REPUBLIC OF KENYA



MINISTRY OF WATER DEVELOPMENT

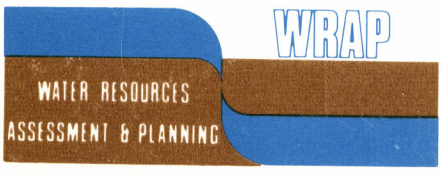
ISIOLO

WATER RESOURCES ASSESSMENT STUDY

MAIN REPORT

June 1991

WATER RESOURCES
ASSESSMENT SECTION
NAIROBI, KENYA



TNO – INSTITUTE
OF APPLIED GEOSCIENCE
DELFT, THE NETHERLANDS

PREFACE

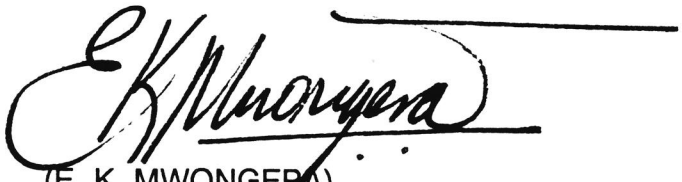
It gives me great pleasure to introduce the District Water Development Study for Isiolo District.

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

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

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

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



(E. K. MWONGERA)
Director of Water Development

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Note: the numbers of the appendices corespond with the respective numbers of the chapters of this report.

ABBREVIATIONS

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

SUMMARY

The Water Resources Assessment and Planning (WRAP) Project

The Water Resources Assessment and Planning Project carried out a Water Resources Assessment Study and a District Water Development Study of Isiolo District as part of the technical development cooperation between the governments of Kenya and the Netherlands. The project is carried out by the Ministry of Water Development with technical assistance from TNO-Institute of Applied Geoscience, Delft, The Netherlands. This summary gives a brief account of the results of the assessment study with emphasis on the potential for water development.

Project Area

The project area, Isiolo District approximately lies within parallel 0° 05'S and 2°N, and the longitudes 36° 50'E and 39° 30'E (Figure 1.1). Isiolo District covers a total area of 25,605 km² and is located in the Eastern Province of the Republic. It shares common borders with Wajir, Marsabit, Samburu, Laikipia, Meru, Kitui, Tana River and Garissa Districts. The total population of Isiolo District in 1979 was 43,478. The District is estimated to have a population of about 64,000 in 1988.

Most of the area of Isiolo District is flat and lies between 180 and 900 metres a.m.s.l. Almost the whole District is drained by the Ewaso Ngiro and its tributaries. But the southern tip of the District is drained by Tana River.

Geologically, Isiolo District is comprised of Precambrian metamorphic rocks outcropping in areas to the west and south of the Merti Plateau and also in the western arm of the District. In the rest of the area, these rocks are either overlain by Jurassic, Tertiary and Quaternary sediments or Tertiary and Quaternary volcanics. Recent sediments are found along the rivers.

The major part of Isiolo District is composed of sandy soil, but along the perennial rivers and swampy areas on the slopes of Mount Kenya and Nyambeni Hills, black cotton and red soils are found. The sandy soils hardly support any vegetation and erosion is rampant in this kind of soil.

All the land in Isiolo District is classified as low potential and is all trustee land belonging to the Government and administered by the Isiolo Local Authority. Land adjudication has not been undertaken in the District. The land area of the District is classified as semi-arid (5%), as arid (30%) and as very arid (65%).

Livestock rearing is the mainstay in the District. The nomadic population continuously moves their livestock around the District in search of good pastures and water. Livestock from North Eastern Province often come to use the better grazing in Isiolo.

Land use for farming activities is very limited. Some irrigation projects exist along the Ewaso Ngiro and in Kinna. The District also has set aside land as Animal Game Reserves.

Four main seasons are identified in the district. These are the hot and dry season from mid-December to mid-March; the long rains from the end of March to the end

of May; the cool and dry season from June to September and the short rains from mid-October to mid-December.

Monsoon winds are present throughout the year and they attain their peak during the months of June, July and August.

The annual rainfall within Isiolo District ranges from 250 to 650 mm.

Investigations

The basic data was gathered through study and analysis of reports of previous studies, from the archives in the MoWD and through field investigations. Fieldwork included rehabilitation of raingauges, installation of additional evaporation pans, stream gauging, geological surveys, geophysical surveys, exploratory drilling, pumping tests and water sampling.

Surface Water Resources

The mean annual rainfall in Isiolo District varies from 150 mm in the eastern and northern parts of the District to about 650 mm around Isiolo Town. And as such the perennial rivers in the District are very few, namely: Ewaso Ngiro and its tributaries (Isiolo, Ngare Mara, Ngare Ndare and Ngare Nything) and tributaries of Tana River system (Bisanadi and Kinna). The Ewaso Ngiro River originates from the northern slopes of Mount Kenya and the Aberdares, while the Bisanadi and Kinna flow from the Nyambeni Range.

Apart from the data on the Ewaso Ngiro River, no other data of sufficient length and continuity exist. The mean annual flow of the Ewaso Ngiro at Archer's Post amounts to around 630 million m^3 with a minimum of 163 million m^3 in 1952 and a maximum of 2,780 million m^3 in 1961. The low flows of the river have gradually decreased due to an increase of water use in Laikipia District. In 1985 and 1986 the Ewaso Ngiro dried up in a reach of about 50 km upstream of Archer's Post.

Isiolo River originating from Mount Kenya is the source of water for Isiolo Town. The mean annual flow for the Isiolo River at R.G.S 5D8 amounts to 6 million m^3 with a minimum of 950,000 m^3 in 1987 and maximum of 110 million m^3 in 1971.

For the short period of the study (March 1989 - September 1990) the Ngare Ndare River was observed to have a lowest flow of 8,000 m^3/day, a highest flow of 50,000 m^3/day and an annual flow of 5 million m^3.

For Ngare Mara and Ngare Nything only miscellaneous current meter gaugings are available. The lowest and highest discharges measured were for Ngare Mara 2,300 and 24,000 m^3/day, and for Ngare Nything 7,800 and 28,500 m^3/day.

An inventory identified 24 springs, mainly along the right bank of the Ewaso Ngiro between Isiolo River and Malka Daka. The springs are fed by groundwater recharged in the Nyambeni Range. The discharges vary between about 120 and more than 4,800 m^3/day. Other springs exist at Kinna (860 m^3/day) and at Kuru Barata (960 m^3/day).

Surface water is of good quality for domestic, cattle watering and irrigation purposes.

Groundwater Resources

Geologically, Isiolo District comprises three major rock units, namely: Basement System, sedimentary rocks and volcanic rocks. The Water Resources Assessment Study, on the basis of recharge and areal extent distinguishes two major aquifer systems: regional (I) and local (II).

In the eastern part of the District the regional aquifer (system IA) is composed of Jurassic, Tertiary sediments and Tertiary and Quaternary Volcanics. In the northern part of this aquifer (zone 2) boreholes will strike water provided they are deep enough. Water is good for human consumption and for cattle watering. But in the southern part of this aquifer (zone 1), many boreholes have failed to strike water. Water is very saline and thus unfit even for livestock use.

In the western arm of the District (slopes of Mount Kenya and Nyambeni Hills) the regional aquifer (system IB) is composed of Tertiary sediments and Tertiary and Quaternary volcanics. Here, boreholes will always strike groundwater. This system has substantial recharge and part of the water is discharged by springs.

Local aquifers occur in the weathered and fissured zones of the Basement System rocks and the alluvial deposits along the rivers. Groundwater recharge in these aquifers of small extent takes place locally. The Basement system rocks (system IIA) have boreholes with low yields and poor water quality. The alluvial sediments (system IIB) contain water of acceptable quality and have boreholes with reasonable yields, especially in areas with coarse sediments.

Surface Water Development Potential

The use of the Ewaso Ngiro upstream in Laikipia District affects the development possibilities of this river for Isiolo District. For domestic supply purposes the river is not a reliable source. For irrigation further development is possible by using the flood waters. However due to the high flood levels and changes in the course of the river siting of surface water intakes is very critical and expensive structures are required.

The Isiolo River provides domestic water for Isiolo Town at approximately 2,000 m^3/day. Irrigation at present uses about 8,000 m^3/day and because the flows during the dry season are already very much reduced, the possibilities for more irrigation are limited.

The Ngare Mara River has an average capacity of about 12,000 m^3/day, of which about 80% is used for irrigation. Further development is not recommended, also because the river is dry nowadays during part of the year.

The seasonal rivers (laggas) carry a lot of water during the two rainy seasons in floods of generally short duration. These laggas can be developed for temporary storage by construction of earth dams and pans.

Rainwater may be used as additional source of water by using roof catchments. However due to the frequency and quantity, rainwater can not be relied upon completely in Isiolo District as a source for domestic water supply.

Groundwater Development Potential

The overall picture is that the groundwater development potential in the Districts limited because of lack of good aquifers and the presence of saline groundwater in large parts of the District.

A good development potential for domestic use exists in the northern part of the Marine Sedimentary area (System IA, Zone 2). Groundwater is encountered in depths ranging between 100 and 120 metres below ground level. The groundwater rest levels vary from 30 to 100 metres, while yields of 3 to 30 m^3/h are expected.

The regional Volcanic Rock aquifers on the slopes of Mount Kenya and the Nyambeni Hills (System IB), covering roughly 10% of the District offer the best development potential. Boreholes strike water between 8 and 70 metres below surface. Groundwater rest levels are less than 20 metres below ground level. Yields of up to 50 m^3/h are possible.

The aquifers occurring in the alluvial deposits along the Ewaso Ngiro River (System IIB) have a good potential for local domestic use. Groundwater is encountered between 10 and 40 metres and the water rest levels are at about 10-12 metre below surface. Yields of up to 20 m^3/h are possible.

Within the Basement System rocks, the development potential for the existing local aquifers (System IIA) is very poor. Most of the boreholes have brackish water if sited away from the seasonal streams which contribute to their replenishment. Siting of boreholes in these aquifers is critical and should be done by use of both hydrogeological and geophysical methods.

1. INTRODUCTION

1.1 Scope of the Present Study

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

The activities of WRAP in Isiolo District include:

- Water Resources Assessment Study
- District Water Development Study.

This report presents the results of the Water Resources Assessment Study. The Study was carried out from September 1988 until June 1991.

1.2 Description of the Project Area

1.2.1 General

The project area, Isiolo District approximately lies within parallels 0° 05'S and 2° N, and the longitudes 36° 50' and 39° 30'E (Figure 1.1). Isiolo District covers a total area of 25,605 km² and is located in the Eastern Province of the Republic. It shares common borders with Wajir, Marsabit, Samburu, Meru, Kitui, Tana River and Garissa Districts. A great part of the District is encompassed by the Middle and the Lower Catchments of the Ewaso Ngiro which enters the District after the Junction (confluence of Ewaso Ngiro and Ewaso Narok) and extends downstream to the Lorian Swamp.

1.2.2 Topography and Drainage

Most of the area of Isiolo District is flat and lies between 180 and 900 metres a.m.s.l., with a small portion, i.e on the slopes of the Mukogodo Hills at the boundary with Laikipia District rising to 1500 metres.

Most of the District is drained by the Ewaso Ngiro and its tributaries. A small portion, i.e the southern tip of the District is drained by Tana River. The Ewaso Ngiro forms the Isiolo/Laikipia boundary from the Junction and then the Isiolo/Samburu boundary all the way to Chanler's Falls after which it flows almost through the centre of the District before it leaves the District near Habaswein.

1.2.3 Soils

The soils found in the District are derived from the Basement System, volcanic or sedimentary rocks and range from well to imperfectly drained. The soils are mainly comprised of calcareous soils, stony and bouldery soils, stony sandy clay loam, clay loam, clay, sandy loam and loam.

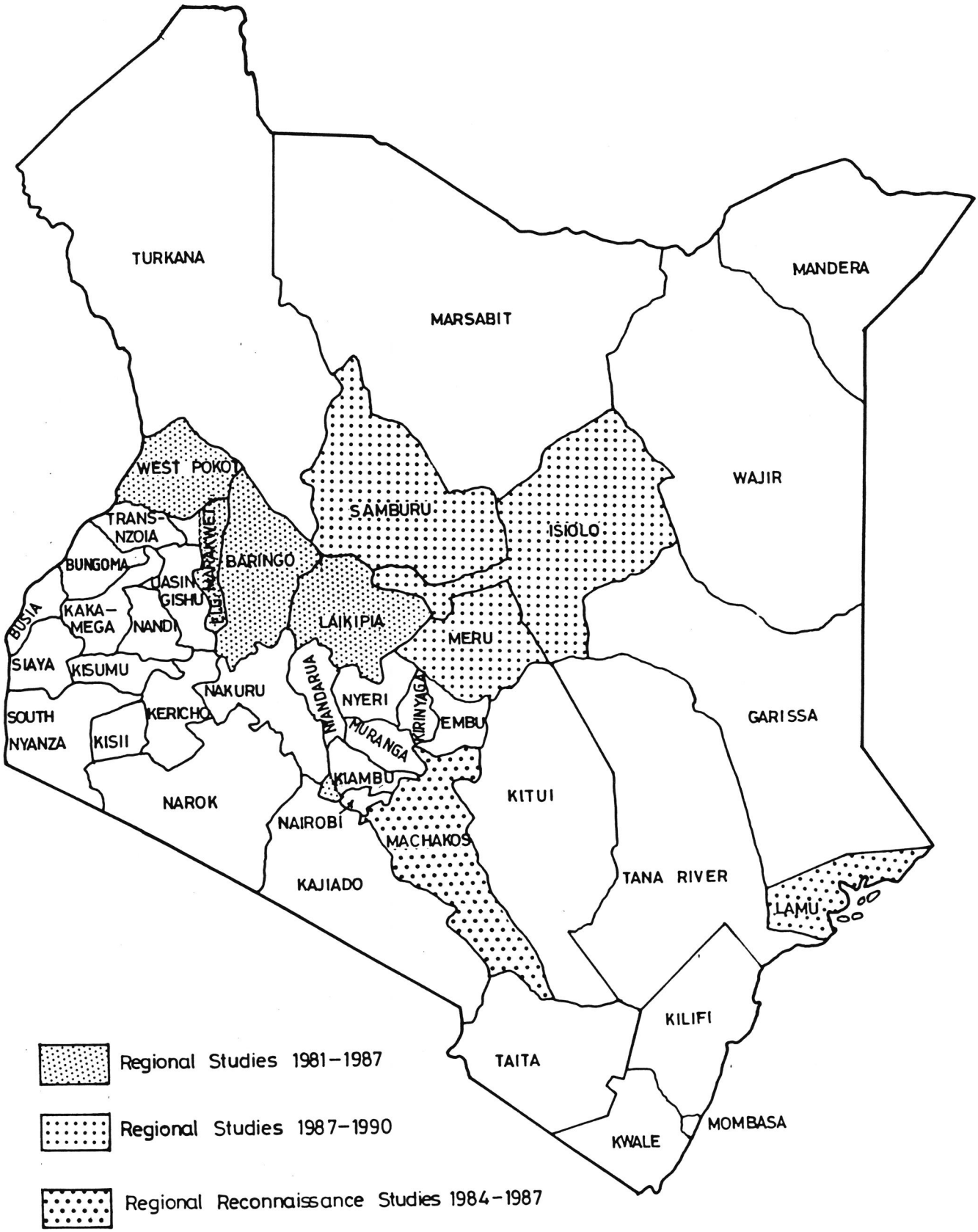


Figure 1.1 Regional Studies under WRAP Programme 1981-1991

1.2.4 Climate

The District falls into three agro-climatic zones, namely: semi-arid, arid and very arid. The Semi-arid zone is at the surroundings of Isiolo Town and receives an average annual rainfall of about 400-650 mm. The Arid zone extends from Barsalinga area to Archers Post-Garba Tula areas, and receives an average rainfall of about 300-350 mm. The very arid zone covers Malka Galla, Merti, Sericho and Modo Gashi areas, receiving an average annual rainfall of about 150-250 mm. The mean annual temperature ranges between 24 and 30°C (Figure 1.2).

