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Water Resources and Water Management in South-Western Marsabit District

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IPAL Technical Report Number B - 4

WATER RESOURCES AND WATER MANAGEMENT IN SOUTH-WESTERN MARSABIT DISTRICT

by

GERNOT BAKE

UNESCO-MAB 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 km^2 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 (1980-83), 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 and anthropological: yellow

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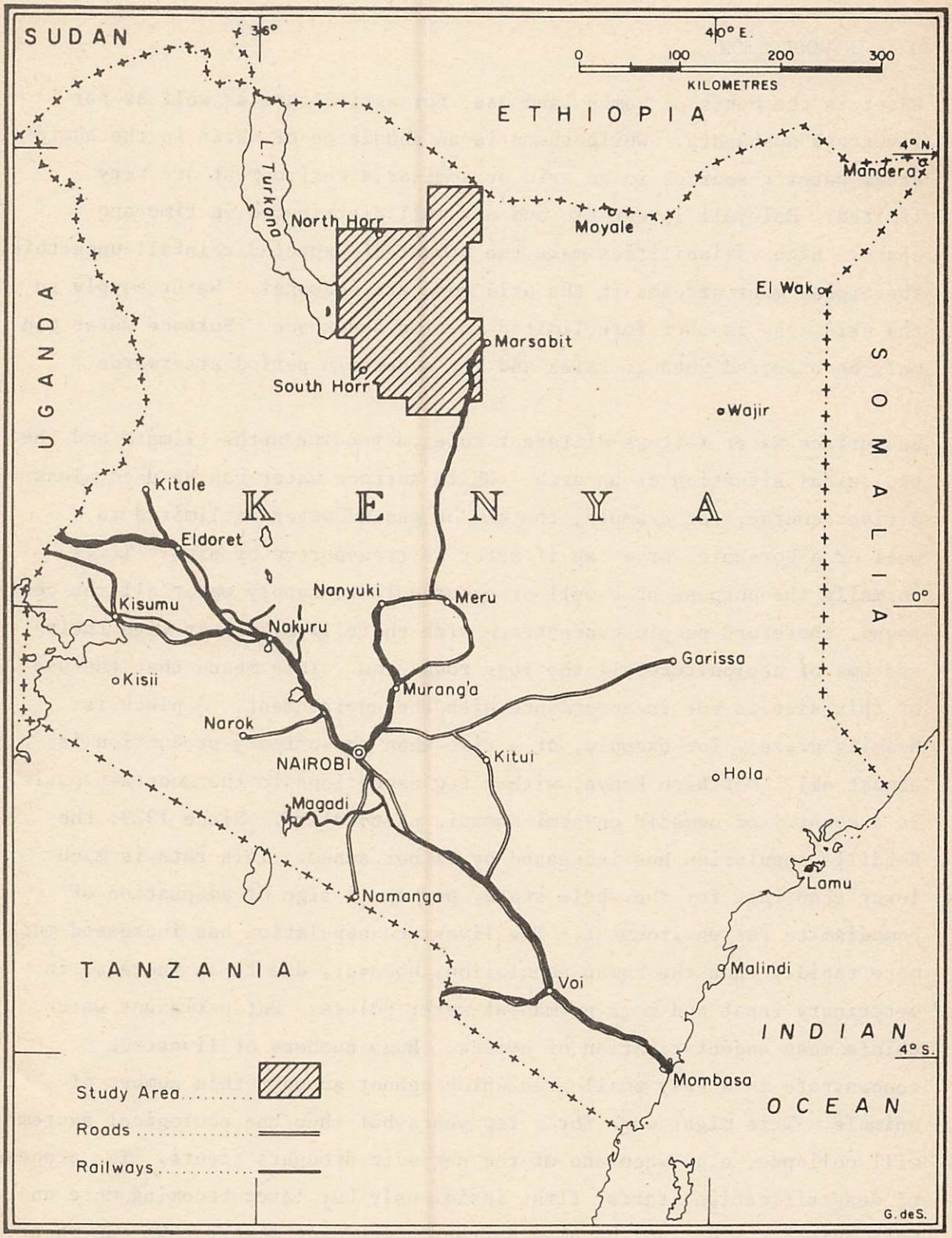
1. INTRODUCTION

Water is the basis of human land use, for agriculture as well as for livestock husbandry. While there is an abundance of water in the humid areas water resources in an arid or semi-arid environment are very limited. Rainfall is erratic and not well distributed in time and space. High variabilities make the amount of expected rainfall uncertain. Therefore, most streams in the arid zone are seasonal. Water supply in the arid zone is therefore limited in time and space. Surface water can only be expected when it rains and for a certain period afterwards.

Subsurface water follows different rules, depending on the climate and the geological situation of an area. While surface water can be used along a river course, for example, the use of ground water is limited to a well or a borehole, or a tap if water is transported by pipe. It is normally the purpose of a well or a borehole to supply water all the year round, therefore people concentrate with their livestock or with their systems of agriculture all the year round too. This means that the use of this site is not in accordance with the environment. A place is heavily grazed, for example, at a time when the primary production is almost nil. Northern Kenya, with a few exceptions in the mountain oasis, is a country of nomadic on semi-nomadic pastoralism. Since 1929, the Rendille population has increased by 2% per annum. This rate is much lower than that for the whole state, perhaps a sign of adaptation of nomadism to the environment. The livestock population has increased much more rapidly than the human population, however, due to an increase in veterinary input and more permanent water points. But permanent water points mean sedentarization of nomads. Huge numbers of livestock concentrate in a very small area which cannot support this number of animals. This might work for a few years but then the ecological system will collapse, e.g. when one of the periodic droughts occurs. The process of desertification starts, first insidiously but later becoming more and more evident. The land becomes barren, a man-made desert. We can observe this process in the IPAL study area around the permanent villages of Korr, Kargi and Loglogo. Can the nomad be made responsible for this process?

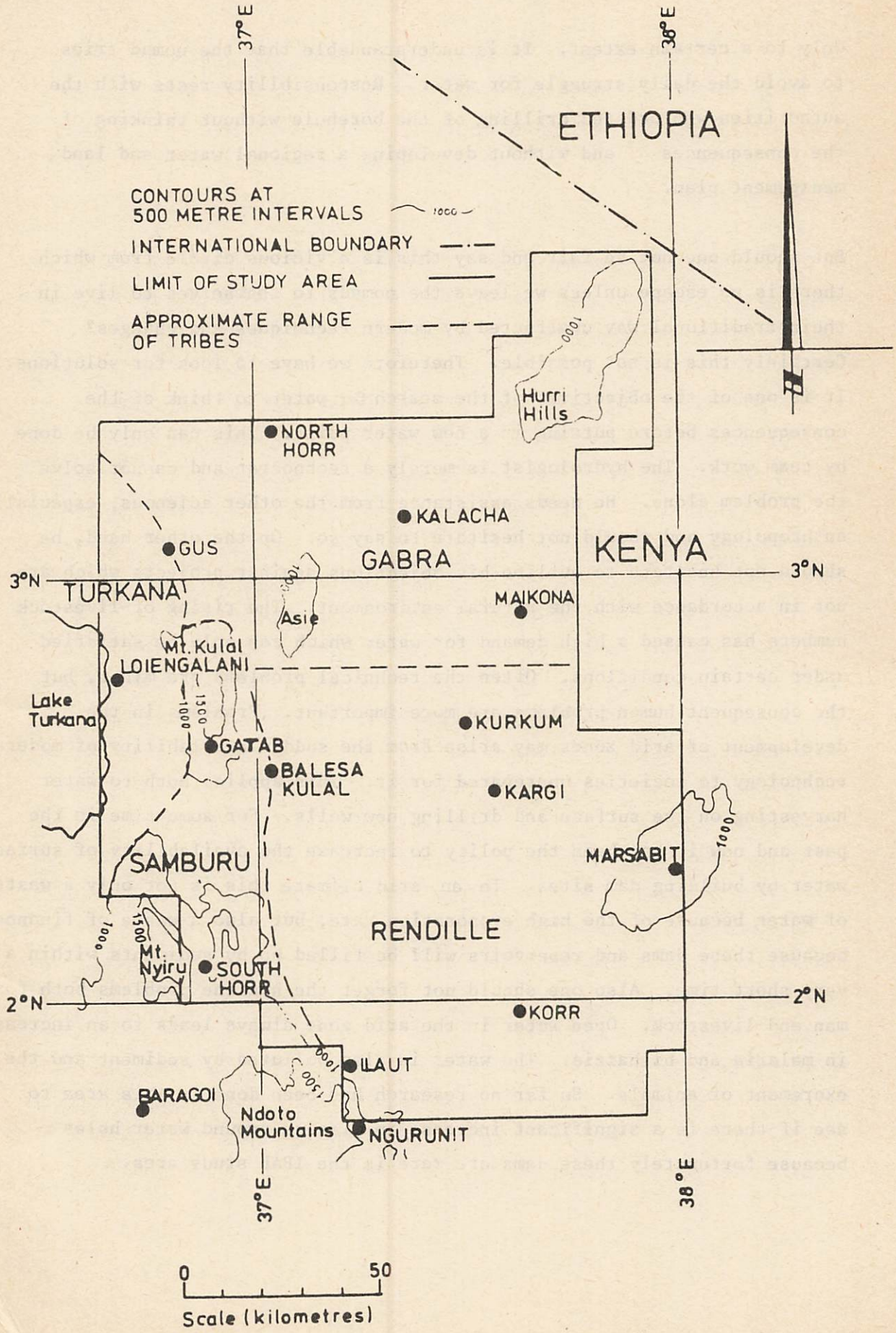
Map 1. Location of IPAL study area



Only to a certain extent. It is understandable that the nomad tries to avoid the daily struggle for water. Responsibility rests with the authorities who ordered drilling of the borehole without thinking of the consequences and without developing a regional water and land management plan.

But should one not be fair and say this is a vicious circle from which there is no escape unless we leave the nomads to themselves to live in their traditional way unaffected by modern techniques and changes? Certainly this is not possible. Therefore we have to look for solutions. It is one of the objectives of the search for water to think of the consequences before putting in a new water point. This can only be done by team work. The hydrologist is merely a technocrat and cannot solve the problem alone. He needs assistance from the other sciences, especially anthropology and should not hesitate to say so. On the other hand, he should not hesitate to outline his objections against projects which are not in accordance with the natural environment. The rising of livestock numbers has caused a high demand for water which can only be satisfied under certain conditions. Often the technical problems are minor, but the consequent human problems are more important. Problems in the development of arid zones may arise from the sudden availability of modern technology to societies unprepared for it. This applies both to water harvesting on the surface and drilling new wells. For some time in the past and now it has been the policy to increase the availability of surface water by building dam sites. In an arid climate this is not only a waste of water, because of the high evaporation rate, but also a waste of finances because these dams and reservoirs will be filled up by sediments within a very short time. Also one should not forget the hygiene problems both for man and livestock. Open water in the arid zone always leads to an increase in malaria and bilharzia. The water is also polluted by sediment and the excrement of animals. So far no research has been done in this area to see if there is a significant increase in disease around water holes because fortunately these dams are rare in the IPAL study area.

Map 2. The IPAL study area



On the other hand, the use of ground water, available in at least 50% of the IPAL area, is not without problems. Modern pumps can bring enormous amounts of water to the surface. Before this study was prepared no research had been done on the question of the age of the ground water. Fossil water is already used at certain places. Due to the very low recharge rates these boreholes will dry up within a certain period. Fortunately no attempt has been made to use ground water for irrigation in the IPAL study area except on Mt. Marsabit. This would have meant an enormous increase in the demand for water and also set an example for adjoining areas. The process of desertification around waterholes, already very apparent, would have accelerated. And therefore this will not be encouraged by this study.

The aim of this study is to give a scientific base to the proper exploration and use of the existing water resources in the IPAL study area. It incorporates, therefore, subsurface and surface hydrology. The first step will be an inventory of the existing water resources. This cannot be comprehensive due to the short research time and the pre-existing materials. Before the start of IPAL in 1976 almost no research had been done on water resources of Marsabit District. Due to the size of the study area not every area and every item could be covered. The results of four former studies on hydrology are integrated here. These are the reports of Borgeson and Ndombi on ground water and Ongweny and Baur on surface water. Their aim was a first attempt at a resource inventory. (The reports are published in the IPAL Technical Report Series No. B-2.) One and a half years research by the author are added. There are still a number of gaps and misinterpretations which will have to be filled in and corrected in coming years. A first water development and management plan has been written for the south of the IPAL area and published in the Integrated Management Plan as IPAL Technical Report No. A-6.

Special problems occur on the mountains of the IPAL area, mainly Mt. Marsabit. The population in the town and surrounding villages increases rapidly. Irrigation projects have been started. There is also a high demand by livestock. More than 100,000m^3 (equivalent to more

than 11m^3/h) were calculated for the eastern side of the upper mountain only. Shortages of water in the town supply are already quite common. Currently they are caused by breakdowns of the old equipment but it can be foreseen that the town faces a real shortage of water for human consumption in the coming years. The mountains are the base of the recharge for all the aquifers in the lowlands.

The question of climatic changes leads to a lot of discussion. So far we do not know if the climate of northern Kenya is changing or if the fluctuations observed are part of normal climate variability. This affects the hydrology. Periods of less rainfall lead to less available surface water and less infiltration and thus less recharge of ground-water. Therefore recharge calculations should be based on the lower side of the rainfall variability for safety. Rainfall prediction is still not possible so that data analysis has to be based on the past. But the water used now is water of the past, so this approach is logical.

For development purposes the quantity of available water is not the only important variable. The quality is equally important. Due to insufficient time and financial constraints in the IPAL budget a comprehensive study on water quality is still lacking. When one is done it should include not only an inventory of water quality but also research on changes in quality. The IPAL area consists of a number of volcanoes of Tertiary and Quaternary age. Hot springs at Loiengalani (L. Turkana) indicate that at least some of them are not completely dead. Also slight earthquakes are not uncommon in the area. Therefore changes in water quality can be expected. At the end of this report there is a suggestion for further research. It is almost certain that there will be several questions which are impossible to answer now. For example sediment transport in the water courses is a problem which affects the planning of surface reservoirs and raise questions of the geomorphology of the area. We will attempt to answer some of these questions. A general problem in remote areas is measuring the discharge of *laggas*. IPAL relies on normal river gauges which make it impossible to cover the entire area.

2. TRADITIONAL FORMS OF WATER USE IN THE IPAL AREA

This can only be a short outline of traditional water use among the pastoralists in the IPAL area. A comprehensive report on this subject will be given in the IPAL report series by Dr. M. O'Leary. There are three major tribes in the area: the Samburu in the south, partly sharing the area with the Rendille in the middle and the Gabbra in the north. At Mt. Marsabit there are Boran and at Lake Turkana El Molos and Turkana. None of these tribes have developed a sophisticated system of water use except the Boran who originate from southern Ethiopia.

Until very recently agriculture on Mt. Marsabit was only rain fed. Possibly there is no highly developed water search and management system because none of these tribes have occupied their present areas for very long and so there has been no adaptation to a new environment. Nevertheless there are a few related traditions, to be discussed later on. In a normal wet season nomads and their herds do not face any severe problems. After the rains surface water is abundant in small pans, rock pools and in depressions in the *laggas*. Due to the discharge character of the water courses, mostly in the form of flash floods, *laggas* are not considered a source of surface water except in the southern mountains where the discharge sometimes continues long into the dry seasons. Permanent open surface water occurs along the escarpment of the Marsabit lava, mainly in the Chalbi desert. A traditional water point for the Rendille camels is the Karole springs. No animal can be watered there after the Easter rains until the Tubcha clan of the Rendille perform the opening ceremony, which consists of sacrificing at the springs.

In the dry seasons all tribes in the lowland plains rely on shallow wells dug in the dry water courses of the *laggas*. Normally water will be found at a depth of less than 5 m. Due to the consistency of the sand and gravel materials of the riverbeds the depth to which they can be dug is limited and therefore the amount of water too. As a result several wells are dug at the same site. This is possible only in favourite positions like Illaut where the course of the *lagga* is determined by the geological situation. None of these wells are

permanent: after each flood the people have to dig the wells again - most often at the same site. A few permanent wells exist around Korr in a *laggа* where there are basement outcrops. This is a recent development so that they cannot be called traditional. The camp sites are not necessarily right at the wells. Water can be transported with camels and donkeys over quite some distance, traditional work for the women. No tribe made attempts to harvest water by construction of small dams. There is almost no knowledge of building deeper wells in favourite locations. Water is drawn by hand, nowadays in tins or plastic buckets and before with skins. If the well becomes dry the people shift to another location with enough water, which can also mean moving the entire *manyatta*.

In colonial times a number of changes occurred. Mainly in the fifties several boreholes were drilled and equipped with pumps to supply large amounts of water. This was the initiation of the sedentarization process in the villages of Laisamis, Loglogo, Korr, Kargi, Kalacha, Maikona, North Horr, etc. Earlier on there was no permanent settlement in the area except at Marsabit. The opening of the Northern Frontier District allowed missionaries to move in. For their own supply, and also to attract people to settle down, they drilled their own boreholes. At Korr at the moment there are 12 different boreholes, some of them dry. Borehole equipment is supervised and maintained by the Kenya Government (Ministry of Water Development), but this only affects the technical equipment. No water management or water distribution is done by Government authorities. Except at Marsabit water is supplied free of charge. There are also some permanent wells built in colonial times and by IPAL and missionaries, but in some of them the water is unfit for human or animal consumption. Wells and shallow boreholes were often equipped with hand-pumps. This equipment was unknown to the local people. As they have to use it themselves almost all of it is out of order. Vandalism by *moran* (warriors) plays a role as well.

3. PHYSICAL FACTORS AFFECTING THE HYDROLOGY OF THE IPAL STUDY AREA

3.1. Climate

Two comprehensive reports on the climatology of Marsabit District are available in the IPAL Report Series therefore here we will concentrate on the major factors.

Rainfall is the only source for recharging groundwater and surface water. Precipitation in the arid areas of northern Kenya largely results from convective processes in the troposphere. This is why rainfall there is generally of limited duration and extent. Nevertheless there are several modifications.

The map of mean annual rainfall (Figure 1) based on five years of records shows the general characteristics which are important for the hydrology of the area. There is a clear division into the better watered mountains (Mt. Kulal, Hurri Hills, Mt. Marsabit, Ndoto and Njiru Mountains) which receive upto 1,000 mm mean annual rainfall and the remaining areas.* Therefore one can divide the IPAL area into an ablation and several catchment areas. Even in the high Ndoto Mountains there is not enough rainfall to allow for perennial water courses. The unevenly distributed rainfall often leads to a *lagga* starting to flow in the middle of its course. The Ngurunit river, for example, flowed only for a few hours during the exceptional second wet period of 1982. This indicates how highly dependent the discharge is on the variability of rainfall. Northern Kenya has one of the highest mean rainfall variabilities in the world (Table 1).

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* The geological characteristics of these mountains which are important for the hydrology of the entire area are discussed later in this report.

Figure 1. Mean annual rainfall

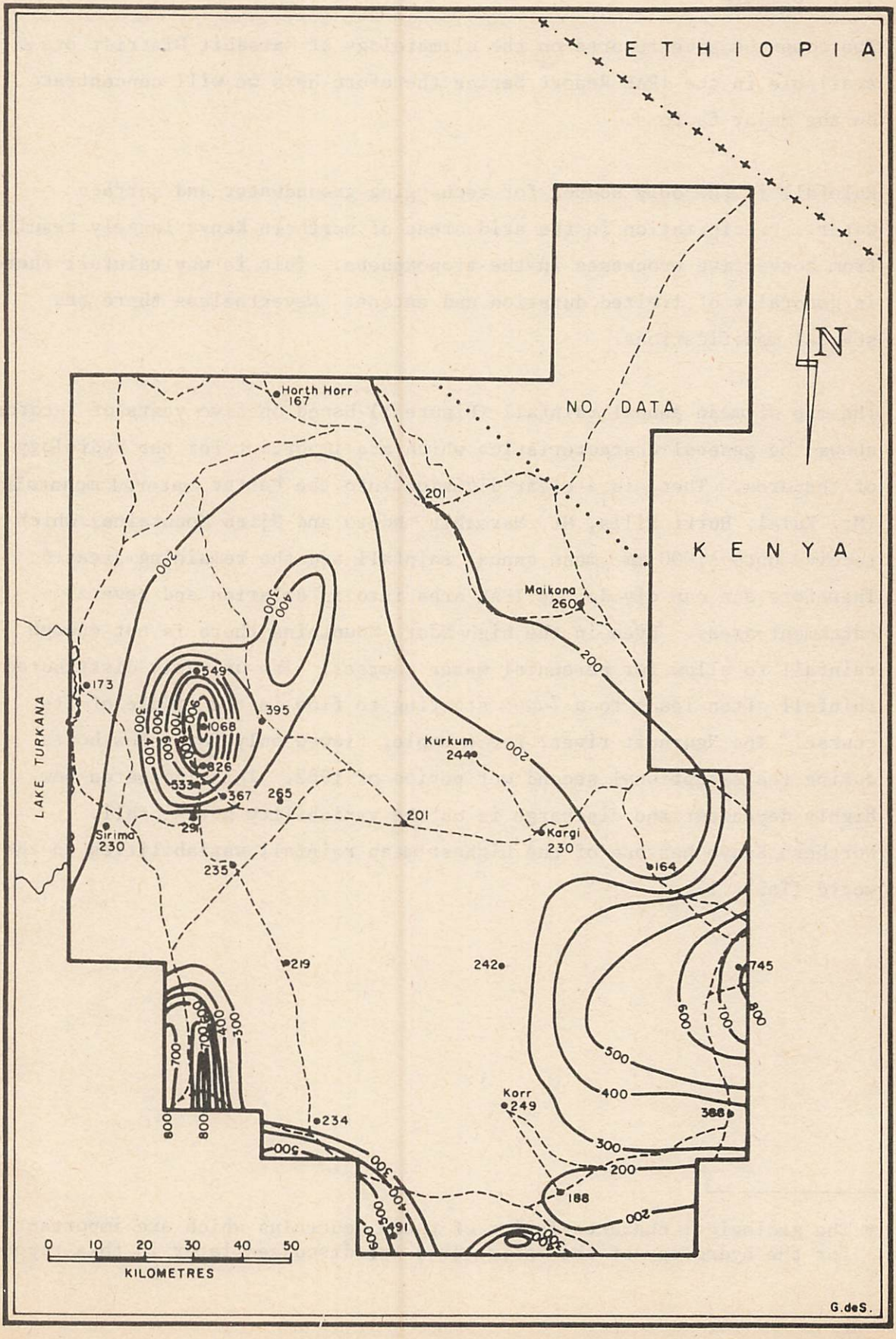


Table 1. Variability of annual rainfall (mm)

Station	Period of record	Mean	Abs. max.	Abs. min.	Mean variabilities		Δ
North Horr	1959-1981	157	385	5	+59.2	-41.4	100.6
Moyale*	1915-1981	713	1290	387	+23.7	-19.4	43.1
Marsabit	1918-1981	859	1816	324	+32.7	-24.3	457.0
Lodwar*	1919-1981	178	498	19	+51.0	-41.9	92.9

* Indicates station outside the IPAL area.

Source: G. Bake, 1983

Monthly variabilities are much higher and reach variation coefficients of more than 350 in the dry seasons and more than 70 (Marsabit) or even 100 (Kargi) in the 'normally' wettest months. Bake (1983) outlined the general problem: 'The water supply by rainfall is only well spread out in a few years, the regularity consists of a shifting between extremes; there is a deficit of water for a long time but there is also an enormous surplus of water in a very short time'. Therefore the probabilities of rainfall are also fairly low. As an example, the figures for Marsabit are given here (Tables 2 and 3, Figure 2). Note that Marsabit is in the semi-arid or even sub-humid (eastern slopes) area of northern Kenya.

The highly permeable lavas lead to a kind of edaphic aridity. Infiltration is fairly high so that there are almost no long river courses from the mountains but quite a number of permanent springs on the lower slopes. Northwards there are gentle sloping lava plains. On the north-western edge of the IPAL area are the volcanic Bura Galadi Hills also connected with formation of the East African Rift Valley. Orientated south-west to north-east the Hurri Hills are another prominent volcanic feature of the area. From the lavas it can be said that they are younger than Mt. Kulal. Also they are less dissected. Their lavas cover a large area and are joined with the lavas of Mt. Marsabit. In the north they even cross the Ethiopian border. Mt. Marsabit forms a plateau volcano rising up to 1,700 m. The lavas cover a large area and drop to the plains in the centre of the study area in the form of an escarpment. There are at least three major plateaus. The age of the volcano is early Quaternary. No post-volcanic activity is evident.

Table 2. Probabilities of rainfall and return periods at Marsabit

(a) Annual rainfall (median 77 mm/a)

Rainfall in mm/a	300-400	401-500	501-600	601-700	701-800	801-900	901-1000	1001-1100	1101-1200	1201-1300	>1301
Probability (%)	5.6	1.9	16.7	9.3	18.5	9.3	9.3	13.0	3.7	3.7	9.3
Return period (years)	17	50	6	11	5	11	11	8	25	25	11

(b) Monthly rainfall probabilities

	J	F	M	A	M	Ju	Jl	A	S	O	N	D
<25 mm	0.61	0.77	0.28	0	0.28	0.93	0.83	0.80	0.82	0.16	0.04	0.30
>50 mm	0.25	0.14	0.44	0.91	0.60	0	0.03	0.06	0.04	0.68	0.80	0.44
>100 mm	0.13	0.05	0.21	0.78	0.41	0	0.02	0.02	0	0.50	0.54	0.26
>200 mm	0	0.02	0.04	0.44	0.14	0	0	0	0	0.23	0.20	0.07
Median	17	4	43	209	70	3	7	7	7	103	116	47

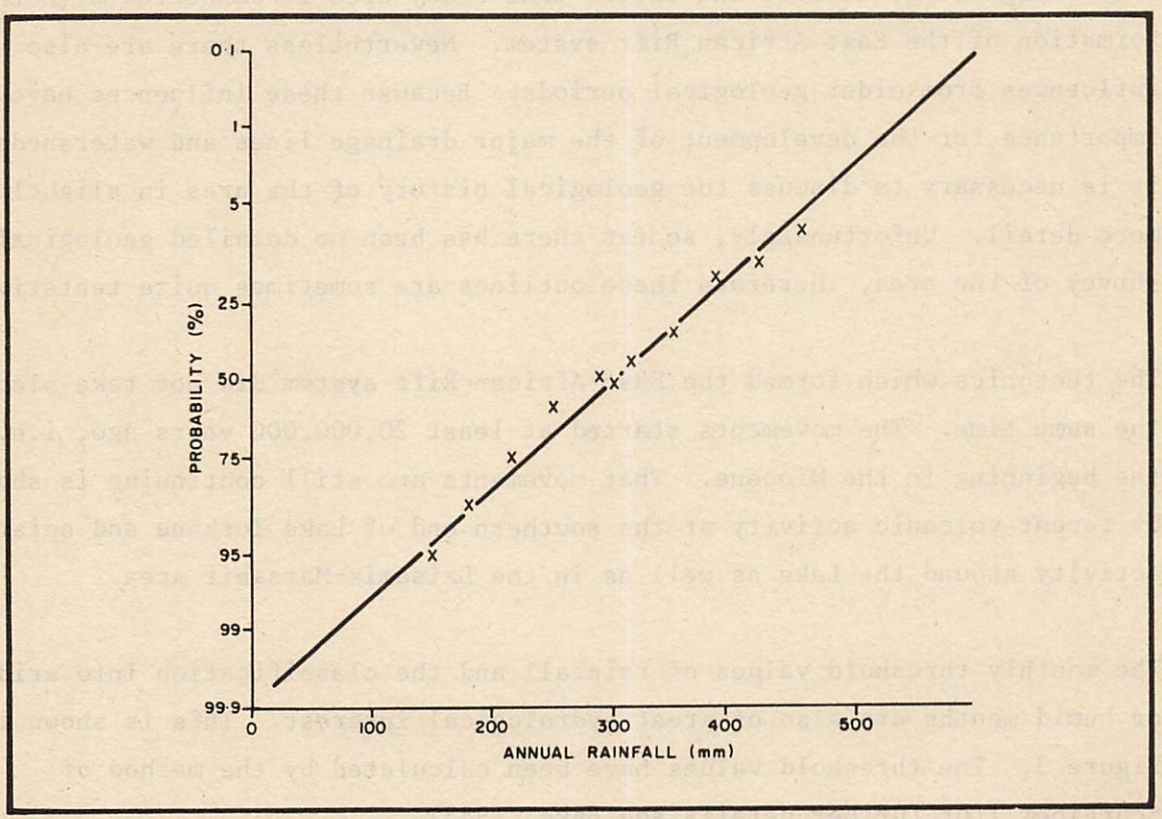
Sources: ILCA, and Bake, 1983.

Table 3. Probabilities of rainfall, Marsabit/3 (median: 259 mm/a)

	J	F	M	A	M	Ju	Jl	A	S	O	N	D
>25 mm	0.86	0.93	0.63	0.14	0.52	1	0.98	0.96	1	0.38	0.36	0.65
<50 mm	0.05	0.02	0.12	0.66	0.28	0	0	0.02	0	0.29	0.38	0.13
<100 mm	0	0	0	0.26	0	0	0	0	0	0.04	0.09	0
<200 mm	0	0	0	0.02	0	0	0	0	0	0	0.01	0
Median	6	1	14	70	23	1	2	2	2	34	39	16

Source: ILCA

Figure 2. Tentative probability of rainfall for the lowlands, Marsabit/3



Mt. Marsabit forms the first prominent landmark for the air masses drifting westwards from the Indian Ocean. Therefore the vegetation cover is denser on the eastern side where there are also more drainage lines. The southern border of the study area is formed by the mountain masses of the Ndotos, Njirus and Ol Donyo Mara. These are not of volcanic origin but consist of various Precambrian basement rocks. They rise up to more than 2,500 m. There are also isolated basement mountains in the south, namely Baio, Illim and Holigum Nder. The Korr hills also consist of basement rocks.

In the centre of the study area are vast plains which slope gently (1°) towards the Chalbi basin. They consist mainly of sandy materials of various origin (see Soil Map in IPAL Technical Report C-1). East of Korr the Kaisut plains descend towards the east. North of the Chalbi basin the altitude increases towards the Mega escarpment and then finally towards the Ethiopian highlands.

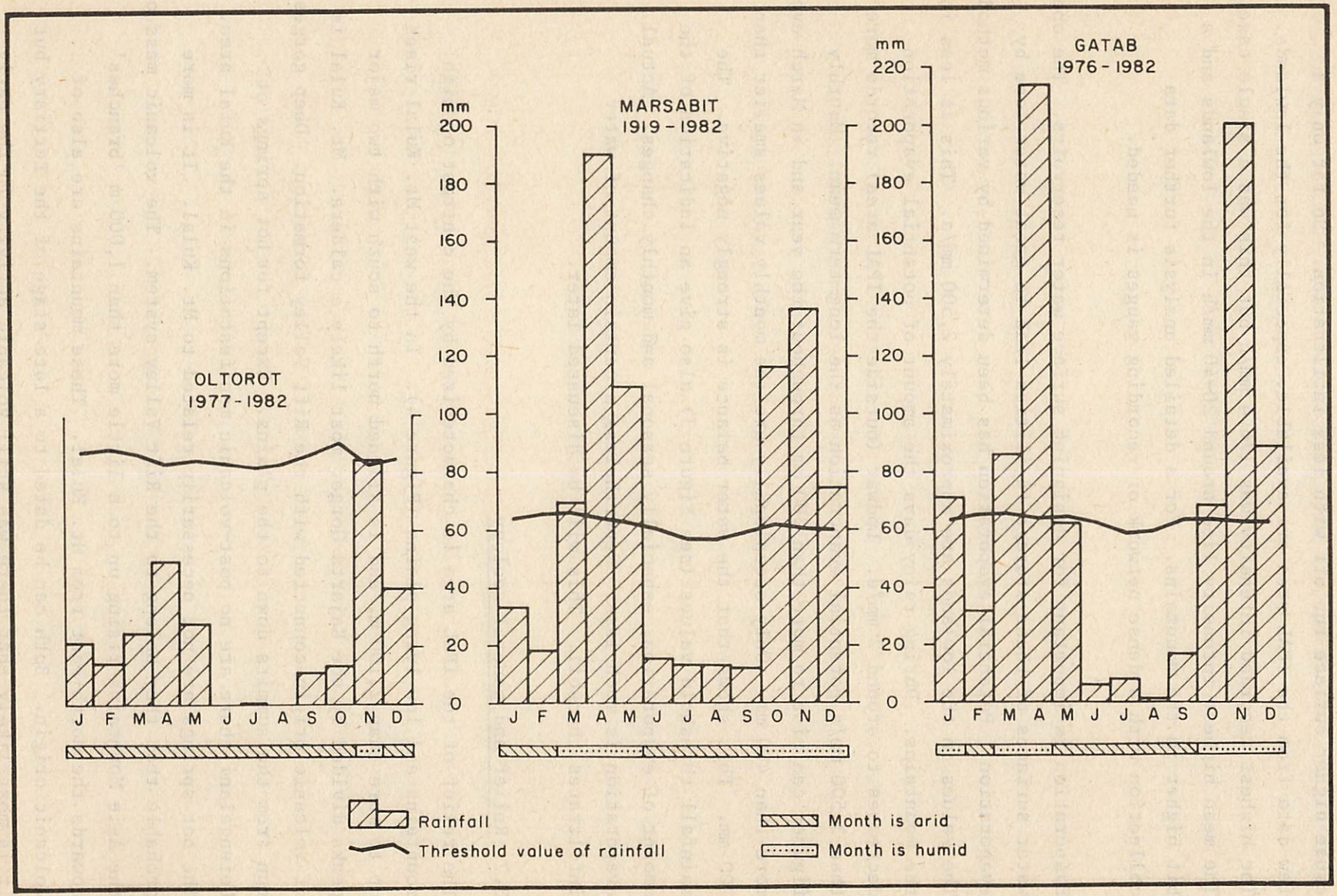
The geological genesis of the entire IPAL study area is connected with the formation of the East African Rift system. Nevertheless there are also influences from older geological periods. Because these influences have an importance for the development of the major drainage lines and watersheds it is necessary to discuss the geological history of the area in slightly more detail. Unfortunately, so far there has been no detailed geological survey of the area, therefore these outlines are sometimes quite tentative.

