15 km below Kargi-Gus road crossing	3	40
53	43	18E, 84N	26 km east of Kargi-Marsabit road junction	5	-
54	43	27E, 12N	23 km north of Marsabit-Maikona-Kargi road junction	16	-