1.2.5 Administration

Isiolo Town is the District Headquarters and the only urban centre. The District is subdivided into four Divisions, namely: Central, Garba Tula, Merti and Sericho. These are further sub-divided into 11 Locations and 27 Sub-locations.

1.2.6 Population

Isiolo District is one of the least populated Districts in Kenya. During the 1979 population census, the District had a total population of 43,478 people. With an estimated growth rate of 3.9% per year, the District is estimated to have 63,931 people in 1988, rising to 77,268 by 1993 (Table 1.1).

Internal and external migration of people is common in the District, and in recent years there has been a tendency by the nomads to settle permanently. Most of them tend to favour settling in Central Division and to a lesser extent in Garba Tula along the few permanent water sources. But due to lack of data, it is difficult to quantify the magnitude of migration within the District.

Table 1.1 Population Projections by Division: 1979-93

Division	Area (km²)	% of total	1979	% of total	1988	1989	1990	1991	1992	1993
Central	2,363	9	17,403	40	25,572	26,570	27,034	28,670	29,772	30,907
Garba Tula	7,442	29	12,522	29	18,412	19,131	19,874	20,642	21,435	22,253
Merti	12,661	49	7,388	17	10,868	11,292	11,731	12,185	12,653	13,136
Sericho	3,139	12	6,165	14	9,078	9,432	9,799	10,178	10,569	10,972
Total	25,605	100	43,478	100	63,931	66,426	69,008	71,675	74,429	77,268

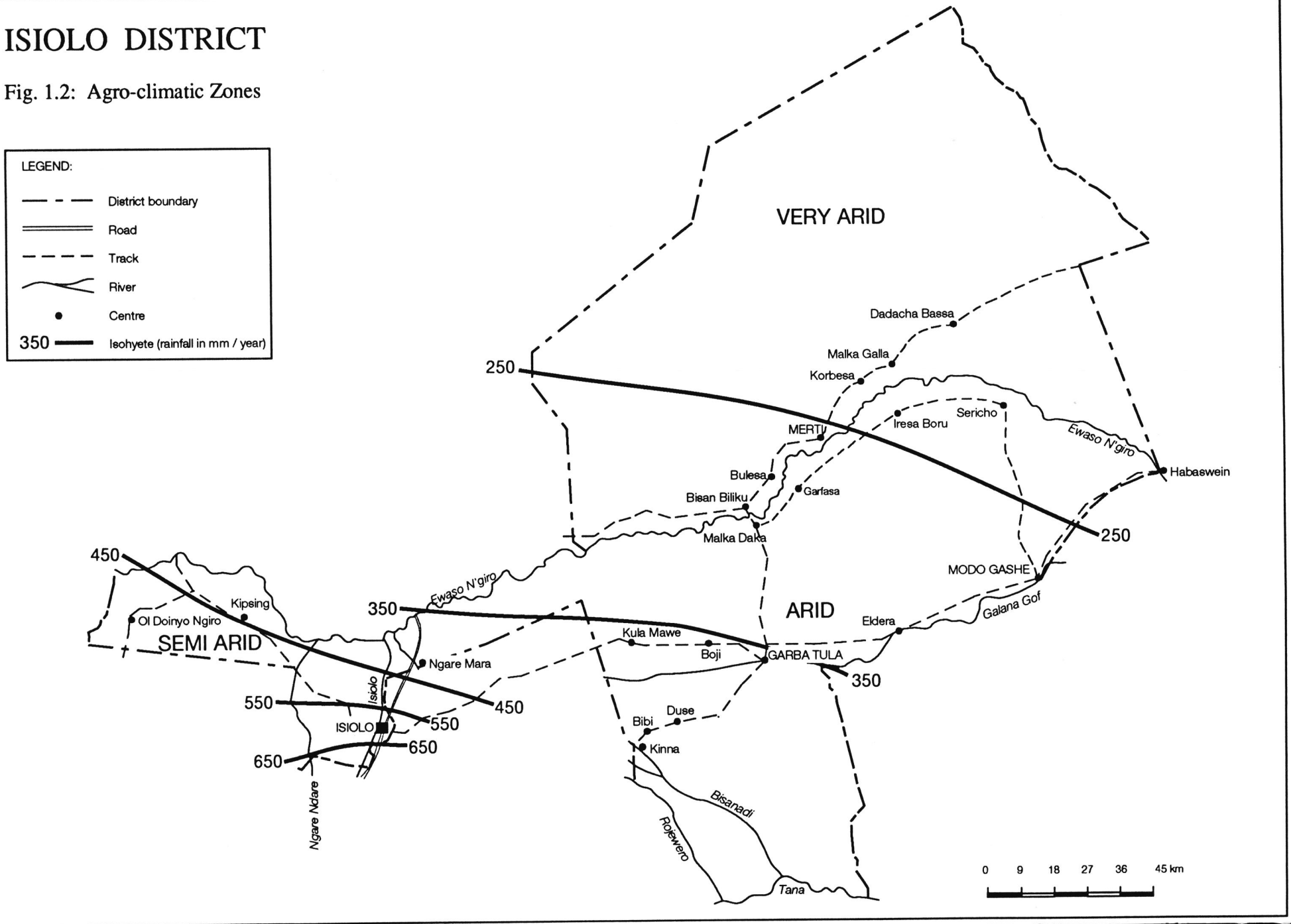
Source: 1987 Population Projections by Rural Planning Department, Ministry of Planning and National Development.

Note: Data assumed decline in fertility and mortality.

The population profile shows that Central Division has 9.2% of the District's total area and is settled by 40% of the District's total population. This is due to the fact that, the Division mainly falls in the Agro-climatic zone V which, to a limited extent favours small-scale or minor farming along the Isiolo River. The bushland which characterizes this type of climate also ensures pasture for livestock for a longer period. These factors have encouraged permanent settlement in the Division, particularly around Isiolo Town

ISIOLO DISTRICT

Fig. 1.2: Agro-climatic Zones



which houses about 25% of the District's total population. Central Division's population density is about 7.4 people per km², the highest in the District.

Garba Tula Division, with 29% of the District's area, holds also 29% of the total population, having a population density of 1.7 person per km². Sericho Division, with 12% of the District's total area, holds 14% of the District's total population, while Merti Division with 49% of the Districts area holds only 17% of the total population.

Merti Division falls in the northern part of the District within the very arid zone which tends to be semi-desert. The major economic activity is livestock rearing and it is also the area where nomadism seems to be at its highest in the District. In this Division, the population density is 2 persons per km².

1.2.7 Livestock

The livestock data in Isiolo District is presented in Table 1.2 and mainly consists of cattle, sheep, goats and to a lesser extent camels.

The District is centrally situated and therefore is a corridor for animal movement, with people moving into the District from neighbouring Districts mainly Wajir, Garissa, and Marsabit with their animals in search of water and pasture. This trend exposes security problems caused by cattle rustlers and bandits associated with the cattle movement into the District. This also results in overgrazing and problems such as soil erosion.

Table 1.2 Livestock Population: 1984-89

Type	1984	1985	1986	1987	1988	1989
Cattle	121,150	127,210	135,570	149,127	162,698	177,503
Sheep	153,427	161,622	164,702	181,172	197,659	215,646
Goats	102,922	108,068	113,468	124,814	136,172	148,564
Camels	20,978	22,082	23,182	25,500	-	-
Dairy Cattle	-	35	78	85	97,344	106,202
Donkeys	-	7,728	81,113	89,224	-	-

Source: Isiolo District Development Plan 1989-1993.

2. GEOLOGY

2.1 Previous Geological Studies

The first geological studies in Isiolo District were conducted by Aston Chanler (1904) and Parkinson (1914 and 1915). In the 1940's systematic geological mapping started (Figure 2.1).

Shackleton (1942-1944) mapped the western part. In 1955, Dodson's and Mason's reports were published. Dodson's report covers the southern western tip of the District while Mason's report covers a small area next to Isiolo town. L.A.J. Williams conducted a geological survey of the Chanler's Falls area in 1958 and 1959. In the same period the geological survey of the Archer's Post area was done by D.J. Jennings. R.G. Dodson also mapped the area north of the Chanler's Falls between 1960 and 1961. A small portion to the west of the Barchuma area is covered by the geological report by P. Rix (1960). In 1967, the geological study by P. Rix was finalised which covered the area around Kinna. F.J. Matheson (1971) studied the geology of the Garba Tula area. Then in 1973, J.B. Wright finalised the geological study of the Kora Wells area.

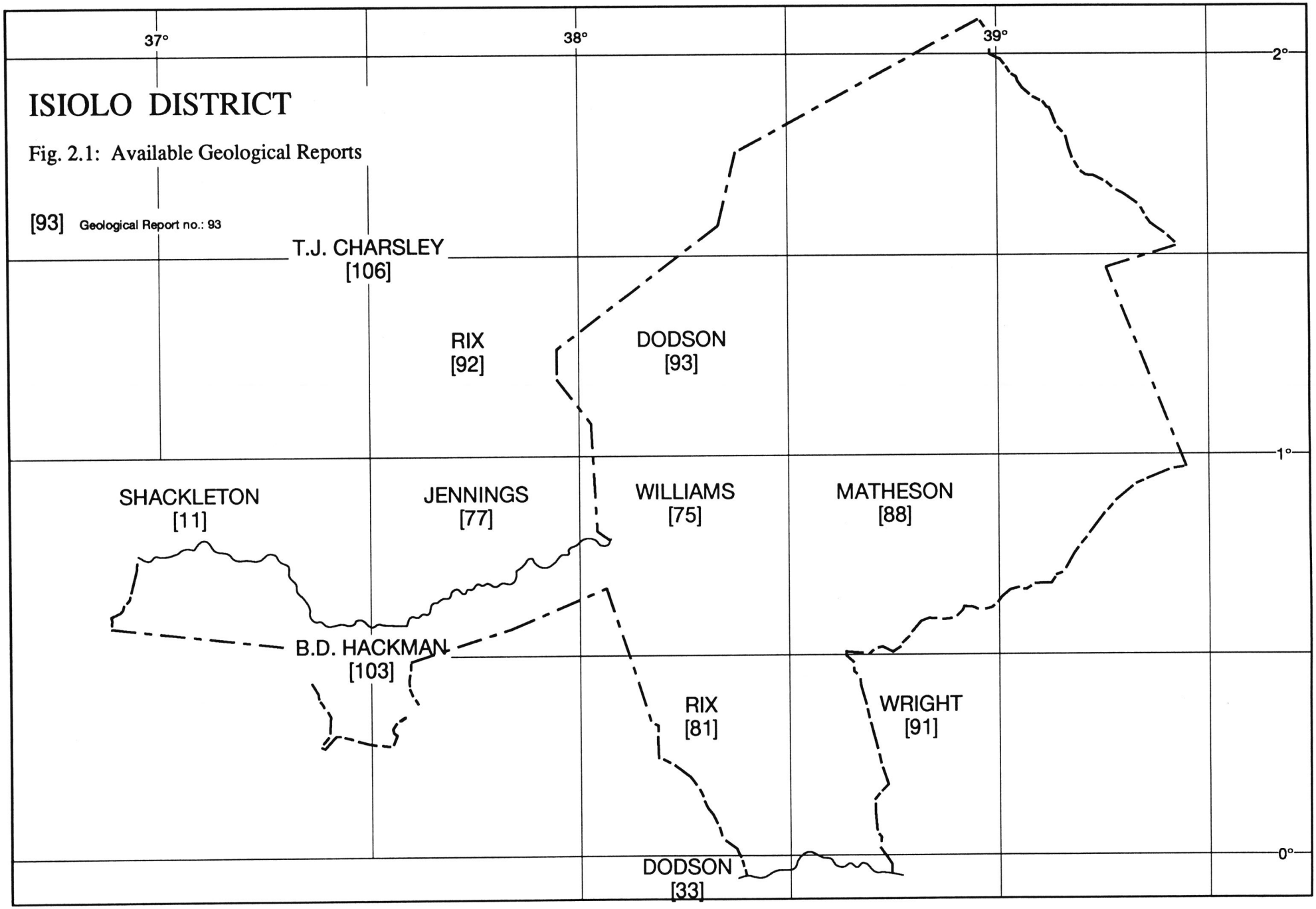
In the beginning of the 1980's a joint Kenyan-British team embarked on a new geological survey of the area between 0° and 4° North and 36° and 38° East. The area previously surveyed by Shackleton, Jennings and Mason is covered in the report by B.D Hackman published in 1989, while the area previously surveyed by Rix is covered by T.J. Charsley's report published in 1987.

Geological reports have not yet been published for the rest of the District, but the Ministry of Energy and Regional Development published in 1987 a geological map covering the Republic at a scale of 1:1,000,000. This geological map shows the general geology of the northern part of the District of which no published geological reports exist.

2.2 Geological Setting and History

Isiolo District is wholly underlain by the Precambrian Basement System. The Basement System rocks are predominantly outcropping in the furthest end of the western arm of the District and also in the areas to the west and south of the Merti Plateau. The south-west of the District (slopes of Mount Kenya and Nyambeni Hills) is mainly covered by the volcanic flows which spread from a multitude of parasitic cones of Mount Kenya and Nyambeni volcanic centres. The rest of the District is part of the Anza Basin and as such is dominated by sedimentary rocks which are sporadically overlain by volcanic rocks as a result of either isolated fissures or lava flow from the Marsabit area.

The Basement System rocks include different types of gneisses and schists, crystalline limestones, quartzites, migmatites and granulites, locally affected by different types of intrusions. The sedimentary rocks found in the District are sandstones, limestones, marls, shales, conglomerates, grits, sands, clays, and gravels. The volcanic rocks include basalts and pyroclastic deposits.


ISIOLO DISTRICT
Fig. 2.1: Available Geological Reports
[93] Geological Report no.: 93
37°
38°
39°
2°
1°
0°
T.J. CHARSLEY
[106]
RIX
[92]
DODSON
[93]
SHACKLETON
[11]
JENNINGS
[77]
WILLIAMS
[75]
MATHESON
[88]
B.D. HACKMAN
[103]
RIX
[81]
WRIGHT
[91]
DODSON
[33]

The geologic history of the District can be followed from the Precambrian era represented by metamorphic rocks of the Basement System. After a long period of uplift and erosion a marine incursion took place in the early Jurassic which led to the deposition of sandstones, shales, limestones and coarse to fine grained sediments with silcrete. A further period of uplift and erosion culminated in the maturation of the sub-Miocene peneplain, but a subsequent cycle of erosion removed traces of that bevel in some areas. During these periods of erosion the Jurassic rocks were largely removed and a latter cycle resulted in the deposition of marine and fluvial sediments on the sub-Miocene surface. However, the plateau lavas (olivine basalts) in the northern part of the District were deposited in the period mid-Miocene to Pliocene. This was as a result of the extrusion of plateau lavas in Marsabit District. In the south-western part of the District the deposition of olivine basalts was caused by lava flows from Mount Kenya and Nyambeni parasitic cones during the Pleistocene. From the mid-Pleistocene to Holocene there has been a time of rapid climatic fluctuation in the area. This has attributed to periods of intense weathering followed by erosion and deposition of the weathered material. Most of the colluvium and calcrete in the area is believed to have been deposited during that time.