The tectonics which formed the East African Rift system did not take place at the same time. The movements started at least 20,000,000 years ago, i.e. at the beginning in the Miocene. That movements are still continuing is shown by recent volcanic activity at the southern end of Lake Turkana and seismic activity around the Lake as well as in the Laisamis-Marsabit area.

The monthly threshold values of rainfall and the classification into arid or humid months are also of great hydrological interest. This is shown in Figure 3. The threshold values have been calculated by the method of Schreiber (for further details see Bake, 1983).

In the lowlands only one month, surprisingly November, exceeds the margin of rainfall while in the wetter highlands the average is six months. This underlines once again the division into ablation and alimentation areas.

Figure 3. Monthly rainfall and threshold values of rainfall



Source: Bake, 1983

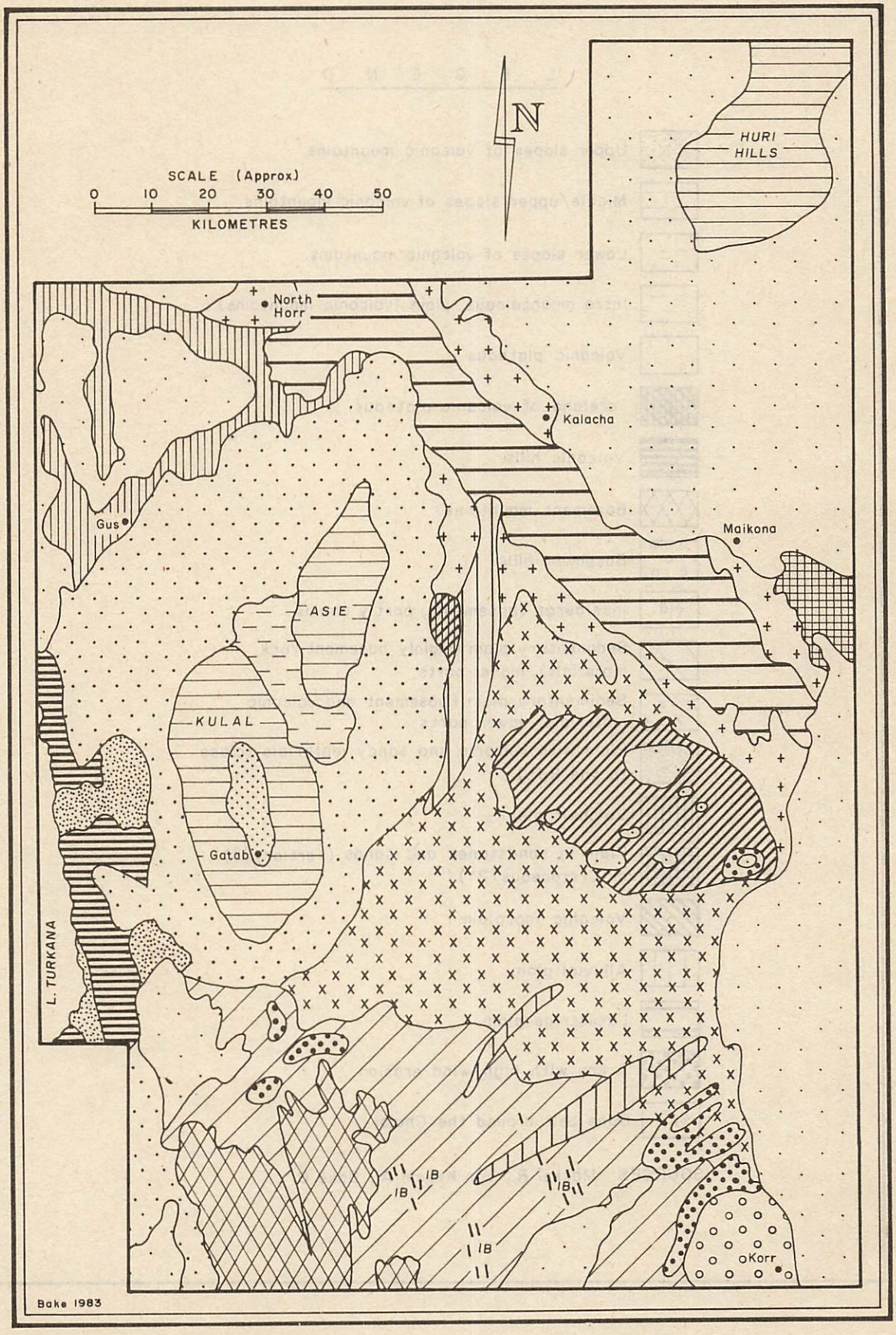
Of great interest is the intensity of the falling rain. High intensities cause higher surface run off with less infiltration. So far only a few data from the IPAL area are available, especially for the lowlands. The highest recorded intensity was 176.4 mm/h but this was a single case. The mean highest intensity lies around 20-40 mm/h in the lowlands and a bit higher in the mountains. For a detailed analysis further data collection with a dense network of recording gauges is needed.

Evaporation is important for designing surface water reservoirs. The open water surfaces of these storage facilities lead to great water loss by evaporation. Potential evaporation has been determined by various methods. The values in the lowlands are approximately 2,500 mm/a. This is less in the mountains. During rainy days the amount of potential evaporation decreases to around 2 mm/d. Lodwar (outside the IPAL area) records more than 3,500 mm/a potential evaporation as the long-term mean. Monthly figures can rise to more than 300 mm throughout the year and in March even more than 400 mm. Only occasionally are the monthly values smaller than 200 mm. This shows that the water balance is strongly negative. The rainfall threshold values (see Figure 3) also give an indication of the amount of evaporation, especially seasonal and monthly changes. Actual evaporation is much less. Nevertheless a certain amount of water infiltrates the soil. This will be discussed later.

3.2 Relief and general geology

The relief of the IPAL area is characterized by the contrast of high mountains and low lying plains (Figure 4). In the west Mt. Kulal rises up to more than 2,100 m, and is aligned north to south with two major peaks divided by the Kajarta Gorge, most likely a caldera. Mt. Kulal is of volcanic origin connected with the Rift Valley formation. Deep gorges run from the summits down to the plains. Except for hot springs at Loiengalani there are no post-volcanic manifestations in the Kulal area. The hot springs are not necessarily related to Mt. Kulal. It is more probable that they belong to the Rift Valley system. The volcanic mass of the Asie Mountains rising up to a little more than 1,000 m 'branches' towards the north-east from Mt. Kulal. These mountains are also of volcanic origin. Both can be dated to a late stage of the Tertiary but it is most likely that there was still volcanic activity in the early

Figure 4. Major landforms of south-western Marsabit District



L E G E N D


Upper slopes of volcanic mountains.


Middle/upper slopes of volcanic mountains.


Lower slopes of volcanic mountains.


Intra mountainous plain (volcanic mountains).


Volcanic plateaus.


Foreland of volcanic plateaus.


Volcanic hills.


Basement mountains.


Basement hills.



Inselbergs (basement), partly chains.


Sedimentary plain (mainly basement rock materials), higher parts.


Sedimentary plain (basement and volcanic materials), lower parts.


Plain with volcanic and sandy materials (close to the Rift).


Volcanic plain.


Plain in sandstones and sands (Tertiary(?) or Cretaceous(?)).


Volcanic footplain.


Alluvial plain.


Lacustrine plain


Areas with high wind erosion.


Dune belt around the Chalbi

SOURCES: Mäckel R., Van Kekem A., Bake G.

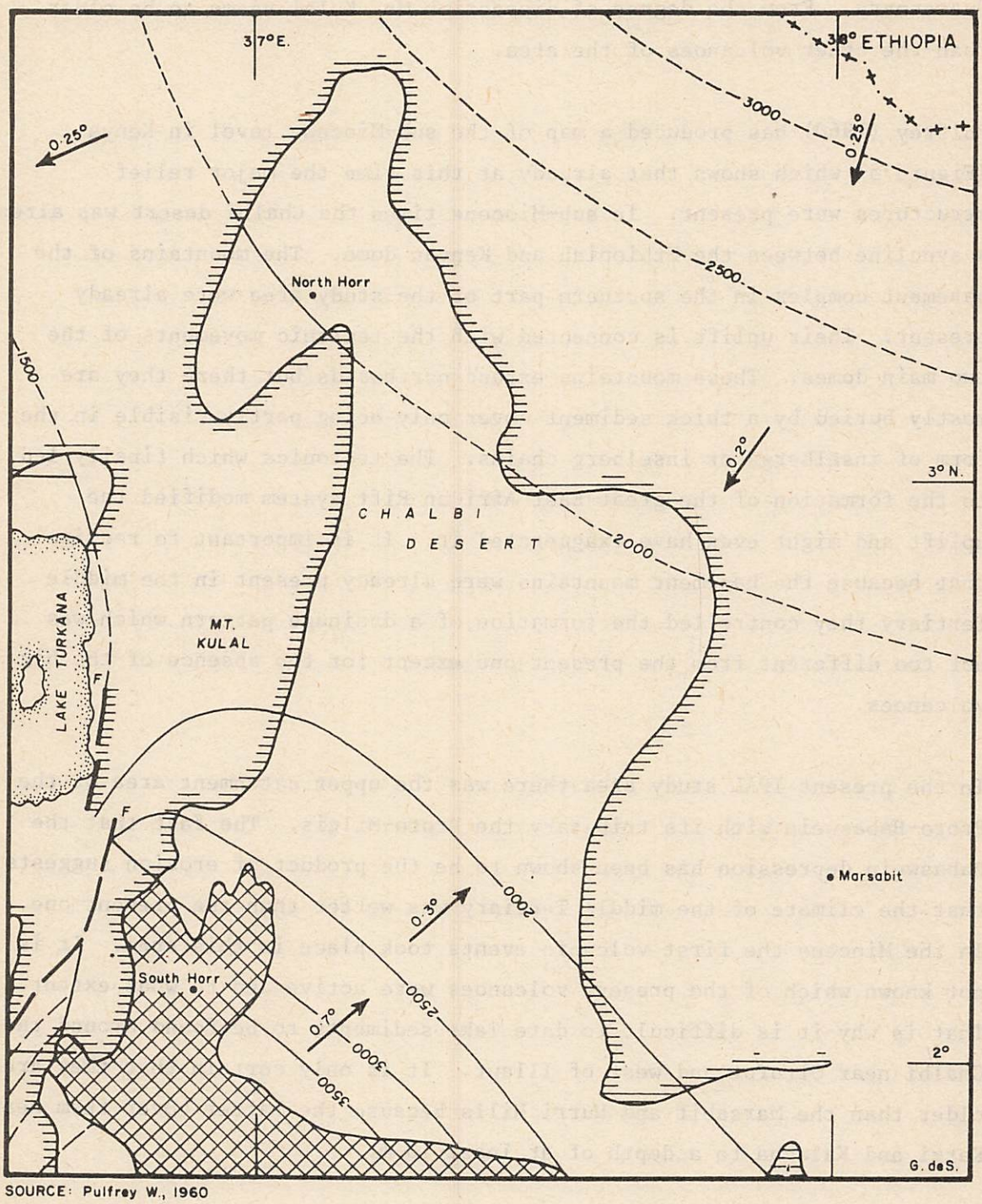
Quaternary. From the degree of dissection Mt. Kulal seems to be older than the other volcanoes of the area.

Pulfrey (1960) has produced a map of the sub-Miocene bevel in Kenya (Figure 5) which shows that already at this time the major relief structures were present. In sub-Miocene times the Chalbi desert was already a syncline between the Ethiopian and Kenyan dome. The mountains of the basement complex in the southern part of the study area were already present. Their uplift is connected with the tectonic movements of the two main domes. These mountains extend northwards but there they are mostly buried by a thick sediment cover only being partly visible in the form of inselbergs or inselberg chains. The tectonics which finally led to the formation of the great East African Rift system modified the uplift and might even have exaggerated it. It is important to realize that because the basement mountains were already present in the middle Tertiary they controlled the formation of a drainage pattern which was not too different from the present one except for the absence of the big volcanoes.

In the present IPAL study area there was the upper catchment area of the Proto-Habaswein with its tributary the Proto-Milgis. The fact that the Habaswein depression has been shown to be the product of erosion suggests that the climate of the middle Tertiary was wetter than the present one. In the Miocene the first volcanic events took place in this area. It is not known which of the present volcanoes were active and to what extent. That is why it is difficult to date lake sediments to be found around the Chalbi near Olturot and west of Illaut. It is only certain that they are older than the Marsabit and Hurri Hills because the latter cover them near Kargi and Kalacha to a depth of at least 10 m.

The sediments of one or more fresh water lakes from the late Tertiary and early to upper Pleistocene are a proof of one of more periods of wetter climate. At least the major drainage lines such as the Milgis, Merille and Balesa Kulal must have been formed during these times when general structural development was fixed. During these wetter periods the sediments of the plains must have been washed down from the southern mountains and partly from the active volcanoes. Certainly these plains

Figure 5. The sub-Miocene erosion bevel



SOURCE: Pulfrey W., 1960

0 10 20 40 60 80
KILOMETRES

Hills and mountains on the bevel.
Edge of main areas of volcanic rocks (shading on volcanic side).

F Faults

3000 Contour lines of the bevel in feet.

1500 Conjectural contours in feet.

0·3° Calculated slope of bevel.

(which slope gently from 800 m, equivalent to an angle of 0.2^{o}) are not only the product of fluvial accumulation. Climatic changes since the middle Tertiary and the genesis of the surrounding volcanoes alternated so that the plains were formed by a combination of geomorphological processes. Accumulation and erosion changed when the climate changed. Old fossil dunes also prove that aeolian processes were taking place as well.

An analysis of the soils in the plains has shown that the parent materials of these soils consist mainly of sediments from unconsolidated basement rocks (van Kekem, 1983). Some volcanic ashes can be found as well. Only very close to the lavas does one find a higher component of volcanic materials. Here the proportion of fluvial volcanic sediments is also much higher. It is not surprising to find a small amount of ash everywhere in the plains. Ashes are a volcanic product which are transported over short distances in the air. Probably wind conditions were not very different from the present day. Prevailing westerly winds must have transported ashes from Mt. Marsabit and the Hurri Hills onto the plains.

Sobania (1979) states that there was a lake, several metres deep, as late as 2,000 years ago. Other workers have postulated a very high lake level for lake Turkana for approximately the same period. Drying out of lakes in a changing climate seems to occur quite fast, as most recent reports from Lake Aral (U.S.S.R.) confirm. Detailed research is continuing, but it is clear that there was a much bigger lake at the site of the Chalbi syncline during the wetter periods of the Pleistocene.

Volcanic activity has not been dated accurately yet either. From its appearance Mt. Kulal is probably the oldest volcano of the area. It follows the general direction of the East African Rift Valley. Several fault lines can be identified following the same trend. Smaller vents show that there was still activity during the Pleistocene. These small hills are hardly dissected at all.

Mt. Kulal determines a great deal of the course of Balesa Kulal which flows almost exactly at the edge of the lava leading it to the erosion level of the Chalbi. The Asie Mountains seem to be younger than Mt. Kulal as they are less dissected and the volcanic forms are better presented. Therefore all of these must have been active at a later stage of the Pleistocene. Volcanic lavas and ashes are normally highly permeable. That is why one rarely finds river beds coming from the wet mountains. The lavas, ashes, tuffs, etc. from Mt. Marsabit and also the Hurri Hills partly cover the deposits, namely shales and limestones, and protect them from erosion. Pebbles baked in the limestone prove that volcanic activity took place when the Lake (Palaeo-Chalbi) was in existence. The lake deposits covered by lava are partly metamorphosed (marbles).

The escarpment near Kargi varies between 10 and 15 m but only 1-2 m of it is composed of volcanic materials. The deposition of such a thickness of lake sediments cannot be done in a short time. Because clear profiles are not visible one cannot see if different phases could be submerged. Also the extent of the lake is unknown. The lake deposits at Olturot and near Illaut are at different levels but tectonic uplifts must be taken into consideration. Towards the south, lake deposits do not appear but they might be covered by Quaternary sediments. Bore profiles at Loglogo, Korr, Halisruwa and in the Hedad (Figure 12) show lava at a certain depth. This means that the extent of the lava flows is greater than is visible. The implications of this for ground water hydrology will be discussed later.

Close to Maikona there are deposits of sandstone at the surface which could not be dated. Presumably they belong to the Tertiary or early Pleistocene but they could also have been formed earlier. Due to their limited extent they are not of great importance. So far Lake Turkana has been excluded. Some of the *laggas* on the western side of Mt. Kulal send their waters to this lake. Also there are a number of permanent springs along fault lines. Because Lake Turkana is on the very western border of the study area, and because of the complexity of the area and lack of time, little research has been done here.

Many problems concerning the geology of the area remain unsolved. It should be repeated that these outlines are tentative: they are a working model which can explain some of the questions raised about the hydrology of the area but they also raise many new questions.

4. DRAINAGE

There are a number of drainage lines all over the study area. They can be divided into three major groups:

- *laggas* in the basement mountains;
- *laggas* in the volcanic mountains;
- *laggas* in the plains.

It is possible for one *lagga* to belong to two of these groups. For example, Ngurunit and Arsim Rivers have their origin in the basement mountains and afterwards flow for a considerable distance in the sediments of the plains.

The drainage lines are determined by a number of factors:

- The actual climate, which determines the fluvial processes involved;
- The past climate (until the middle Tertiary) which determined the earlier form of the riverbed;
- The relief which determines the direction of the flow;
- The lithology of the area which determines infiltration, direction, etc.

Using these categories the IPAL area can be divided into 11 different catchment basins and the base level of the Chalbi desert (see Figure 6). The catchment areas cannot all be shown on the map in detail. Of course, they do not correspond with the boundaries of the IPAL area which are mainly straight lines. A map showing all the catchment areas which influence the IPAL area would extend from the Ethiopian highlands in the north to the Maralal-Wamba area in the south.

4.1 The Hurri drainage areas

These drainage areas have a large number of *laggas* mostly originating from the top of the Hurri Hills. There are a number of sub-divisions determined by the general slopes of the Hurri Hills. Because of the high permeability of the volcanic rocks few of the *laggas* reach the base level (Chalbi basin, Dida Galgullu, etc.). Riverbeds are often covered with boulders but there is also a high sandy component. None of these *laggas* has been monitored for discharge rate because of the remoteness of the Hurri Hills.

4.2 The northern Chalbi

This catchment area consists mainly of volcanic plains and plateaus partly covered with sand and active dunes. High infiltration rates do not allow high run-off but high flows are possible during heavy rainstorms. Run-off systems from the northern slopes of the Asie Mountains join the *laggas* of the plains which are clearly divided from the northern part of the Chalbi Basin. The high permeability is shown by the *laggas* from the Bura Galadi Hills which disappear in the foot hills. Due to the limited rainfall in this area the amount of infiltrated water for aquifer recharge is limited.

4.3 The middle Chalbi and Balesa Kulal

These catchment basins extend from the Chalbi desert (base level) to the Nyiru Mountains in the south. They are also determined by Mt. Kulal and the Asie. Balesa Kulal is the most prominent run-off system in the IPAL study area. It derives from the wetter Nyiru Mountains and follows closely the eastern border of the lavas from Mt. Kulal and Asie. The riverbed is often very broad with several islands and its length is about 150 km. Tributaries come from the basement mountains (Nyiru, Ol Donyo Mara) and from the eastern volcanic mountains as well. The riverbed is rarely completely filled with water. Heavy floods occur only episodically (once a century, perhaps). Monitoring discharge in broad sandy rivers like the Balesa Kulal is very difficult. Since the river gauge was placed it has only been touched by water once.

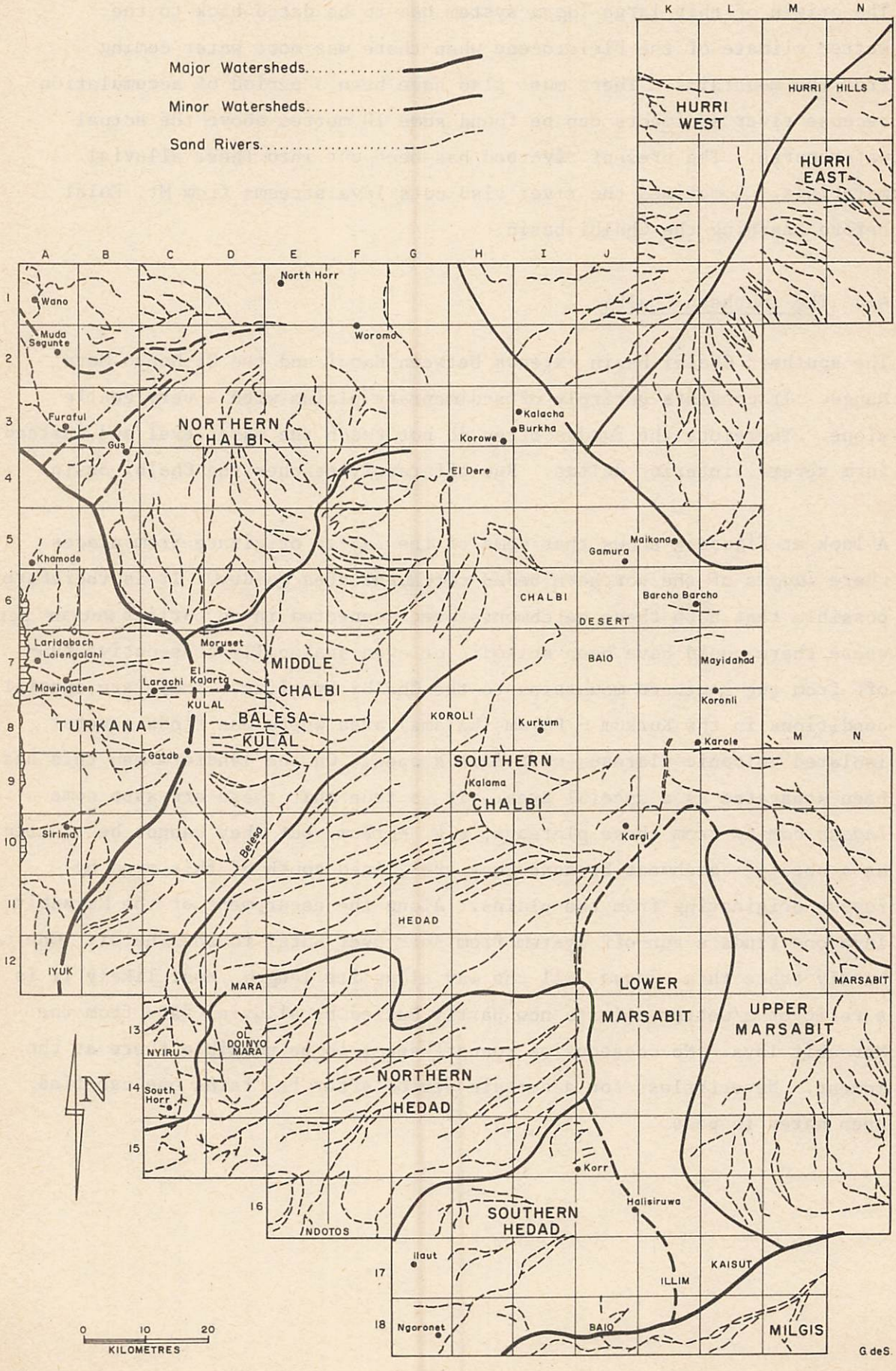
The origin of this large *lagga* system has to be dated back to the wetter climate of the Pleistocene when there was more water coming from the mountains. There must also have been a period of accumulation because river sediments can be found some 10 metres above the actual watercourse. The present riverbed has been cut into these alluvial materials. Sometimes the river also cuts lava streams from Mt. Kulal before reaching the Chalbi basin.

4.4 The southern Chalbi

The southern Chalbi basin extends between Kargi and the Ol Donyo Mara Range. It consists entirely of sedimentary plains with a very gentle slope. Therefore the *laggas* often do not reach the base level and instead form several interior deltas. Run-off rarely reaches the Chalbi Basin.

A look at Figure 6 shows that some of the *laggas* originate from places where *laggas* of the northern Hedad catchment area go dry. It is therefore possible that both these catchments were connected in an earlier wetter period where there could have been episodic or even seasonally consecutive run-off from the southern mountains to the Chalbi syncline. There are special conditions in the Kurkum - Falam (Kalama) area where one finds several isolated volcanic plateaus with foot slopes. On the landform map this has been separated as a special area. It is true that there are also some *laggas* coming from these plateaus, e.g. Kurkum, but they cannot be treated as a special catchment because they are joined south of this area by *laggas* originating from the plains. Along the escarpment of the Marsabit lava one finds a run-off system from Korr over Kargi to the Chalbi. One can hardly trace this *lagga* all the way along its length. Most likely it is a relic of a wetter climate now partly buried by alluvial fans from the Marsabit lava. No consecutive run-off seems to be possible there at the moment. Nevertheless for a certain period after the rains one can find open water in pans.

Figure 6. Watershed map of the IPAL study area



4.5 The northern Hedad and the southern Hedad

These catchment areas are more complex than the others and are related to the neighbouring southern Hedad areas. Most of the *laggas* originate from the southern basement mountains of Ol Donyo Mara and the Ndotos as well as from the isolated Mt. Baio. In the mountains they are mainly covered by boulders of different sizes. In the foreland sands prevail but there are also clay areas. There, water can stay for some time because of the very low permeability. Often the entire river bed is covered by *Duosperma* dwarf shrubs. Some of the *laggas* in the northern Hedad join the above-mentioned *lagga* at the Marsabit lava escarpment. In the upper parts of the *laggas* run-off continues into the dry seasons for some time (see discharge characteristics of Ngurunit River). Most of the *laggas* of the southern area can be followed towards the Halisurwa area where there is a local base level (Ugo swamp on topographic maps). Only during heavy rains is the base level reached. Very few *laggas* originate from the Korr Hills. They are cut 2-5 m into the basement rock which is certainly not part of the present fluvial process (Korr mean annual rainfall 235 mm). The river beds follow tectonic fault lines or fractures.

4.6 The Milgis system

The Milgis system does not originate in the IPAL study area but in the wetter parts of the Mathews range and the Maralal area. It is the only part of the study area which does not belong to the endorheic catchments of the Chalbi basin and the Turkana area. Theoretically, run-off to the Indian Ocean is possible but not under present climatic conditions. The watershed between the Milgis and Chalbi drainage systems is hardly visible on the landscape but could be traced from maps, aerial photographs and satellite images. The Milgis itself is a typical *wadi* with 2-5 m high river banks. The Milgis could be called an allogenous *lagga* because there is sometimes run-off in the northern dry season which originates from an intermediate rainy season in the Maralal-Wamba region.

4.7 The Turkana basin

All of the *laggas* on the western side of Mt. Kulal run towards Lake Turkana (lake level approximately 370 m, 1968). Due to the rainshadow effect this area is so dry that there is hardly any continuous run-off. Because of the volcanic rocks* the infiltration rate is very high. A high percentage of the waters infiltrates and comes back to the surface in a number of springs.

4.8 Lower and upper Marsabit

The lower plateaus of Mt. Marsabit do not have any prominent run-off system. Low rainfall and the high permeability of the volcanic rocks allow only short erosion rills and gullies. On the upper plateaus there are several *laggas* but none of them goes down very far on the western slope. This is different to the southern, and especially the eastern slopes, where there is higher rainfall. Also the forest there influences the surface run-off because it stores the water and stretches the time of discharge. One finds a lot of boulders in the *laggas* but there is also a high sandy material component.

4.9 The Chalbi basin

The Chalbi basin forms the base level for almost 80% of the IPAL study area. Most of the water courses are directed to this sedimentary syncline between the Kenyan and Ethiopian domes. Few of the surface waters reach this old lake bed because they infiltrate or evaporate. Nevertheless, in the rainy season quite a large amount of water concentrates in this deepest area. The area becomes muddy and cannot be crossed by cars. In some places there are open ponds. Also there are a number of run-off lines in this vegetation-less area, which show that not only accumulation but also erosion is present here. It should be noted that the Chalbi Desert is not one of the driest parts of the area. That there is no vegetation is a result of the high salt content of the soil (van Kekem, 1983).

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* In geology the term 'rock' also means loose materials.

4.10 The major catchment areas

Using the polygon method the extent of the major catchment areas has been determined (Table 4).

Table 4. Extent of catchment areas

Drainage region	Area in km^2	Total Area %
Hurri west	1,750	7.7
Hurri east	1,850	8.1
Northern Chalbi	2,250	9.7
Middle Chalbi Balesa Kulal	2,150	9.3
Southern Chalbi	2,400	10.5
Turkana	1,750	7.6
Central Hedad	2,300	10.0
Southern Hedad	1,150	5.0
Milgis	450	1.9
Lower Marsabit	2,300	10.0
Upper Marsabit	1,450	6.3
Chalbi basin	3,200	13.9
Total	23,000	100

4.11 Lakes

There is one permanent lake at the western boundary of the study area - Lake Turkana. It is a Rift Valley lake, with most of its waters coming from the Ethiopian highlands. The lake level was noted as approximately 370 m in 1968. Fluctuations were quite common during the geological past, as shown by lake terraces, but they also occur now. Otherwise there is only one seasonal lake south of Baio which lasted over the first dry season of 1983 because there was heavy rainfall during the second wet season of 1982. This lake is close to the Milgis River and is sometimes filled by water from the Milgis. In the first wet season of 1983 there

was a lake in a clay depression on the lava east of Kargi. This one occurs only episodically. During the rains and some time afterwards there are also smaller lakes in several of the deep craters on Mt. Marsabit where these are sealed by a high silt content of the soil (see van Kekem, 1983).

During the rains surface water occurs all over the area. The distribution is highly irregular. Aerial surveys show this quite well. Some figures of this can be found in Lusigi (1981).

5. INFILTRATION AND RUN-OFF

Infiltration capacity or potential infiltration is the maximum rate of movement of water into the soil. If rainfall is higher than this value the result will be a certain amount of surface run-off which is also determined by the amount of evaporation/evapotranspiration. So far no infiltration measurements have been carried out in the IPAL area. Therefore one has to rely on various formulae to get an approximate idea of the amount of infiltrated water. This is very important for obtaining information on the recharge of the different aquifers. Not only is rainfall a source of infiltrating water but also run-off water.

Several formulae have been developed to describe the infiltration of water into the soil. A very suitable one which has been used successfully in the Sahel is given by de Ridder.

$$i = \frac{s}{2\sqrt{t}} + k_s \qquad (1)$$

where

i = infiltration capacity of the soil in mm of water per hour
s = absorption capacity of the soil
k_s = conductivity of saturated soil in mm of water per hour
t = time in hours

Sand has to be determined by experiments or, as in this case, from figures for similar soils in the tropics.

Table 5 gives examples for infiltration in a sandy soil. The figure shows that the infiltration diminishes with time. This means that run-off increases when the rainfall intensity remains constant. From this formula it is easy to determine the theoretical run-off. This is a theoretical figure because in the field soil conditions change from place to place quite frequently. Hard rocks, for example, have no infiltration capacity but a run-off of almost 100%. The run-off under constant rainfall is determined as follows:

$$\int_{t_0}^{t_i} c\,dt - \int_{t_0}^{t_i} \left(\frac{s}{2\sqrt{t}} + k_s\right) dt - E_t = R \qquad (2)$$

where

R = run-off
C = rainfall intensity
t_0 = start of rainfall
t_i = end of rainfall
E_t = evapotranspiration

It is not easy to describe a normal rainstorm with a formula but sometimes it should be possible. Then the run-off is:

$$R = \int_{t_0}^{t_i} f(t)\,dt - \int_{t_0}^{t_i} \left(\frac{s}{2\sqrt{t}} + k_s\right) dt - E_t \qquad (3)$$

$$= \int_{t_0}^{t_i} \left(f(t) - \left(\frac{s}{2\sqrt{t}} + k_s\right)\right) dt - E_t$$

A rainstorm with an intensity of 25 mm/h and a duration of 4 h will produce 100 $1/m^2$. A run-off figure of 40% is quite realistic. That means that 60 $1/m^2$ will infiltrate while 40 1 will run off. The amount lost by evapotranspiration still has to be subtracted from these 40 1. Due to the often isolated character of rainstorms the run-off water soon reaches areas where the soil has a higher infiltration capacity and will infiltrate there.

Also a 100 mm rainstorm does not occur very often.

Table 5. Calculated infiltration rates for the IPAL area

Mean annual rainfall (mm)	Area (km^2)	Total amount of water (m^3)	Infiltrated water (m^3)
150	2,700	4.05×10^8	1.62×10^8
200	14,100	2.82×10^9	1.128×10^9
250	2,500	6.25×10^8	2.5×10^8
300	1,800	5.4×10^8	2.16×10^8
400	1,500	6×10^8	2.4×10^8
Total		4.99×10^9	1.996×10^9

After the first rain there is already water in the soil so that the infiltration capacity is less. In an ideal case it would be possible to determine the water balance for a minor catchment by simple calculation by recording only rainfall, stream run-off and, possibly, evapotranspiration. But even for a small catchment like the Ngurunit basin with an area of 168 km^2 this is impossible because rainfall varies greatly with the different altitudes of the surrounding mountains. In the smaller catchment areas of the plains this is not so but here very often rainstorms are localized and therefore cover only parts of the catchment.* There are other factors influencing infiltration and run-off which can be summarized as follows:

- Rainfall intensity;
- Infiltration capacity;

* IPAL has started catchment trials at various locations. The aim is to determine the run-off rate for various soils as well as to determine the impact of vegetation and grazing. But the results are still too few to discuss here.

- Slope of the site and the physical and biological factors of the same site.

For example, there would be no infiltration on a lava boulder, but quite often the rain drops (low intensities only) evaporate when they hit the stone.

The total amount of water which infiltrates in the IPAL area has been determined to be almost 2×10^9 m^3, assuming an infiltration rate of 40% and a mean annual rainfall as indicated in Figure 1 . If we made a conservative estimate of only 20% infiltration the total amount of water infiltrating would still be 10^9 m^3. But, as will be shown in a later section, not all this water can be exploited.

6. SURFACE WATER

Except in the mountain areas open surface water can only be found during the wet seasons. Its occurrence is, therefore, highly variable depending on rainfall. Some aspects were discussed in the section on drainage.

6.1 The distribution of surface water

The distribution of surface water was recorded during the aerial surveys for the IPAL livestock census (Table 6).

Table 6. Number of spots of open surface water as recorded by aerial surveys.

Flight dates	Number of spots		
(a) Dry season			
July 1977	6	$\bar{x}$ = 8	v = 35 (limited value due
August 1977	10	δ = 2.8	to very small sample size).
(b) Wet season			
March 1977	65	$\bar{x}$ = 24.7	v = 87.6 (highly variable)
October 1978	7	δ = 21.6	
January 1976	15		
June 1977	33		
October 1977	12		
April 1979	16		v = coefficient of variation

Most of the flights show that open surface water is more common in the northern part than in the south, which is surprising because the north gets less rain. This might be influenced by water from the *laggas* which creates local ponds in their course after the real run-off has finished. Also local rainfall events can modify the picture. It is obvious that range management cannot rely on open surface water except in the western part of the IPAL area where Lake Turkana is situated.

It is not certain that the seasonal lake south of Baio is a reliable water source in the dry seasons. In 1982, for example, after the first wet season it dried up. It seems that the lake depends not only on local rainfall but also on floods of the Milgis. Feeding of the lake is on the surface as well as subterranean. Further research is necessary here.

In May 1983 another lake was recorded east of Kargi on the lava where there is a pan sealed by high silt content of the soil. So far this lake occurs rarely and therefore has to be classified as episodic. It cannot be seen as a reliable water source.

6.2 Run-off characteristics of the *laggas*

The *laggas* (local name for seasonal/episodically dry water sources) have special run-off characteristics comparable to the *oueds* of North Africa or the *wadis* of Arabia.* However, we have to differentiate the *laggas* originating in the volcanic and basement mountains as well as those originating in the plains. Because of the dense vegetation (caused by the higher rainfall) *laggas* in the basement mountains have a longer period of run-off which continues after the end of the rainy season. Hermann (1977) has made a simple model which describes the processes in the catchment basin (Figure 7).

One should not forget that most of the time it is difficult to get data for the different parameters and that in an arid environment long-term (at least 5 years) data are required. There are a number of river gauges in the IPAL area and for most of them discharge rating curves exist (Ongweny, 1983). The vastness of the area makes it almost impossible to read every gauge when there is run-off, however, only the gauges near IPAL stations are read. These are Ngurunit and Olturot (Balesa Kulal). Unfortunately the Balesa Kulal gauge was touched by water only once. Therefore only the Ngurunit results can be presented here.

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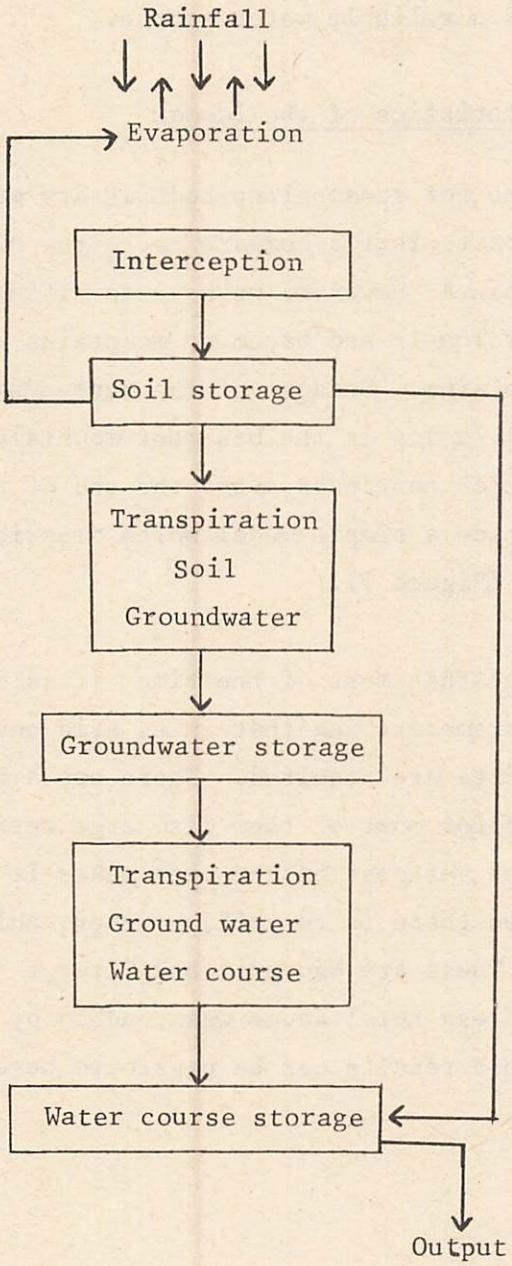
* In fact *oued* and *wadi* are both derived from the same Arabic word. The term *lagga* is limited to northern Kenya.

Figure 7. Model of water flow directions in the catchment area using linear stores



Source: Hermann, 1977

The advantage of this model is its simplicity. Outflow is always proportional to the amount of stored water.

$$s = k.q \qquad (1)$$

where

s = storage

q = outflow

k = storage constant factor

Also the continuity equation is valid

$$p = q + \frac{ds}{dt} \qquad (2)$$

where

q = outflow

p = inflow

s = storage

It follows from (1) and (2) that the differential equation for each store is:

$$p = q + k \frac{dp}{dt} \qquad (3)$$

which can be solved by the function

$$q(t) = e^{-t/k} \left(\frac{1}{k} \int_{t_0}^{t_i} p(\tau)\, e^{t/k}\, dt + q(t_0)\, e^{tdk}\right) \qquad (4)$$

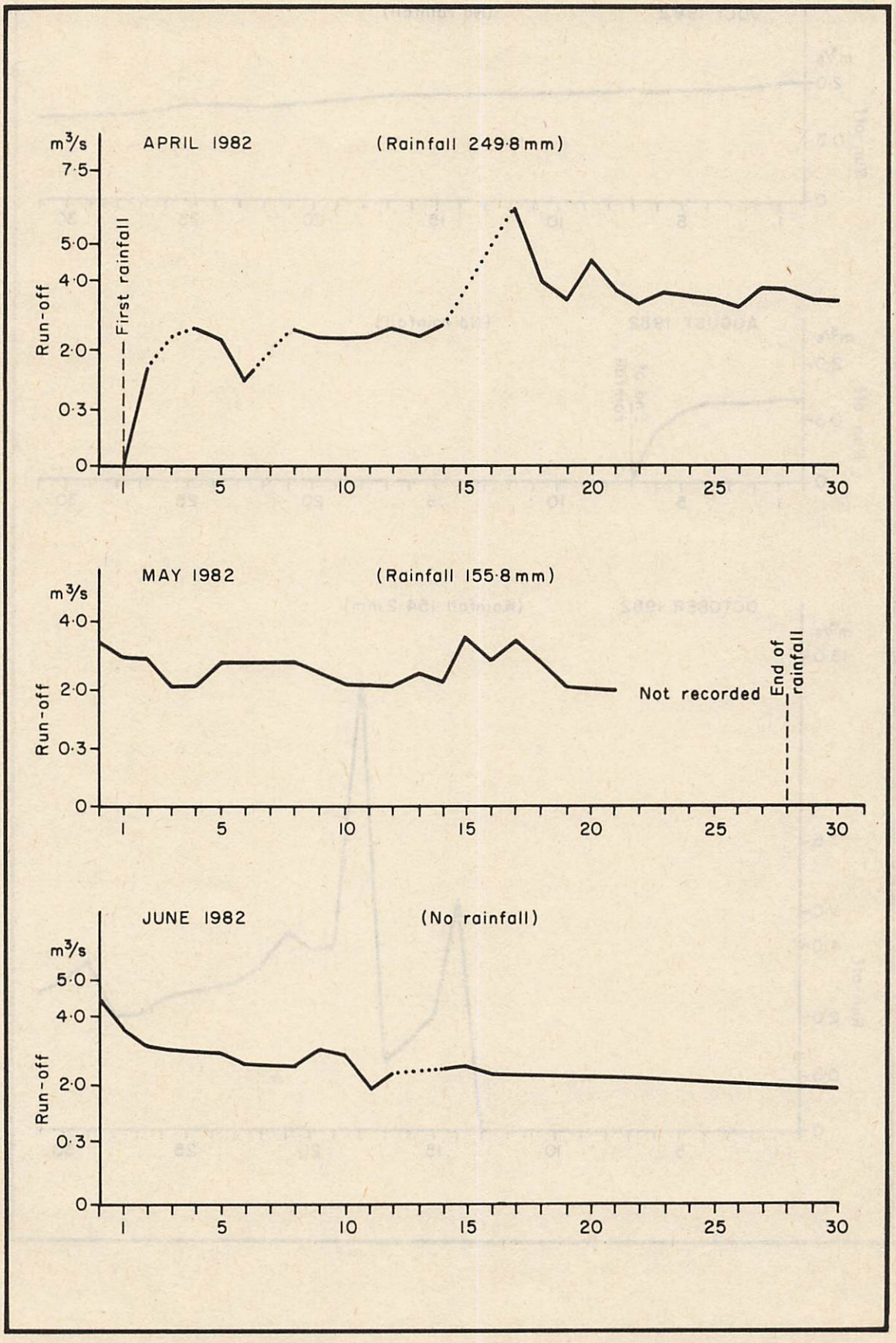
The Ngurunit River is one of the major *laggas* coming from the basement mountains. The upper course is mainly covered by boulders and partly steep with rapids and whirlpools. A few hundred metres behind the IPAL camp the river changes its character completely now flowing in its own sediments - mainly coarse sand and sand. Sometimes it cuts through basement. outcrops. Approximately 8 km downstream of the IPAL station (road crossing) the Ngurunit River forms an interior delta where most of the water infiltrates and some evaporates. No diurnal changes have been observed so far.

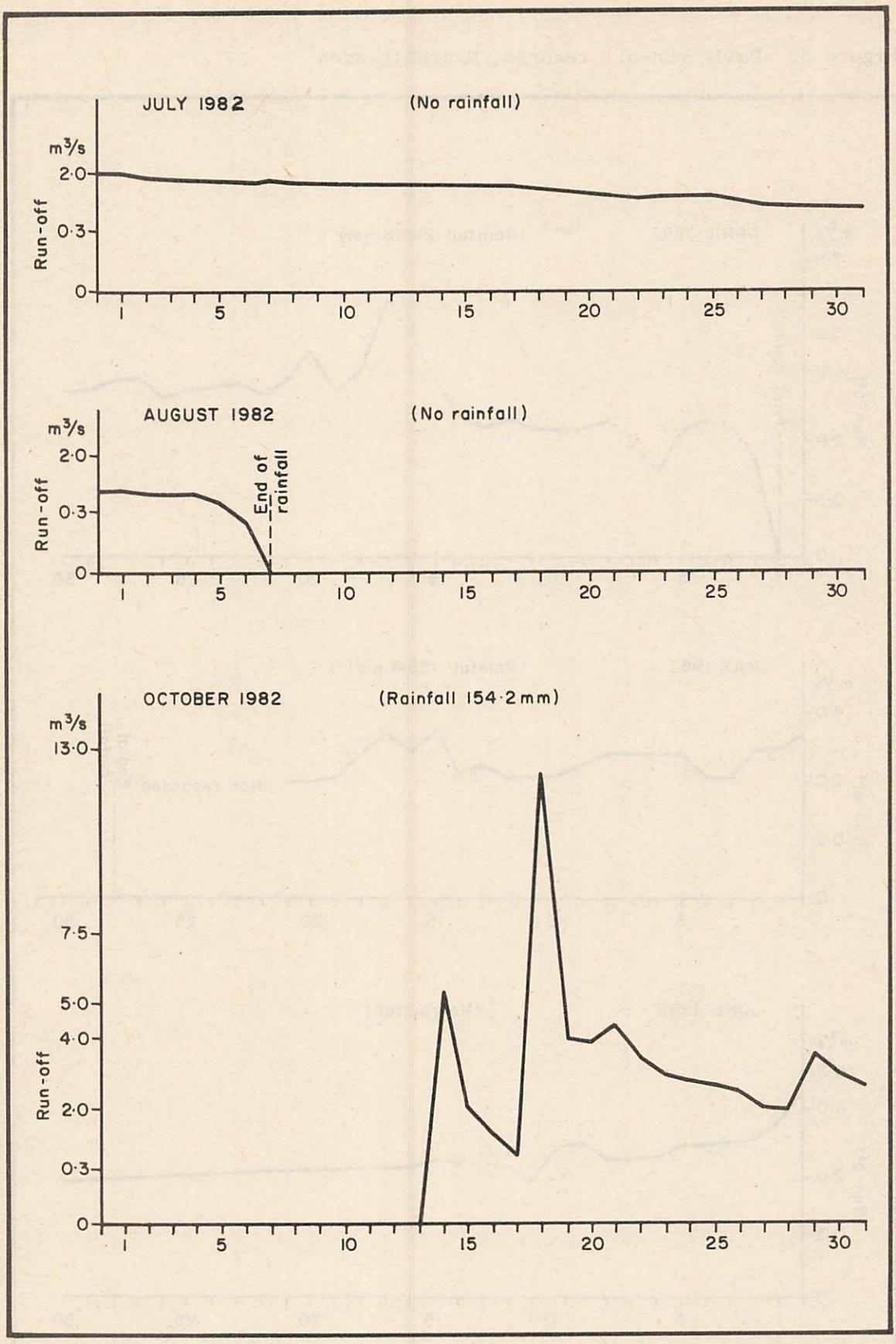
Upstream of the river gauge there are no major tributaries. Ongweny (1983) estimated the whole catchment area towards the outlet of the basin at 100 km^2 but did not include a major tributary coming from Mt. Boi. Including this, the catchment area from the mountains to the outlet of the basin at Lependera is some 168 km^2. The river gauge close to the IPAL camp has a catchment of some 20 km^2, about half of it being classified as forest. This is a very small catchment area, nevertheless a lot of information can be obtained here, especially when one considers the importance of the mountain *laggas* for the recharge of the different aquifers of the plains and even of the Chalbi syncline.

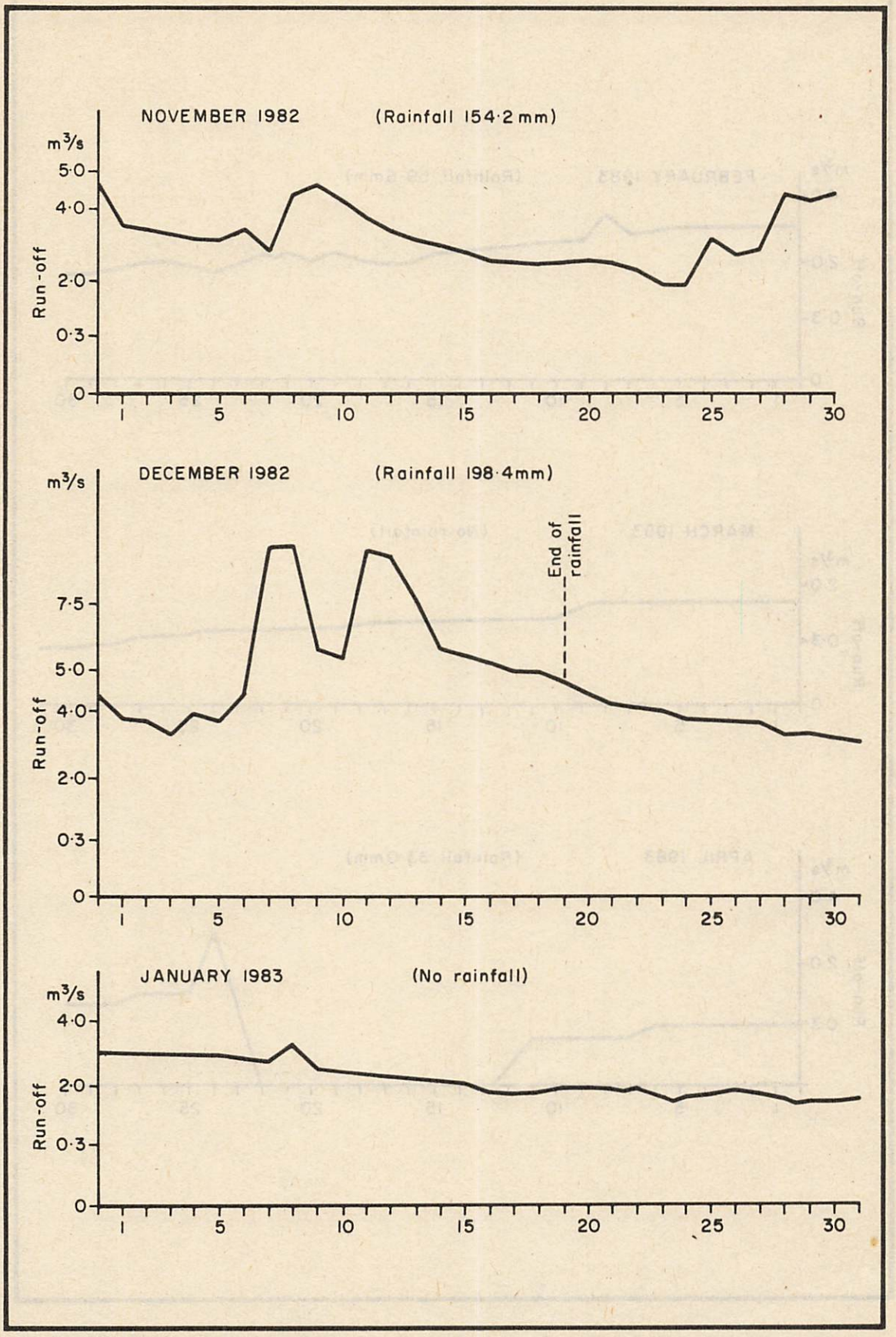
The daily and monthly discharge rates of the Ngurunit River are shown in Figures 8 and 9 which also show the rainfall of the respective period. It should be noted that the amount of rainfall in the upper parts of the catchment is much higher; it increases with altitude. The peaks of the Ndotos in the area are around 1,800 m high. From the vegetation composition and comparison with other higher highland stations rainfall should be more than 800 mm/a, while Ngurunit has about 500 mm.

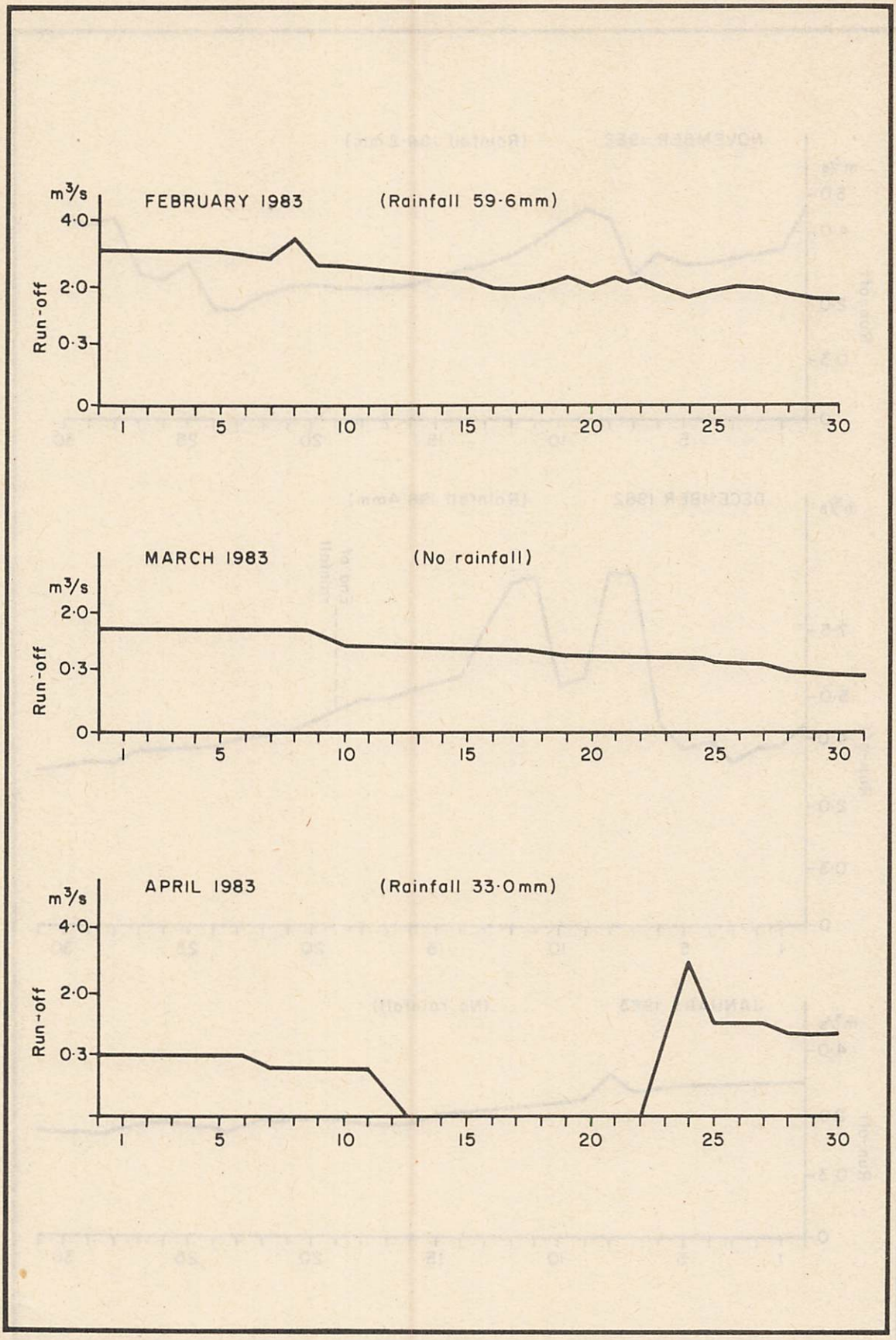
Figure 9 shows the high correlation between discharge and rainfall. Normally the first rains will not cause any significant run-off. Most of the rainfall water will evaporate or infiltrate the soil, which is almost completely dry, and be stored there. Heavy rainfall in April 1982 also caused heavy run-off - about 3.2 m^3/s on average. There were 15 days with rain in that month. The fact that the rainfall in the upper catchment is much higher than at Ngurunit station is proved by the comparison of rainfall figures and measured run-off which is almost double the amount. Also one has to remember that a lot of water is stored by interception. The calculation for the 5 months of run-off during the first rains gives a mean area rainfall of 1,300 mm which is high. In the upper parts of the mountains moisture is also obtained from clouds and fog. Hermann (1977) states that this can be as much as 4 mm/h. Clouds are quite common in the upper parts of the Ndoto Mountains. It has been observed that the Ngurunit River reacts directly to this. Even when there was no rainfall in the mountains the river rose by a few centimetres.

Figure 8. Daily run-off records, Ngurunit area




JULY 1982
(No rainfall)
m³/s
2·0
0·3
0
Run-off
1
5
10
15
20
25
30
AUGUST 1982
(No rainfall)
m³/s
2·0
0·3
0
Run-off
End of rainfall
1
5
10
15
20
25
30
OCTOBER 1982
(Rainfall 154·2 mm)
m³/s
13·0
7·5
5·0
4·0
2·0
0·3
0
Run-off
1
5
10
15
20
25
30


NOVEMBER 1982
(Rainfall 154·2 mm)
m³/s
5·0
4·0
2·0
0·3
0
Run-off
1
5
10
15
20
25
30
DECEMBER 1982
(Rainfall 198·4mm)
m³/s
End of rainfall
7·5
5·0
4·0
2·0
0·3
0
Run-off
1
5
10
15
20
25
30
JANUARY 1983
(No rainfall)
m³/s
4·0
2·0
0·3
0
Run-off
1
5
10
15
20
25
30


FEBRUARY 1983
(Rainfall 59·6mm)
m³/s
4·0
2·0
0·3
0
Run-off
1
5
10
15
20
25
30
MARCH 1983
(No rainfall)
m³/s
2·0
0·3
0
Run-off
1
5
10
15
20
25
30
APRIL 1983
(Rainfall 33·0mm)
m³/s
4·0
2·0
0·3
Run-off
1
5
10
15
20
25
30

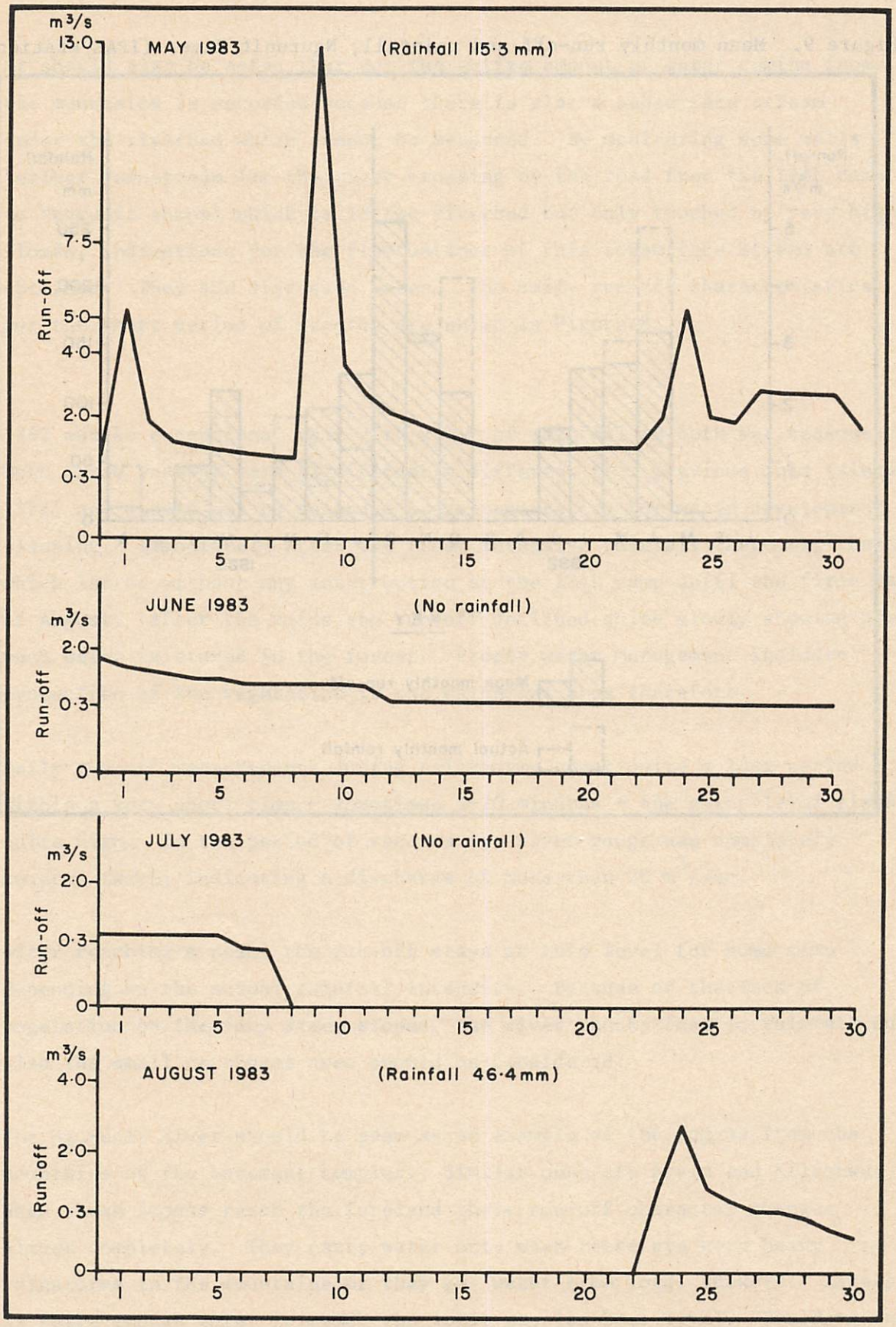
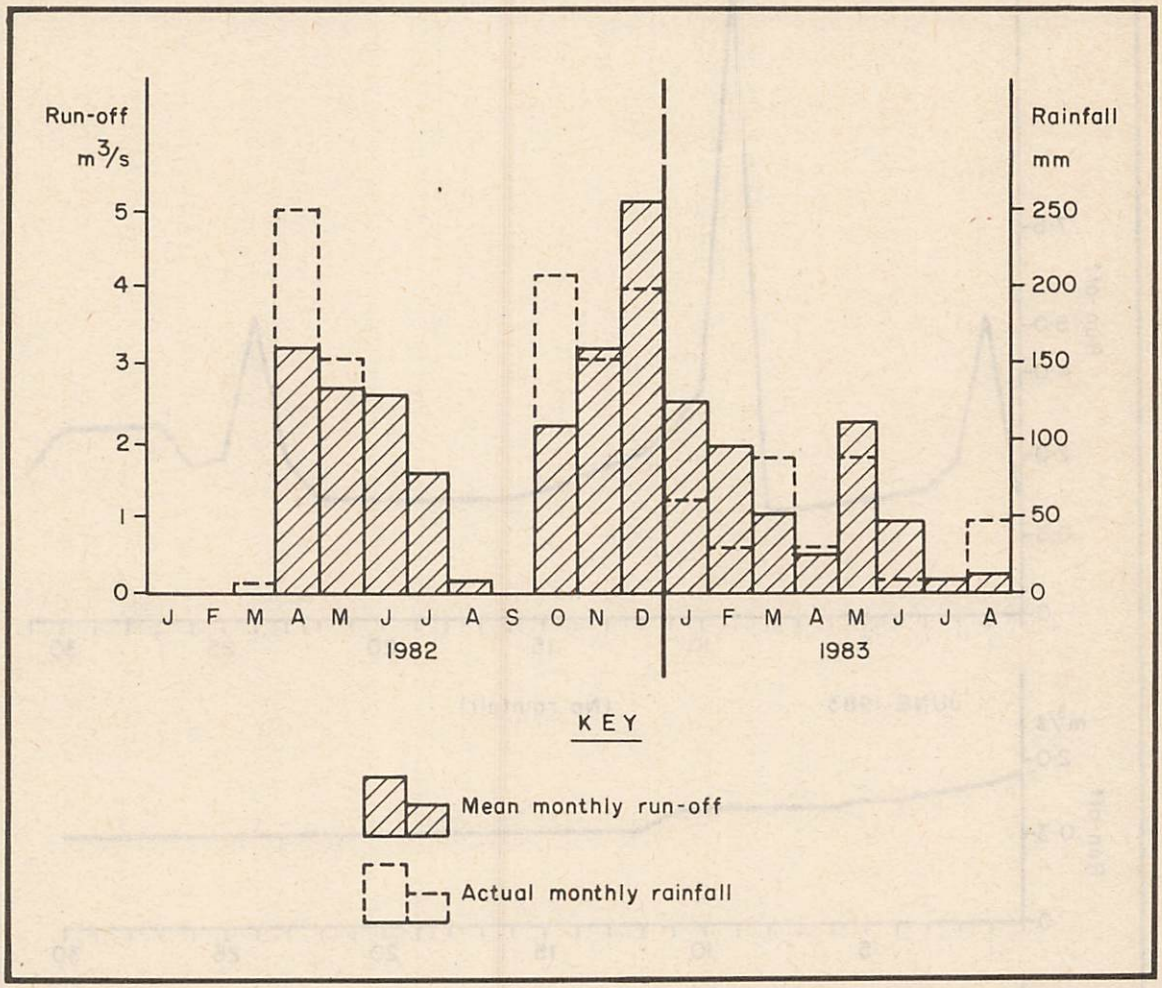

m³/s
13·0
MAY 1983
(Rainfall 115·3 mm)
7·5
Run-off
5·0
4·0
2·0
0·3
0
1
5
10
15
20
25
30
JUNE 1983
(No rainfall)
JULY 1983
(No rainfall)
AUGUST 1983
(Rainfall 46·4mm)

Figure 9. Mean monthly run-off and rainfall, Ngurunit River (IPAL station)



It should also be noted that not the entire amount of water coming from the mountains is recorded because there is also a subsurface stream under the riverbed which cannot be measured. By monitoring some wells further downstream (at the river crossing by the road from the IPAL camp to Ngurunit shops) which is in the riverbed but only touched by very high floods, indications for the fluctuations of this subsurface stream are obtained. They are discussed later. The daily run-off characteristics for the short period of records are shown in Figure 8.