2.3 Stratigraphy

The stratigraphic description of Isiolo District is mainly based on the geological reports listed in section 2.1. According to these reports, the rock formations in the District are divided into four groups.

(i) Metamorphic rocks of the Basement System
(ii) Mesozoic Sedimentary Rocks
(iii) Tertiary Sediments and Volcanics
(iv) Quaternary Volcanics and Sediments

The areal distribution of the geological formations in Isiolo District is shown in Plate 2 whereas a summary of the lithostratigraphy is presented in Table 2.1.

2.3.1 Basement System

The rocks of the Basement System are the oldest in the project area and form the floor upon which other rock units rest. They comprise various types of sediments which were transformed by regional metamorphism into gneisses, schists, quartzites, granulites, crystalline limestone, amphibolites and migmatites. Basement System rocks outcrop in the western and southern part of the District.

2.3.2 Mesozoic Sedimentary Rocks

The sedimentary rocks of Mesozoic age in the area consist of Dogogicha, Matasade, and Kubi Dakhara Beds. Dogogicha Beds comprise sandstones and shales whereas the Matasade Beds consist of Oolitic limestones and sandstones. Kubi Dakhara Beds consist of sandstones. These formations overlie the Basement System rocks in the northern part of the District (Anza Basin) and outcrop at Dogogicha, Matasade and Kubi Dakhara.

Table 2.1 Simplified Lithostratigraphic Table of Isiolo District

PERIOD	EPOCH	FORMATION	LITHOLOGY
QUATERNARY	Pleistocene/ Holocene	Superficial Deposits Sediments	Alluvium Colluvium Calcrete, Lacustrine sediments
	Pleistocene	Upper Nyambeni Osirua Basalts	Basalts Basalts
TERTIARY	Miocene/ Pliocene	Olivine Basalts	Basalts
	Miocene	Merti Beds Sediments	Sandstones, Grits, Conglomerates Coarse to Fine Grained Sediments with Silcrete
MESOZOIC	Jurassic	Kubi Dakhara Beds Matasade Beds Dogogicha Beds	Sandstones, Sandstones, Oolitic Limestones Sandstones and Shales
PRECAMBRIAN		Intrusives Basement System	Gneisses, Schists, Migmatites, Quartzites, Crystalline Limestones

2.3.3 Tertiary Sediments and Volcanics

Tertiary Sediments

These are rocks that consist of sandstones, grits and conglomerates and are best exposed on the flanks of the Merti Plateau and Barchuma where they have been preserved from erosion by the capping of olivine basalts. They also outcrop east of Dogogicha, approximately at 20 kilometres. Other exposures are to the south east of the Yamicha Plateau and in the area north of the Eldera-Modo Gashe road.

Their exposure is poor on the featureless plains, since they easily erode on account of their friable nature which leaves them covered by thick soils. The grits are however exposed along rivers, notably the Galana Gof and Madadubdera. The grey sandy soil is an indication of the grit's presence since the soil is identical to that formed from them. In the western arm of the District, coarse to fine-grained sediments with soils and silcrete outcrop.

Tertiary Volcanics

These volcanic rocks outcrop on the Merti Plateau and at Sukela, Barchuma, Sigite, and Yamicha. They are composed of a lower olivine basalt and an upper basanite which outcrops locally on top of the olivine basalt.

2.3.4 Quaternary Volcanics and Sediments

Quaternary Volcanics

These volcanic rocks outcrop in the south-western part of the area and comprise Osirua Basalts and Upper Basalts of Nyambeni volcanics.

The Osirua Basalts outcrop in the same area where the upper Basalts of Nyambeni volcanics outcrop. The former are olivine basalts. The latter are composed of general volcanics (mainly basaltic pyroclastic deposits), deposits of partly degraded volcanic centres and also of lavas (mainly basaltic), some unsaturated types and relatively unaltered lava flows.

Quaternary Sediments

The Quaternary sediments in the area are composed of lacustrine sediments with limestones, calcrete and superficial deposits belonging to both Pleistocene and Holocene. The lacustrine sediments are of coarse to fine-grained texture. The superficial deposits comprise alluvium consisting of sands and silts along the river courses, and colluvium consisting of crudely stratified mixtures of clay, silt and rock fragments, along the slopes of large inselbergs.

2.4 Structures

Even though no major faults have been indicated in the geological maps, a recently published geological map for the Republic on the scale, 1:1,000,000 by the Ministry of Energy and Regional Development indicates major faults affecting the sedimentary rocks. The southern part of the District where the Basement System rocks surface has been affected by faulting. These (minor) faults have a general north-south trend.

3 GEOPHYSICS

3.1 Introduction

This chapter contains a summary of the geophysical investigations carried out by the Water Resources Assessment Project in Isiolo District. On geological grounds, Isiolo District can be classified as follows:

(a) Basement areas
(b) Volcanic areas
(c) Areas covered by recent and older sediments

During previous studies in the Meru and Samburu Districts, ample experience was gained with the use of geophysical methods for ground water assessment in Basement and volcanic areas.

Therefore, in Isiolo District, geophysics was applied mainly for borehole siting in priority areas for local water supply.

In addition a comprehensive geophysical survey was carried out in the Merti East sedimentary area, to establish the extent and origin of a fresh water body identified in previous hydro-geological investigations (Roberts, 1958-1961; Swarzenski and Mundorff, 1977).

In Basement areas, Vertical Electrical Soundings (VES), Electromagnetic profiling (EM) and resistivity profiling (RP) were used. On sedimentary and volcanic terrain, only the resistivity method was applied.

The details of this study, the final interpretation of the collected data and the results of the drilling programme are given in chapters 3.2 through 3.5 and Appendix 3.

3.2 Previous Geophysical and Related Studies

Several hydrogeological reports have been written for various parts of Isiolo District. However, none of these has given attention to geophysical investigations for groundwater.

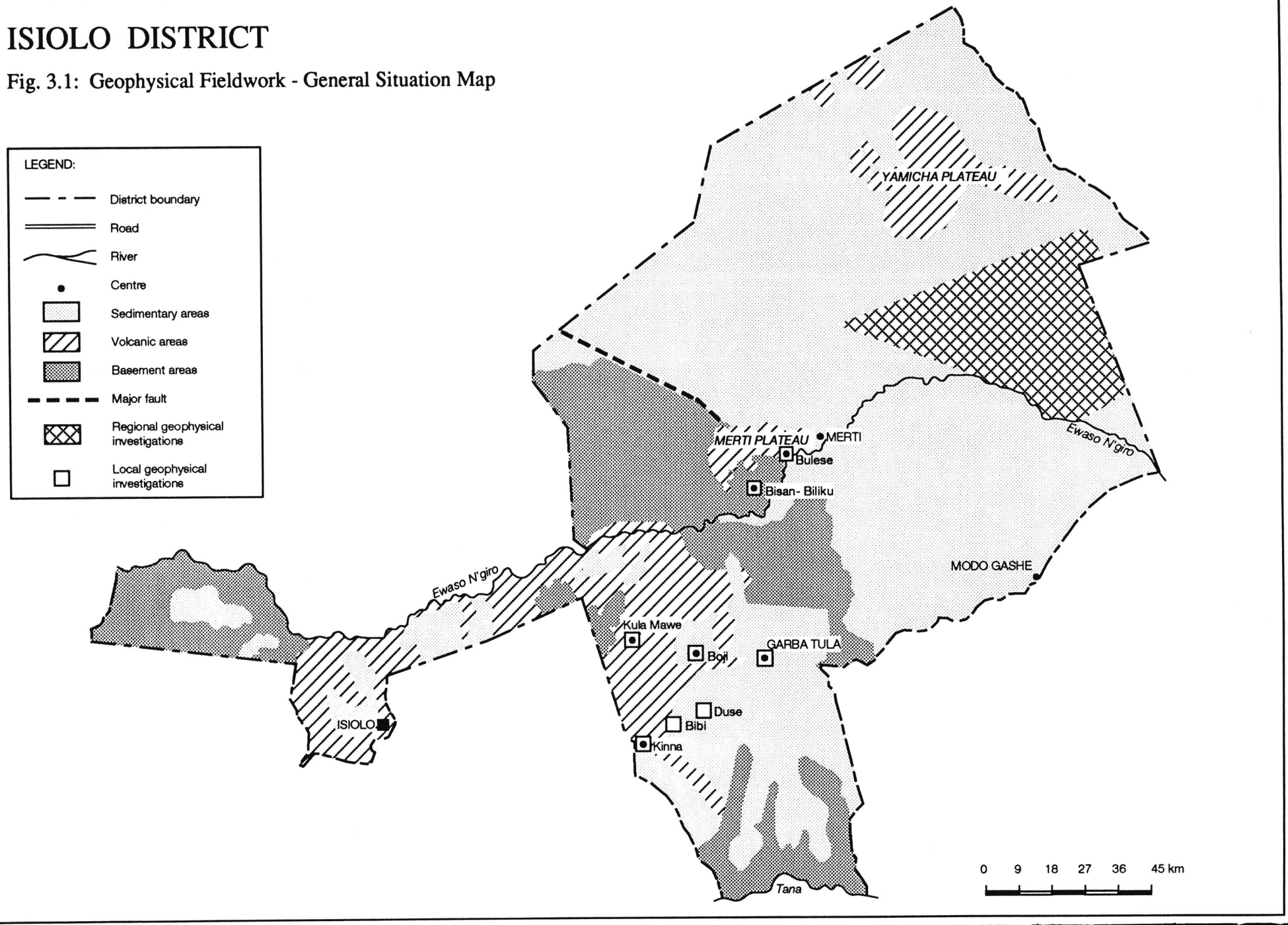
A recently (1987) published set of geological maps of Kenya, on scale 1:1,000,000, contains a map with Bouguer Gravity Contours. This map shows the major fault zones identified over Isiolo District and in Merti area among other areas. It also shows areas where paleo-grabens filled with marine and other sediments exist.

The Total Oil Company while prospecting for petroleum in Isiolo District in 1986 carried out extensive Reflection Seismic profiling and concluded that such paleo-grabens indeed exist.

Other geophysical work in the area constituted of only 5 soundings made by MoWD geologists to investigate the groundwater potential for water supply purposes.

ISIOLO DISTRICT

Fig. 3.1: Geophysical Fieldwork - General Situation Map



Roberts (1958-1961, Technical Version) investigated the Ewaso Ngiro basin up to the Lorian Swamp and hinted the possibility of the river losing water in the interval between Melka Bulfayo and Melka Heda. Swarzenski and Mundorff (1977) delineated (using borehole data) a fresh water aquifer extending from the Kenya/Somali border in a northwestern direction up to Habaswein (Appendix 3 inset) and suggested that the recharge for this aquifer is probably in the Mount Marsabit area.

3.3 Geophysical fieldwork

The objective of the geophysical fieldwork in Isiolo District was to investigate the possibilities for groundwater exploitation. In the Basement and volcanic areas, the geophysical work was basically intended to locate suitable drilling sites. In the sedimentary areas a comprehensive regional survey was carried out to establish the fresh/saline groundwater contact (Figure 3.1).

Details of the site investigations are given in Appendix 3.

Two geophysical methods were used viz. the Electro Magnetic (EM) and geo-electrical resistivity methods.

For electromagnetic profiling the EM34 Equipment was used while the soundings and all resistivity profiles were made with the SAS300 Terrameter and at a later stage with the GEA51 TNO Equipment.

3.3.1 Basement Areas

In the Basement areas only local aquifers exist. Site investigations of limited lateral extent were therefore made.

Bisan Biliku Centre (including the old abandoned Bisan Biliku also called Kitterman's Camp) was the only site which was lying purely on Basement rocks. Five electromagnetic profiles, two of which at Kitterman's Camp, and one resistivity sounding were made (Appendix 3).

3.3.2 Volcanic Areas

Three sites were investigated on volcanic areas. These were Bibi (also covering Moliti area), Kinna and Kula Mawe.

Like in Meru District usually one or several volcanic layers overlie the Basement. The Basement itself was expected to be weathered in its upper zone. Groundwater was expected to occur at the interfaces between the various lava flows, the contact between the volcanics and the underlying Basement and the weathered parts of the Basement.

A total of 8 soundings (4 at Bibi, 2 at Kinna and 2 at Kula Mawe) were made mainly for determining suitable drilling sites. The length of the soundings varied according to the required penetration depth (Appendix 3).

3.3.3 Sedimentary Areas

Geophysical fieldwork in sedimentary areas was carried out in Merti and Garba Tula Divisions. Three types of sedimentary deposits were investigated.

a) Tertiary marine sediments (Merti Beds) comprising of an alternation of clays and sands. These occupy most of the area east of Merti Plateau. Geophysical data (gravimetric and Reflection Seismic) revealed that the sediment complex deposited in deep paleo-grabens reaches a thickness of several kilometres in some areas.

   The geophysical fieldwork in these areas constituted of 81 resistivity soundings made over an area roughly between Malka Galla, Hadado and Diri (near Habaswein). To the southeast of this zone earlier studies (Roberts, 1958-1961; Swarzenski and Mundorff, 1977) indicated a narrow fresh water aquifer between Habaswein and Liboi on the Kenya/Somalia border. North of the investigated area boreholes drilled for water supply by TOTAL Oil Co. yielded fresh groundwater around the Yamicha Plateau. Hence the geophysical study was aimed at investigating the linkage between these two fresh water bodies and at establishing the source of recharge for the Habaswein/Liboi aquifer.

b) Recent sedimentary deposits accumulated along the major river courses in channels eroded in the Basement rocks (buried river channels). Similar deposits are also found along the contact between the Basement and the Tertiary marine complex mentioned above. The sediments are generally less than 40 metres thick and consist of coarse to fine sands and clay.

   Geophysical work was done at Bulesa for selecting a suitable drilling site. A total of 13 soundings, 4 electromagnetic profiles and 4 resistivity profiles were made.

c) Within the Basement areas especially in Garba Tula Division large patches have been covered by secondary limestone called "Kunkar Limestones". These limestones are generally thin but in some areas they are up to 20 metres thick and have acquired significant hydrogeological importance.

   Geophysical investigations in these limestone areas comprised ten soundings; four at Garba Tula trading Centre, four at Duse and two at Boji. The soundings were for investigating the thickness of the limestones and of the underlying weathered Basement. The information was used to select suitable sites for drilling.

3.4 Data Interpretation

Interpretation of the EM profiling data was qualitative, whereby anomalous zones (minima) were expected to indicate either fault zones or buried river channels. These were identified from the profiles and further investigated with soundings. Resistivity profiles were used where electromagnetic profiling was found to be inadequate to deal with the thick soil overburden.

For data storage and presentation, the electromagnetic data was digitized into the computer using the CALCOMP Digitizer and was plotted automatically. The final copies for the resistivity profiles were made manually on semi-logarithmic paper.