1982 was an exceptional year with a lot of rainfall in both wet seasons. Both these seasons were significantly different from previous ones (since 1976) and should not be regarded as representative for water development planning. Immediately after the first intensive rainfall there was run-off which lasted without any interruption at the IPAL camp until the first days of August. After the rains the run-off declined quite slowly showing how much water is stored in the forest. Proper water management includes protection of the vegetation in the catchment area therefore.

Daily run-off measurements during rainstorms cover quite a long period. Within a very short time - sometimes 5-20 minutes - the water level rises quite high. In the period of records the river gauge was completely covered twice, indicating a discharge of more than 20 m^3/sec.

After reaching a peak, the run-off stays at this level for some time depending on the actual rainfall intensity. Because of the lack of vegetation on the very steep slopes, the river reacts fast to rainfall but also the small catchment area should be considered.

The Ngurunit River should be seen as an example of the *laggas* from the mountains of the basement complex. Similar ones are Arsim and Kileshwa. When these *laggas* reach the foreland their run-off character changes almost completely. They carry water only when there are very heavy rainstorms in the mountains or they get water from local showers. Rarely is there enough water to reach the local erosion base level. Boulders and bigger stones are rare, even in the *laggas* of the Korr hills. Prevailing

particle size is sand to coarse sand. Base level for all the *laggas* except the Balesa Kulal is the alluvial plains where most of the water infiltrates and evaporates, if it reaches there at all.

The plain *laggas* north of this area (see Figure 7) have similar run-off characteristics. They only flow for a very short time after rain storms. The run-off rises very quickly to its maximum level depending on the amount and intensity of rainfall, and then decreases slowly.

7. SUB-SURFACE WATER

7.1 Introduction

Normally ground water resources can only be detected by using geophysical methods unless the ground water is so close to the surface that the vegetation shows its presence. Therefore IPAL commissioned two surveys which were carried out by Messrs. Borgeson and Ndombi. The results are published in IPAL Technical Report B-2 and will not be repeated here.

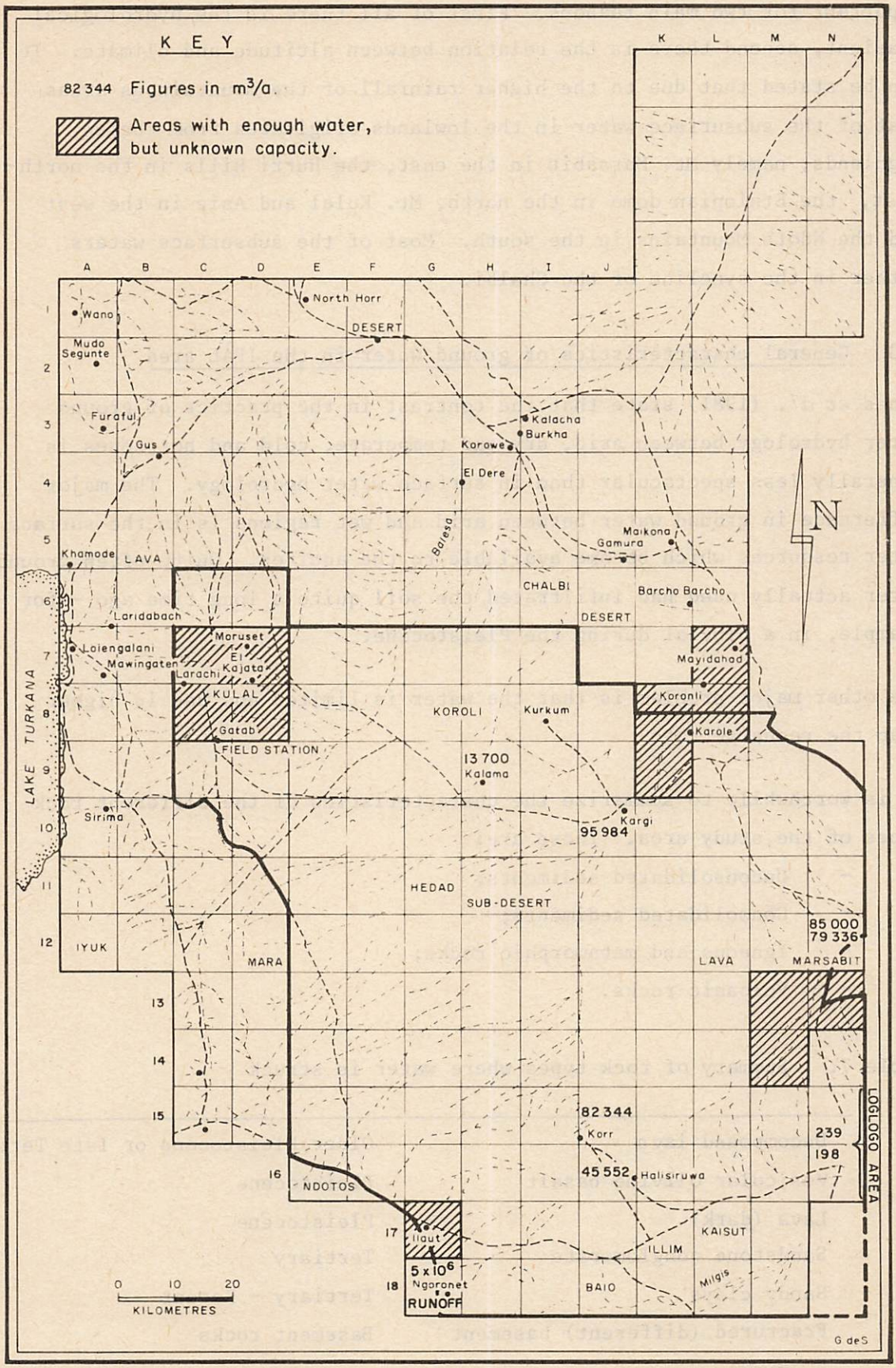
Ground water is the most important water resource in arid areas as surface water only occurs for a few days during the wet seasons. So the local people use the shallow aquifers. Beaman (1981) discussed in detail the different types of wells used by the Rendille. For camels they rely mostly on the springs at Korole which cater for most of the Rendille area. Temporary hand-dug wells are made in the sandy rivers. This type of well has the disadvantage that it has to be re-dug after every episode of run-off in the *lagga*. At Illaut some 20 of these wells become dry after every rainy season and are used for livestock watering. In other places these wells are rarely used for livestock but as a source for humans. Nowadays the Rendille tend to rely on the permanent boreholes drilled by the Kenyan Government or during the colonial period. (See Figure 10.)

7.2 The hydrogeological zones of the IPAL area

Hydrogeology is directly determined by the geology of an area. The geology of the IPAL area has been briefly outlined. There are three main hydrogeological units:

- The volcanic areas;
- The basement mountains and hills;
- The sedimentary plains of the lowland.

Figure 10. Water supply in the southern part of the IPAL area



Ndombi (1983, pp.298ff) has discussed this in detail and also presents a regional geological map. A tentative map of the different directions of water flow underground has been drawn and includes relief. Relief is important for two main reasons. First of all there is the hydrological gradient, second there is the relation between altitude and climate. It can be stated that due to the higher rainfall of the mountainous areas most of the subsurface water in the lowlands originates from these highlands, namely Mt. Marsabit in the east, the Hurri Hills in the north-east, the Ethiopian dome in the north, Mt. Kulal and Asie in the west and the Ndoto Mountains in the south. Most of the subsurface waters gather in the syncline of the Chalbi.

7.3 General characteristics of ground water in the IPAL area

Jones *et al.* (1981) state that the contrast in the practice of ground water hydrology between arid, dry and temperate, cold and hot zones is generally less spectacular than in surface water hydrology. The major difference in ground water between arid and wet regions is in the surface water resources which become available to the aquifer. Quite often ground water actually used had infiltrated the soil quite a long time ago - for example, in a pluvial during the Pleistocene.

The other major problem is that the water is limited and use is higher than the recharge rate.

It is worthwhile to summarize the characteristics of the different rock types of the study area. These are:

- Unconsolidated sediments;
- Consolidated sediments;
- Igneous and metamorphic rocks;
- Volcanic rocks.

Table 7. Summary of rock types where water is struck

Decomposed lava	Older Pleistocene or late Tertiary
Vesicular olivine basalt	Pleistocene
Lava (dark)	Pleistocene
Sandstone conglomerate	Tertiary
Sandy clays	Tertiary - Recent
Fractured (different) basement rocks	Basement rocks
Fractured basement	

The extent of unconsolidated sediments is only known in two dimensions. This is shown by the geomorphological maps of Bake (1983) and the soil map by Van Kekem (1983). It is not known to what extent the often very deep sediments are already consolidated or in a stage between consolidation and unconsolidation. Unconsolidated sediments can have quite high infiltration rates depending on the particle size. Generally, infiltration increases with particle size. If there is an impermeable layer underneath they can be seen as very good aquifers. Under and beside actual *laggas* there is usually an unconfined, often perched, aquifer seasonally or even episodically recharged from the run-off in the *laggas*. The occurrence of such water layers often depends on the presence of an impermeable clay layer underground. As the ground water flows following the hydraulic gradient it might leave the clay layer and infiltrate deeper layers of unconsolidated sediments. Almost no exploitable water can be found in dunes like the ones around the Chalbi. The rainfall water can infiltrate easily but it also easily reaches deeper aquifers or evaporates at a very high rate.

The consolidated sediments have much less water potential than the unconsolidated ones as the infiltration rate is lower and also the flow is very slow.

The igneous and metamorphic* rocks of the basement system have a very poor water potential because they are almost completely impermeable. Water can only be found in pockets where the rocks are fractured and/or weathered. Therefore the storage capacity is very limited. This is of great importance for areas like Korr where all boreholes are drilled in basement rocks. On the other hand the impervious basement rocks play an important role as they underlie the permeable sediments of the lowland plains and prevent the water from further infiltration. The location of boreholes in the IPAL area is shown in Figure 11.

From borehole logs (see appendices 1A and 1C in Ndombi, 1983) the major aquifers of the IPAL area have been determined. The logs are shown in Figure 12. It should be noted that the altitude of the land surface at the borehole site is not known.

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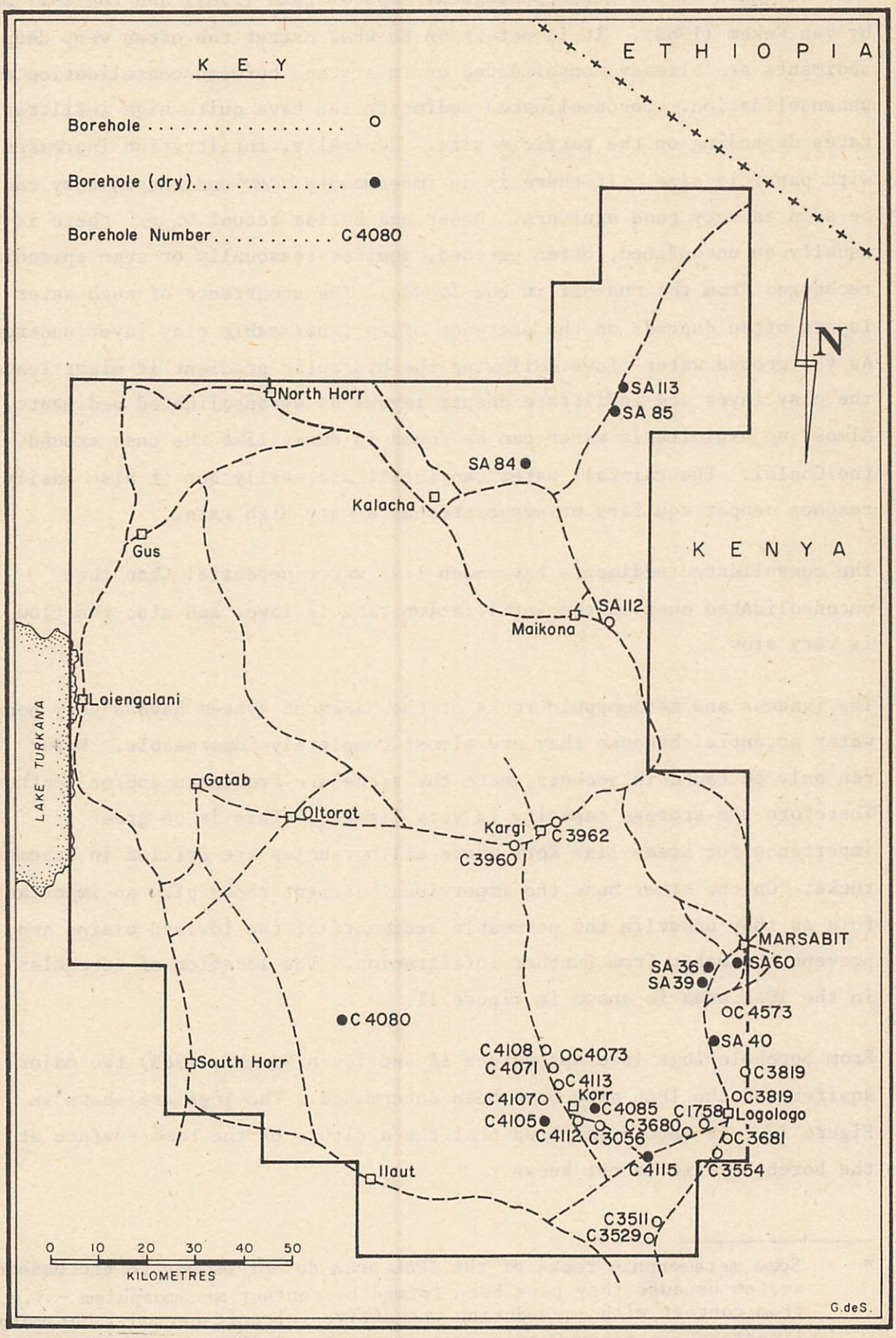
* Some metamorphic rocks of the IPAL area do not belong to the basement system because they have been formed by contact metamorphism - i.e. from contact with lava during the active volcanic period. Metamorphosed limestone (Tertiary-Quaternary) can be found close to Kargi at the escarpment of the Marsabit lava.

Figure 11. Location of boreholes in the IPAL area



Source: Naombi, J., 1983. (Slightly changed)

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.

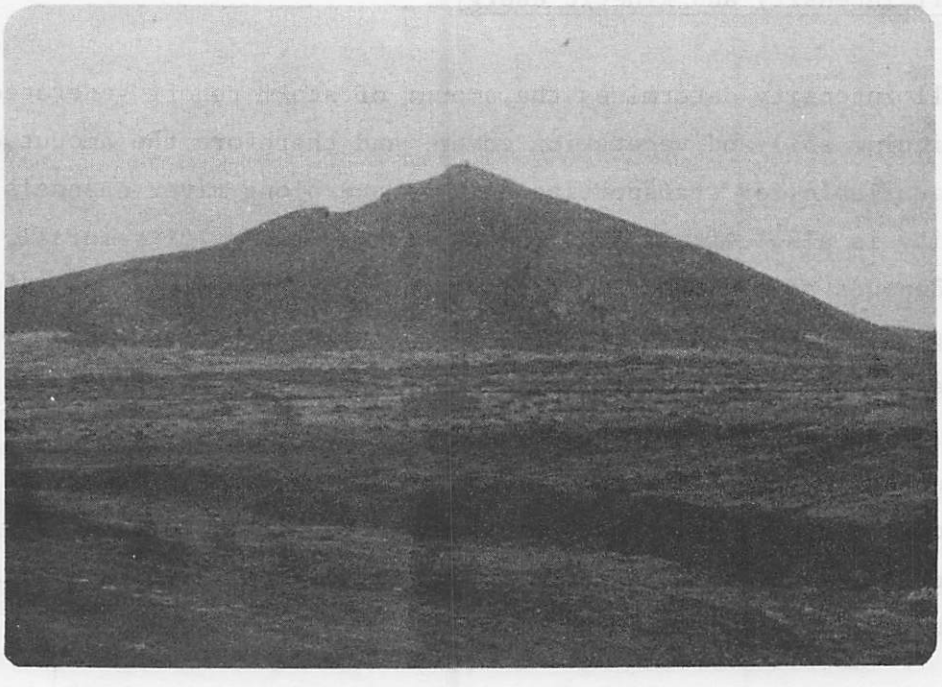


Figure 36. Unprotected Marsabit-Moyale road bank (4 km from Marsabit) is a major source of sediment.

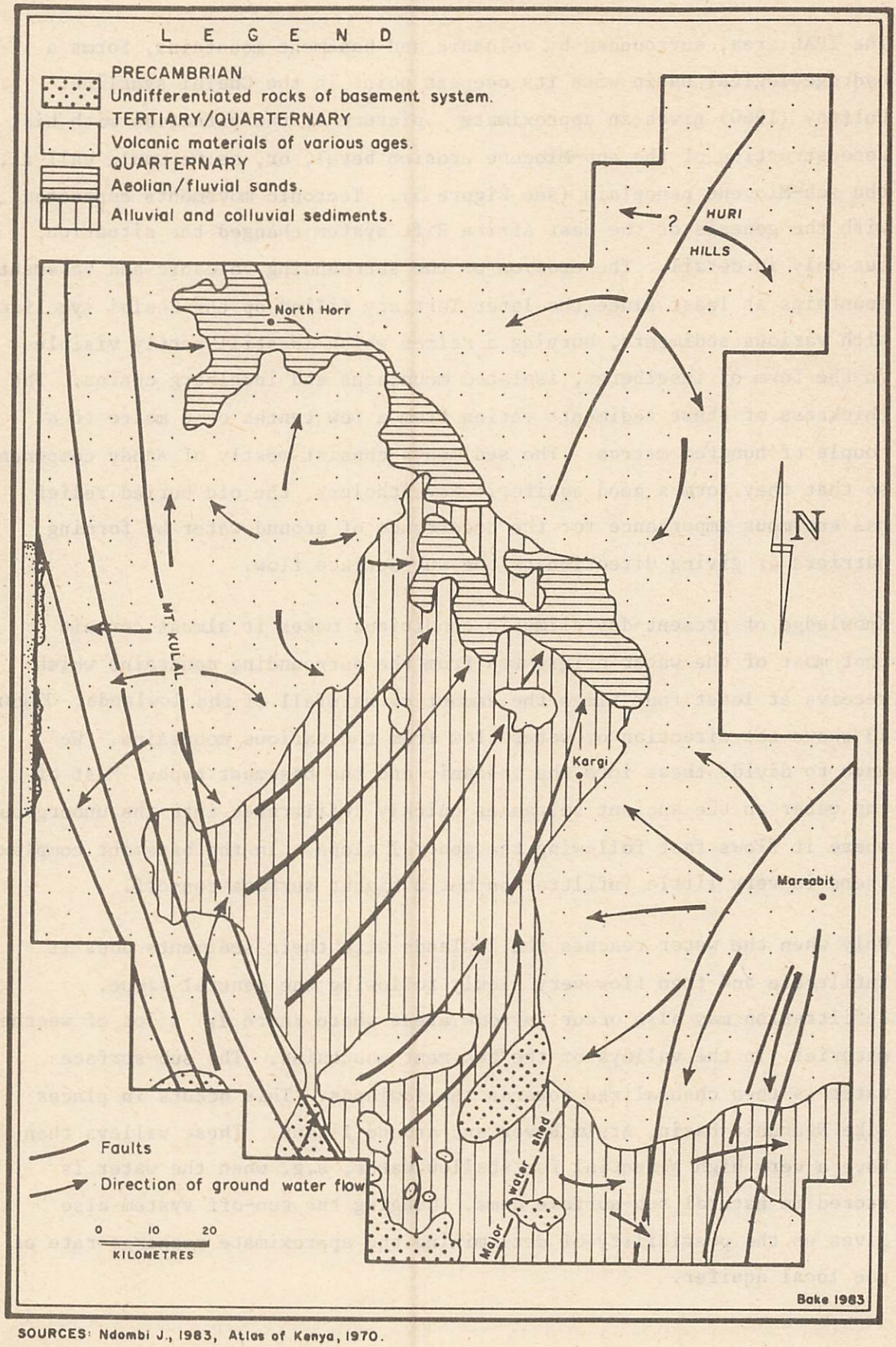
7.4 The origins of sub-surface water

The IPAL area, surrounded by volcanic and basement mountains, forms a hydrogeological basin with its deepest point in the Chalbi syncline. Pulfrey (1960) gives an approximate picture of the situation with his reconstruction of the sub-Miocene erosion bevel, or, as we would call it, the sub-Miocene peneplain (see Figure 5). Tectonic movements connected with the genesis of the East Africa Rift system changed the situation, but only in detail. The erosion of the surrounding volcanic and basement mountains at least since the later Tertiary filled up the Chalbi syncline with various sediments, burying a relief which is still partly visible in the form of inselbergs, isolated mountains and inselberg chains. The thickness of these sediments varies from a few tenths of a metre to a couple of hundred metres. The sediments consist mostly of sandy components so that they form a good aquifer. Nevertheless, the old buried relief has enormous importance for the occurrence of ground water by forming barriers or giving direction to the sub-surface flow.

Knowledge of present-day climatic conditions makes it almost certain that most of the water originates from the surrounding mountains which receive at least four times the amount of rainfall of the lowlands. Figure 13 shows the direction of water flow from the various mountains. We have to divide these into the volcanic and the basement type. Most of the water on the ancient volcanoes quickly infiltrates into the underground where it flows fast following the general slope. In the basement complex there is very little infiltration but a higher surface run-off.

Only when the water reaches the lowlands with their sediments does it infiltrate and then flow very slowly following the general slope. Infiltration may also occur in some areas where there is a lot of weathered material in the valleys of the basement mountains. The sub-surface water is then channalized towards the lowlands. This occurs in places like Ngurunit basin, Arsim River and around Illaut. These valleys then have a very high potential for shallow water, e.g. when the water is stored in natural sub-surface dams. Gauging the run-off system also gives us the possibility of determining the approximate recharge rate of the local aquifer.

Figure 13. Directions of sub-surface water flow



SOURCES: Ndombi J., 1983, Atlas of Kenya, 1970.

Figure 14 shows the general direction of ground water flows in the IPAL area. This is only a rough map where local influences have been neglected, but it gives a first approximation of the situation. Modifications are mainly necessary in the areas directly north of the basement complex where we have to deal with a buried relief which will channalize the ground water streams (see Figure 15). To incorporate this in a map, a lot of geophysical research, e.g. seismic soundings, would be essential.

7.5 The speed of ground water flows

Knowing the areas of ground water origin brings up the question of the speed of ground water flow. Due to our little knowledge of the underground we cannot give definite figures, but we can give approximations. From there it is possible to determine the recharge time for specific areas. In addition an isotope analysis will be carried out soon which will tell if the water supply touches fossil water.

Not only is the age of water determined by the speed of flow but also by the recharge rate for boreholes and wells. The velocity of the flow is mainly determined by the regional gradient and the hydraupic conductivity of the soil and/or aquifer materials. So far, neither can be changed by human impact.

Estimates for gradients can be obtained from well levels and electric resistivity soundings. Using Darcy's equation for the velocity of ground water flow, speeds were determined as in Table 8.

Table 8. Velocity of ground water

Area	Maximum speed	Maximum speed	Mean speed
Hedad	0.015 m/d	0.3 m/d	0.16 m/d
Marsabit Mt.	*	38 m/d	-

* The minimum in lavas would be almost 0 if there are dykes, etc.

Figure 14. Altitude of groundwater

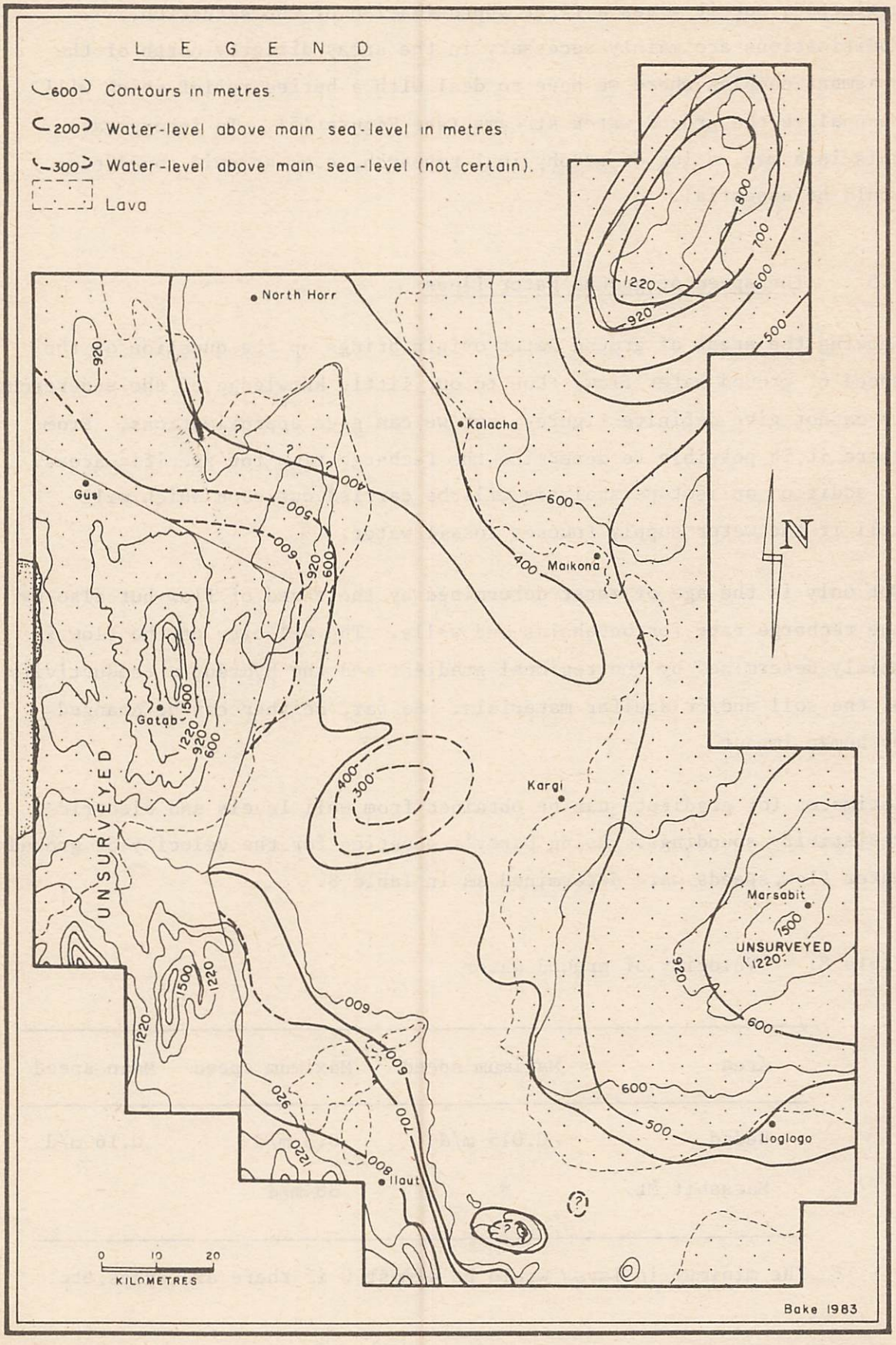
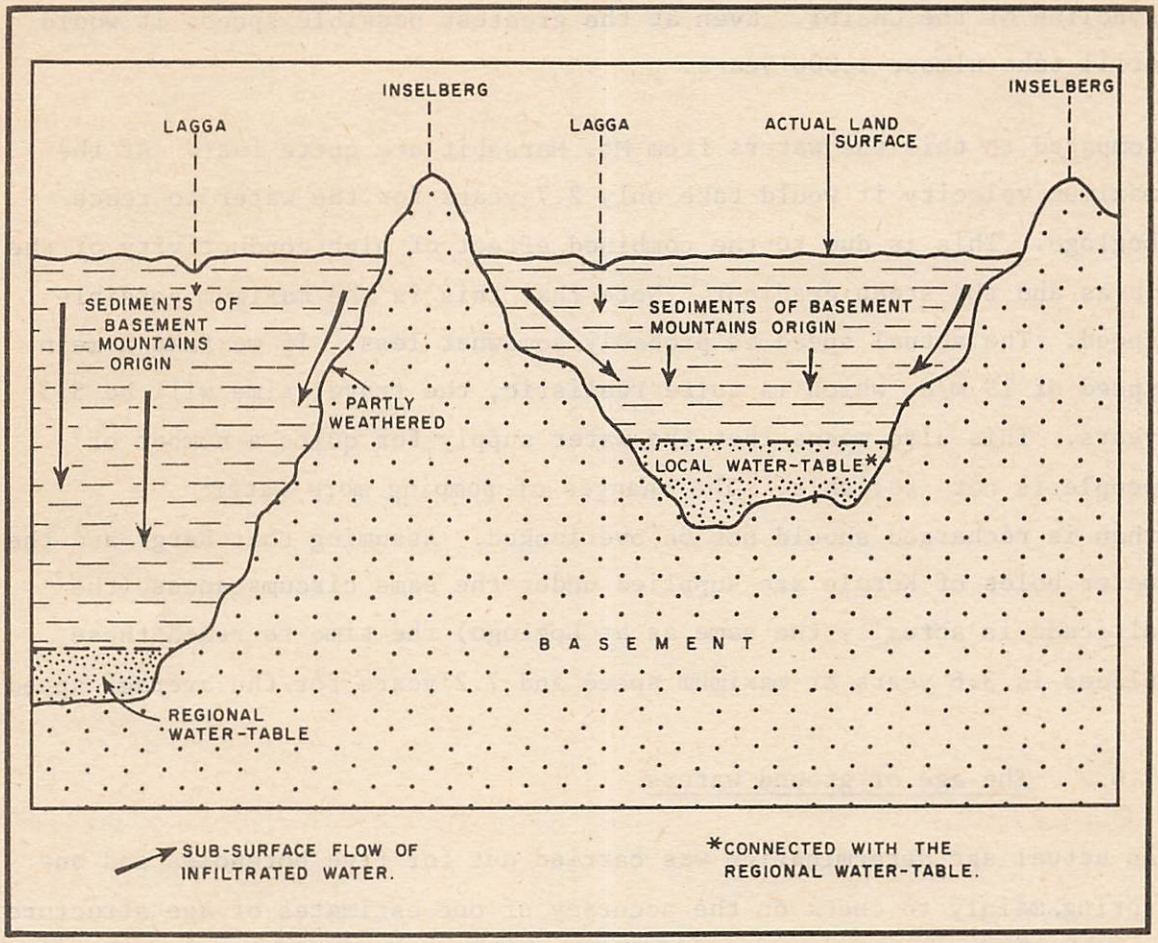


Figure 15. Model of buried relief and its importance for the occurrence of groundwater



From these speeds we can predict when the water would reach the syncline, etc. A water particle infiltrated at the foot slopes of the basement mountain will take an average of more than 1,700 years to reach the syncline of the Chalbi. Even at the greatest possible speeds it would still take almost 1,000 years.

Compared to this the waters from Mt. Marsabit are quite fast. At the maximum velocity it would take only 2.7 years for the water to reach Loglogo. This is due to the combined effect of high conductivity of the lavas and the steep gradient. Note that this is the maximum possible speed. The actual speed is probably somewhat less. If we take a mean speed of 19 m/d, which is quite realistic, the travel time will be 5.3 years. This also means that the water supply for quite a number of people is not reliable. The changes of pumping more water than is recharged should not be overlooked. Assuming that Kargi and the water holes of Korole are supplied under the same circumstances (the altitude is actually the same as at Loglogo) the time to reach these places is 3.6 years at maximum speed and 7.2 years for the average speed.

7.6 The age of ground waters

An actual age determination was carried out for five boreholes and one spring, mainly to check on the accuracy of our estimates of age structure as described in the previous section. The age determination was carried out by the ^{14}C and ^{3}H laboratory of the Niedersächsisches Landesamt für Bodenforschung (Agency for Geo Research of Lower Saxony) in Hannover (Federal Republic of Germany).

At the first attempt tritium (^{3}H) analysis was used. Tritium is the radioactive isotope of hydrogen. It has a half life of 12.26 years. The tritium content of natural materials is shown in tritium units (TU). By definition 1TU = 1 tritium atom per 10^{18} hydrogen atoms. In rain water the natural tritium (derived from cosmic altitude radiation) has a concentration of 4-6 TU. Since 1953, especially in the years 1958-1959 and 1963-1964, the artificial tritium content rose by more than 100 times because of nuclear explosions. That is why in a lot of cases it can be decided if the rain waters infiltrated before or after 1953. If the waters are older than 50 years the tritium content cannot be directly analysed. The results are given in Table 9.

Table 9. Age of ground water

Place	Lower side age (years)	Higher side age (years)
Korr North	16	25
Korole (spring)	25	37
Korr (road to Illaut)	18	43
Loglogo	23	35
Halisruwa	23	35
Loglogo	41	50

Because of the high pumping rates of certain boreholes it was already assumed that rechargeable water was being pumped. But it was surprising to find that at certain places the water was very old. The discharge rate was much higher than the recharge.