The geophysical well logging data was interpreted in terms of layer thicknesses and resistivities which were then used for the final interpretation of the resistivity soundings.

Interpretation of the soundings was done in the office using an AT Personal Computer. The data was stored in a computerised data base system especially designed for the work under the WRAP Project. A quantitative interpretation of the soundings was done using the indirect method. The interpreted layer thicknesses and layer resistivities were correlated with geological and hydrogeological layer units. In most cases re-interpretation was carried out after the completion of the exploratory drilling.

3.5 Results and Conclusions

Basement Areas

The geophysical survey at *Bisan Biliku* showed several low resistivity anomalous zones. The anomaly, which had the closest position to the Ewaso Ngiro river, was selected for drilling.

The borehole, (C9382) struck water at 34 metres in a fractured zone, but the water was extremely saline (electrical conductivity of 19,000 microSiemens/cm) despite the proximity of the borehole to the river. The high salinity indicates that, the water struck is probably fossil, apparently with no recharge of fresh water.

It can be expected that this situation prevails in the entire Basement area in eastern Isiolo, which was formerly covered by the Jurassic - Tertiary sea.

Volcanic Areas

In the volcanic areas, soundings were done to find the depth to the contact between the potentially aquiferous layer complex and the underlying impervious metamorphic rocks. In general, the groundwater potential is best in areas with the largest thickness of the volcanic layers. This conclusion was used for siting boreholes in the present study.

At *Bibi*, 4 soundings were made. Borehole C9577 was drilled at the site of VES 1 which gave the greatest depth to the fresh Basement. Water was struck at 40 m in weathered Basement, with a proved yield of 5 m^3/h and EC of 785 microSiemens/cm.

At *Kula Mawe* a similar situation was found. Borehole C9641 penetrated several types of mainly compact and dry volcanic rocks before striking water at 50 metres in weathered Basement. Its yield is 2 m^3/h and the EC is 1,500 microSiemens/cm.

At *Kinna*, a volcanic old-land-surface type (perched) aquifer was struck between 13 and 17 metres in borehole C9578, with a yield of 7.5 m^3/h and an EC of 1,100 micro-Siemens/cm. Unfortunately, no casing could be installed in a deeper weathered Basement aquifer due to serious caving of the borehole.

In the investigated areas, ground water was principally found in weathered Basement underneath the volcanic and some sedimentary (limestone, sand) layers. Consequently the yield is quite limited (less than 10 m^3/h) which is characteristic for this type of aquifers. In areas closer to the Nyambeni range with a thicker and partly saturated volcanic cover, considerably higher yields can be expected.

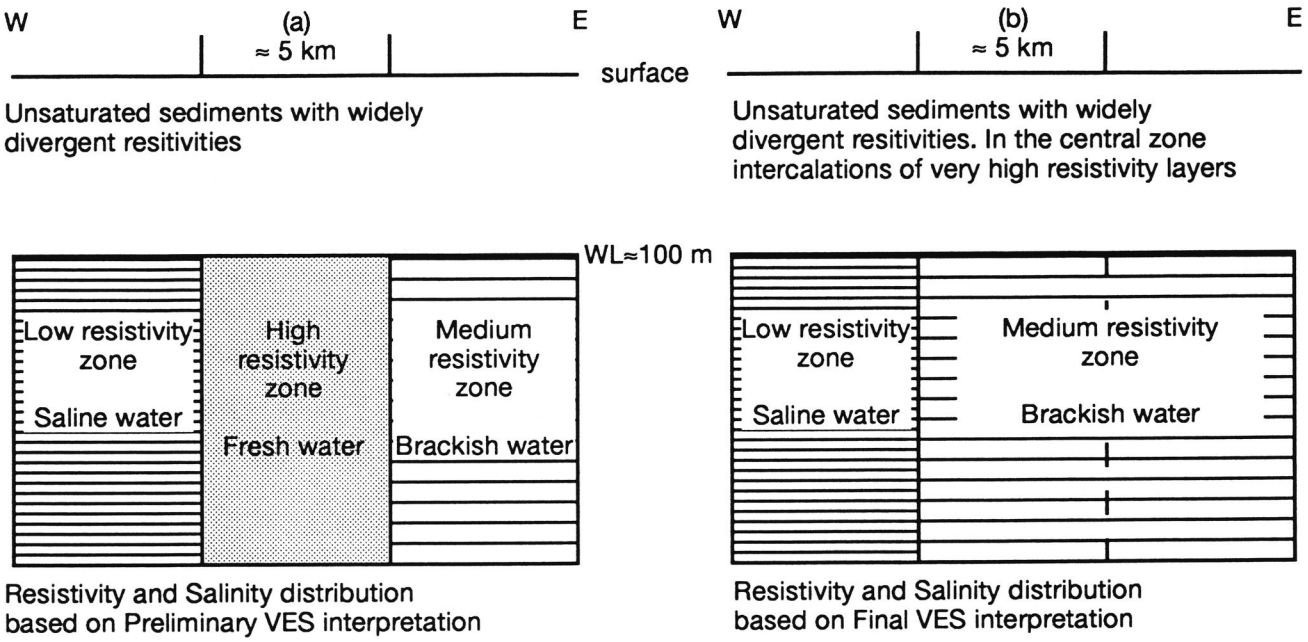


Fig. 3.2: Schematic W-E Profiles of the Tertiary Sedimentary Area.

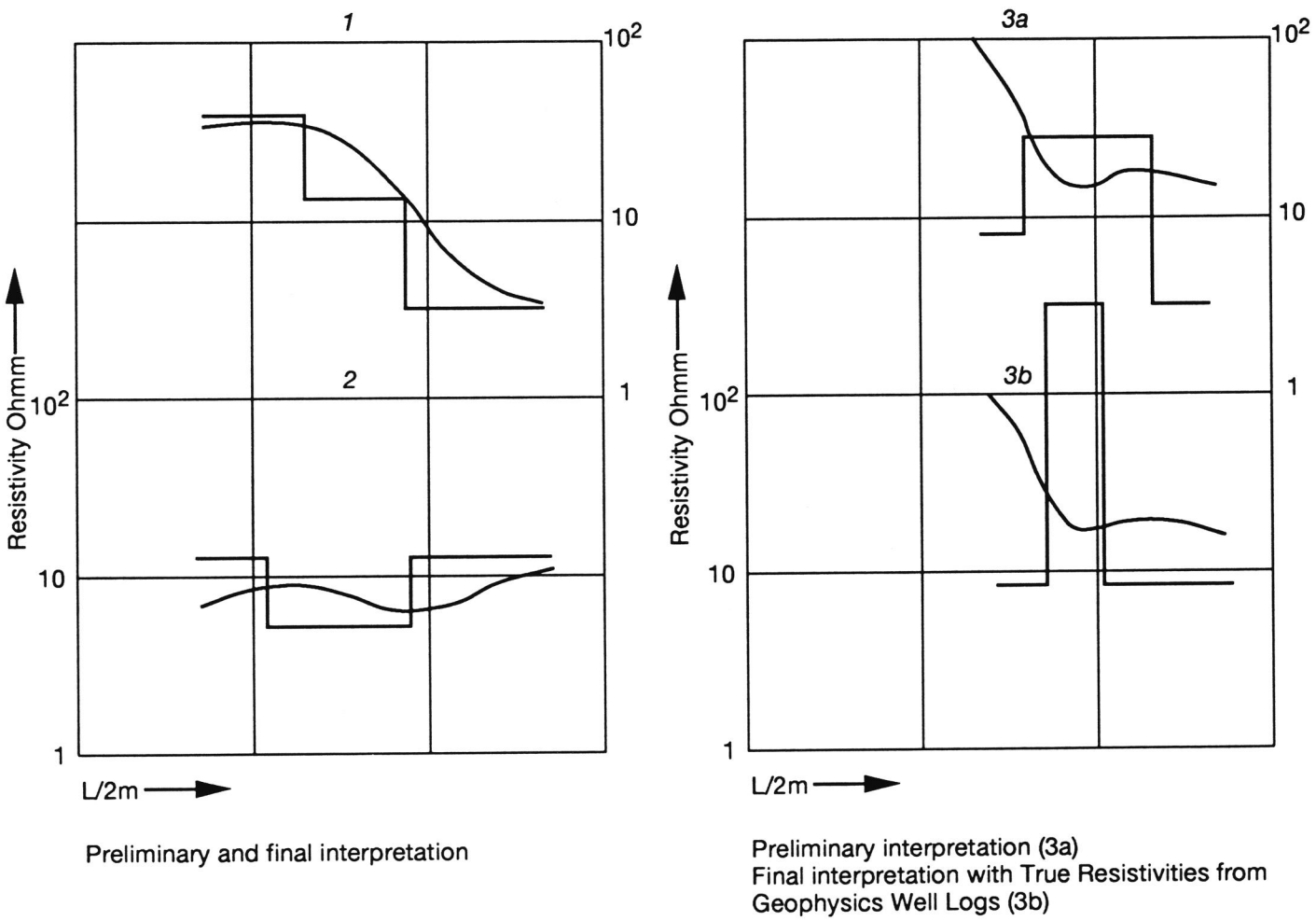


Fig. 3.3: Typical VES Graphs for (1) Western, (2) Eastern and (3a & 3b) Central Zone of the Tertiary Sedimentary Area.

Sedimentary Areas

In *Bulesa* an extensive geophysical survey was conducted to define the most suitable location for drilling. It was expected to be in the deepest part of the sandy alluvial deposits (buried channels) along the Ewaso Ngiro river. Earlier experience showed that drilling elsewhere (e.g in Basement rocks or Merti beds) produces only highly saline water.

Borehole C9381 encountered a bed of coarse alluvial gravel from 11-18 m, but it was dry. Apparently there is no hydraulic connection between this potential aquifer and the Ewaso Ngiro River, probably due to the impervious clay deposits underneath the river.

If any infiltration takes place, the water probably drains towards the east through buried channel(s). Boreholes in Merti and other locations further to the east produce abundant water from these deposits.

In *Garba Tula*, enough well recorded borehole data is available to adequately assess the general hydrogeological situation. In addition, a few soundings were made at the selected borehole sites in order to assure the correctness of this selection.

Three boreholes, C9573, C9574 and C9575, were sunk within the town area. Water was found between 8 m and 16 m in highly cavernous limestones and underlying fractured Basement. Due to the small size of the testpump, only a yield of about 15 m^3/h was produced. The actual yield could be considerably higher. The EC of the water from these boreholes is around 1,500 microSiemens/cm.

The Garba Tula limestone aquifer supplies the highest yield in the hitherto investigated areas in Isiolo district. The seasonal Galana river which crosses this area is probably an adequate source of recharge. Whether or not other limestone areas have similar yields or not, depends on the local hydro-geological situation (e.g. limestone thickness, recharge etc.) and should be investigated individually. To be noted, that the limestone occurrences have quite a limited areal extension

Three of the electromagnetic profiles made at *Duse* indicated an anomalous minimum south of the location of the abandoned Duse Village. A borehole C9576 was drilled in this anomaly. It penetrated through less than 4 metres of very weathered limestone below which loose fine sand was found up to a depth of 16 metres. Some water was struck at 13 metres but it was very little and saline (electric conductivity of 4,450 microSiemens/cm). The hole was consequently abandoned.

At *Boji* the four electromagnetic profiles each identified an anomalous minimum zone which could indicate a greater aquifer thickness than the high resistivity zones. However, the spatial distribution of these zones was very random. An examination of the terrains where these anomalies appeared revealed that they occurred only at places with signs of frequent flooding in wet weather. Patches of clay have accumulated in these areas probably causing the anomalies, which are due to the sensitivity of the EM responses to such superficial very low resistivity deposits.

One of the two soundings made (VES 2) was on such a clay patch and indicated a very high resistivity limestone layer underlying a thin clay layer. VES 1 carried out on the limestones showed a limestone thickness of about 4.5 metres and about 3.5 metres of weathered Basement. Drilling was recommended about 300 metres east of 3 existing dug wells. The borehole, C9639, struck water at a depth of 3 metres. The

tested yield was 2.9 m^3/h and the electric conductivity was about 1,780 micro-Siemens/cm. Borehole C9640 drilled about 200 metres west of the dug wells up to a depth of 9 metres was dry, probably due to its higher topographical position.

Preliminary interpretation of the soundings made in the *Tertiary Sedimentary areas* east of Malka Galla indicated a narrow (about 5 kilometres wide) zone running northwest-southeast, with resistivities for the saturated subsoil of about 30 - 50 ohmm. This zone seemingly fitted very well with the expected northwestward extension pattern of the Habaswein/Liboi aquifer and therefore seemed to support the Swarzenski and Mundorff theory. Two boreholes, C9383 and C9384 were sunk to confirm the preliminary interpretation results. In both wells, several dry gravelly sand layers were encountered between 40 m and 100 m with resistivity values (from the geophysical well logs) exceeding 200 ohmm.

In C9383, located at the western edge of the high resistivity zone, only clay was found in the saturated underground below 110 m. Consequently, no water sample could be taken.

Water samples from C9384 and the already existing Boji borehole C5486 in the area showed brackish water (electric conductivity of 3,900 microSiemens/cm), which was not in accordance with data obtained from the preliminary interpretation.

A re-interpretation of the VES on the base of true resistivities from the well-logs gave a satisfactory conformity with the actual hydrogeological situation (Figures 3.2 and 3.3).

Farther to the east the same brackish water is encountered in the Hadado borehole C3893. The salinity of the water seems to increase both eastward and southeastward, but at Habaswein there is a sudden improvement in the water quality as evidenced by the old boreholes drilled there for the local water supply. The results are given in Plate 3 and Appendix 3 and are also illustrated in Figures 3.2 and 3.3.

The conclusions drawn from these investigations can be summarised as follows:

a) The brackish water zone identified between Malka Galla, Hadado and Diri is probably fossil water with some dilution from fresh water leaked from the Yamicha Plateau area.

b) There is also the possibility that the narrow channel-like sandy structure (probably a paleo-channel) which crosses the whole investigated area from northwest to southeast, could have been a source of a fresh water infiltration in the past, that has partially diluted the connate water along its course.

c) The fresh water surrounding the Yamicha Plateau probably extends only for a few kilometres and is locally recharged from precipitation on the plateau itself, probably with some supplement from the Mount Marsabit area. Therefore it does not recharge the Habaswein/Liboi aquifer.

d) Although this geophysical work did not explicitly succeed in identifying the recharge zone for the Habaswein/Liboi aquifer it is believed that the recharge is from the Ewaso Ngiro River probably through some sandy sections of the river-bed which are hydraulically communicating with this aquifer. An east-west running fault exists between Diri and Habaswein and this could have some influence on the recharge.

4. HYDROLOGY

4.1 Introduction

The hydrological studies are aimed at obtaining a basis for the estimation of the surface water and groundwater potential of the project area. This should enable evaluation of the possibilities and limitations that exist in the utilization of water resources in Isiolo District. The studies cover the rainfall, evaporation and runoff distribution in the District.

The District area is 25,605 km^2 and covers the middle and lower catchment area of the Ewaso Ngiro basin. The District has varied physiographic and climatic features.

The Ewaso Ngiro river is the major perennial river system together with its tributaries. The tributaries include Ngare Ndare, Isiolo river and Ngare Mara together with a number of springs such as Buffalo Springs, Shaba Springs and Chanler's Falls Springs and many other smaller springs. The south of the District, is drained by Bisanadi, Kinna and Rojeweru rivers which empty their water into Tana river. For some of these, preliminary estimates were made concerning their reliability as water sources by using the scanty data available mainly collected by the project since early 1989.