In most of the cases the laboratory advised IPAL to carry out ^{14}C analysis to get exact age determinations. This will be done in 1984 when all the boreholes of the area and several wells will also be included. The conclusion of these results is that if the high pumping rates are maintained the boreholes can become dry. That means that the basis of life in that particular area will be destroyed. This is especially the case in places like Loglogo and Korr where several boreholes are operating. It was surprising to realize that the water of the Korole springs is also older than expected. A possible explanation is that without any use the water level would be higher. Due to the enormous number of animals being watered here (on one day a herd of more than 1,000 camels was observed) the water cannot reach its natural level. The offtake can reach more than 10 m^3/h. Further information could be obtained by pumping tests, including observation in a number of ground water observation pipes.

The most serious situation seems to be at Korr. Recharge of the aquifer is limited by the low rainfall and the low permeability of the basement rocks. Water can only infiltrate and recharge the aquifer through fractures. It is most unlikely that there is a linked water table under the entire Korr Hills.

Most likely there are only water pockets of limited extent. This is proved by the high number of dry boreholes in the area. Several dry wells (about 50% of over 150) show that water flows underground only in a limited space where there are fractures. It is not known if there is any lateral infiltration to the Korr aquifers by waters from Mt. Marsabit and the regional aquifer of the lowlands. This could help explain the age of the ground water. But this is probably not the case because of the low gradient and the impermeability of the rocks. In other words the hydraulic pressure is not high enough to press water into fractures of the basement rocks.

7.7 The different water levels

Ground water is found at different levels in the IPAL area (see Table 10). Therefore we can assume with a high degree of certainty that there are several different ground water tables. It is not necessary that these tables extend all over the study area. Local influences will cause a lot of variation.

In the basement mountains water can only be found in alluvial/colluvial or weathered materials of the valleys and depressions. Often there are only pockets which do not form a general water table.

In the forelands the water tables are influenced by several factors. First of all there is the porosity of the sediments, then the buried relief and the actual drainage patterns.

Locally around the *laggas* we find a shallow water table which is built up by the infiltration of the *lagga* water every wet season. This aquifer is an unconfined one of limited extent.

Most of these aquifers are not completely sealed at the bottom so that there is infiltration to deeper aquifers and therefore we call them leaky aquifers. Their depth and extent are not yet completely known but we assume that we have to deal with at least two of them. There is a second local aquifer at a depth of around 40-60 m which does not extend all over the study area. It is partly sealed at the bottom by clay layers formed during the plain's genesis by fluvial and aeolian processes.

Table 10. Electrical resistivity results

Resistivity Station No.	Location	Depth of ground-water (m)		Depth to bedrock (m)	
		Ndombi	Borgeson	Ndombi	Borgeson
1	Olturot	10.40	70	-	-
2	Hedad	6	4	45	45
3	Hurri hills	-	160	150	-
4	Hurri hills	-	40	150	-
5	Hurri hills	-	125	150	-
6	Hurri hills	-	30	150	-
7	Hurri hills	-	47	-	285
8	Ngurunit	10	8	20	24
9	Korr	3	5	20	35
10	Kargi	6	4	8	-
11	Segel	40	-	184	250
12	Maikona	40	33	-	-
13	Balal	6.14	-	-	130
14	North Horr	40	37	-	-
15	Kargi	2.20	12	32	32
16	Kargi	3.72	10/40	-	-
17	Falam	-	-	-	-
18	Balesa Kulal	10.5	11	-	175
19	Hedad	20	15	105	105
20	Hedad	15	11	120	220
21	Hedad	4	4	15	59
22	Karante	2	10	20	20
23	Balessa	4	4	8	245
24	Balessa	3	1	4	30
25	Balessa	5.5	3	-	-
26	Gus	10	20	56	150
27	Karonde	14	-	80	-
28	Illim	10	-	-	-
29	Loglogo	10	-	-	-
30	Ngurunit	3	-	20	-
31	Ilaut	5	-	10	-
32	Elgess	-	-	-	-
33	Hedad	3	-	30	-
34	Hedad	40	-	-	-
35	Hedad	-	-	-	-
36	Kalacha	14	-	80	-
37	Hedad	8	-	28	-
38	Hedad	-	-	20	-
39	Hedad	4	-	-	-
40	Hedad	10	-	30	-
41	Hedad	-	-	-	-
42	Korr	3.10	-	20	-
43	Hedad	-	-	56	-
44	Hedad	8	-	-	-
45	Hafarican	5	-	-	-
46	Korr	2	-	5	-
47	Balessa Kulal	3	-	-	-
48	Kargi	4	-	20	-
49	Balessa	8.28	-	-	-
50	Balessa	14	-	56	-
51	Balessa	3	-	40	-
52	Balessa	3	-	4	-
53	Kargi	3	-	-	-
54	Maikona	16	-	-	-
55	Kalacha	6	-	-	-

We also find the influence of the buried relief.

Then there is the major regional water table - also a semi-confined one. The basement rocks at depth form an almost impermeable layer. The depth of this aquifer is shown in Figure 16. There are leakages in the basement rock but it is impossible to make estimates of the amount.

This water in the regional aquifer flows toward the syncline of the Chalbi where there is very shallow water and at a number of places even permanent surface water. At the surface the Chalbi forms an endoreic drainage area. It is not known yet if there is a constant underground outflow from this syncline. It is possible that there is an underground stream from the Chalbi through the corridor between the Hurri Hills and Marsabit Mountain eastwards and then towards Wajir. Due to the high water table it is also most probable that a lot of underground water evaporates at certain places.

Direct evaporation of groundwater is possible when the water is close to the surface, say 0.5-0.2m. The unsaturated hydraulic conductivities in the vadose zone may then be sufficiently large to permit upward flow from the water table in response to an evaporative demand at the soil surface (Bouwer, 1978). Evidence for this is salt accumulation. Especially when the soil surface is dry (arid climate) the flow rates are significant. Even if the evaporation rate was only 5% of the potential, in the Chalbi this would be an annual loss of water of almost 200×10^6 m^3. Under these circumstances we would not have to postulate a significant flow out of the syncline. Also we should not neglect the high probability that the basement is not completely sealed. Connections between the water sources in the area are shown in Figure 17.

7.8 The different geological aquifers

There are only a few data available on the rocks of the different aquifers. More than half of them come from an area around Korr which is not representative of the whole study area. The others are grouped around the edges of the Marsabit lava (Loglogo, Halisiruwa).

The Korr area is a large outcrop of basement rocks, where one would normally expect only a little groundwater. Nevertheless, several boreholes (12?) have been drilled. Even when most of them are dry there are a few which produce a reasonable amount of water.

Figure 16. Electrical resistivity profiles in the IPAL study area

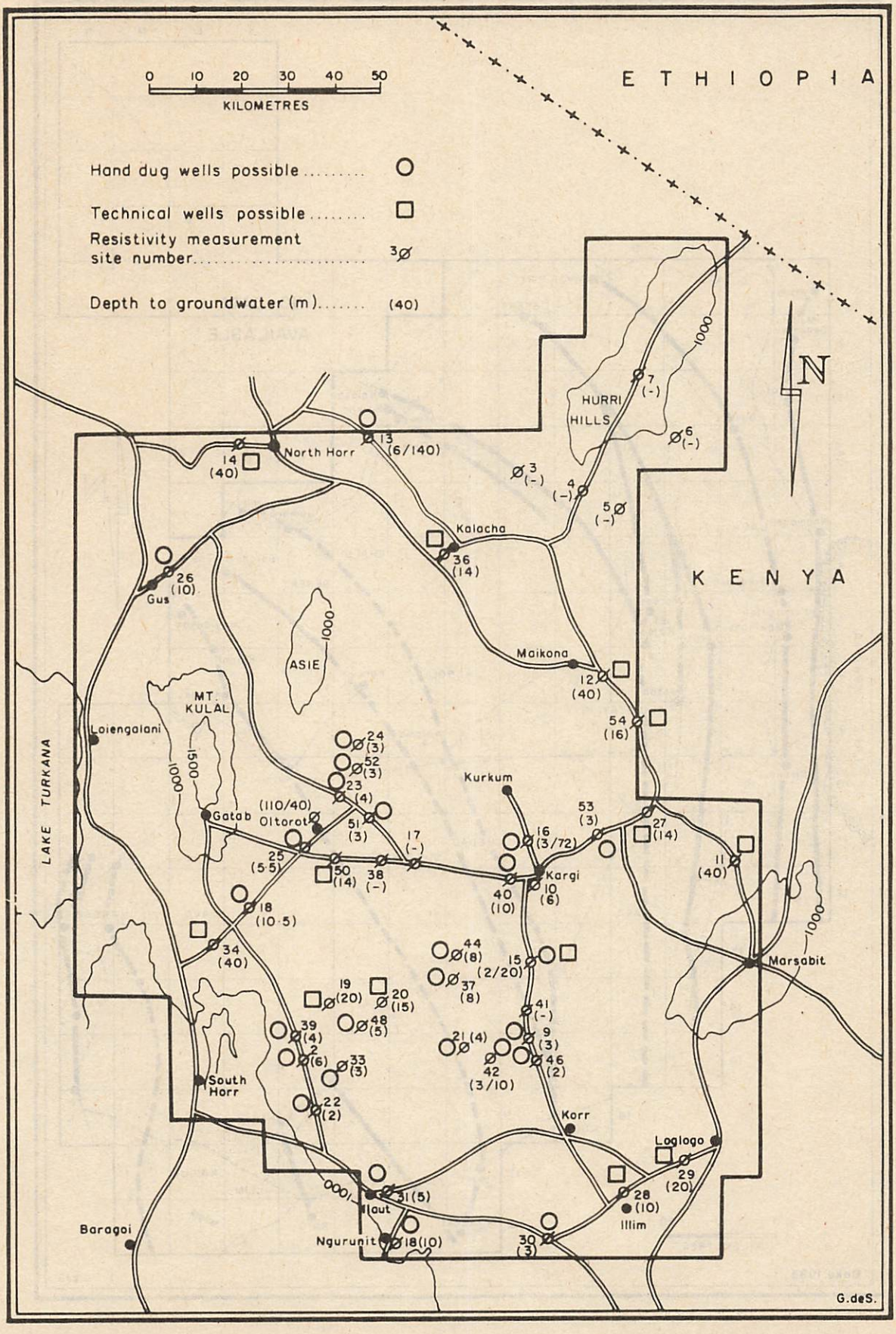
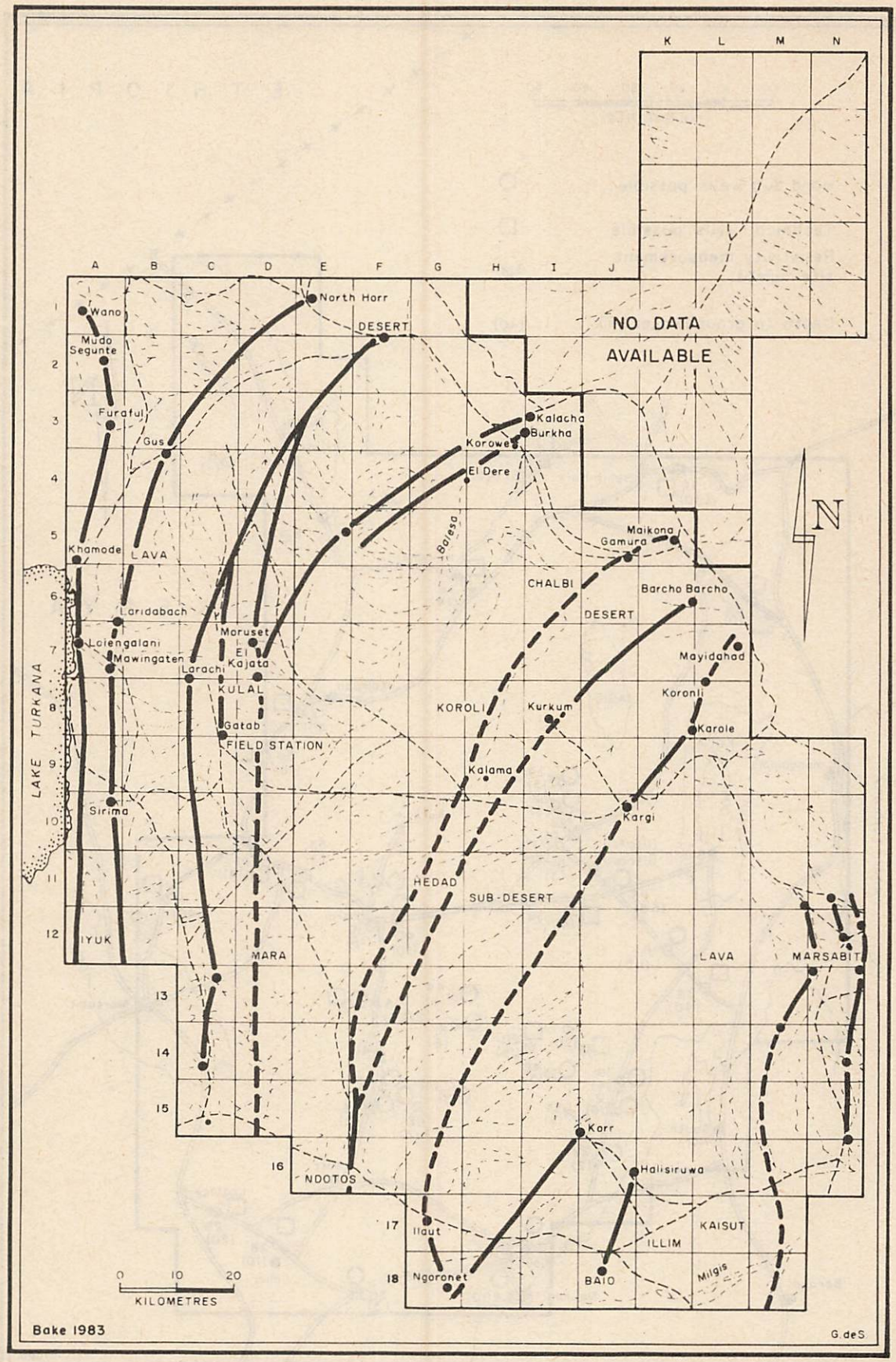


Figure 17. Connections between Permanent water Sources



There are also a number of shallow wells which have been dug by the local people.

Generally we can say that there is water in weathered basement rock which is recharged during the wet seasons. Then there is water along fault lines in the basement. As it looks as though some *laggas* follow such faults, this increases the amount of infiltrated water. Therefore most of the boreholes of Korr struck water in fractured and/or weathered basement. There is one which struck water in pyroxenite. Also the borehole at Halisiruwa is influenced by the basement rocks. The water struck lies exactly at the contact between sediments and basement. In this case the basement rocks act as an impermeable layer. At Loglogo the aquifer is decomposed lava lying over other lavas while the basement is almost 20m below the water. Here there is still the influence of the volcanic activity which gave rise to Mt. Marsabit. Layers of different lavas, basalts, tuffs, etc. form the upper part of the geological profile. At Kargi the water can also be found in the lava which is 65m thick. According to the borehole description, below this there is sandstone with a second water table. There is only one borehole in the sediments of the plains. West of Illaut it is dry. The 200 m level is still in the sediments so it should not have touched the regional water table. It is certain that buried relief plays an important role here.

7.9 Water resources in the Ngurunit area

Some 30 electrical resistivity soundings were carried out in the Ngurunit area to get more information about water resources in the basement mountains (see Table 11). The implications for the surface water resources have already been discussed. The soundings in the Ngurunit area were done shortly after the first rains but the soil was still dry from 10 cm downwards. The main task was to determine at what distance ground water can be found from the Ngurunit River. This would also be of great help for the woodland ecologist in explaining the good condition of the *Acacia tortilis* woodland in this area.

The physiography shows that the depth of bedrock is highly variable. Outcrops of basement rocks can be found all over the area so that the thickness of weathered and alluvial/colluvial materials and of the soil should be highly variable. This was confirmed by the soundings.

Table 11. Depth to groundwater and bedrock in the Ngurunit area

No.	Location	Depth to water m	Depth to bedrock m	Remarks
1	Ngurunit station	2	35	Close to lagga
2	Road to mission	8	57	-
3	Road to station	2	13	-
4	Lagga crossing to shops	0.5	13	in dry lagga
5	In tributary lagga close to 4	1.5	20	in dry lagga
6	Junction mission/station	5	22	-
7	Southern end of IPAL airstrip	-	19	-
8	IPAL airstrip northern end	1	8	-
9	Junction shop/airstrip roads	1.5	30	-
10	Ngurunit River 200m downstream road	0.5	18	in dry lagga
11	Interior delta Ngurunit River	5	38	"
12	Lagga 5 km towards Illaut	3	40	"
13	Same lagga but 1.5 km downstream	2	40	"
14	Road north of IPAL airstrip	2	13	-
15	Exclosure near road	-	2	-
16/17	Road to Illaut near crossing road to shops	2	22	parrallel soundings with same results
18	Alluvial fan near Lependera	50	60	-
19	Middle IPAL airstrip	5	35	-
20	Lagga south of airstrip	2	19	in dry lagga
21	Junction to airstrip	1.5	19	-
22	Road near station to Illaut	5	41	-
23	Road to mission	3	62	
24	Lependera	5	70	outlet of basin!
25	Mission airstrip (shops)	2	18	-
26	West side of airstrip	2	9	-
27	Ngurunit school	2	27	-
28	Tributary lagga near road to shops	2	33	-
30	Lependera	2/10	40	two aquifers

Therefore there are only local water pockets in underground depressions. Careful use of these might be possible but the reaction of the woodland should be monitored closely to prevent overuse.

Towards the outlet of the Ngurunit basin (Lependera) close to the dry plains a reasonable amount of water is available and could be used for watering animals from the plains so that these animals do not have to walk too far into the basin. Conservation of vegetation would be the result (see Figure 18).

7.10 Fluctuations in ground water level

The groundwater level is not static. It changes horizontally. First of all there are the shallow ground water layers built up every season by the run-off of the *laggas* The movement caused by the hydraulic gradient can be very slow or faster (as in the mountains). Also there is a vertical movement depending on the permeability of the rock. The deeper regional water table is more stable, depending on the overall recharge and, recently on the pumping of deeper waters. In several cases the pumping exceeds the recharge rate. In the IPAL area the fluctuations of the regional water level have not been measured.

Some of the wells in the area have been monitored twice a day at 7 a.m. and 6 p.m., respectively. To facilitate the task for the mostly unskilled staff only the depth of the water was measured. This can easily be calculated by the depth to the water level. Assessing the depth by direct resistivity measurement is more accurate as the terrain around the well is often uneven and it is difficult to find a fixed measuring point.

Three major wells were monitored. This number seems to be very small for an area of 23,000 km^2, but staff problems and also the remoteness did not allow further activities. The well at Olturot (Fig. 19a) lies almost in the plains on the lower footslopes of Mt. Kulal. The recharge comes from two sides: from the waters of Mt. Kulal and the waters of the nearby Balesa Kulal. There was not sufficient time to analyse the different effects of both recharges. Therefore isotopes injected into the ground water have to be used. As the well is used only for the IPAL station and for smallstock it does not have to have a very great capacity. The total depth of the well is 9.20m, and the discharge has been determined at 0.8 m^3/h with an apparent specific capacity of 1.07 $m^3/h/m$. Fluctuations

Figure 18. Over view map of Ngurunit River catchment area

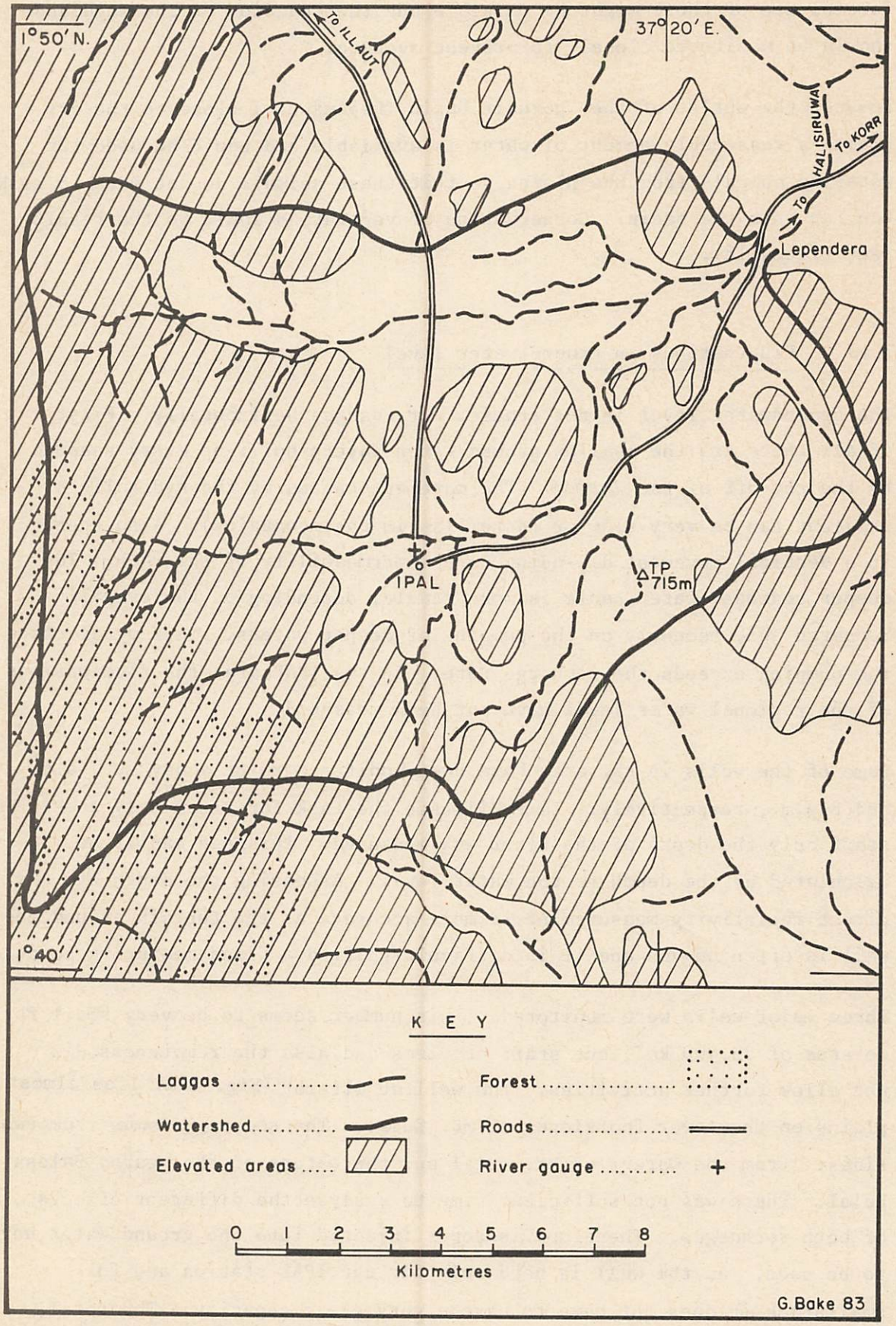


Figure 19a. Daily water levels, IPAL well, Olturot, April 1982 to May 1983

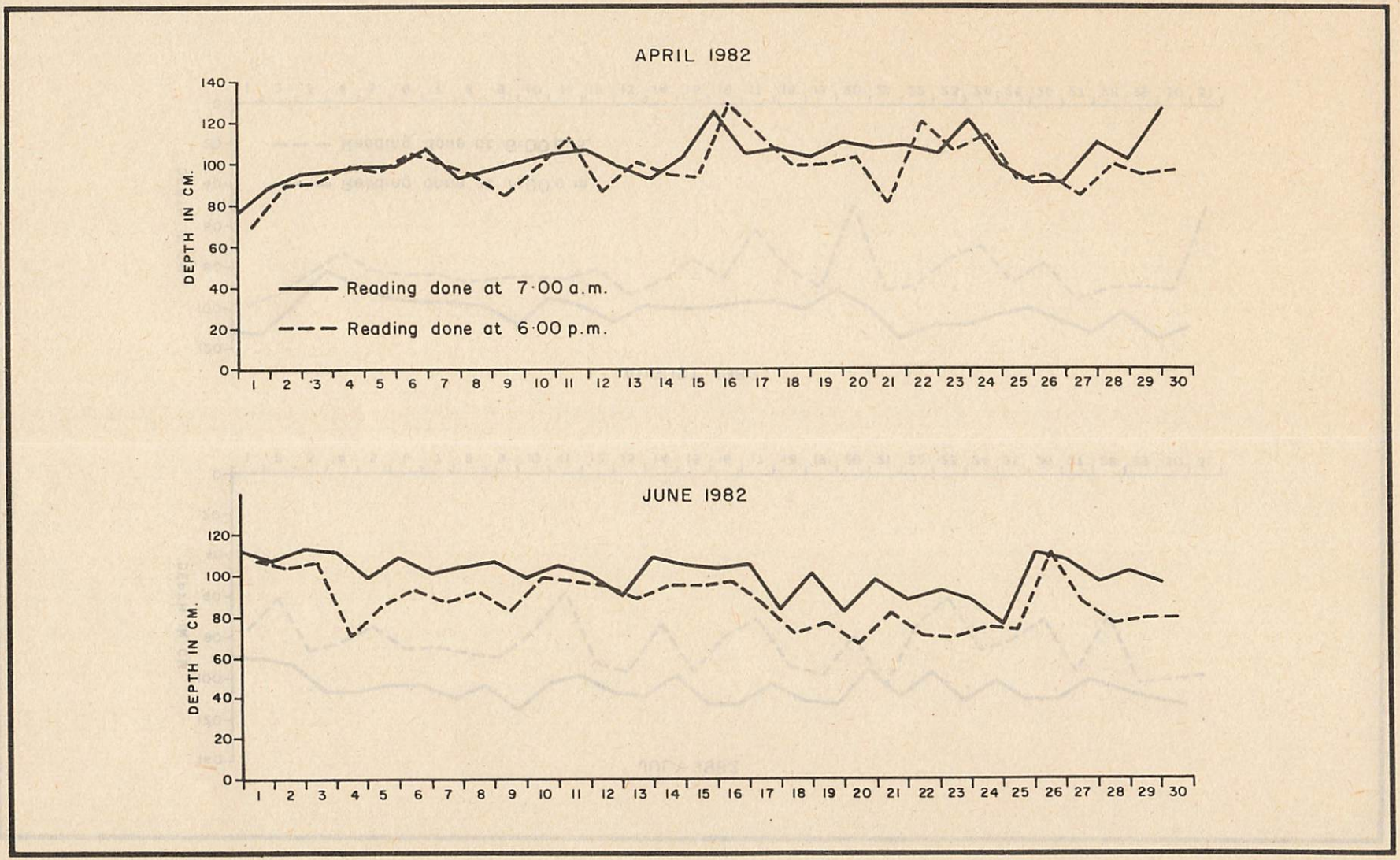


Figure 19a (contd)

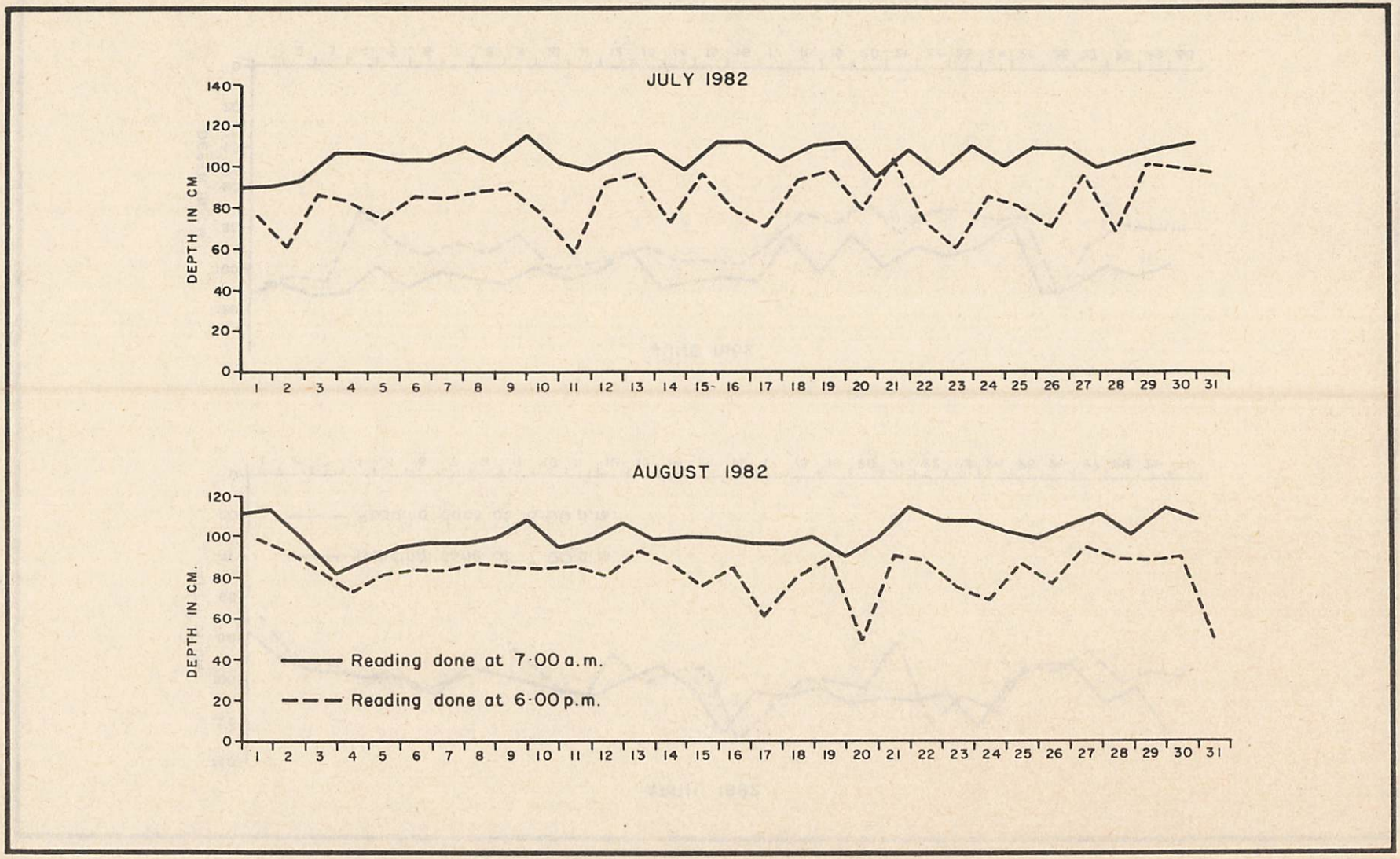


Figure 19a (contd)

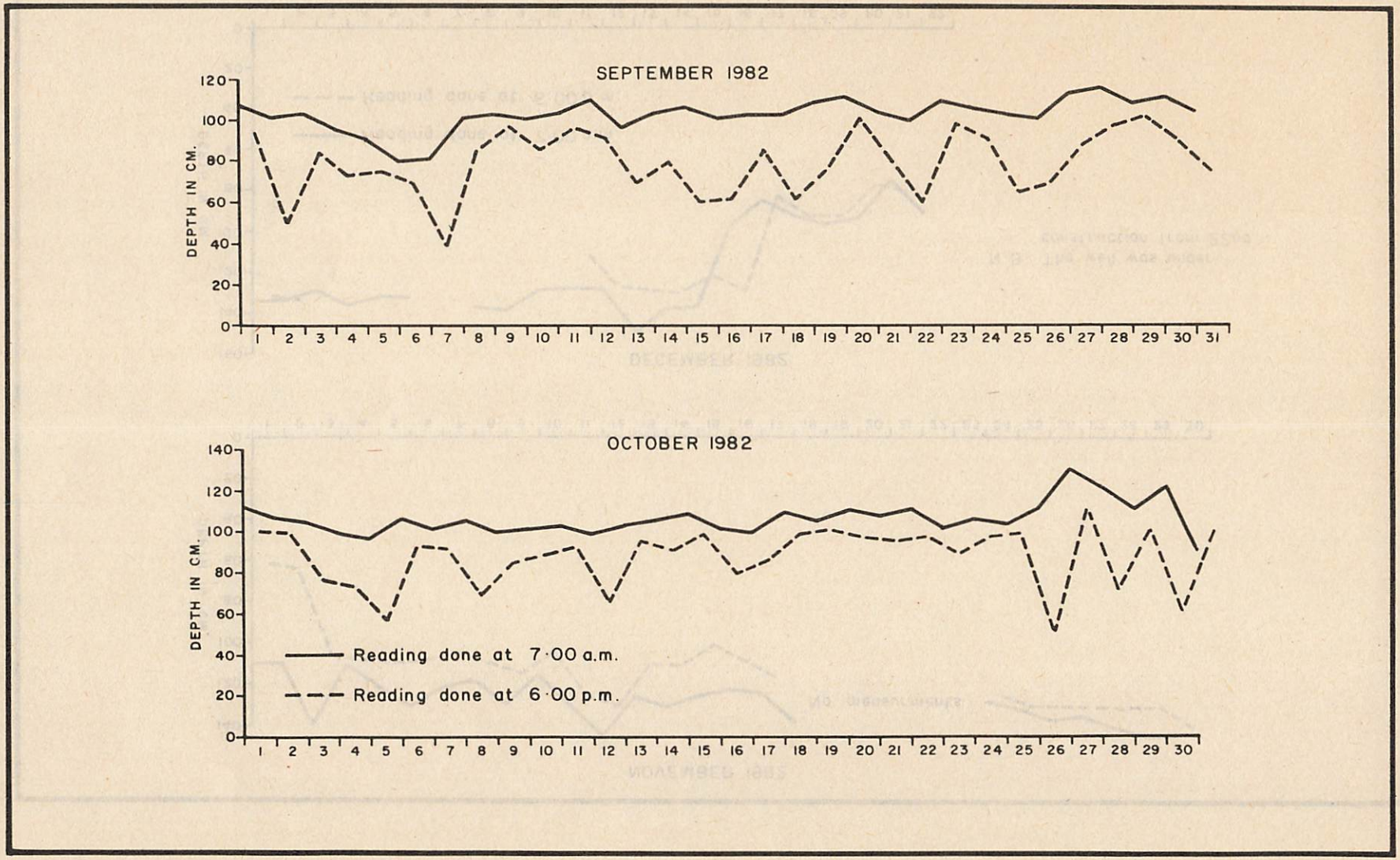


Figure 19a (contd)

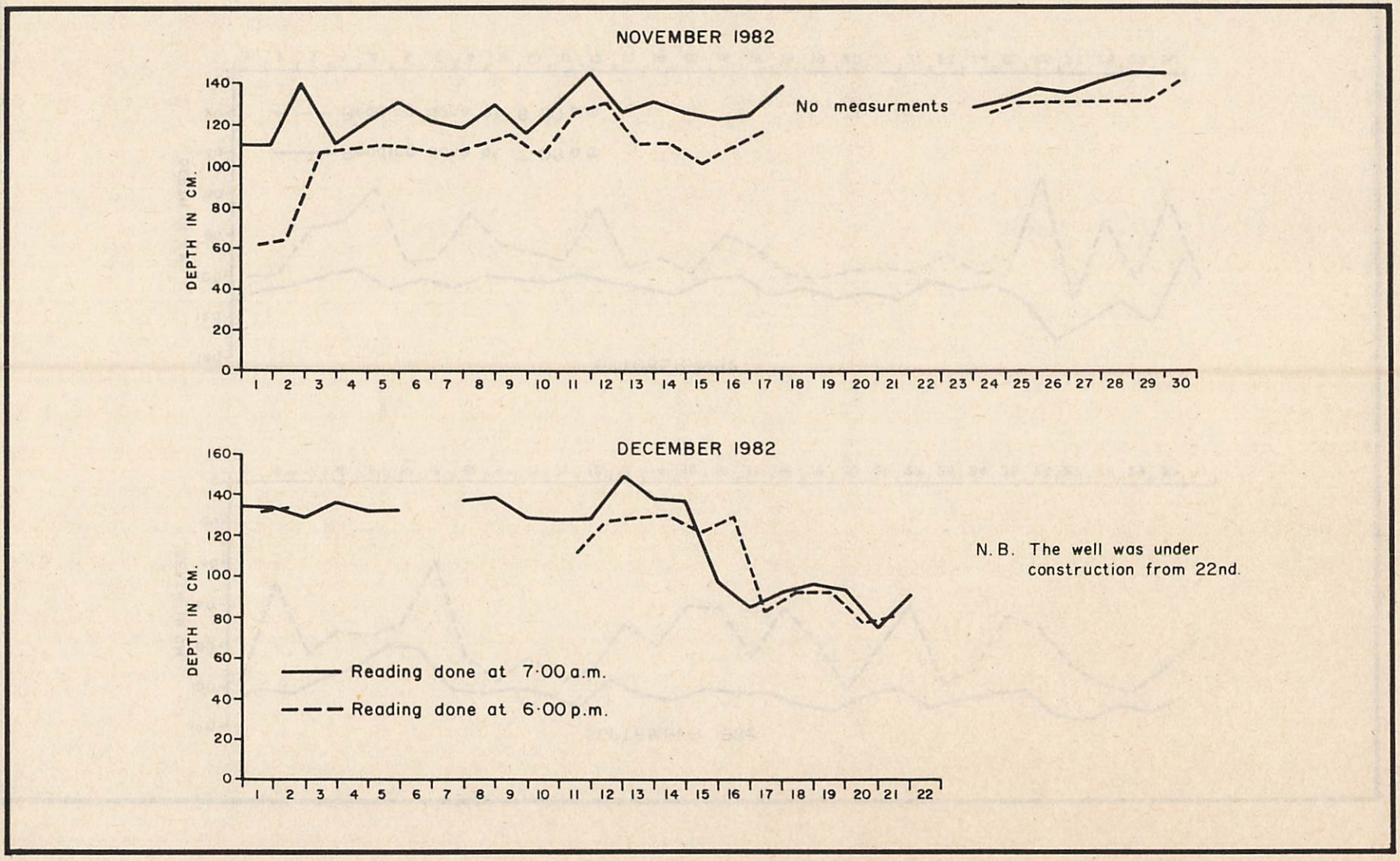


Figure 19a (contd)

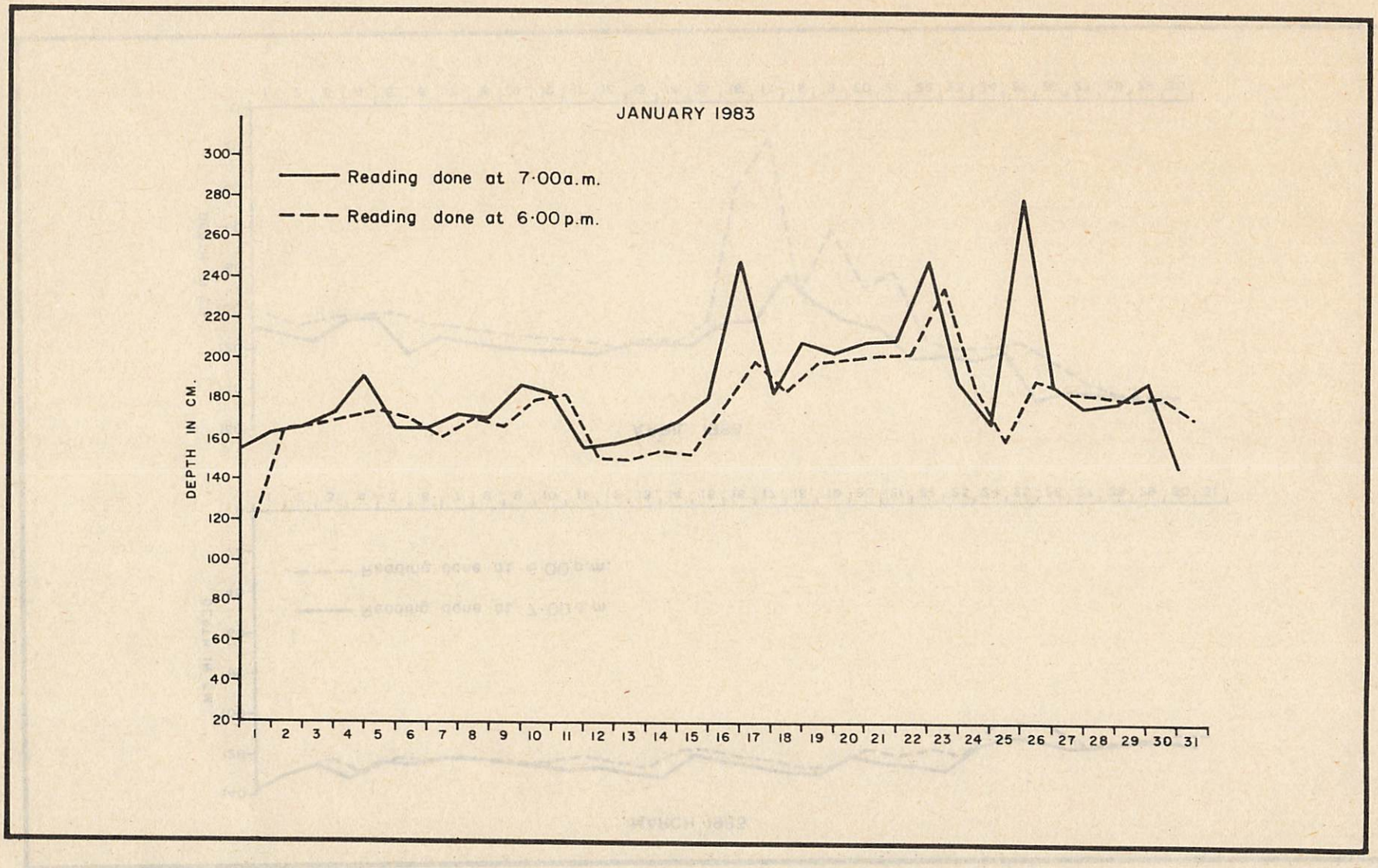


Figure 19a (contd)

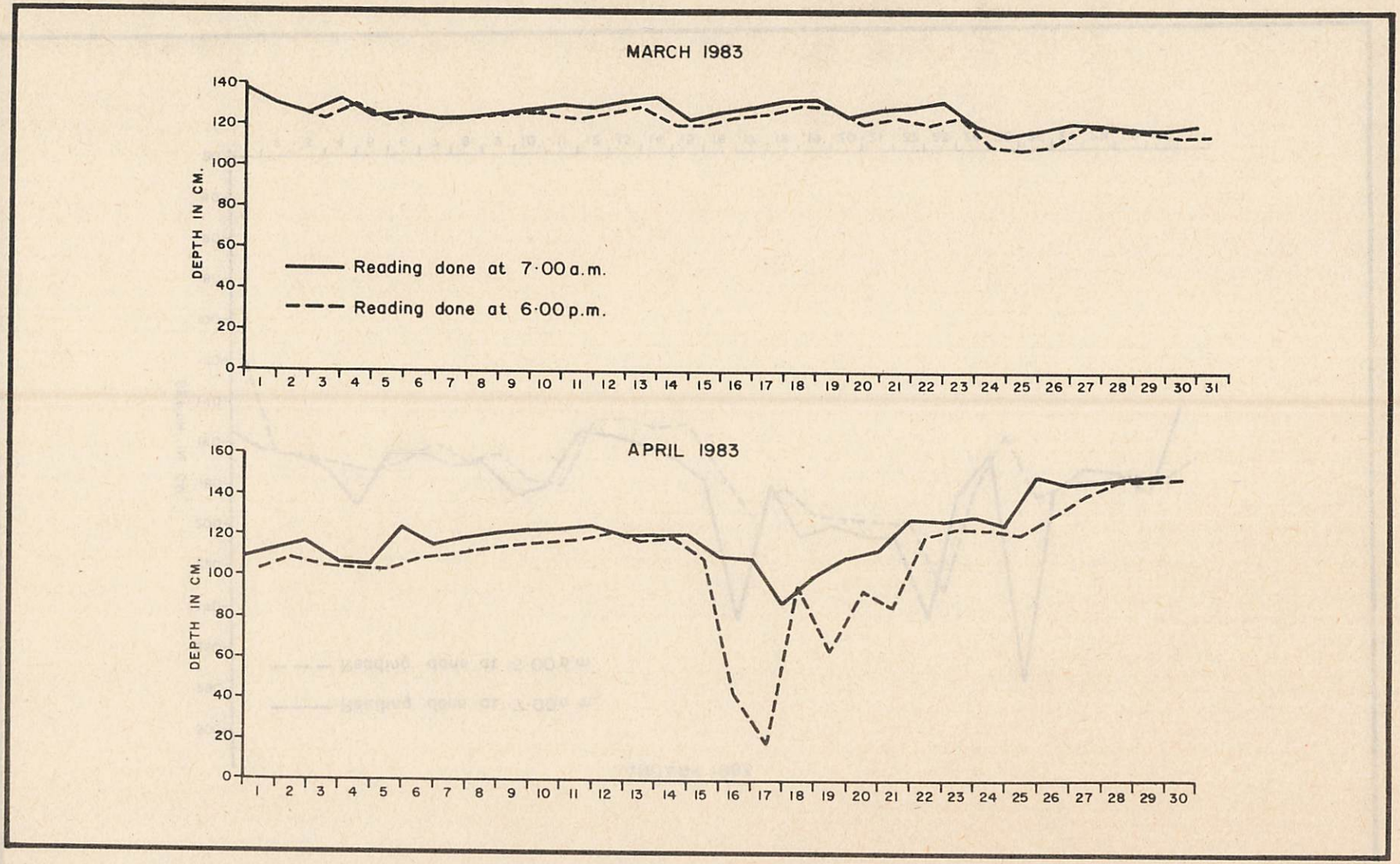
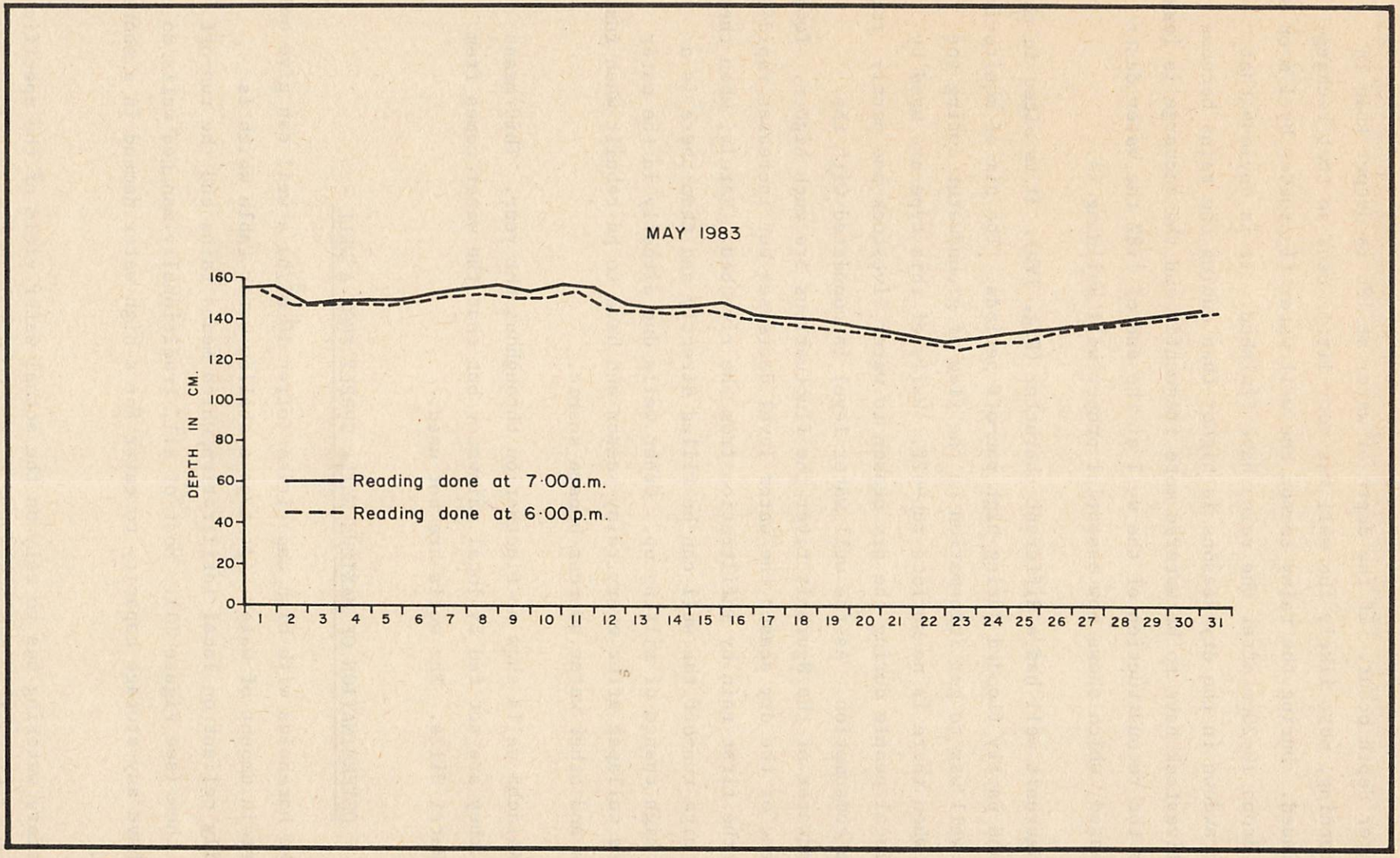


Figure 19a (contd)



in water depth occur. If the depth of water at 18h is deeper than in the morning, most likely the well was very little used so that recharge continued. During the rainy season the well water fluctuates by 1 m or so. This drops 10-20cm after the rains have finished. It is obvious that the drawdown in the dry seasons is higher than during the rains because the livestock have to be watered more frequently and the recharge is less. After the reconstruction of the well at the end of 1982 the water depth increased, which shows how essential proper well building is.

The Ngurunit well has a different character (Fig. 19b). It is sited in the river bed and partly flooded during high run-off periods. The aim of monitoring this well was to get information on the flow of groundwater during the time when there is no surface run-off. Wells of this type are used by the local people during the dry season to water livestock and partly for human comsumption. As the well water level is connected with the groundwater of the Ngurunit river the fluctuations are much higher. Towards the end of the dry season the water level decreases but increases rapidly with the first rain by infiltration from the riverbed. Rarely, when there is a high run-off the well can be filled directly and then there is a very high chance of silting up. Other wells dug directly in the water course collapse after every rainy season and have to be rebuilt when run-off stops and other water sources became scarce.

The Kalacha wells show no fluctuation throughout the year. This means that they are not fed by local rainwater but that the water comes from the Hurri Hills. The wells are not used.

8. DETERMINATION OF MAXIMUM WATER SUPPLY FROM A WELL

Unlike boreholes with high capacities (often 10 m^3/h) a well can give only a certain amount of water. It taps a shallow water table which is heavily reliant on local infiltration, which means rains and the run-off from them (see Figure 20). Most of all, traditionally managed wells do not have any storage capacity to cater for a high water demand in a short time.

Therefore watering has to rely on the actual water yield of the specific well, which rarely exceeds $1m^3/h$. How much water can be drawn from the depths of the well also depends on the capability of the people managing it. Water demands of the various livestock species are not evenly

Figure 19b. Daily water levels, Ngurunit well, April 1982 to April 1983

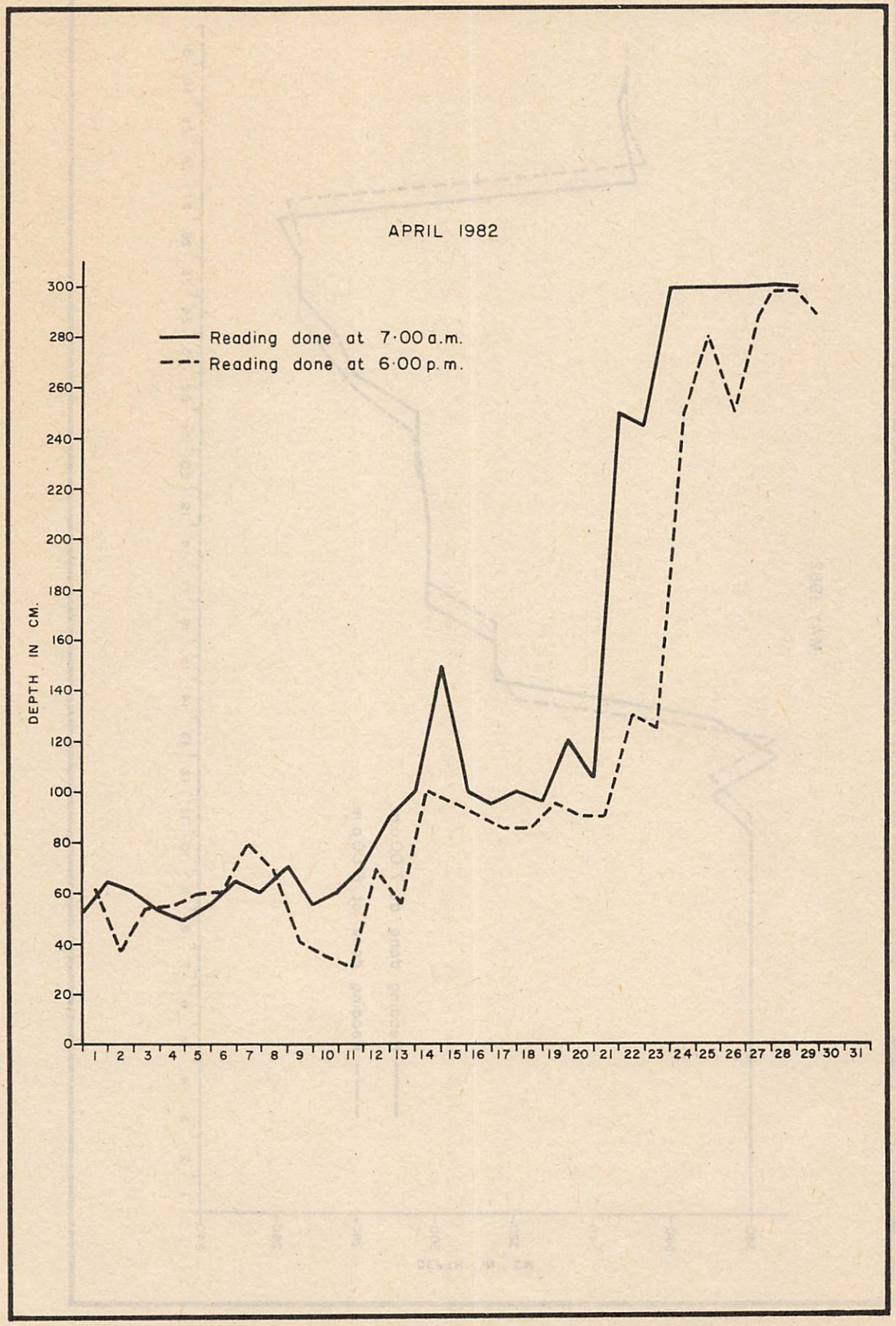


Figure 19b (contd)

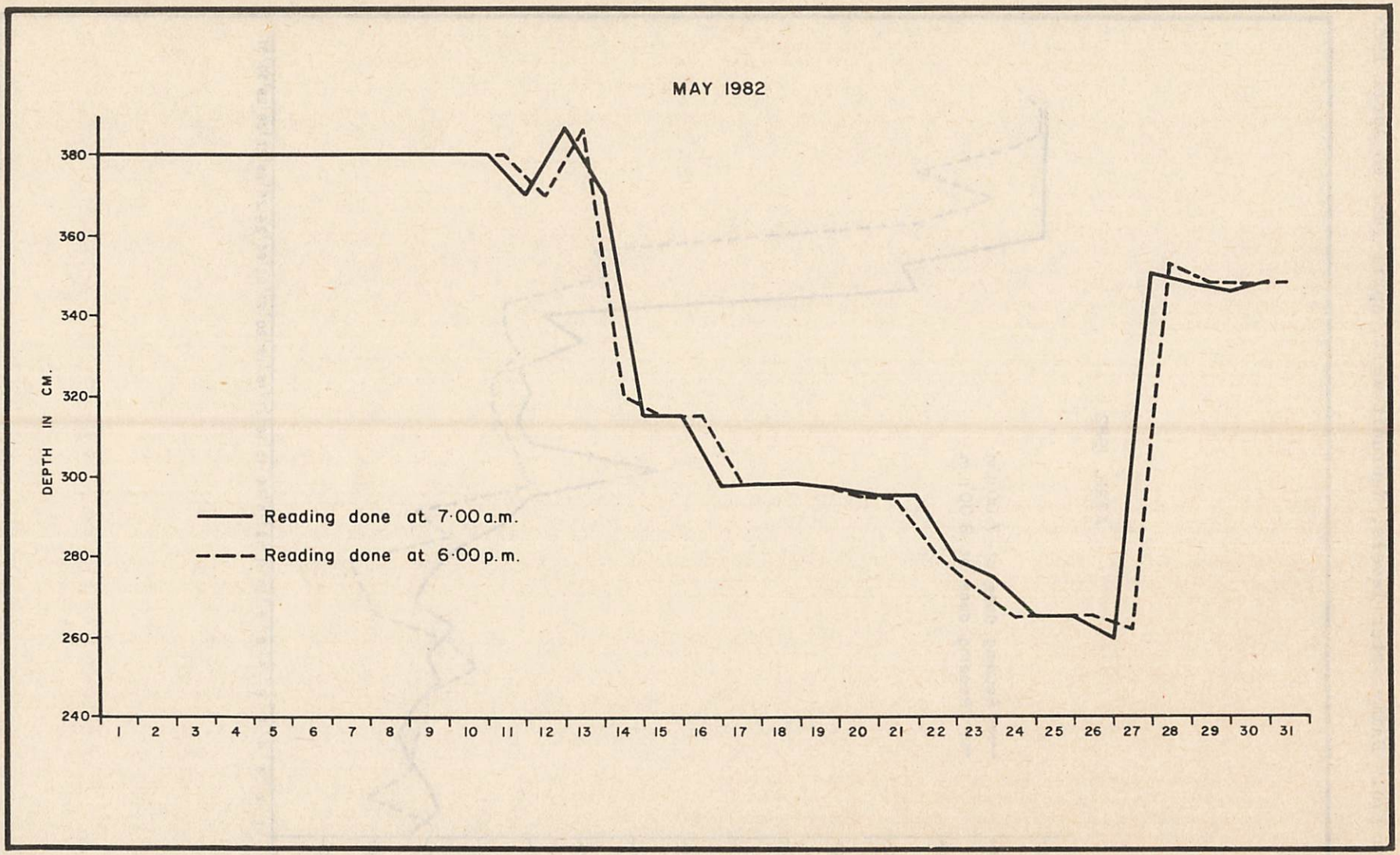


Figure 19b (contd)

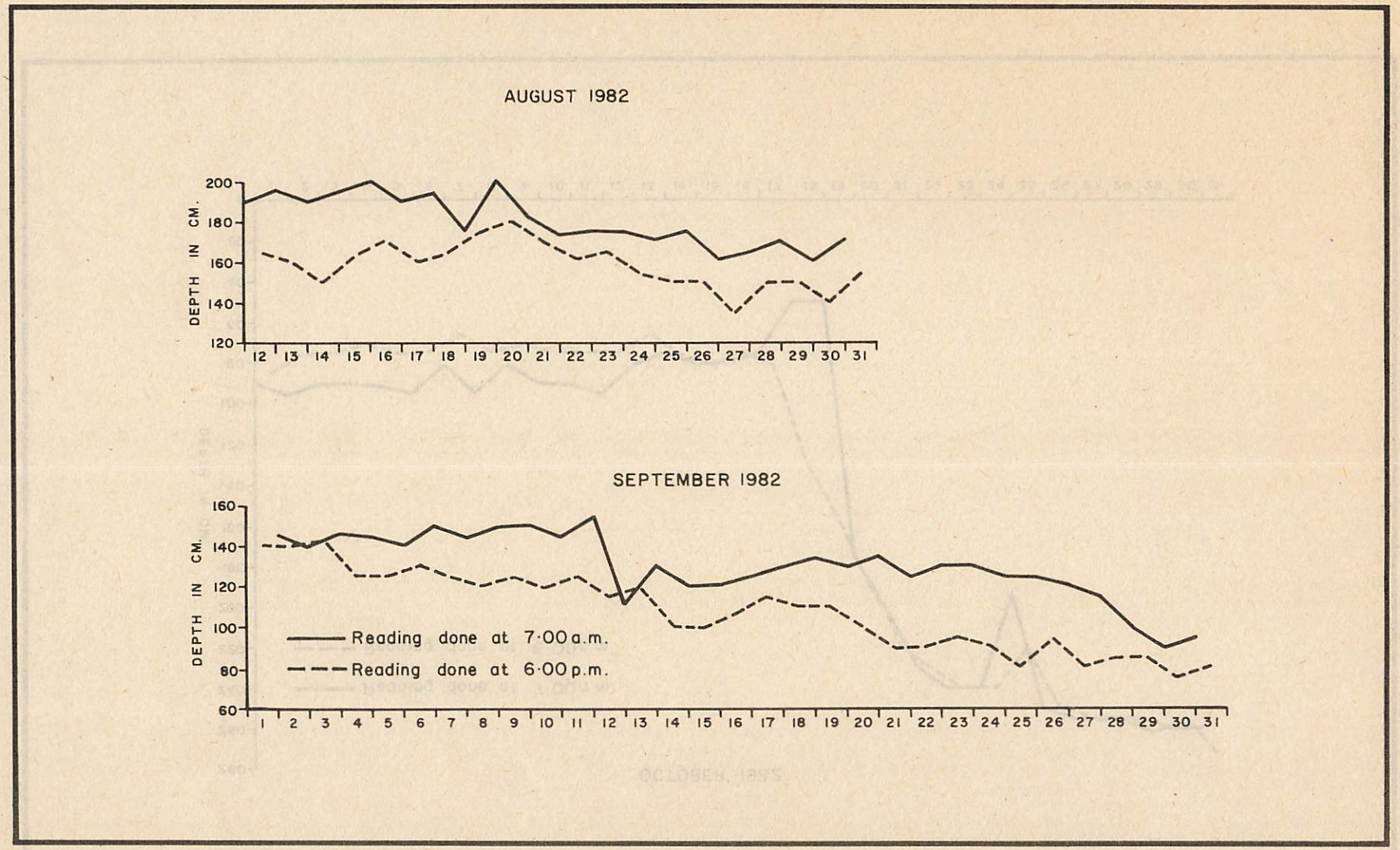
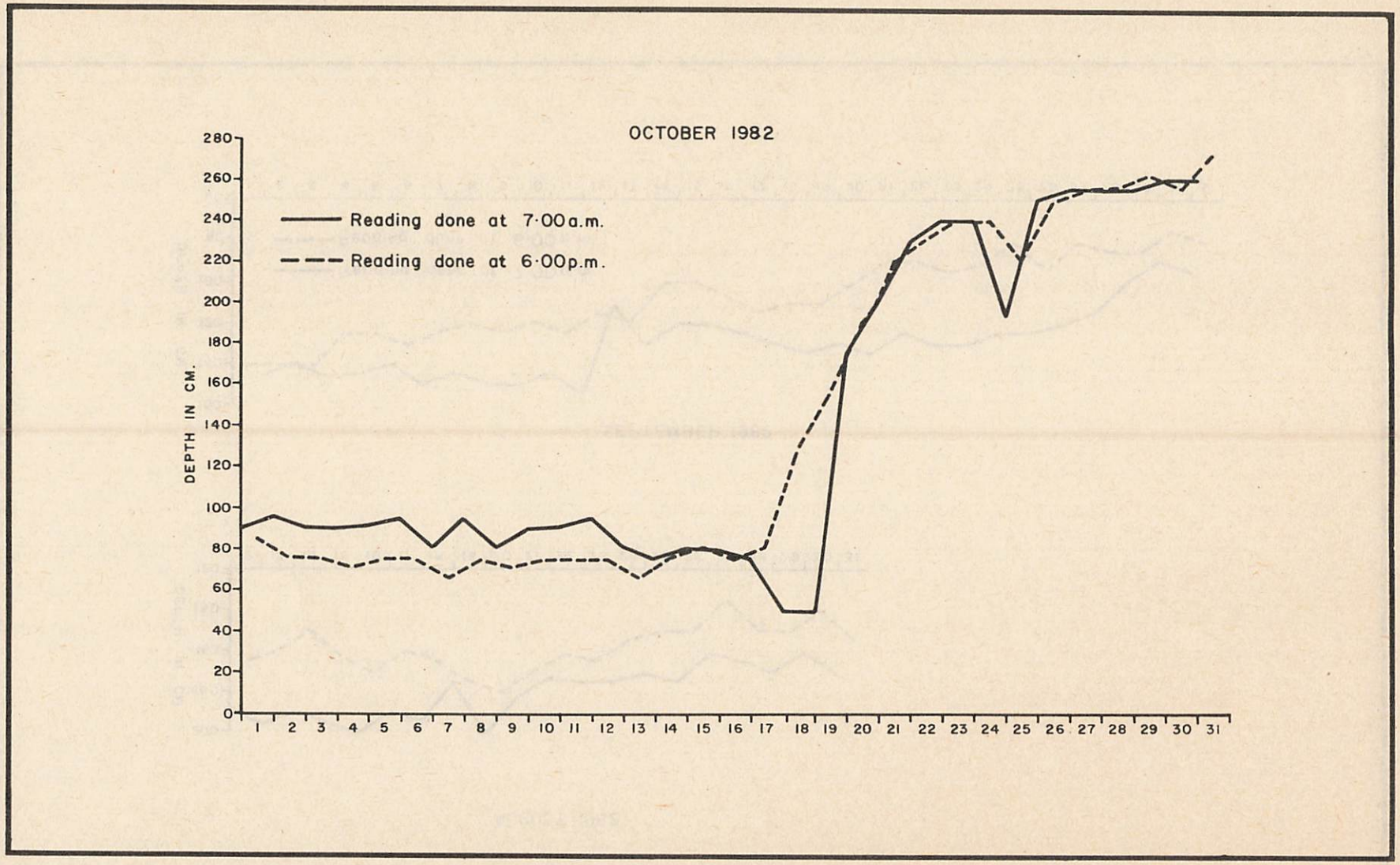


Figure 19b (contd)