The general form of the topography in the catchment is a broad reflection of the geology. To the south lie the main mountain masses of Mt. Kenya and the Nyambeni's. The lava from these two sources have resulted in a gently sloping relief. The river makes its way along the northern edge of these lavas occasionally cutting across a projecting tongue of lava, giving rise to several springs which emerge from under these lava edges. In the lower catchment area, the topography is marked by thick sediments together with marked changes of scenery. Apart from the prominent basalt-capped Plateau of Merti, the river valley is practically featureless. The river stretches away for many kilometres in an open plain, splitting apart in many branches and gradually fades out towards the Lorian Swamp.

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

The District lies in a semi-arid to very arid climatic zone. The arid zone extends from the Barsalinga area to Archer's Post and receives an average annual rainfall of about 350 mm. The semi-arid zone is within the surroundings of Isiolo town and receives an average annual rainfall of about 600 mm. The very arid zone covers Malka Galla, Merti, Modo Gashe and Sericho areas and receives an average annual rainfall of about 250 mm.

4.2 Previous Hydrological Studies

(a) 'The Uaso Nyiro Catchment Hydrographic Survey' by Tetley (1940) was the first major survey of the catchment carried out. Prior to this no systematic investigation had been made into the water resources of the basin. Tetley concentrated particularly on the area of the then European settlement with an objective of setting up an equitable system of water allocation in an area which

was developing rapidly. Extensive measurements were carried out at periods of low flow in the dry season of 1938/1939 on all the major tributaries of the Ewaso Ngiro east of the Mutara river. He concluded that the equivalent normal low flow of the Uaso Ngiro was 85 cusecs, he also briefly investigated the lower reaches and recognised that the large losses below Kitterman's Camp (Melka Bulfayo) were the result of the river flowing over porous alluvial material.

(b) 'The hydrology of the Uaso Ngiro river' by Dr. Dixey (1943) was a brief report; despite it's title no attempt was made to deal with the whole of the catchment except in extremely general terms. He was investigating the lower reaches of the river and gave a masterly summary of the salient feature of the human and physical geographical changes. In his conclusion he realised that changes in the river were not largely related with the main problem of over stocking and consequent destruction of vegetation over a wide area on either side of the river.

(c) By 1948 it was realised that a new survey of the Ewaso Ngiro catchment should be undertaken and Sir Alexander Gibb and Partners wrote a published report and gave a sketch of the general conditions in the Upper Catchment, but was mainly concerned with provision of watering points east of Archer's Post. They concluded that the water passing Archer's Post at times of low flow was wasted and would be best used in the upper farming areas, provided that adequate alternative sources of domestic and stock water, such as boreholes, were developed in the lower catchment.

(d) 'An investigation into the Water Resources of the Ewaso Ngiro Basin Kenya', Ministry of Works (1958-1961) is a full technical report covering hydrology, agricultural potential and a complete summary of the conclusions and recommendations resulting from the investigation. In this investigation the hydrology of the whole area was examined on a comprehensive scale. Major tributaries of the Ewaso Ngiro were identified as the Isiolo River and the flows originating from springs below Archer's Post. Losses from Ewaso Ngiro were found to be mainly from seepage and evapotranspiration. Major contributions to floods were found to originate from the laggas as major run-off collectors and could account for about 50% of the total flood flow.

(e) 'The Ewaso Ngiro Irrigation Cluster', Ministry of Agriculture (1982) is a background document which gives a brief summary of the climatology and hydrology of the Ewaso Ngiro River Basin. Considered are: rainfall at three stations, Malka Daka, Garfassa and Merti; flows at the station 5E3 (Archer's Post) where estimates of mean monthly flows at the station between 1949 and 1968 were given and potential evapotranspiration as estimated from the modified Penman formula given for the above three stations.

(f) In the 'WRAP Water Resources Assessment Study on Laikipia District', Ministry of Water Development (1987), the Ewaso Basin was studied in some detail. The report contains some hydrological information on the run-off characteristics of the Ewaso Ngiro at Archer's Post for regular gauging station 5E3.

4.3 Hydrometeorological Network

4.3.1 Rainfall Stations Network

The 17 rainfall stations in Isiolo District are unevenly distributed. Most of the rainfall stations are concentrated in the middle and southern parts of the District. The northern parts are not covered (Figure 4.1). A few stations have been installed or rehabilitated by WRAP (Appendix 4.1).

The main problems affecting the rainfall data collection at established rain gauge stations are negligence and unreliable data given by some of the observers. However, regular monthly inspections and lectures to the observers on the importance of having reliable data improved the data collection.

4.3.2 Evaporation Network

The Surface Water Division of the Ministry of Water Development uses class A pans for the estimation of potential evaporation from open water surfaces. When the project moved into Isiolo District, there were only two evaporation stations in operation, one at Isiolo and one at Archer's Post. These are old stations established in 1946 and have continuous daily pan evaporation records (Appendix 4.1).

Four new class A pans were installed by the project in Kula Mawe, Garba Tula , Modo Gashe and Merti. The old pan at the Isiolo Water Office was replaced by a new one because of leakage problems. Regular inspection of the evaporation pans was done for data collection and maintenance of the pans. The Kula Mawe station was later abandoned because of an unreliable observer.

4.3.3 Runoff Stations Network

Only two gauging stations existed in the District before the project started. These two stations are Archer's Post-5E3 on Ewaso Ngiro River and 5D8 in Isiolo river. The project installed a gauging station on Ngare Ndare stream and also shifted 5D8 to a location upstream of the new water intake on the Isiolo river as summarised in Appendix 4.

Figure 4.1 shows the locations of the gauging stations established by the project and the existing ones at Archer's Post and Isiolo river.

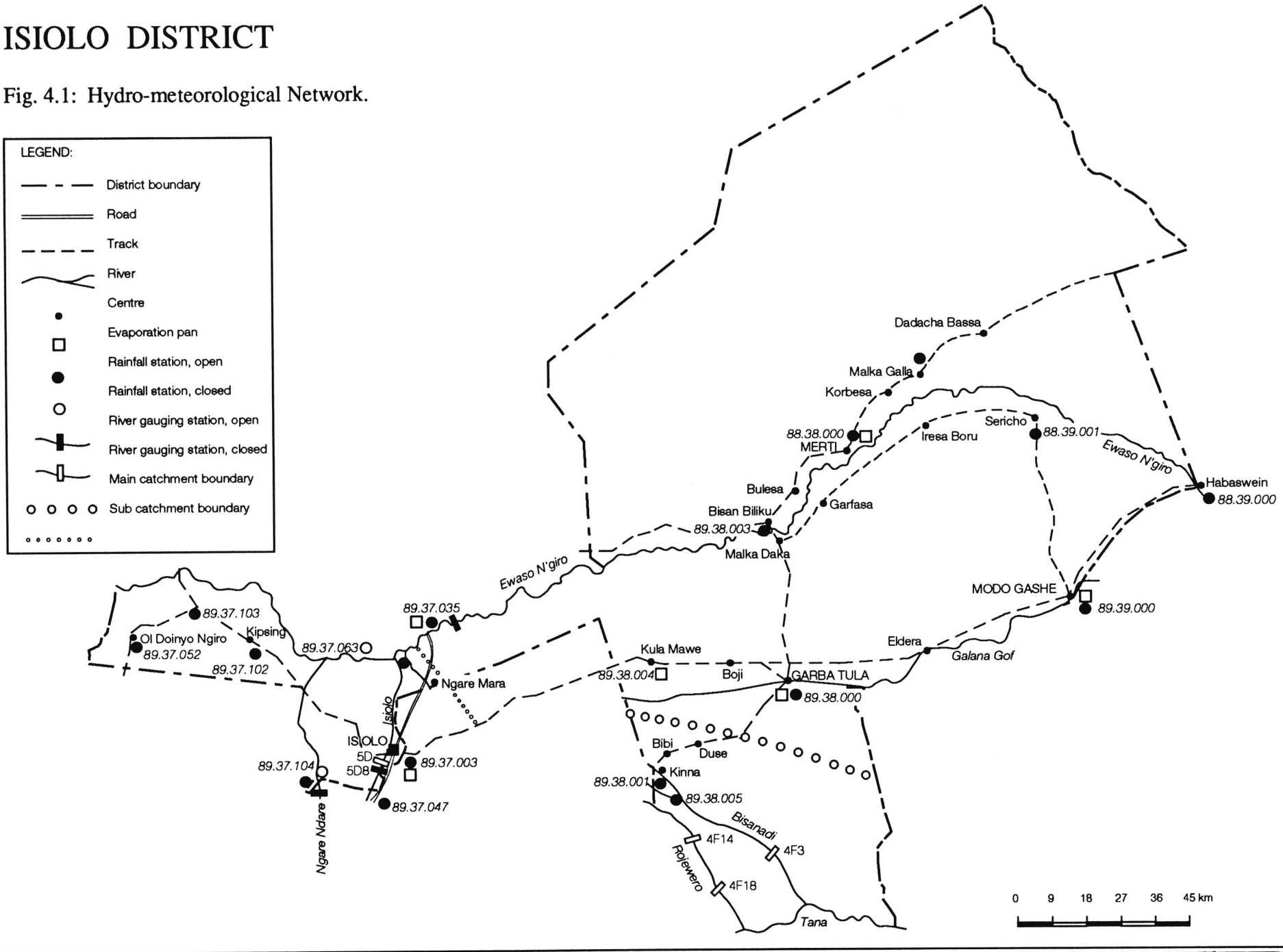
4.4 Rainfall

4.4.1 Available Data

The rainfall data has been collected and evaluated to give information on the quantity and distribution in the District. Most of the rainfall data was provided by the Kenya Meteorological Department (KMD) and the Ministry of Water Development (MoWD), Hydrology Section.

ISIOLO DISTRICT

Fig. 4.1: Hydro-meteorological Network.



Rainfall data in Isiolo is limited in areal coverage, length of record and continuity of observations. The earliest rainfall observations were made at Isiolo District Office. (88.37.003) from 1930 onwards. Other stations with relatively long period are Archer's Post, Garba Tula, Modo Gashe and Habaswein Police Posts.

The rainfall data of many stations in the District are of poor quality due to negligence of observers and very many gaps in monthly and annual rainfall data exist. The available data from the stations were entered in a Personal Computer for storage and analysis. The entries were checked to ensure that they conform with the original file records. To study rainfall patterns in the District eight stations have been selected for detailed analysis to indicate rainfall distribution in the District and its variation with time.

Generally, the arid regions which include Barsalinga to Archer's Post receive an annual average rainfall about 300-350 mm. The semi-arid region which is in the surrounding of Isiolo town receives an annual average rainfall of 400-650 mm. The very arid zone covers the eastern and northern part of the District and receives an annual average rainfall of between 150-250 mm.

4.4.2 Monthly Rainfall

Monthly rainfall data has been analyzed for eight stations distributed in the study area except in the northern part of the District. Statistical characteristics of the monthly data were calculated (Appendix 4.2). The distribution of the mean monthly rainfall is shown in Figure 4.2.

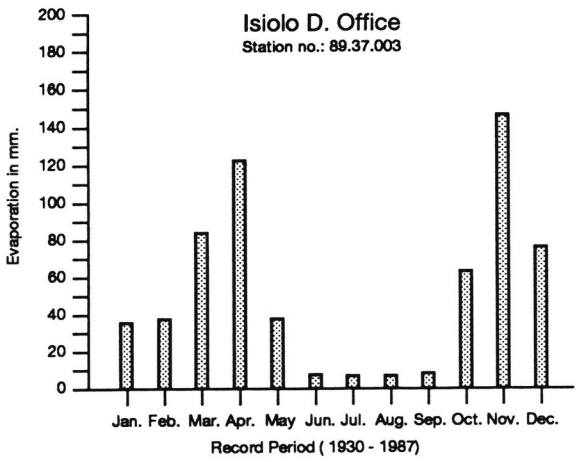
The analysis shows that the monthly rainfall is strongly variable both spatially and temporally. As the amount of monthly rainfall is strongly variable from year to year, the monthly rainfall is unpredictable. The distribution of the monthly rainfall in the District occurs in two distinct seasons and the two contribute about 80-95% of the total annual rainfall. The lowest rainfall occurs in the months January - February and June - September, while the highest rainfall occurs in April and November. This seasonality in occurrence of rainfall has a direct influence on the surface water resources. Most rivers are seasonal and carry only rain water. Perennial ones have little baseflow and only increase their discharge during the rainy period.

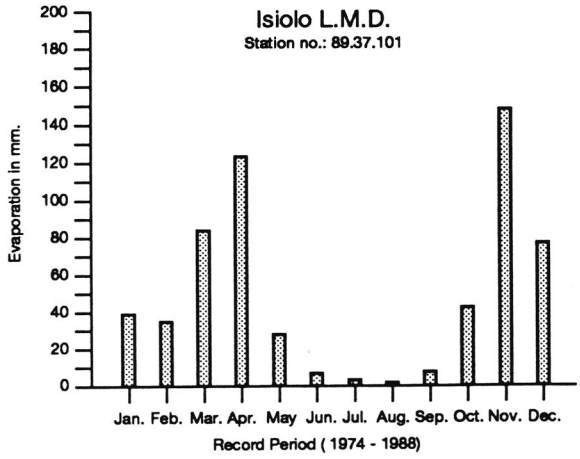
Table 4.1 summarizes the occurrence of the rainfall patterns.

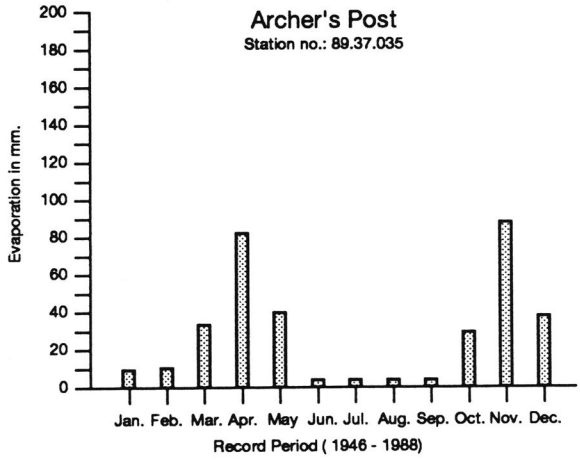
4.4.3 Annual Rainfall

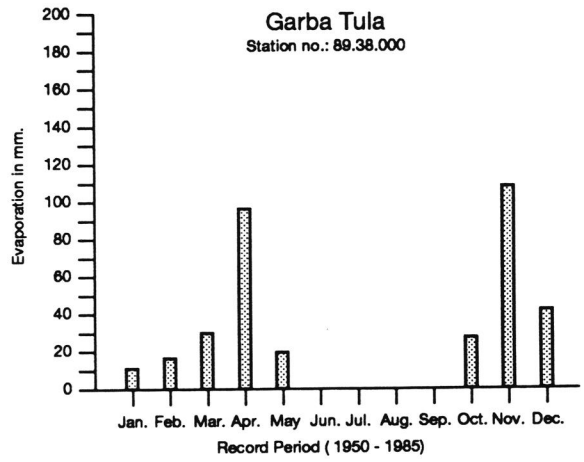
Statistical characteristics of annual rainfall have been computed for 7 stations around the study area and are listed in Appendix 4.3. The annual rainfall distribution varies both in time and space. The lowest is observed in the eastern part of the District. The highest rainfall occurs in the surrounding of Isiolo Town. Generally the annual rainfall is directly related with altitude, but the amount of rainfall is also influenced by local weather conditions. In general Isiolo District Office at an altitude of 1104 m receives more rainfall than Habaswein at a lower altitude of 195 m. This difference is also reflected in the rainfall distribution during the long and short rains.