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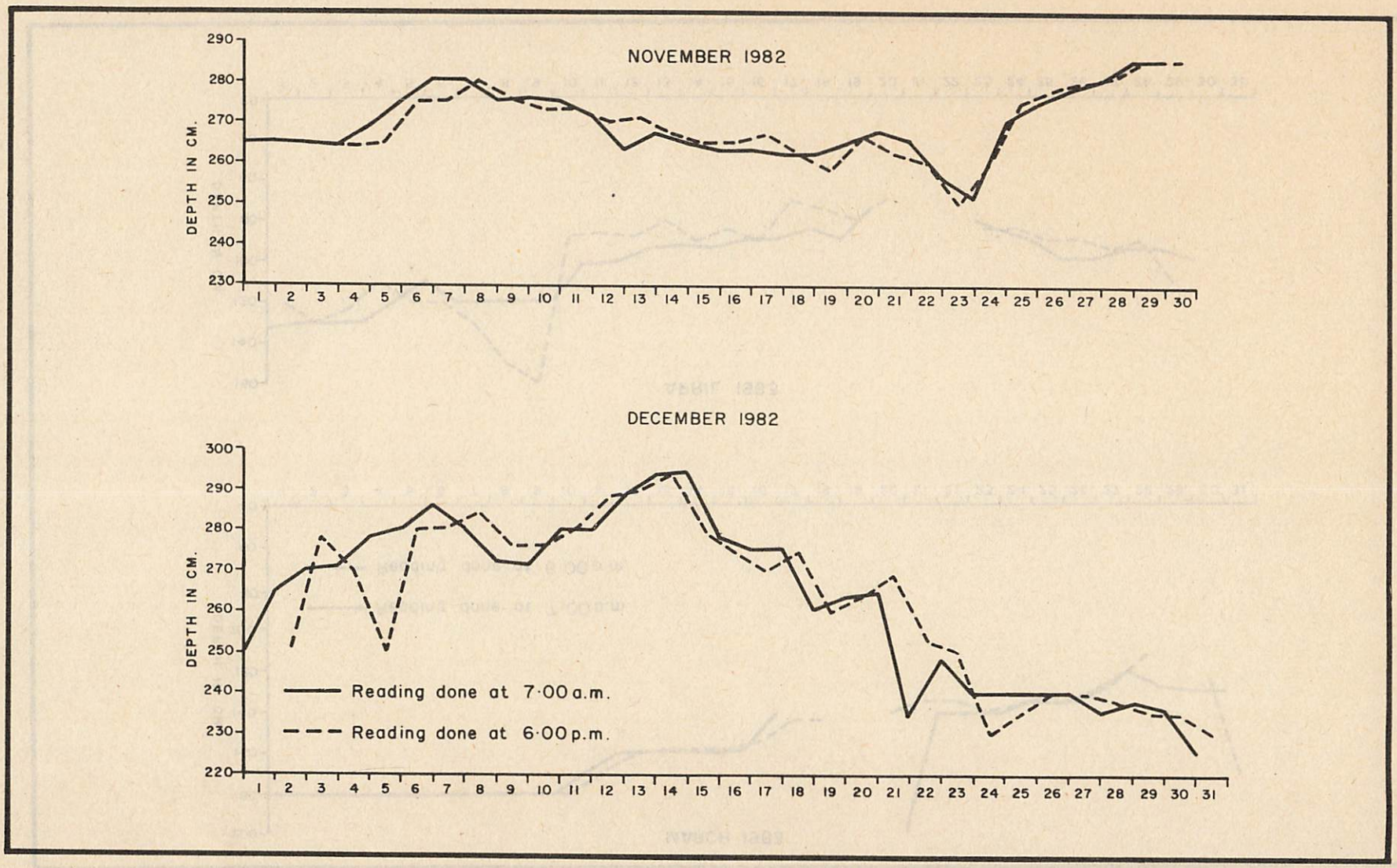


Figure 19b (contd)

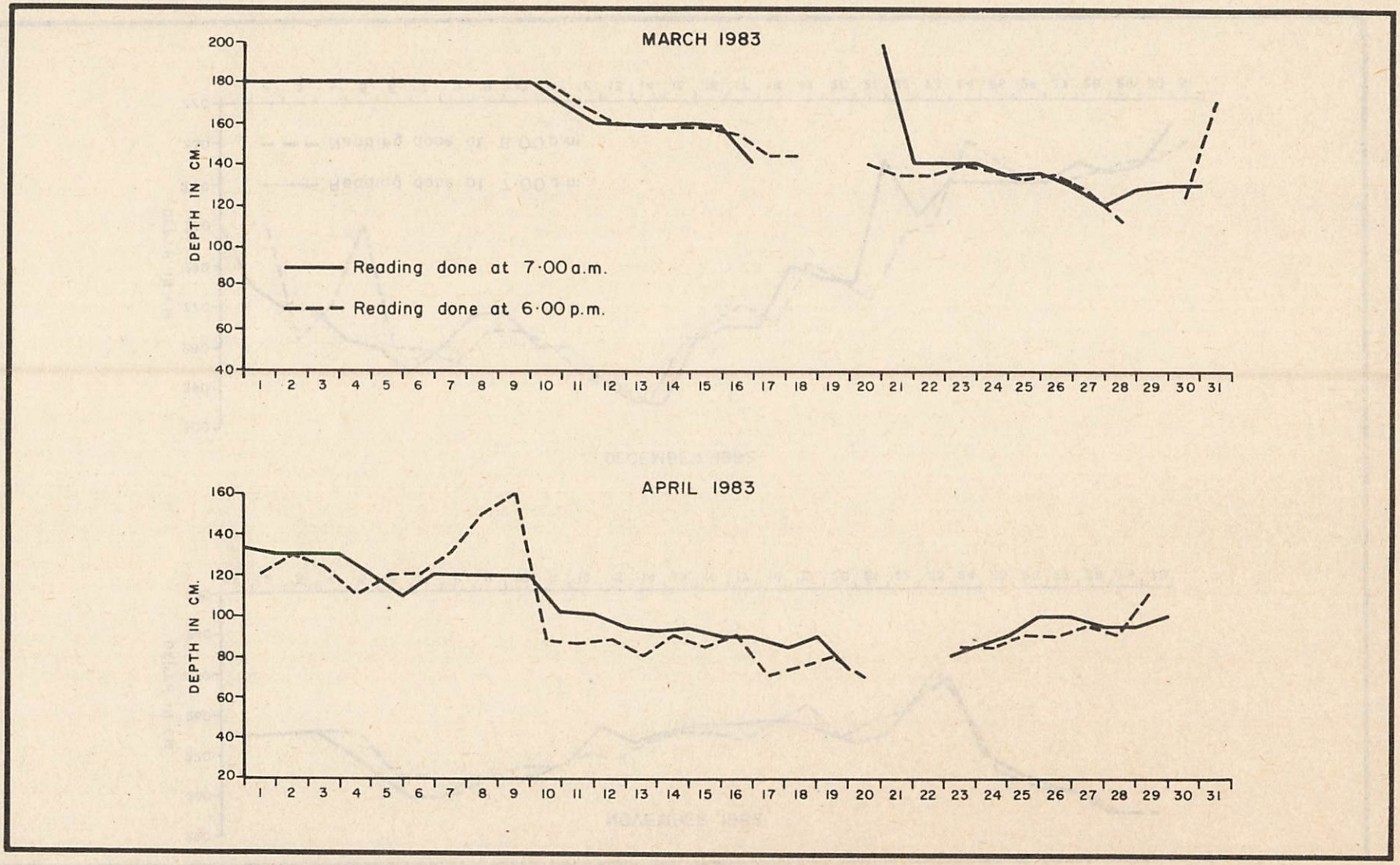
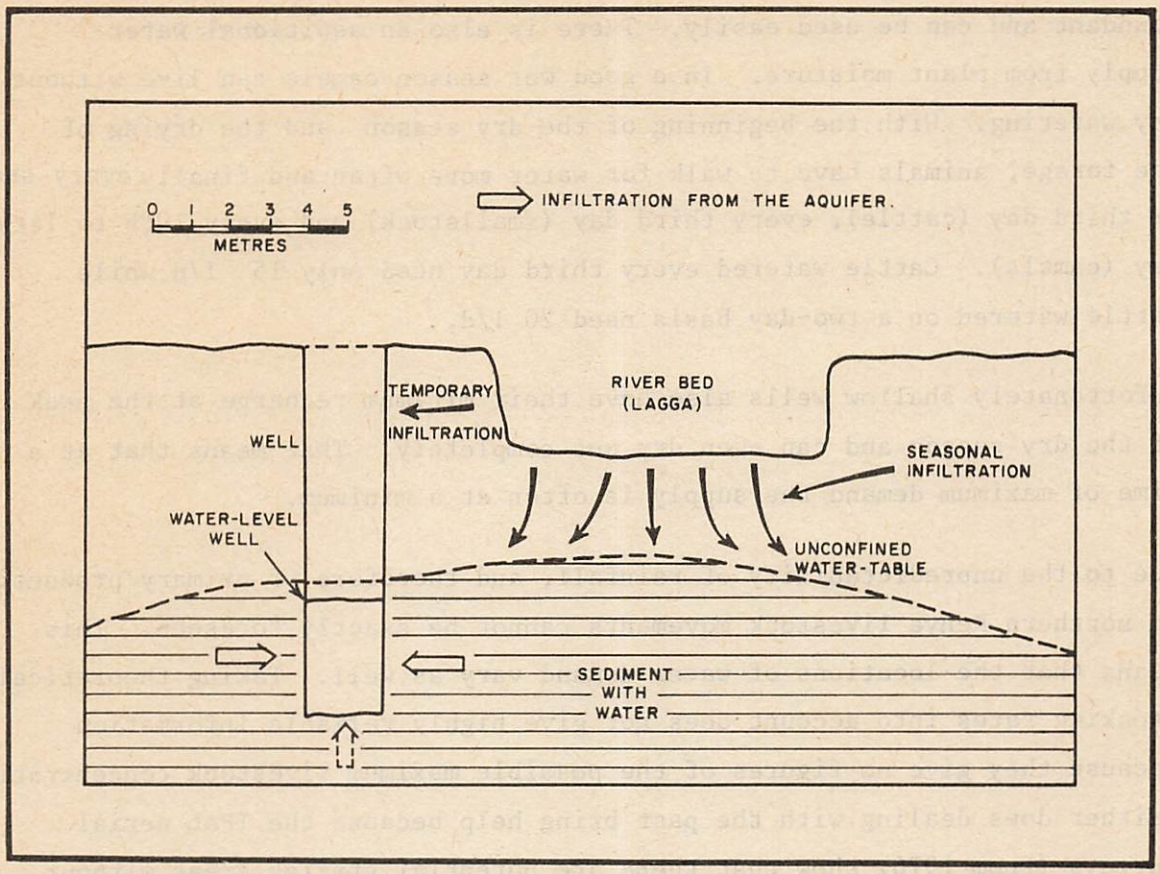


Figure 20. Model of a shallow well



distributed throughout the year. In the wet seasons surface water is abundant and can be used easily. There is also an additional water supply from plant moisture. In a good wet season camels can live without any watering. With the beginning of the dry season and the drying of the forage, animals have to walk for water more often and finally every second or third day (cattle), every third day (smallstock) and every 10th to 14th day (camels). Cattle watered every third day need only 15 l/d while cattle watered on a two-day basis need 20 l/d.

Unfortunately shallow wells also have their minimum recharge at the peak of the dry season and can even dry out completely. That means that at a time of maximum demand the supply is often at a minimum.

Due to the unpredictability of rainfall, and therefore of primary production, in northern Kenya livestock movements cannot be exactly foreseen. This means that the locations of water demand vary as well. Taking theoretical stocking rates into account does not give highly reliable information because they give no figures of the possible maximum livestock concentration. Neither does dealing with the past bring help because the IPAL aerial surveys (from 1976) show that there are potential grazing areas without any livestock at the moment. The envisaged stocking rates demand very high figures for water supply - figures that are impossible to cater for without the financial input for at least three boreholes. Meeting this demand in the form of traditional wells seems to be impossible unless we build a large number of wells. Making the wells more reliable in the dry season means increasing their depths so that they can tap a deeper water table but this will also increase the cost. In a way it is desirable that a well is not permanent. Drying out forces the people away from this well so degradation is less. It is preferred that a well dries up before the surrounding pasture is finished.

Using stocking rates derived from the annual rainfall the following water demands are given. (Water demand in m^3/day is valid for the dry season - in the wet season it is less. The stocking rate in this area is the same throughout the year.)

Table 12. Well water demand as a function of radii of grazing areas (rainfall 250 mm/a)

Grazing radius km	Le Houérou /Hoste m^3/d	Pratt/Gwynne m^3/d
5	23.6	14.7
10	71.3	42.1
15	153.4	87.2
20	282.8	164.6

This means that one well can normally service an area within a 5km radius. With an increase in radius the number of wells increases non-linearly. For a radius of 10km three wells are needed, for 15km six, and for 20km twelve would be needed (see Figure 21).

The IPAL range survey gave carrying capacities for each range unit (see Table 13).

This gives us a mean stocking rate of 12.3 which is almost the same as the one from Le Houérou and Hoste so that the data from Table 12 are also valid by this way of calculation.

The required water needs are listed in Table 14 which shows that they are hard to fulfil. For practical purposes we have calculated a mean stocking rate for the lowlands, including the lower plateaus of Marsabit lava which have higher rainfall but highly permeable soil.

Table 13. Mean stocking rates for the Rendille grazing block (animals/ha)

Camels	3.8
Cattle	8.3
Sheep	5.8
Goats	3.5
In terms of TLU these figures are:	
Camels	3.0
Cattle	8.3
Sheep	0.6
Goats	0.4

Figure 21. Well number and water demand as a function of the radii of grazing circles

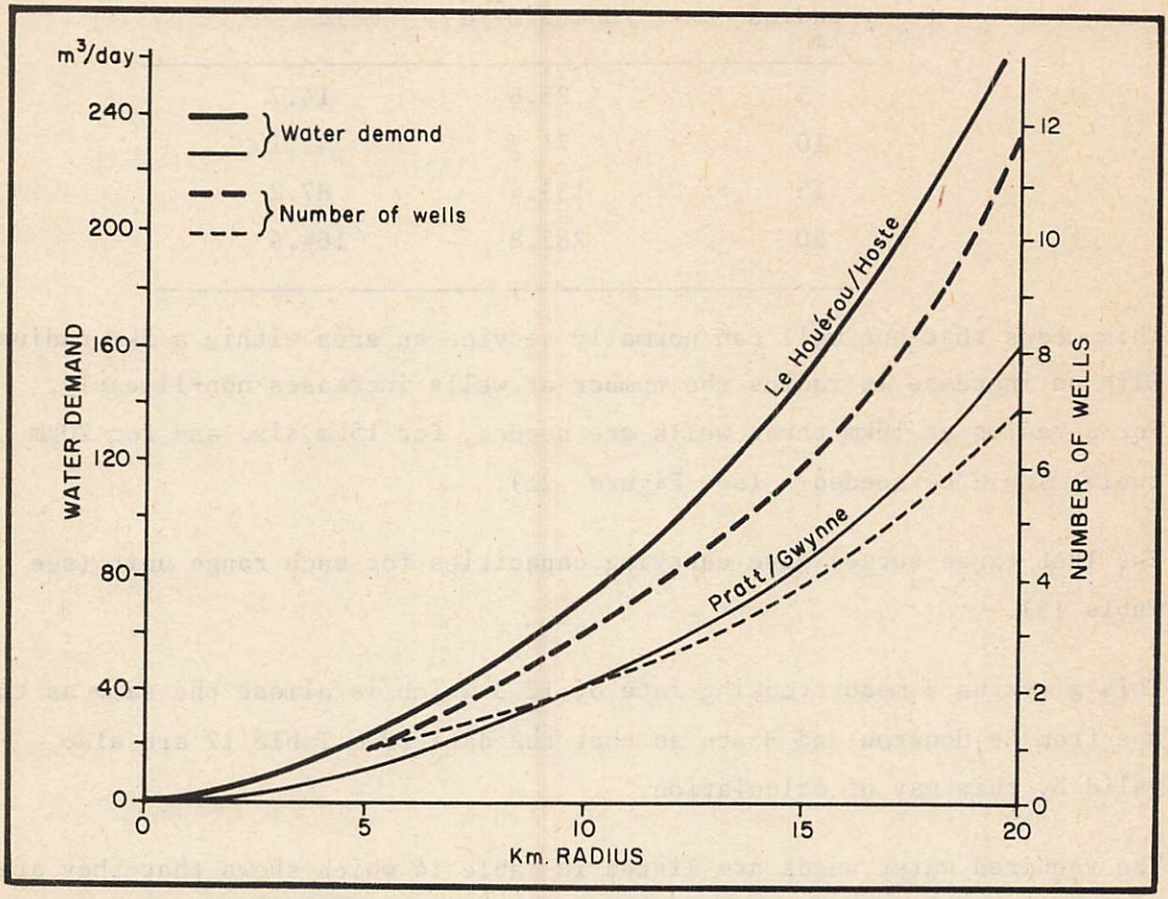


Figure 14. Water demands of Livestock

Species	Number	Water (m^3)	+ 10% waste	Total (m^3)
Sheep/goats	107,547	430.2	43.0	473.2
Cattle	24,552	491.0	49.1	540.1
Camels	18,643	186.4	18.6	205.0
Livestock total	150,977	1,107.6	110.7	1,218.3

9. WATER CONSUMPTION IN THE RENDILLE GRAZING BLOCK

9.1 Water for livestock

Here we give figures for the entire grazing scheme because the spatial distribution of the livestock is highly variable in time. Nevertheless times and areas of livestock concentration have to be well known because there will be an enormous demand for water within a very short time. Otherwise livestock are capable of moving over large distances towards watering points.

Water demands of livestock

Livestock have the following water demands:

(a) Sheep and goats 4 l/day
(b) Cattle 20 l/day
(c) Camels 10 l/day

These figures are theoretical because livestock in arid areas are not watered every day. The watering frequencies are as follows:

(a) Sheep and goats 3 days
(b) Cattle 2 days
(c) Camels 11 - 14 days

This brings problems for the water supply because the water demand for one day is higher than estimated from the average.

The demand for water in the grazing block as a whole is determined from the actual numbers of livestock and the specific needs per day with 10% added for waste caused by the animals and the watering people.

The total demand for water per day by all the livestock has been

determined as 1,218.3 m^3 per day.

9.2 Domestic use

Use of water by people is directly related to distance from the well (Table 15). The further the water has to be carried the less people will use.

Table 15. Domestic consumption of water per person

Distance to water source	Consumption /day
15 km	2 - 3 l
1 km	3 - 6 l
Next to house	10 - 20 l

Thus mean consumption per man per day is 10 l. The population of the Rendille block is estimated at 13,000 inhabitants (excluding Marsabit). This means that the water demand is 130 m^3/day + 10% waste = 143 m^3/d. Water demand for the whole area is 1,361.3 m^3/day. A conservative estimate for the entire block, therefore, would be 1,500 m^3/day. This does not include the water needs of game animals.

10. THE SPATIAL DISTRIBUTION OF WATER NEEDS

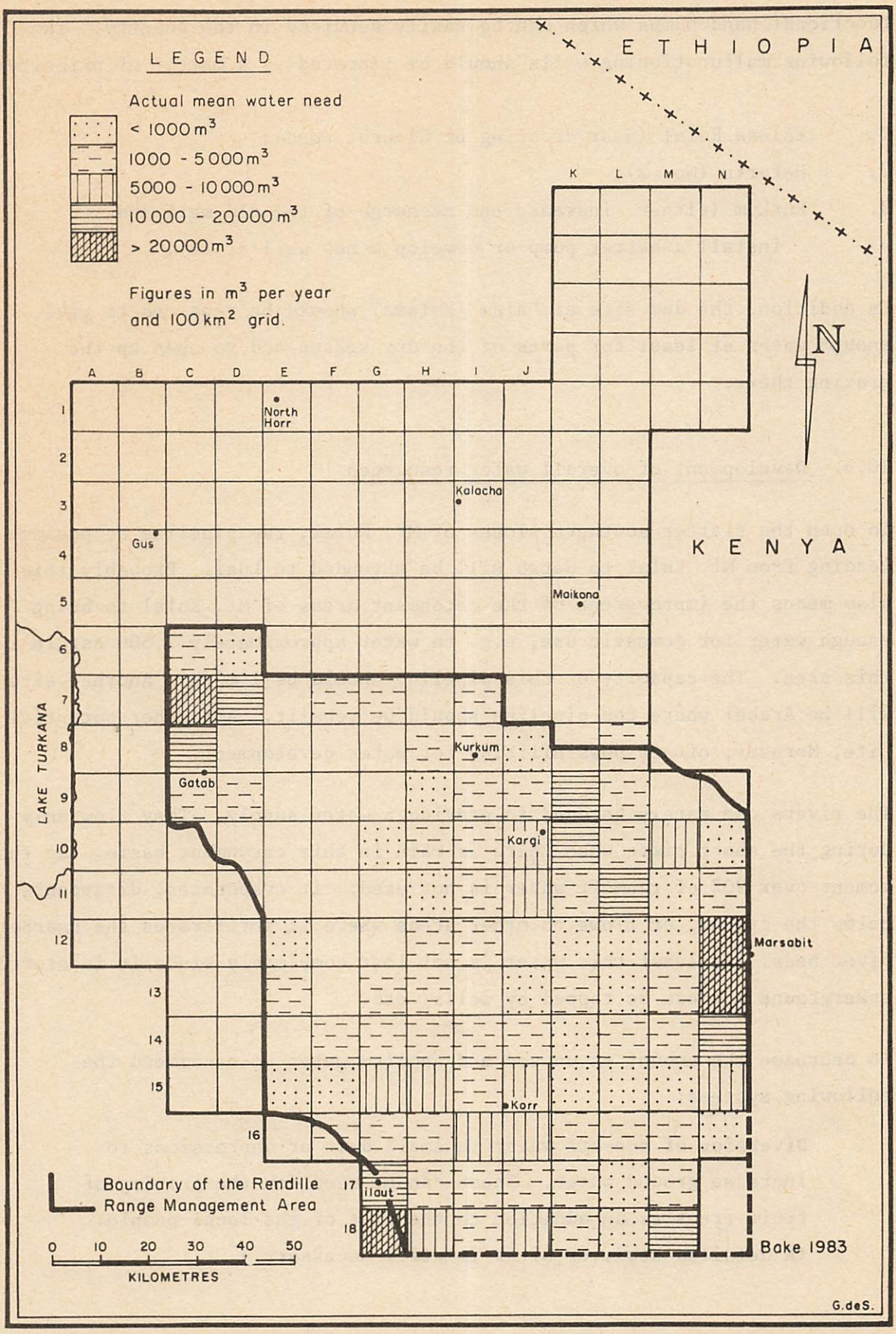
10.1 Livestock

From the aerial census (IPAL Management Plan, Vol. I, p. 263 ff) the mean livestock densities per sq km have been taken and multiplied by the water needs per day of the livestock species. Multiplying by 100 gives us the actual water need per 100 sq km per day. The standard deviations have also been taken into account. By this method maps of the actual water needs in the area have been drawn (see Figure 22). For the quality of water it has been considered that each species has other water tolerances. These data still have to be computed for up to one year.

10.2 Development of existing wells

Many existing wells are not operating to their full capacity due to various malfunctions and breakages. Priority should be given to the fitting of new pumps at these wells. Emphasis should be on simple and

Figure 22. Annual mean water need in the southern IPAL area



functional hand pumps which can be easily serviced in the country. The following malfunctioning wells should be improved as a matter of priority:

1. Balesa Kulal (near crossing of Olturot road);
2. Hafarin (No. 2);
3. Kurkum (either increase the recharge of the old well and install a better pump or develop a new well at 16).

In addition, the dam site at Falam (Kalama) should be repaired to give enough water at least for parts of the dry season and to open up the grazing there.

10.3 Development of overall water resources

To open the flatter southern slopes of Mt. Kulal, the pipeline at present leading from Mt. Kulal to Gatab will be extended to Luai. Probably this also means the improvement of the catchment areas of Mt. Kulal to bring enough water for domestic use, e.g. to water approximately 2,500 cattle in this area. The capacity of this pipeline should be 1 m^3/h. Another site will be Arabel where the pipeline should be rebuilt. A further potential site, Moruset, offers possibilities for water development.

The rivers can rarely be used to provide a water supply. They flow only during the short times when there is rain in this catchment basin. At the moment over 90% of run-off water is not used: it evaporates, disappears below the ground, or flows to other areas where it infiltrates the nearby river beds. At least this water is not lost completely since it is stored underground and can be tapped by wells, etc.

To decrease the amount of unused and spoiled water we recommend the following systems:

- Diversion of run-off water to small dams or depressions to increase ground water. These can be used for the growing of fruit trees as an addition to the diet of the local people. (A detailed study of sites is still necessary.)

- Where bedrock (lava, basement) is present at a shallow depth, the construction of small surface dams for watering animals. (Possible sites exist only in the basement complex areas and the Balesa Kulal, where lava crosses the river.)

11. MANAGEMENT OF WATER RESOURCES

11.1 Principal objectives

(a) The first consideration in water development should be the provision of adequate waterpoints for domestic use.

(b) The second is the provision of adequate water for livestock, which is well distributed to facilitate even grazing of the range and to reduce walking stress for livestock.

11.2 Water development

We noted earlier that the results of studies on the water potential indicate that adequate water resources exist in the Rendille country. The only constraint on its development is cost. Studies have also shown that there is adequate shallow water such that hand-dug wells would adequately cater for the water needs of the area. Priority should therefore be given to the development of hand-dug wells rather than boreholes, whose development costs are exorbitant.

11.3 Well density

The ideal situation with regard to water development in the Rendille area would be to have a waterpoint on every 25 km^2. Then livestock would not have to walk long distances to water and this would also redistribute grazing pressure and alleviate the deterioration of the range. If distribution on such a scale were to be implemented, the Rendille area alone, which is approximately 10,000 km^2, would need 400 wells. An estimated KShs 30,000 would be needed per well or a total of KShs 1,200,000. Even if the area to be served by each well was increased to 50 km^2, 200 wells would still be required.

In this plan it has been decided to base calculations of the needed well density on the actual available ground water determinations and actual water needs of people and livestock (Table 16) as well as on the expected future distribution of livestock if range management becomes effective. Figures 23 and 24 show the areas where there is an urgent water need at present based on the distribution of permanent water sources and an effective area served by each well of 761.5 km^2 (15.6 km radius). This mean area is calculated from the fact that cattle, smallstock and camels can graze or browse in radii of 10 km, 25 km and 50 km, respectively, around a well.

Altogether 26 new wells are proposed. For their location see Figure 25 and Table 17. The areas without sufficient water supply at the moment have been given priority as well as the insecure areas of the Hedad. All the proposed wells should be hand-dug wells with cement culverts to avoid collapse of the wall. Building with concrete culverts will cost about KShs 2,500 per metre. On average one well will cost KShs 25,000 if the local people contribute their labour (see Appendix 3).

The sinking of boreholes and the mechanical drilling of deeper wells should, however, not be attempted at this stage until the monitoring of the proposed network of wells has produced concrete results. Also, the cost of drilling boreholes is prohibitive (100 - 150 m will cost up to KShs 600,000).

In addition it is proposed to extend the pipeline from Gatab to Luai (KShs 200,000) on Mt. Kulal and to rebuild the pipeline at Arabel (KShs 300,000). Further research is necessary here.

Table 16. Annual water demand in various range units

No.	Area	Camels	Cattle	Sheep	Goats	Per km^2	Total
1	395.2	6,300	8,855	3,619	5,622	61.7	24,383
2	494.0	3,935	25,601	10,366	3,535	88.1	43,537
3	178.8	325	11,745	4,803	235	95.8	17,108
4	112.9	3,216	2,139	922	2,819	80.9	9,096
5a	178.8	2,091	13,549	566	184	9.3	16,380
5b	272.9	1,722	22,469	11,174	1,984	136.9	37,349
6	160.0	2,153	15,418	6,381	1,962	162.0	25,194
7	240.0	1,226	9,986	2,843	1,121	63.7	15,276
8	244.7	5,895	7,504	3,026	5,288	88.7	21,713
9	672.8	16,454	28,973	11,886	19,366	106.5	71,679
10	1,025.7	21,338	50,918	10,632	18,569	98.1	101,457
11	23.5	102	854	350	84	59.1	1,390
12	112.7	1,318	1,730	756	1,136	43.8	4,940
13	635.2	5,333	12,979	5,472	4,822	45.0	28,606
14	376.4	2,062	32,149	13,078	1,924	130.7	49,213
18	668.1	3,807	12,191	4,974	4,584	38.3	25,556
19	3,011.2	49,458	276,192	100,675	45,711	146.8	442,046
20	390.5	5,701	12,541	2,965	4,845	66.7	26,052
21	329.4	120	67,327	27,557	96	288.7	95,100
22	211.7	-	-	-	-		
23	258.8	-	-	-	-		
24	207.0	-	-	-	-		
25	18.8	-	-	-	-		
Total	10,219.1						

Camel 3.65 m^3/year head
Cattle 7.3 m^3/year head
Sheep/goat 1.46 m^3/year head

Figure 23. Distances to permanent water.

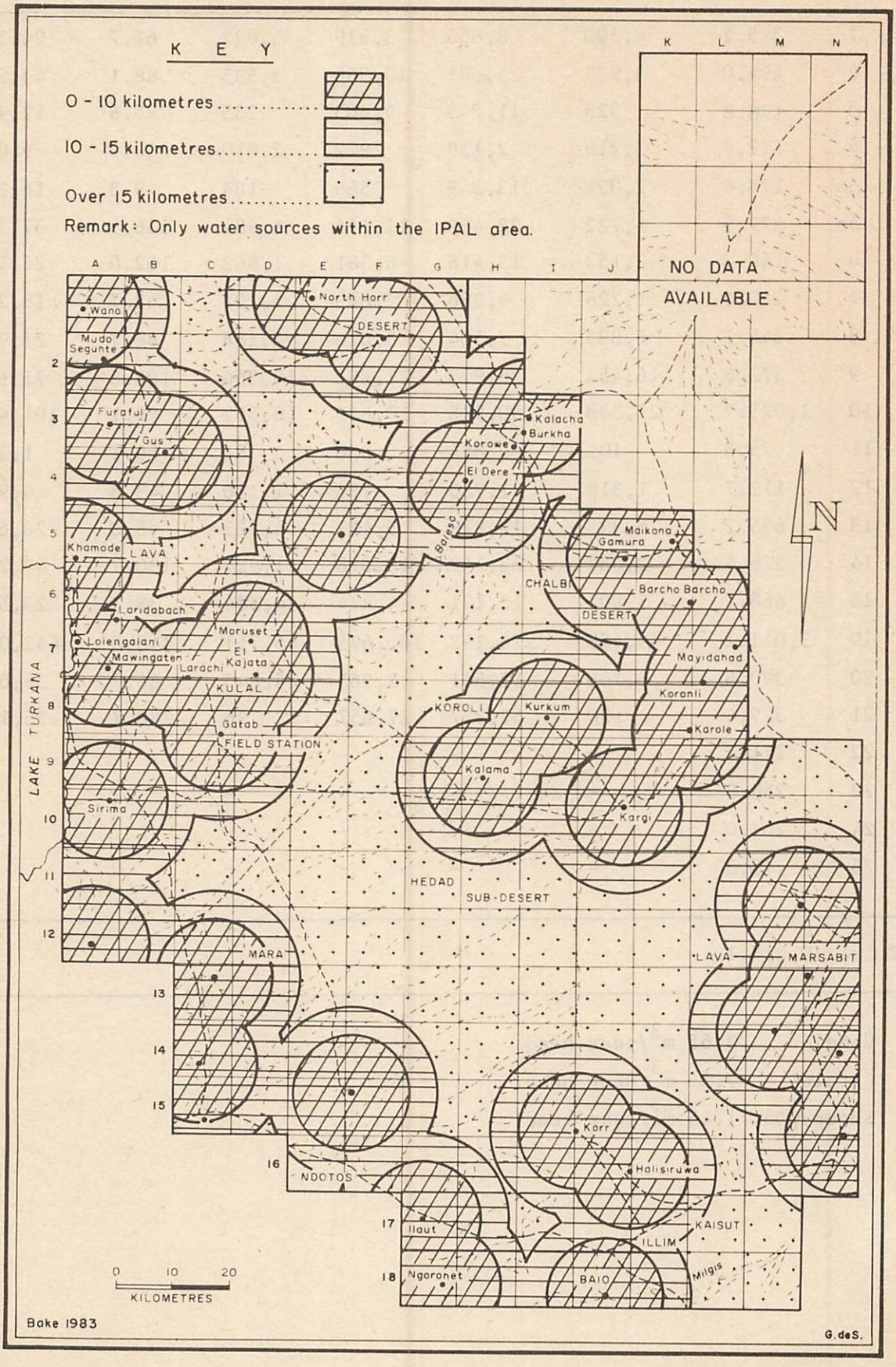


Figure 24. Grazing areas around existing water sources and two boreholes in the Hedad.

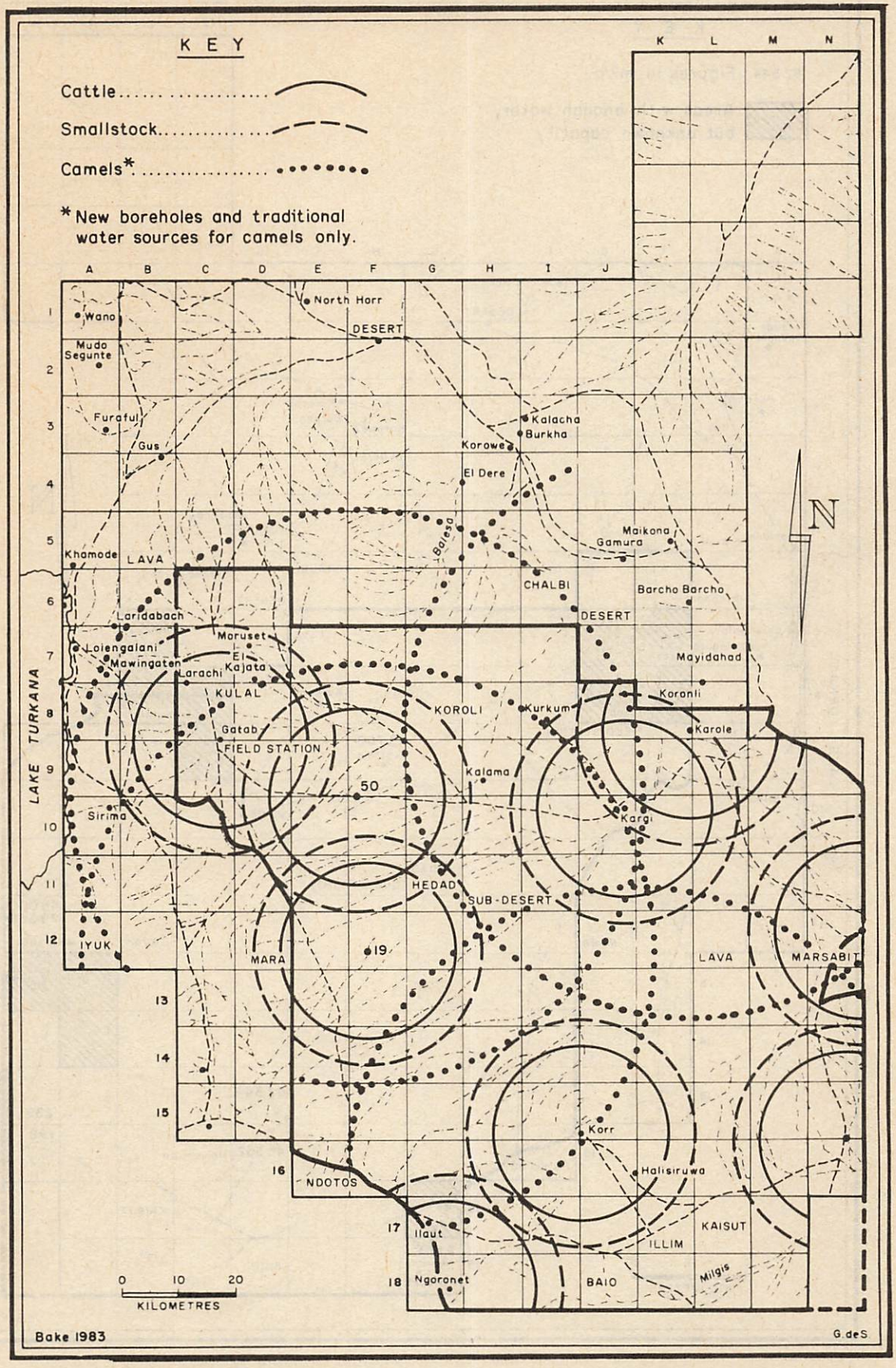


Figure 25. Water resources in the grazing area

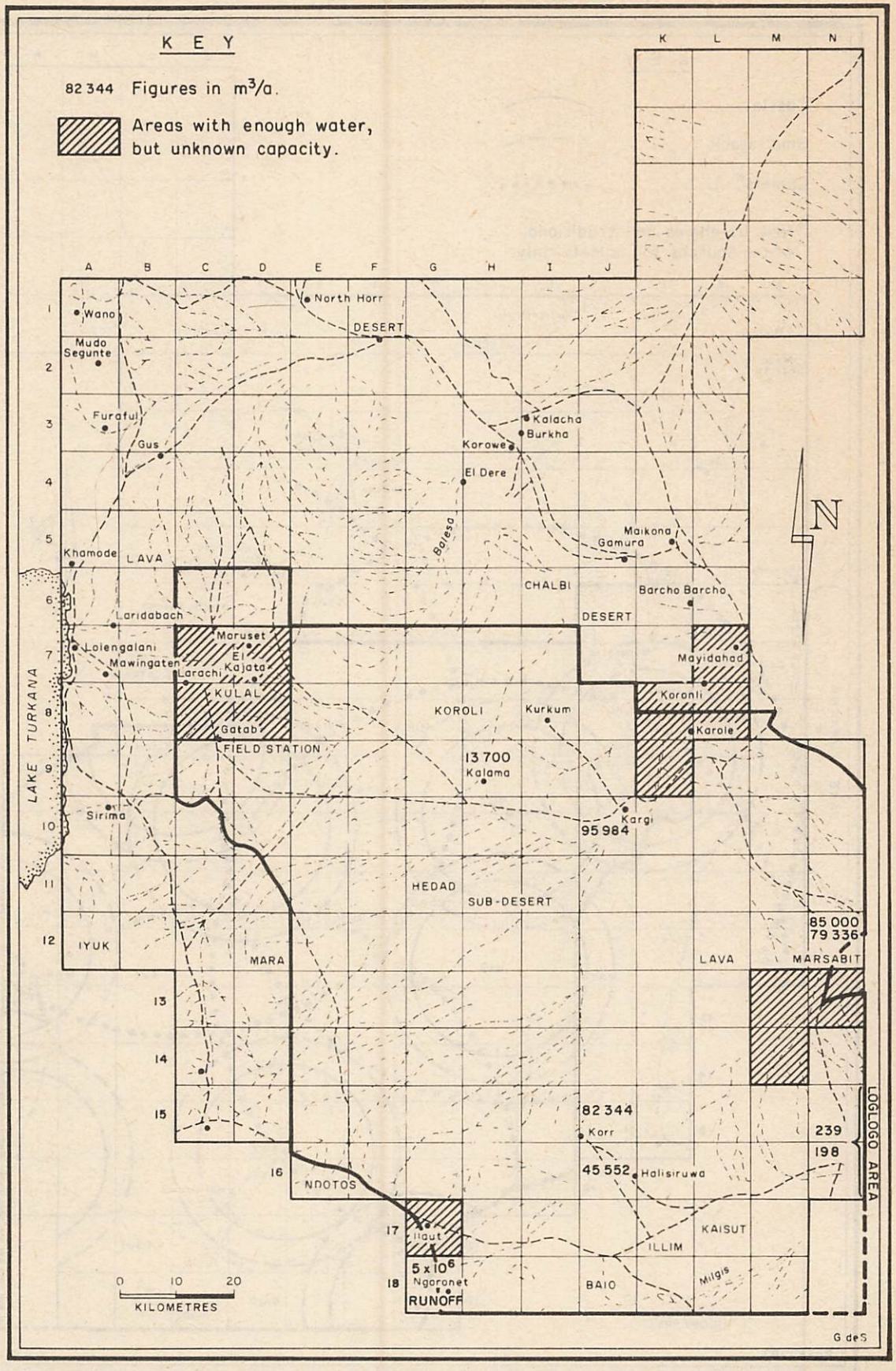


Table 17. Proposed new well sites

Resistivity number	Location	Depth to water		Range Unit
		Dry season	Wet season	
1	Olturot	10/40	-	12
2	Hedad	6	4	3
9	Korr	3	5	2
10	Kargi	6	4	24
15	Kargi	2	12	2
16	Kargi	3	10	10
18	Balesa Kulal	10	11	12
19	Hedad	20	15	9
20	Hedad	15	11	7
21	Hedad	4	4	5
22	Korante	2	10	1
23	Balesa Kulal	4	4	12
24	Balesa Kulal	3		12
28	Illim	10		-
29	Loglogo	10	No data	-
30	Ngurunit	3	available	20
33	Hedad	3		7
37	Hedad	8		3
39	Hedad	4		10
40	Hedad	10		10
44	Hedad	8		8
45	Hafarein	5		1
46	Korr	2		24
51	Balesa Kulal	3		10
53	Kargi	3		10

11.4 Priority of wells

From the range carrying capacities the maximum water needs have been calculated in total and per km^2. The last figure has been used to compile the priority list in Table 18. It has to be noted that the surveys of the water resources took place before the carrying capacities were known. That is why, for example, no sites were detected in Range Unit 19 which has one of the highest water demands. However, in this unit there is a high potential but it can only be exploited by boreholes. As usual in hydrology, maxima have to be taken into account. Seen over the whole year the actual figures will be less.

Table 18. Priority list of new wells

Site No.*	Range Unit No.
19	9
40	10
51	10
53	10
16	10
2	3
39	3
21	5a
44	8
15	2
9	2
30	20
20	7
37	7
45	1
22	1
33	1
23	12
24	12

* For details see tables 10 and 11

11.5 Constraints on the construction of several wells at the same site

One well tapping water from a depth of less than 10 m cannot give enough water for all the livestock in a certain area. Normally its capacity will be around 1 m^3/h. Often the local people try to increase the capacity of a specific site by digging more wells in the area immediately surrounding. This might work in certain places like in the *lagga* at Illaut where there is a constant channelized sub-surface stream from the wet Ndoto Mountains. Even in the Balesa Kulal it is possible, but not in most of the streams flowing in the Hedad. One well only creates a depression in the local upper water table so that the other wells around might become dry. There are several methods for determining the most suitable distance from one well to another but each of them involves a lot of capital and technical input. Therefore, in *laggas* in the Hedad it is proposed that wells be 2 - 5 km apart if there are no other favourable sites for sub-surface dams. Surveys might reveal further good sites.

Another point which has to be noted is that the building of a new well will cause livestock and human concentration around it which will lead to degradation of the environment. If the well is permanent, severe damage is almost unavoidable. The damage increases non-linearly with the amount of available water so that additional wells would increase this effect. It is likely that proper water management will be the most difficult aspect of range management. Therefore it is not a bad thing if the wells in crucial areas where there is a high danger of degradation dry out at certain times. In a dry year when there is only a little production by the vegetation the well will become dry earlier so that the people are forced to move with their livestock. This is part of a natural ecological cycle. It has been shown all over the world that an abundance of water favours human sedentarization and thereby desertification.

12 PRECAUTIONS AGAINST DROUGHT

Droughts are a common feature in the arid and semi-arid lands. Traditional nomadism was able to face the challenges and gives the people a fair chance of survival.

Today the system has changed. Increasing populations of people and livestock and a tendency to sedentarization have made the pastoralists more vulnerable to these natural phenomena. During recent droughts livestock died and the people had to be fed from external sources.

Drought as a climatological feature also affects hydrology of the area. With decreasing rainfall the surface run-off also becomes sparse so that there is no reliable water source for the nomads. Sub-surface water is not recharged. Normally this will not affect the deep regional water table but the local ones will become almost dry. In periods of drought the new wells will become dry because they tap the local aquifer. The reaction of the nomads is to concentrate near the reliable water sources, e.g. boreholes. Such areas have already been under high grazing pressure so there is little forage available. In order to take part of this pressure to other areas it is proposed that two deep boreholes be drilled in the central Hedad to tap the reliable regional water table (see Figure 24). These boreholes should not be used unless there is a long drought period in the area. The boreholes will be sealed and the necessary equipment (pumps, storage tanks) will be stored at Marsabit. Therefore this equipment should be easily transportable.

The two boreholes should be at sites 19 and 50 (see Figure 24). There is water available at around 100 m and 60 m respectively. Also one can find a shallower water table which could be used by wells during normal periods. Before drilling starts a new hydrogeological survey should be done.

Figure 23 also shows the possible grazing areas surrounding these new boreholes and other reliable water sources during periods of drought. More than half of the Rendille grazing block could be used for grazing of smallstock and cattle. The whole area could be used by camels. The limits for grazing and browsing will then be given by the primary production rate of fodder plants.

13. OUTLINES OF A WATER MANAGEMENT POLICY

13.1 Objectives

The objective is to supply people and their livestock with adequate water for domestic use and livestock watering all over the area and throughout the year. Water management has to be integrated in the general policy of combating desertification in Marsabit District.

13.2 Statement

Exploration has determined that there is enough water to supply the entire area at the present stocking rate. But these water resources are not distributed equally (see Figure 25).

Theoretical capacity is never reached. This amount of water could only be made available if the pumps are kept running 24 h a day throughout the year. Even 50% of capacity is rarely reached due to breakdowns and shortages of fuel. A working rate of 20 - 30% is therefore considered adequate for the existing conditions. This would not be enough water to supply both people and livestock in certain places, especially with the continuing trend to sedentarization and concentration of livestock in a very few places. In places in the central Hedad there is already insufficient water in the dry season.

13.3 Research policy

Research is constrained by the enormous costs of drilling deep boreholes. This, of course, limits the possibilities of finding rich water tables. However, it does give the local people the opportunity to contribute their labour to the development of the identified well sites.

At the moment it is proposed to dig only shallow wells (approximately 10m) and make them permanent by the use of concrete rings. It is hoped that all the suggested wells will have a practical capacity of 1 m^3/h throughout the year. This gives a usable amount of 12 m^3/day, or 4,380 m^3/year which is enough to water more than 700 TLU if they are well mixed in species composition.

13.4 Management of water resources

The people using the different water sources have to learn and to understand that proper handling of the materials, technical equipment and the water is to their own benefit and is absolutely essential for their welfare. Therefore deliberate damage to equipment should lead to immediate action. Those responsible should pay for the damage either in cash or in livestock. Access to water sources should only be granted to people who have contributed to the installation in some way. Boreholes

run by Government should not provide water free but should charge enough to cover the costs of fuel and maintenance. The charge would also depend on the numbers of livestock watered. All livestock owners have to be ordered (and we use the word 'order' purposefully) that grazing is strictly prohibited within a radius of 1 km around the water source and that they have to use the marked tracks. Range managers should consider using this area around water sources for demonstration and even experimental plots. Also marketing facilities should find their place here.

APPENDIX 1. PROCEDURES TO BE FOLLOWED FOR THE CONSTRUCTION OF THE PROPOSED NEW WELLS

Phase 1

- Analysis of when and if this specific well will be necessary, also estimation of the livestock density for well yield estimation;
- Contacts with the local people to get their opinions and ascertain the required labour force.

Phase 2

- Specific site check by the hydrologist;
- Repetition of electric resistivity measurements or test drilling.

Phase 3

- Preparation of needed materials and equipment as required by the hydrologist;
- Transport of materials to well site.

Phase 4

- Digging of the well;
- Test pumping for yield determination;
- Sealing of the well by metal or concrete lid;
- Setting in of the handpump;
- Trough building (number and size of troughs according to the livestock density);
- Fencing of site, if required.

Phase 5

- Handing over of the well to the local people with one specific person in charge.

APPENDIX 2. A MODEL OF WATER DISTRIBUTION FOR THE IPAL STUDY AREA

This model is based on:

- The water needs of different species of livestock over a specific period;
- The wandering capacity of this species.

In regard to the second point there is no allowance for abiotic and biotic factors or for costs. It is assumed that water is available at all desired points. The spatial distribution of livestock is not taken into account.

Water needs of animals

The intake of water by the four different species is highly variable and depends on many factors. Climate and the available diet are the most important of these. Sheep and goats seem to need between 4 and 6 litres per day; camels have to come to a watering place only once a week but then they take almost 100 litres each. Cattle need about 20 litres per day. This gives us the following conclusions:

(a) Sheep and goats which need water every third day can graze an area 25 km from the distribution point;

(b) Cattle have to be watered every second day and their walking distance is 10 km;

(c) Camels which have to be watered only once in a week in the dry season have the biggest range. That is why they should graze and browse in an outer circle and come to the water point using narrow tracks. They can go as far as 50 km from the water point.

Wandering capacity

The wandering capacity of the four livestock species is related to their water needs. From the above figures the wandering capacity of livestock is estimated as follows:

Camels	20	550 km^2	)
Cattle	10	314 km^2	)
Sheep)			) Effective grazing area
Goats)	15	392 km^2	) on one day around a water point

Walking in this case means that the herds and flocks are moving slowly continuing with their usual browsing and grazing.

The potential walking capacity on tracks without grazing is much higher, as follows:

Camels	40 km/day
Cattle	15 km/day
Goats and Sheep	25 km/day

The water supply of this theoretical area is based on a number of similar waterholes equally distributed all over the area. The borehole itself is not a point of water distribution. From here a number of pipelines supply water to a series of troughs at a specific radius around the hole. Settlements are not allowed at these troughs and in their surroundings. The pipeline system can be constructed to different patterns (see Figure 26).

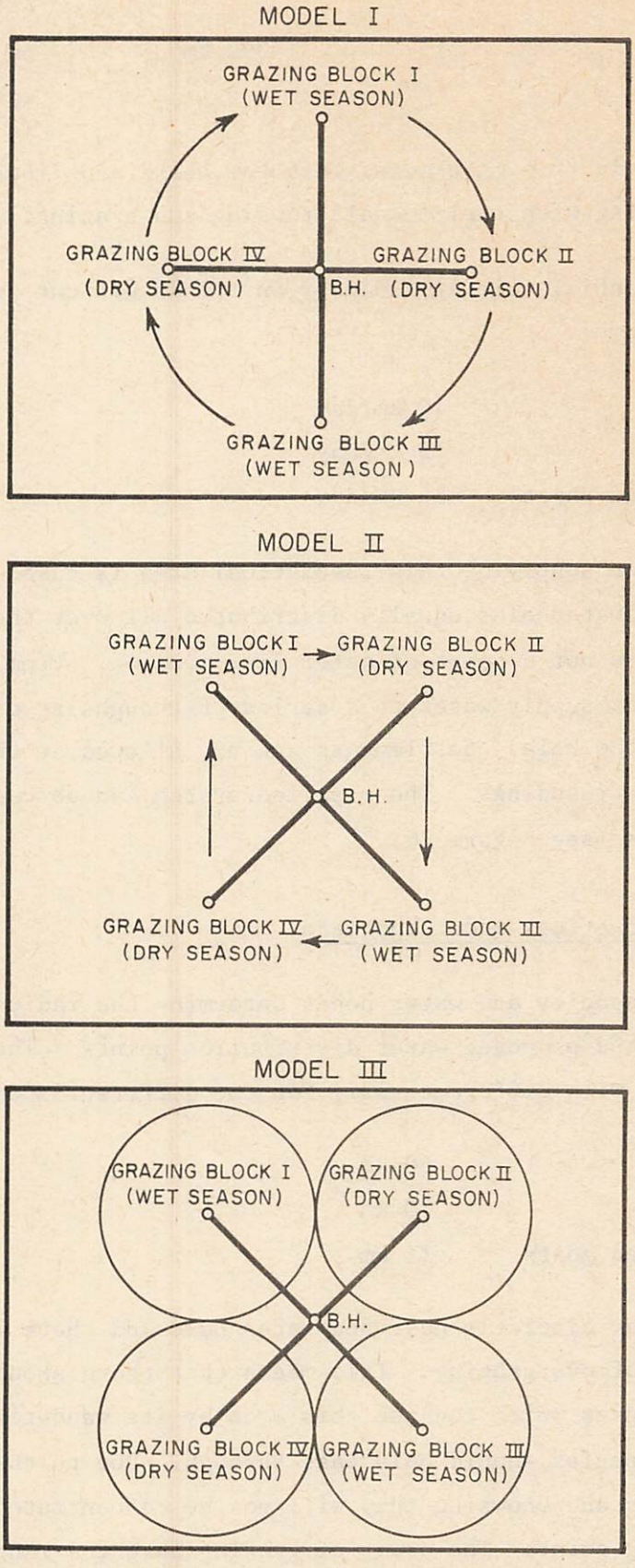
The theoretical model approach

Water capacity and water needs determine the radius of the grazing area around the proposed water distribution points. These will be three circles with different radii for the different species:

Camels	50 km
Cattle	10 km
Sheep and goats	15 km

The inner circle is near the water hole and there is, therefore, a danger of overgrazing. This means that there should only be grazing by the species which can use this area by its wandering capacity. The other species should only pass through. Due to the habit of animals grazing and browsing they will now be concentrated on the tracks to the watering point. The areas of grazing have the range:

Figure 26. Three water supply and grazing models



$$A_1 = \Pi\, r_1^2$$

$$A_2 = \Pi\, r_2^2 - \Pi\, r_1^2 = (r_2^2 - r_1^2)\,\Pi$$

$$A_3 = \Pi\, r_3^2 - A_2 = \Pi\, r_3^2 - \Pi^2_2 - \Pi\, r_1^2$$

$$= (r_3^2 - r_2^2 - r_1^2)\,\Pi$$

A_i = area i in sq km

r_i = radius i

r_i is a function of wandering capacity c_i and water need n_i

$$r_i = f(c_i, n_i)$$

That means

$$c_i = g(n_i) \qquad i = 1,2,3$$

$$\Rightarrow r_i = f(g(n_i)) = h(n_i) \text{ if } h = g.f$$

Until this point we were only discussing and looking at the water needs. The next step is to look at the biomass needed by each species. This can be expressed in an area which gives this biomass to a specific amount of livestock. B_i shall be this area for the species i (i = 1,2,3). Then the radius p_i is a function of the biomass needs of the species and the productivity k_i of the area.

$$p_i = f(b_i, k_i) \qquad i = 1,2,3$$

The productivity seems not to be independent for the different species. This is quite correct from the botanical point of view. But we have to include in our thoughts that livestock have food preferences so that the offtake in each area will vary a little bit by the species selection. So the areas B_i can be determined as:

$$B_i = \Pi\, p_1^2 \qquad B_2 = \Pi(P_2^2 - p_1^2)$$

$$B_3 = \Pi(p_3^2 - p_2^2 - p_1^2)$$

The task now is to make $B_i = A_i$ for $i = 1,2,3$
Normally this will not be possible due to the conditions of the arid and semi-arid environment. It is the aim of this study to present an optimal model.

Discussion of the three models

General

There is an area for grazing with a surface of A. This has to be divided into four sections for each season. In the first approach we assume that vegetation is equal all over the area and that there are no changes throughout the year either in food needs or vegetation. This is an unrealistic assumption, but we have to concede that in the arid and semi-arid environment it is better to calculate with the data for the dry season so that there is enough security if the rain doesn't come.

Area A is divided into four sections A_k ($k = 1, \ldots 4$) with a surface of a quarter of A. The watering point is in the centre of the triangle. Yet A has a surface area $= a^2$. Then the unused area U is

$$U = \frac{a^2}{4} - \Pi r_3^2$$

This area can be used for milk herds or flocks and as a settlement area.

APPENDIX 3. CONCRETE TUBES FOR HAND-DUG WELLS

The purpose of these concrete tubes is to allow communities to develop permanent water sources for human and animal consumption. Their ease of construction allows local communities to dig the wells and construct the tubes with a minimum of outside assistance. The experience of MCC development personnel is that after instruction in the construction of two or three tubes the ring forms can be left with the local population who can finish the construction of the requisite number of rings to the desired depth of their well. The following description is based upon the accumulated experience of Mennonite Central Committee volunteers in several communities in various developing countries and is meant to be an aid to be modified as local conditions warrant. A size of 1 metre in diameter was chosen because it is the smallest size within which an adult can dig comfortably.

The ring forms themselves are most easily made in a metal shop with facilities for bending the light-gauge sheet metal, and cutting and welding it. The thickness of metal is relative to the availability of stock and funds for the project. Galvanized steel of approximately 1/16 inch thick provides the best compromise between strength, workability and lightness. Wooden jigs can be made to facilitate repeated construction if more than one set of forms is desired. Frequently a local metal shop can be rented on a per diem basis and the technology passed on to the local metalsmith to construct subsequent forms. In Kenya it may be desirable to employ one of the local training schools such as the Maasai Training Centre at Isinya.

Once the forms have been constructed they can be taken to the well site. We try to make the well digging and tube construction a community project and establish a sense of local involvement and worth in the project. One group can begin digging the wells while others gather sand and stone. If necessary, the rock can be broken at the job site by people using hammers. Obviously the involvement of local people and materials can reduce costs tremendously. Unless one is absolutely sure of finding water it is advisable to wait until the well site is proven until the tubes are made. The concrete tubes are difficult to transport should the well prove to be too salty or insufficient. When the water supply is verified the tube construction can commence while the well itself is conditioned.

With extreme care and an early start in warm climates two rings can be constructed daily. It is advisable to cure the concrete rings for three days. Damp gunny sacks wrapped around the rings will help the concrete to cure slowly. If water is a limiting factor a simple shade over the concrete tubes should be sufficient.

The cured rings are then lowered into the well using a block and tackle hung from a tripod. A log supported at both ends with a rope wrapped around it to provide a braking effect works sufficiently well. It is not necessary to cement the rings together. Their weight and the earth packed around them will keep them in place. After the rings are in place, with the last ring at least 50 cm above the surface of the ground to prevent mud and faeces from flowing back into the well, stone or sand is placed around the rings at water level to aid the flow of water into the rings. Finally a concrete lid 4 - 8 cm thick should be placed over it for safety and sanitation.

We had good results using hand pumps - either of a commercial variety or locally made, low technology windmills, or simple buckets and pullies to extract water. The key factors in the opinion of MCC development workers are the participation of those for whom the service is intended on a voluntary basis, the use of locally available materials for construction to reduce costs, and the use of locally available inputs to ensure replication and maintenance of the project.

In sandy areas where the well walls will not support continuous digging of the well, availability of water can be ascertained using a test hole hand dug or augered with a hand auger. If there is sufficient water the well can be enlarged and the first ring put in place at whatever depth is permissible by the soil structure. Then through alternate digging around the perimeter the tubes are slowly dug into place, each new ring added as one descends.

Concrete Mix (To fill one form)

Sand

3 five-gallon buckets, debbies, etc.

Crushed rock

3 five-gallon buckets.

Portland cement

1 five-gallon bucket.

Water

To form typical concrete mix.

(a) Through trial and error one can determine if an extra shovel of sand or gravel will fill the rings exactly to the top.

(b) Coarser sand (larger grains) may require reduced quantities of gravel. Experience will probably be the greatest guide in determining exact mixes.

(c) It is imperative that sand be free from organic matter and it is advisable that the aggregate be less than 2" in diameter to ensure uniform distribution within the form.

(d) Used motor oil should be smeared onto the face of the forms to ensure an easy release from the concrete. It also helps to preserve the metal when not in use.

(e) Once the concrete mix is prepared and poured into the forms it must be beaten down constantly using axe handles, hoe handles or sticks. This vibrating action distributes the mix evenly within the forms. Wire (such as fencing wire) should be added at 2 - 3 inch intervals within the concrete for added strength and safety.

(Prepared by Peter James Grill of
Mennonite Central Committee for

UNESCO-IPAL)

Figure 27. Construction of concrete tubes for hand-dug wells

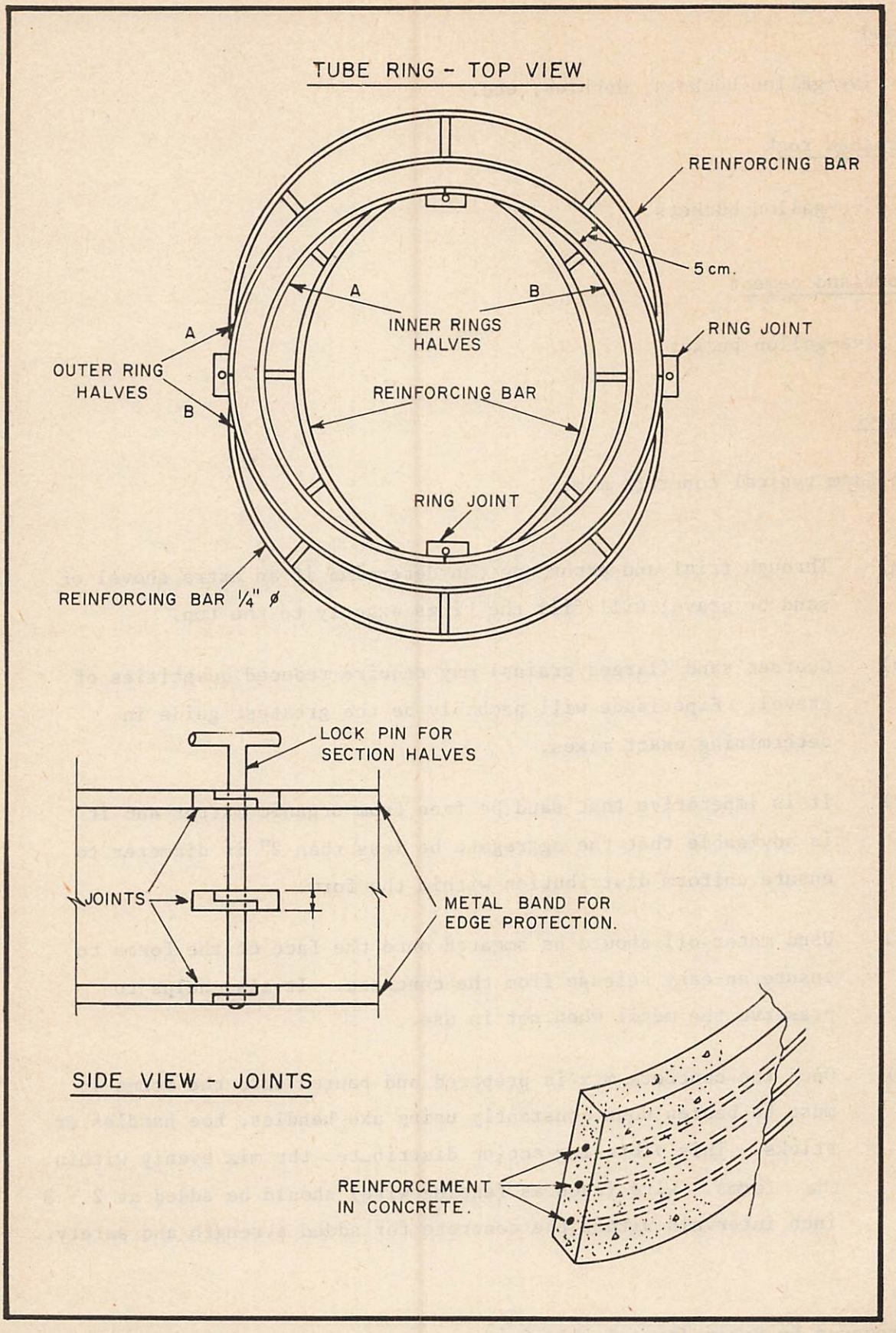
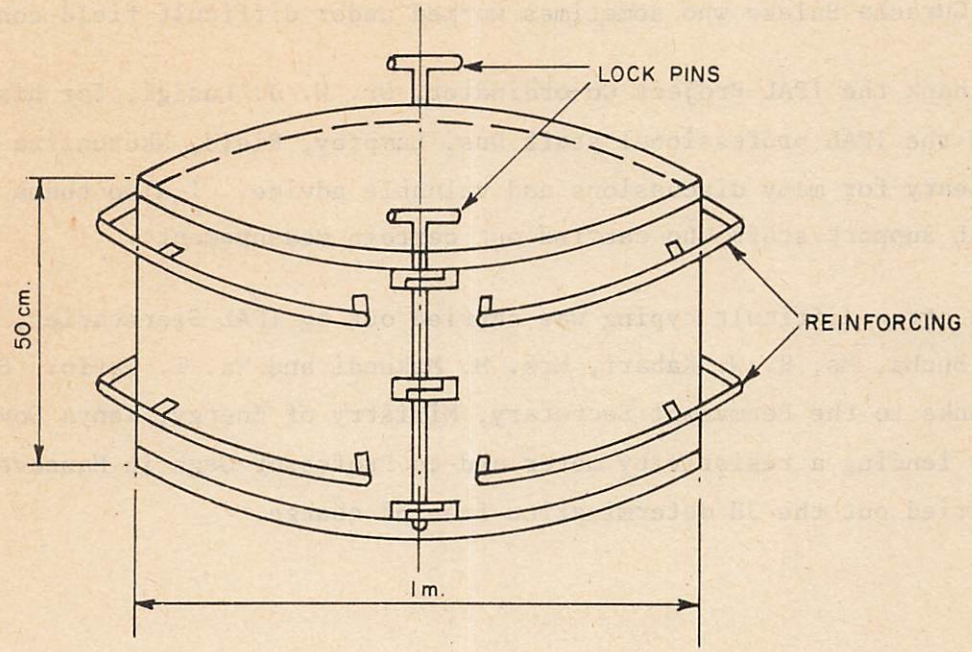
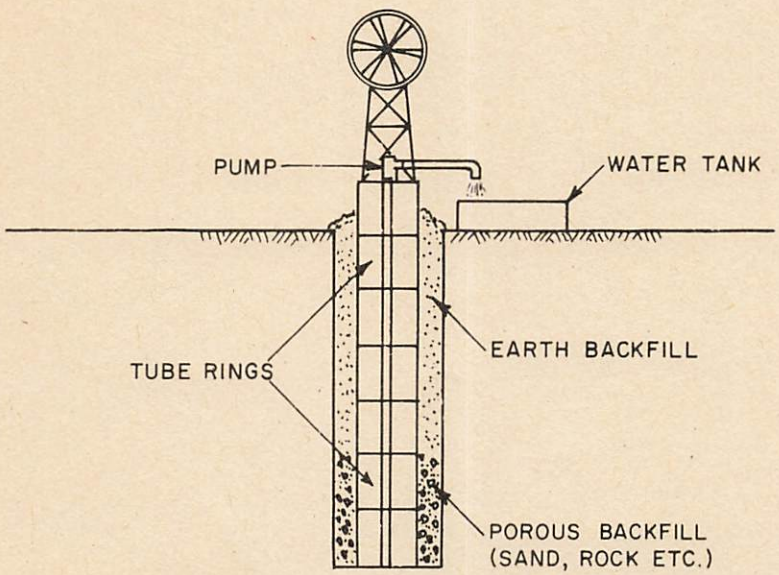


Figure 27 (contd)





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