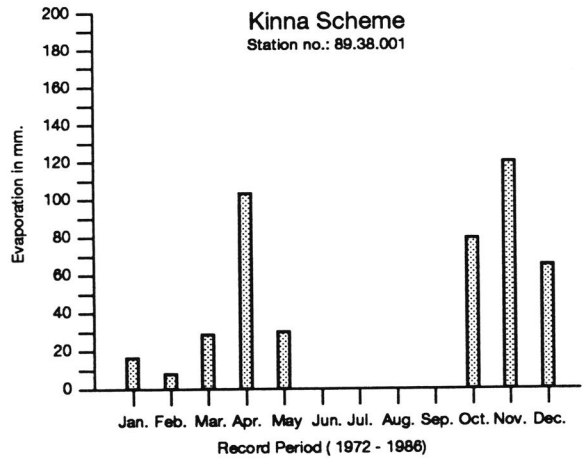
Figure 4.3 shows an isohyetal map indicating the mean annual rainfall which is based on available rainfall records and which uses topography and vegetation cover to estimate rainfall in areas without rainfall records.

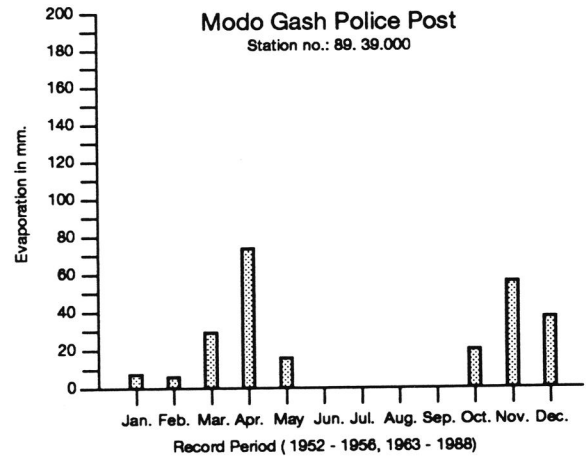












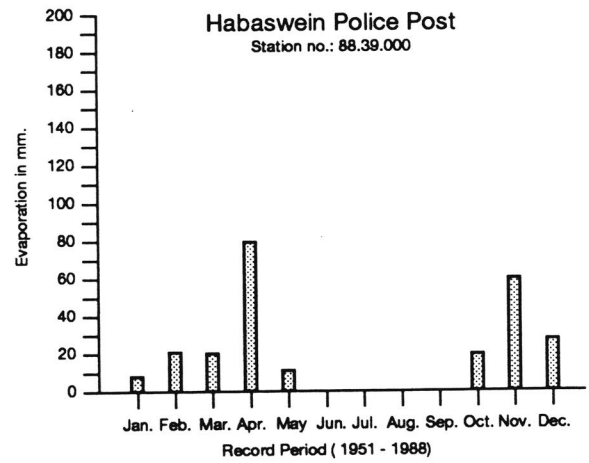


Fig. 4.2: Mean Monthly Rainfall

Table 4.1 Low and High Rainfall Distribution

Rainfall Station	Annual Rainfall	Low Rainfall	High Rainfall
Isiolo Town	618.5 mm	June-September	April, November
Archer's Post	313.6 mm	June-September	April, November
Garba Tula	343.4 mm	January-February	April, November
Kinna	451.6 mm	January-February	April, November
Modo Gashe	254.7 mm	January-February	April, November
Habaswein	248.9 mm	January-February	April, November

4.4.4 Annual Rainfall Trend

The annual rainfall was analyzed on the occurrence of periods of wet and dry years by calculating the 5 year moving average. The analyses were done for four stations in the District with annual rainfall record at least longer than twenty years (Appendix 4.4). The years when annual rainfall is below the long term annual average are analyzed as dry years, whereas those above average are wet years for the area. Sequences of dry years exist at all the stations analyzed. Dry periods are more pronounced than the wet periods.

Table 4.2 Dry and Wet Periods

Years: 1930	1940	1950	1960	1970	1980	1990
Isiolo Town	↓↓↓↓↓↓↓↓↓	↓↓↓↓↓↓↓↓↑↑	↑↑↑↑↑↑↑↑↑↑	↑↑↓↓↓↓↓↓↓	↓↓↓↓↑↑↑↑↑	↓↓↓↑
Archer's Post		↓↓	↓↓↓↓↓↓↓↑↑↑	↑↑↑↑↑↑↑↑↑↑	↓↓↓↓↓↓↓↓↓↓	↑↓↓↓↓↓
Garba Tula			↓↓↓↓↓↓↑	↑↓↓↓↓↓↓↑↑↑	↑↓↓↓↓↓↑↑↑↑	↑↓↓↓
Habaswein			↓↓↓↑	↑↑↑↓↓↓↑↑↑↑	↑↓↓↓↓↓↓↓↓↓	↓↓

Key: ↑ 5 year moving average above long term average
↓ 5 year moving average below long term average

4.4.5 Annual Rainfall Reliability

The frequency of occurrence of annual rainfall is useful for the long term planning in the water resources development and management. Probability analysis was done using annual rainfall data to estimate probabilities of exceedance or non exceedance of annual rainfall. This was done by ranking annual rainfall in descending order. The formula used for plotting position was Weibul's plotting position formula.

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

Where P = Probability of non-exceedance.
m = event ranking
n = total years used.

Results of this analysis for each of the five stations are graphically presented in Appendix 4.5. Some values of probabilities of exceedance are summarized in Table 4.3. The results show the 50%, 60% and 90% probability of getting an amount of annual rainfall equal to or greater than the stated value.

ISIOLO DISTRICT

Fig. 4.3: Isohyetal Map of Mean Annual Rainfall

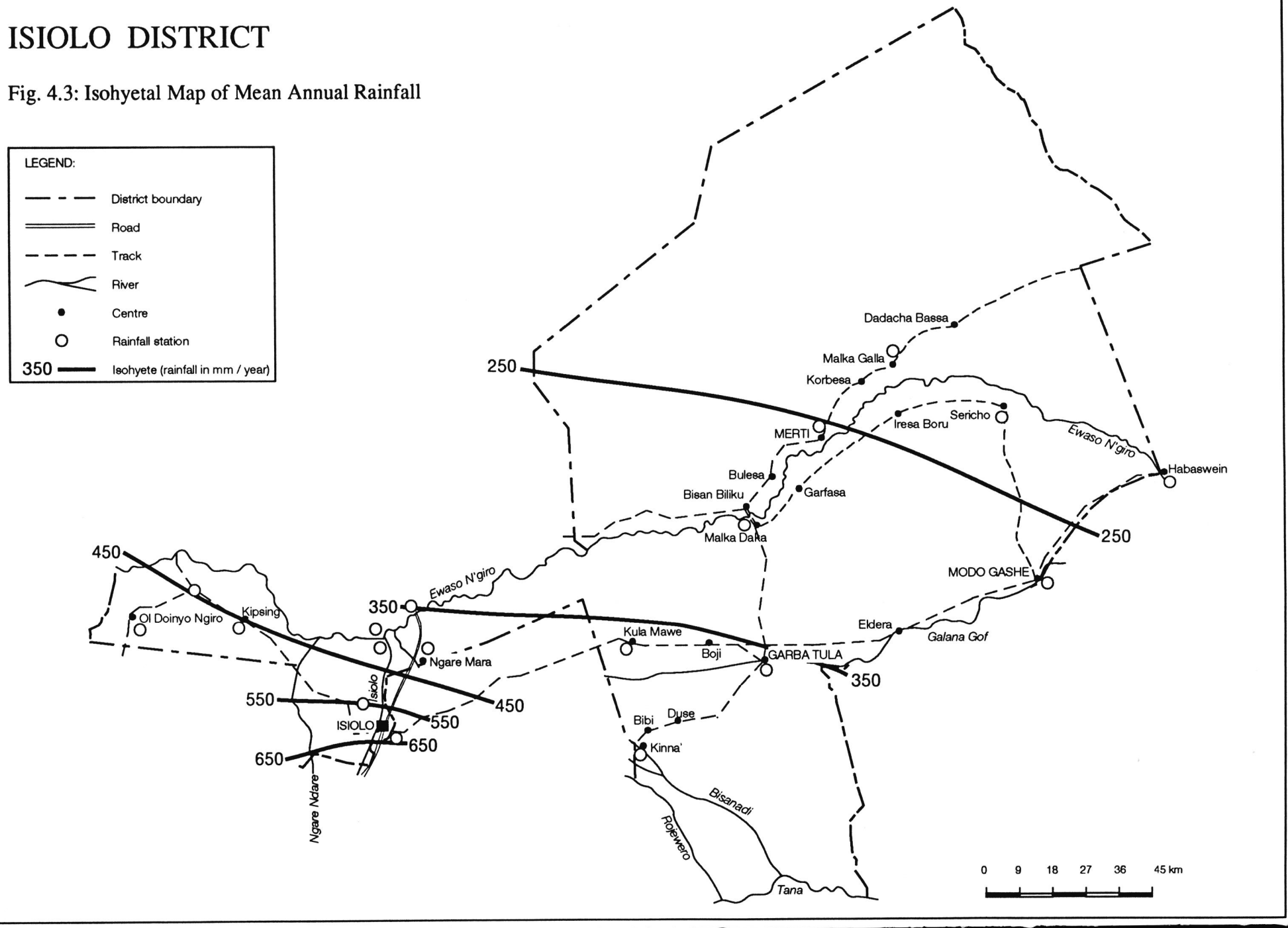


Table 4.3 Annual Rainfall Reliability in (mm)

Station Name K.M.D. No.	Record Period	Annual Average	50% Prob.	60% Prob.	90% Prob.
Isiolo D. Off. 89.37.003	54	622.7	583.4	538.3	438.7
Archer's Post 89.37.035	43	349.7	316.7	274.1	170.3
Garba Tula 89.38.000	36	364.3	283.8	252.3	153.7
Modo Gashe P.Post 89.39.000	29	251.6	206.0	168.7	79.8
Habaswein Post 88.39.000	25	256.6	205.0	158.7	66.7

Note: The annual rainfall values refer to the probability of exceedance. For example, in 60% of the years (6 out of 10 years), the annual rainfall at Isiolo D. Off. is expected to be equal to or greater than 538.3 mm.

4.4.6 Annual Maximum Daily Rainfall Frequency

The analysis for the maximum daily frequencies is important as it is of direct application in the design of various water related projects with economic importance. The data may be used in the design of drainage networks, design floods for storage dams etc. These and other water project designs are usually on the basis of a certain amount of rainfall to be expected during a selected period of time.

The analysis for the annual maximum daily rainfall frequency was done for two stations. The annual series of maximum daily rainfall were ranked. The plotting positions were determined by the Weibul's plotting position formula. The results were plotted on the Gumbel extreme probability paper (Appendix 4.6). The Gumbel theoretical distribution was fitted to the data for extrapolation of higher return periods of up to 100 years since the range of data used was up to 49 years. Some examples of annual maximum daily rainfall of some commonly used return periods in design works is presented in Table 4.4.

Table 4.4 Annual Maximum Daily Rainfall Frequency.

Station Name	K.M.D Reg.No.	Return Period in Years 10	25	50	100
Isiolo D.Off. n = 49	89.37.003	77	92	102	115
Archer's Post n = 39	89.37.035	82	102	116	128

n = Number of years used
Tr = Return period, which refers to the average interval in years for an event of a given magnitude to be equalled or exceeded. Thus at Isiolo D. Off. once in 50 years, a maximum daily rainfall of 102 mm can be expected.

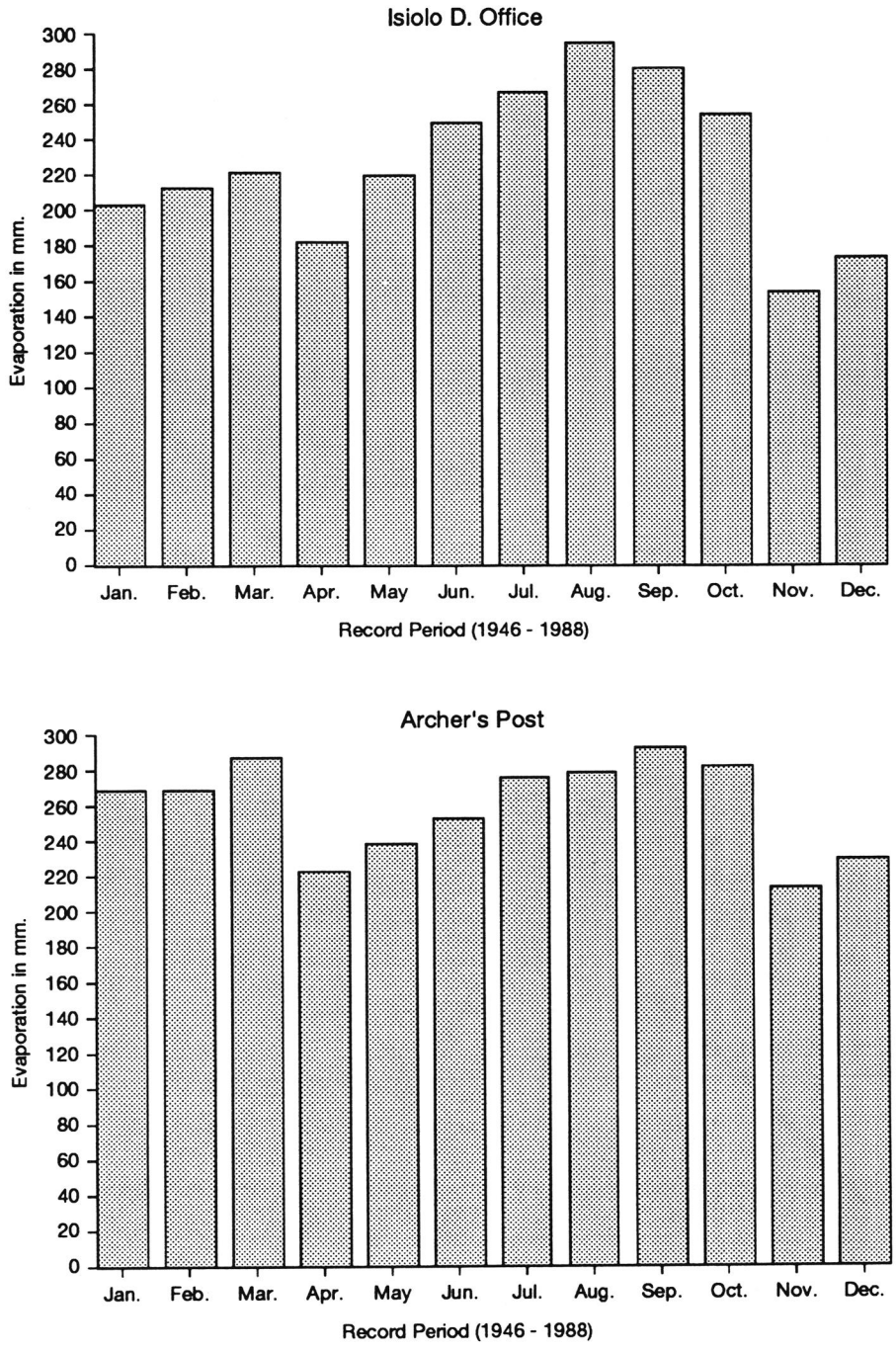


Fig. 4.4: Mean Monthly Evaporation

4.5 Evaporation

4.5.1 General

Evaporation is a continuous deduction from any body of stored surface water and constitutes a major water loss from impounding reservoirs. The estimation of evaporation rates from water surfaces is important especially in arid and semi-arid regions as Isiolo District, where existence depends on very limited water supply. The evaporation rates are essential in studies of crop water requirements, catchment area research and management and in the design of reservoirs for irrigation and hydropower generation. In design of these structures, evaporation must therefore be estimated to determine the net volume of water available.

4.5.2 Monthly Evaporation

Data on monthly evaporation for a relatively longer period exists for only two places in the District. These are at Isiolo Town and Archer's Post and are shown in Appendix 4.7.

Statistical characteristics of monthly evaporation data for the two stations have been calculated and are presented in Table 4.5. Generally the monthly evaporation rates are fairly uniform from month to month as the area experiences permanent sunshine throughout the year. The highest monthly evaporation is in September and August with lower values in November. Figure 4.4 shows the mean monthly evaporation for the two stations.
The evaporation pan stations installed by the project provide data of at least one complete year of observations and the observed monthly distribution of evaporation for this period is also summarized in Table 4.5.

4.5.3 Annual Evaporation

Annual evaporation data from the Class A pan at Archer's Post and Isiolo Town are included in Appendix 4.7. The average annual pan evaporation at Archer's Post is 3,125 mm and at Isiolo 2,708 mm. The potential evaporation is not very much variable from year to year as indicated by the low variation coefficients of 0.198 and 0.193 for Archer's Post and Isiolo respectively.

4.6 Surface Runoff

4.6.1 General

The surface water drainage system of the study area is shown on Figure 4.1. Most of the rivers in the study area are seasonal or ephemeral. The District is mainly drained by one river system, the Ewaso Ngiro.

The perennial Ewaso Ngiro originates from the Aberdares and the north-western slopes of Mt. Kenya and is fed by a few streams from the southern part of the District.

Table 4.5 Evaporation Data (in mm)

Station Name		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max	Min	Annual
(a)....Average Monthly Pan Evaporation at Archer's Post and Isiolo Office (1946-89)																
Archer's Post	X	269.7	268.4	287.3	224.1	239.3	255.8	275.9	281.2	292.8	283	214.8	233.0	292.8	214.1	3125.4
	CV	0.15	0.11	0.14	0.20	0.17	0.19	0.12	0.19	0.09	0.11	0.17	0.21			
	%	8.6	8.6	9.2	7.2	7.7	8.2	8.8	9.0	9.4	9.1	6.9	7.5			
Isiolo Off.	X	199.9	210.2	218.2	180.9	216.1	245.4	261.4	286.3	276.9	248.7	165.1	172.5	286.3	165.1	2708.7
	CV	0.19	0.25	0.27	0.25	0.27	0.30	0.30	0.27	0.26	0.24	0.26	0.22			
	%	7.5	7.8	8.2	6.7	8.0	9.2	9.8	10.8	10.3	9.4	5.9	6.5			
(b)....1989 & 1990 Pan evaporation Data from Project Installed Stations																
Merti	1989			66	443.8	353.9	462	621	*	440.5	534.8	369.6	236.5			
	1990	540	537	468.7	432.1	610.5	746.5	725.5	824.3	710.5	*	*	*			
Garba Tula																
	1989			188.8	458.7	250.9	292	311.5	331	304.5	320.1	170.8	128.4			
	1990	157.6	189.8	144.1	205.9	323.5	269	214.5	305	295	285.0	139.7	136.6	323.5	136.6	3060.7
Modo Gashe																
	1989			223.5	281.0	250.5	267.5	293.5	303.5	310.5	319.0	184.9	184.9			
	1990	166.4	183.5	318.3	200.3	243.0	257.5	225.5	266.5	276.5	218.0	262.6	208.4	318.3	166.4	3311.2

The tributaries of the Ewaso Ngiro river within the District are the Isiolo river which originates from the highland north of Mt. Kenya and the Ngare Ndare stream which also originates from Mt. Kenya. These two streams are perennial. Other smaller streams include the Ngare Mara which originates from the Nyambeni Hills and the Ngare Nything which originates as a spring from the highlands north of Mt. Kenya. In the south of the District there are the Kinna and the Bisanadi streams which originate as springs in the Nyambeni Hills and flow into Tana River.

Apart from the data on the Ewaso Ngiro river no other runoff data of sufficient length and continuity exist. Therefore the estimation is difficult of the reliability as a water source of the few existing perennial streams such as Ngare Ndare and Ngare Mara. Although these two streams are said to be perennial, the critical low flow discharges in the dry periods are unknown.

4.6.2 Ewaso Ngiro at Archer's Post - RGS 5E3

The Ewaso Ngiro system covers the whole of the 5B sub-drainage area and has a catchment area of 15,300 km^2 at Archer's Post - RGS 5E3. The rivers draining this system originate from both the northern Nyandarua mountain ranges and Mount Kenya where the annual rainfall is over 1,000 mm. Downstream RGS 5E3 up to Lorian Swamp the climatic conditions are arid to very arid with annual rainfall of about 300-350 mm and 150-250 mm respectively. Runoff characteristics of this system have been evaluated in the WRAP Laikipia District report 1984 at three key regular gauging stations i.e RGS 5BC4 on Ewaso Ngiro itself at Ngare Ndare Police Post, RGS 5BE20 on Nanyuki river upstream of the Nanyuki - Dol Dol road and RGS 5D5 before the Junction.

The RGS 5E3 was opened in April 1949 and was equipped with staff gauges, a compound weir and a less sensitive silt free air flow autographic water level recorder. This recorder operated until 1952 and was removed due to operational problems.

A second recorder was installed in May 1959 and was in operation up to 1961. A third recorder, a pneumatic type, was installed in March 1980 but its delicate operational procedures makes it unoperational most of the times. Water level observations have been made twice daily from 1949 to present due to the presence of a full time employee at the station.

The RGS is rated to cover discharges in the range 0.6 to 1900 cumecs. Thus the station is well equipped for high flows but not so for low discharges.

Daily discharge data for the period April 1949 - 1990 have been computed and flow hydrographs have been drawn for each year. Copies are kept in the WRAP Documentation Section. A summary of the mean monthly flow data for the period is shown in Appendix 4.8. The overall mean flow is 20.29 cumecs, the minimum mean monthly flow is 5.2 cumecs and the maximum mean monthly flow is 88.1 cumecs. The lowest daily flow recorded in 1981, 1985, 1986, 1987 and 1988 is 0.098 cumecs. The highest daily flow is 1,836 cumecs recorded in 1961.

The bimodal runoff distribution pattern of this station is shown in Figure 4.5 in which most of the flood flows are generated during the long and short rains.

Low Flow Analysis

The lowest flow recorded at 5E3 originates from the contribution of the Isiolo tributary and a number of springs. Investigations carried out in March 1985 indicated that upstream of the confluence with the Isiolo River the Ewaso Ngiro was dry. This is caused by abstractions for irrigation purposes upstream of the Junction during the dry seasons and by major losses due to seepage and evaporation in the section below the Junction.

The analysis of the minimum one day and seven days consecutive flows shows that flows equal to or greater than 0.3 and 0.4 cumecs are possible 9 out of 10 days respectively (Table 4.6). These flows, however, do not take into account water abstractions upstream.

Water availability on a daily basis is determined from the flow duration curve in which the 95% and 90% duration flows are 0.81 and 1.58 respectively (Appendix 4.8).

Flood Analysis

Flood flows at 5E3 were estimated using floats and a temporary cable way during the 1958-61 investigation period. The data were used to rate the station up to a maximum of about 1,900 cumecs but unfortunately, due to lack of flood gauging equipments, the validity of this rating curve at medium and high water levels cannot be confirmed now. Except for the 1949-52 and 1959-61 periods, most of the peak water levels have been read from staff gauges in which the actual water levels have been underestimated.

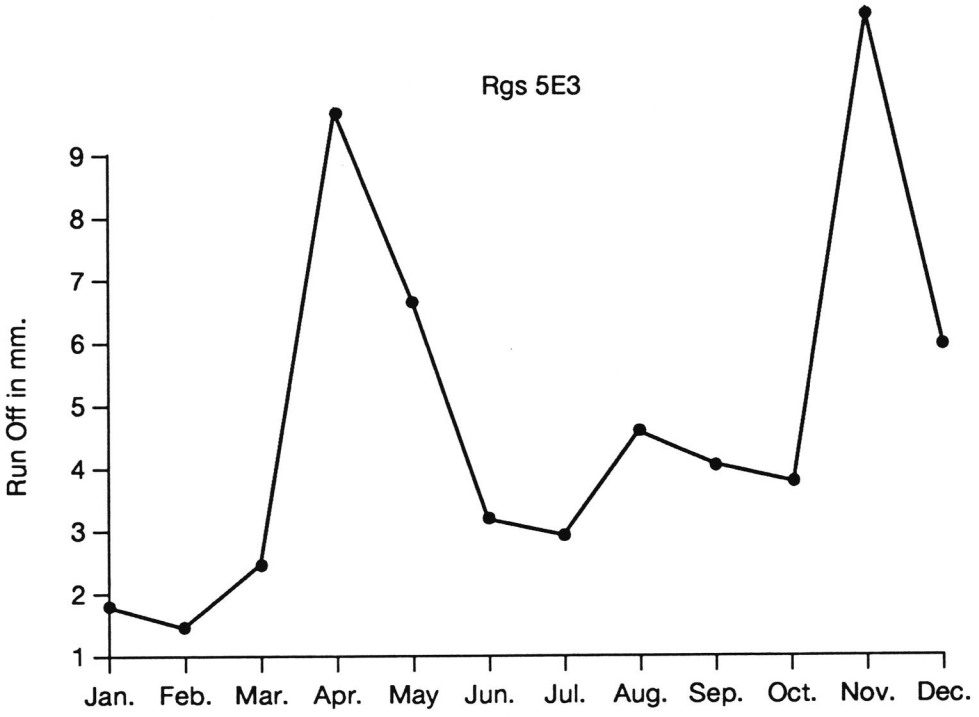


Fig. 4.5: Bimodal Runoff Distribution Pattern of the Ewaso Ngiro.

Table 4.6 Comparison of Flow Characteristics Along the Ewaso Ngiro (cumecs)

RGS	5BC4	5D5	5E3
Catchment area (km^2)	1,870	4,561	15,300
Minimum -1 day	0.075	0.075	0.3
-7 day	0.095	0.12	0.4
Mean monthly	3.28	7.88	20.29
- per km^2	0.0018	0.0017	0.0013
Minimum mean monthly	0.404	1.017	1.613
Daily flow - 95%	0.347	0.661	0.81
duration - 90%	0.468	0.955	1.58
Maximum flow	244	766	1836
Floods: 50-year	310	870	1400
100-year	380	1500	1800

The 1961 flood was the highest at 1,836 cumecs followed by the 1951, 1968 and 1982 floods of 658.6, 598.3 and 554.2 cumecs respectively. The lowest flood for the 39 years of record is 28.2 cumecs observed in 1952.

Weibul's plotting position has been used to plot the flood flow data on log-normal probability paper (Appendix 4.8). This data was then fitted with the log-Pearson type III distribution which gives the 100-year flood at about 1,780 cumecs. The 1961 flood of 1,836 cumecs has a return period of about 150 years.

The MoW report of 1962 on the "Investigation of the water resources of the Ewaso Ngiro basin" has shown that more than 50% of the flood flows at Archer's Post (RGS 5E3) originates from the middle catchment area below the Junction. This area is known to receive intense high maximum daily rainfall amounts which falling on bare soil produces the observed flash floods.

A break down of flows (in %) passing through Archer's Post for a wet year (1951), dry year (1952) and average year (1960) was done in 1962 and these are reproduced below in Table 4.7. It shows that the Ewaso Ngiro system contributes equal flow to Ewaso Narok system during wet years, but this is drastically reduced in dry and average years when the Ewaso Ngiro contributes 4 and 6 times more flow than the Ewaso Narok respectively.

Table 4.7 Breakdown of Flows at RGS 5E3 (in percents)

System	1951 (wet)	1952 (dry)	1960 (average)
Upper Basin			
-Ewaso Narok	22	18	11
-Ewaso Ngiro	22	75	67
Middle Basin			
-Below Junction	56	7	22
Total at RGS 5E3	100	100	100

4.6.3 Isiolo Stream - RGS 5D8

The station covers a catchment area of about 230 km^2. The RGS 5D8 consists of a staff gauge installed in 1976. In April 1989 the staff gauge was shifted by WRAP to the upstream of the new Isiolo water supply intake.

From the daily discharge data of 13 years (1976-1988) the overall minimum mean monthly flow is 0.04 cumecs and the long term mean monthly discharge is 0.18 cumecs. On a daily basis the 95 and 90% duration flows are 0.025 and 0.031 cumecs respectively (Appendix 4.9), although most of the data is unreliable due to the fact that most of the flows were taken downstream from the intake.

The rating curve and recession curves are difficult to draw because of disturbances by the increased water abstractions from the river during periods of low flows.

4.6.4 Ngare Ndare Stream - RGS 5D4

The discharge measurements that have been made on the Ngare Ndare Stream are summarized in Table 4.8.

The Ngare Ndare stream is perennial but there is not enough run-off data. The station 5D4 was closed in 1963. The project has established a gauging station on this stream. Continuous daily water level records and regular discharge measurements are now being taken. This data has been used in the report to present some preliminary estimates on the flow characteristics and hence reliability of this stream as a water source for future development.

The waters of the Ngare Ndare stream are extensively tapped by furrows for irrigation and other farm uses in the reaches near the old Nanyuki - Isiolo road. Discharge measurements on the furrow shows that the river is abstracted by 0.046 cumecs (3974.4 m^3 per day). Abstraction takes place above the installed gauging station. The position of the gauging station means that any flood flow is flashy and difficult to gauge without autographic equipment, so flood peaks may well pass unrecorded.

Rating Curve

To estimate the discharges from the recorded water levels for the period of observation, a provisional rating curve was prepared. This was based on discharge measurements taken between March 1989 and September 1990.

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

$$\text{Log } Q = \text{Log } a + b \text{ Log } H \quad \text{(for straight line rating curve on log-log scales)}$$

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

See Appendix 4.10 for the rating curve.

Daily Discharges

Daily discharges were estimated by use of the daily water levels and the provisional rating curve equation developed. The lowest daily discharge estimated was 0.10 cubic metres per second (cumecs) recorded in September and October 1989. The highest daily discharge estimated was 0.59 cubic metres per second in April 1989.

A daily flow duration curve covering the period from March 16, 1989 to September 1990 was constructed based on the estimated daily discharge (see Appendix 4.10). During this period, the 96% daily flow for the Ngare Ndare was 0.1995 cumecs.

Table 4.8 Ngare Ndare Stream, Discharge Measurements

DATE	DISCHARGE	
	Cumecs	m^3 /day
20.04.89	0.18	15552
24.04.89	0.18	15552
12.04.89	0.16	13824
16.06.89	0.16	13824
12.09.89	0.10	8640
10.11.89	0.11	9504
19.04.90	0.25	21600
14.07.90	0.10	8640
13.10.90	0.12	10368

4.6.5 Ngare Nything Stream

The Ngare Nything emerges from springs in the Ngare Ndare Forest near the highlands north of Mt. Kenya and joins the Ngare Ndare downstream. It is a small perennial stream. The discharge measurements that have been made on the stream are summarised in Table 4.9. The results of the discharge measurements indicate that the flow is not much reduced in the dry periods and interviews with the local people indicated that the stream is perennial.

Table 4.9 Ngare Nything Stream, Discharge Measurements

DATE	DISCHARGE	
	Cumecs	m^3 \day
19.04.89	0.30	25920
20.04.89	0.33	28512
24.04.89	0.21	18144
13.06.89	0.17	14688
12.09.89	0.11	9504
10.11.89	0.11	9504
19.04.90	0.28	24192
13.10.90	0.09	7776

4.6.6 Ngare Mara Stream

The Ngare Mara Stream emerges from the Nyambene hills. It is a small perennial stream and the discharge measurements that have been made are summarised in

Table 4.10. The result of the discharge measurement indicate that the flow is reduced in the dry period.

The Ngare Mara is much used downstream for a small irrigation project and therefore during the dry periods the stream does not reach the Ewaso Ngiro.

Table 4.10 Ngare Mara Stream, Discharge Measurements

DATE	DISCHARGE	
	Cumecs	m^3 \day
19.04.89	0.15	12960
26.04.89	0.11	9504
24.04.89	0.09	7776
16.06.89	0.08	6912
14.09.89	0.03	2592
09.11.89	0.28	24192
13.07.90	0.24	20736
11.10.90	0.11	9504

4.7 Surface Water Quality

Data on water quality exists for the surface water of the Isiolo River and the Ewaso Ngiro River. The samples from the Isiolo River were taken at the water intake and that of the Ewaso Ngiro River at Archer's Post. The data were taken in 1986 and 1987 by WRAP in order to investigate the suitability of the Isiolo water for domestic or other purposes. Table 4.11 shows the concentrations for the major ions.

The data shows the fluoride concentration well below the WHO - recommended limit value (1.5 mg/l). The samples of Ewaso Ngiro shows high turbidity. However the water is suitable for domestic use after treatment. The surface water samples are generally of the sodium-bicarbonate type.

Table 4.11 Chemical Data collected by WRAP

River Location Date of sampling	Ewaso Ngiro Archer's Post 9.10.86	Isiolo Intake 19.11.87
pH	8	6.9
EC (mS/cm)	0.275	0.221
Hardness (CaCO3)	96	75
TDS (mg/l)	165	133
Na	24	20.3
K	6	18.5
Ca	16	-
Mg	10	-
Fe	7.9	-
Mn	0.2	-
Cl	11	23
HCO3	126	84
SO4	0.3	<0.3
NO3	0.12	-
F	0.28	0.24
SiO2	-	-

5. HYDROGEOLOGY

5.1 Introduction

The main objectives of the hydrogeological part of the assessment study are:

- to delineate the aquifer systems in the District;
- to define the hydraulic properties of these aquifer systems;
- to estimate the groundwater potential of the aquifer systems;
- to establish the quality of groundwater in the aquifer systems.

This hydrogeological study is a continuation of the geological study of the area where the geological formations are identified and of the geophysical study which contributes to the description of the hydrogeological properties of the geological formations and to the delineation of fresh and saline groundwater zones.

The classification of aquifer systems (see Chapter 5.4.1) corresponds with the geological units defined in the chapters on geology (Chapter 2) and on geophysics (Chapter 3).

5.2 Previous Hydrogeological Studies

The report "An Investigation into the Water Resources of the Ewaso Ngiro Basin, Kenya" (Ministry of Works, 1963) generally deals with groundwater resources of the middle and lower Ewaso Ngiro catchments, which encompass approximately 66% of the project area (Isiolo District). The conclusions are:

> *"Groundwater is present in the gneiss and basalt area south of Ewaso Ngiro River but borehole sinking has proved risky. Within the area of sand rivers to the north, a few boreholes have been drilled close to the sand rivers which yield useful supplies for stock and further drilling is possible. Groundwater resources of the sedimentary areas are considered to be substantial but are, as yet unapproved by boring. The seepage losses sustained by the river below Melka Bulfayo feed a major water table which extends for many kilometres outside the area, and boring indicate that more than 2.7 m^3/h are obtained from a similar geological formation. Additional recharge is obtained from the Huri Hills and Mount Marsabit. It is believed that, with the exception of areas near Mado Gashi and north-east of Habaswein, groundwater of good quality can be obtained by drilling anywhere".*

The report "Geohydrology of North Eastern Province, Kenya" (by W.V. Swarzenski and M.J. Mundorff, 1977) deals with groundwater resources of the eastern Isiolo, that is the area approximately enclosed by a line drawn from El Dera along the district boundary to Hadado, the Hadado - Merti - El Dera. In this report, zones of fresh and saline groundwater in the Merti aquifer were delineated. According to this report, saline groundwater is encountered in the Mado Gashi - Sericho - Merti area and also to the east of Habaswein, and leaving a fresh groundwater zone in the Habaswein area.

The report "Hydrogeology of Eastern Isiolo District" (by B. Lester) gives the following conclusions:

> *"A comprehensive geophysical survey is necessary to determine the groundwater characteristics of Eastern Isiolo District. Such a survey would be expensive, but the long term benefits would justify the initial cost. In the meanwhile, until funds are available for such a survey, the following is recommended;*
>
> *Deep boreholes drilled in the Merti Beds should be confined to the fresh groundwater zone, to a recommended minimum depth of 110 metres.*
>
> *Fresh water supplies could be developed along the Ewaso Ngiro from shallow gravel-packed boreholes drilled within the immediate floodplain, to a recommended maximum depth of 50 metres. Judicious exploration would be necessary to reveal permeable beds that are hydraulically continuous with river channel deposits. Generally speaking, boreholes should be as close to the river as possible for maximum recharge potential, yet far enough away so as to avoid serious inundation.*
>
> *Developing water supplies from such an unpredictable source, as the Ewaso Ngiro, is a difficult and risky operation, as it is not possible to foretell future river floods and diversions. However, until the flood water can be controlled by dams, pipelines, irrigation schemes, gabbions etc., one must design, keeping the risks in mind.*
>
> *No boreholes, either shallow or deep, should be drilled along the Galana Gof east of Benane. Fresh water supplies can be developed from clay fill subsurface dams in the sandy river bed".*

The geological reports published by the Geological Survey of Kenya (see Chapter 2) give a brief summary on groundwater availability for each corresponding mapsheet.

5.3 Available Data

5.3.1 Landsat Data

Landsat MSS data on the scale 1:250,000 are available. Landsat imageries yielded information on the major drainage patterns, vegetation cover and lithological boundaries (Basement System/volcanic rocks, Basement System/sedimentary rock and sedimentary/volcanic rocks). It was possible to identify some faults.

5.3.2 Springs

During the spring inventory exercise, the existence of 24 springs was established (Table 5.1). With the exception of Loburua, Kinna and Kuro Bisani Owo springs, the springs are located on the right bank of the Ewaso Ngiro River. A number of seepage zones were observed still on the right bank on the Ewaso Ngiro River. Both the springs and the seepage zones occur in the zone between Isiolo River and the Malka Daka Bridge, a stretch of approximately 100 kilometres.

Table 5.1 Springs

Spring No.	Elevation (m)	Name of Spring	Discharge (m^3/h)
SP 1	885	Isiolo	36.00
SP 2	890	Kubi Panya	-
SP 3	855	Maji ya Chumvi	-
SP 4	855	Buffalo Lodge	-
SP 5	855	Buffalo	164.00
SP 6	850	Archers	-
SP 7	865	Game Complex	1.44
SP 8	855	Game Complex B	-
SP 9	855	Natorbe	3.96
SP10	810	Sarova	360.00
SP11	820	Natorbe 2	7.20
SP12	823	Natorbe 3	7.20
SP13	850	Dudubata	3.60
SP14	850	Dudubata 2	-
SP15	820	Shaba	-
SP16	823	Shaba 2	7.20
SP17	775	Chaffa	252.00
SP18	730	Chana Falls	30.60
SP19	705	Boji	-
SP20	640	Gotu	270.00
SP21	550	Kuru Barata	41.04
SP22	485	Kuro Bisani Owo	2.00
SP23	730	Kinna	36.00
SP24	1370	Loburua	50.40

- Low discharges not taken

5.3.3 Boreholes

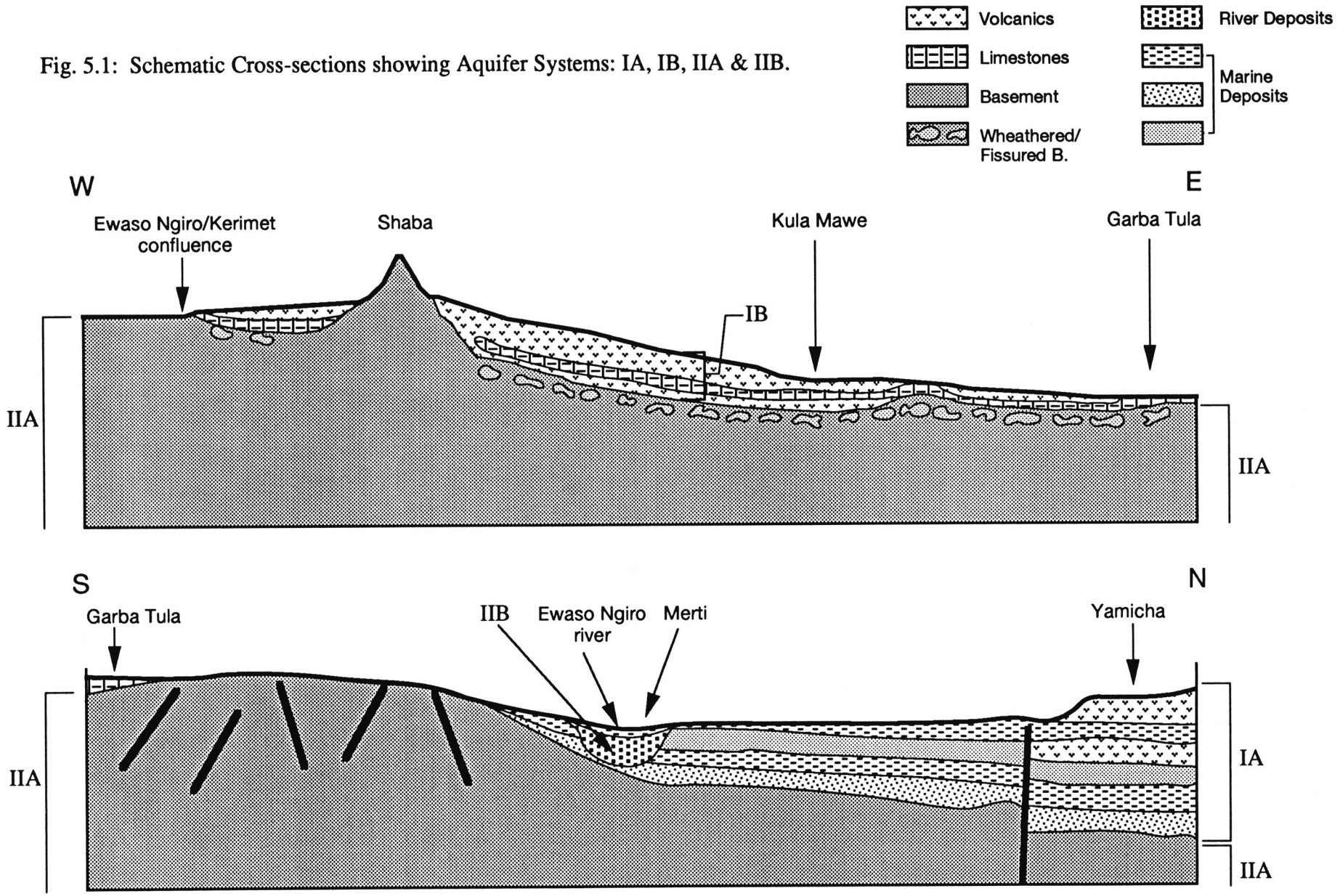
During the inventory phase of the study, 67 boreholes were traced in the files of the Groundwater Section, but the field inventory traced 82 boreholes (Appendix 5.1). The project has drilled 20 boreholes. The selection of the locations of the additional boreholes was based on hydrogeological investigations and water demand (Plate 5).

5.3.4 Well-test Data

The tested yields for the existing boreholes, as listed in Appendix 5.1 are based on the capacity of the pump since drawdowns were measured only in twenty two boreholes within Isiolo District and three in Meru District but near the Meru - Isiolo District boundary. Within Isiolo District, boreholes SA 10, C90, C3655, C3830, C3864, C4514, C4561, C4586, C4643, C4662, C4699, C7406, C7631 and C7632 have been test pumped before the WRAP project. But the test pumping data was of poor quality and impossible to interpret with the exception of data obtained from C7406. In addition to test pumping of the newly drilled boreholes C9380, C9573, C9574, C9575, C9577, C9578, C9639 and C9641 by the project, two old boreholes C3665 and C4699 were also test pumped. The three boreholes within Meru District drilled and test pumped by WRAP are: C7925, C7926 and C7927.

The test pumping data were analyzed using the Jacob's and Theis' methods for pumping and recovery phases, respectively (Appendix 5.2). The transmissivity and specific capacity values were calculated.

Fig. 5.1: Schematic Cross-sections showing Aquifer Systems: IA, IB, IIA & IIB.



5.3.5 Groundwater Levels

The data on water struck and water rest levels are tabulated in Appendix 5.1. The water struck levels correspond to the depth below the ground level at which groundwater is encountered. The water rest levels represent the final levels to which groundwater rose or fell. The groundwater level elevations above mean sea level were estimated by use of an altimeter. The water rest levels as listed in Appendix 5.1 were recorded during the completion of the boreholes.

5.3.6 Chemical Data

Before the start of the project activities in Isiolo District, water samples had been collected for chemical analyses from 15 boreholes (Appendix 5.3). The WRAP project has collected 34 water samples for chemical analyses from boreholes, wells and springs (Appendix 5.3).

The results of the chemical analyses of water samples collected from Isiolo District are of poor quality since in 78% of the samples, the difference in percentage of the reacting values (anions and cations) exceed 6% (Appendix 5.3). Nevertheless the chemical data has been used in the analyses of the groundwater quality.

5.4 The Groundwater System

5.4.1 Classification of Aquifer Systems in Isiolo District

The analysis of the prevailing aquifer systems in the area is based on the available geological information (Chapter 2), geophysical information (Chapter 3), borehole data (Appendix 5.1), and analysis of pumping test data (Appendix 5.2).

Based on this analysis two different aquifer systems can be distinguished, viz. regional aquifer systems, allowing continuous groundwater flow over large areas, and local aquifer systems with isolated groundwater pockets and no flow relation to their surroundings. For the set-up and location of these aquifer systems see Figures 5.1 and 5.2.

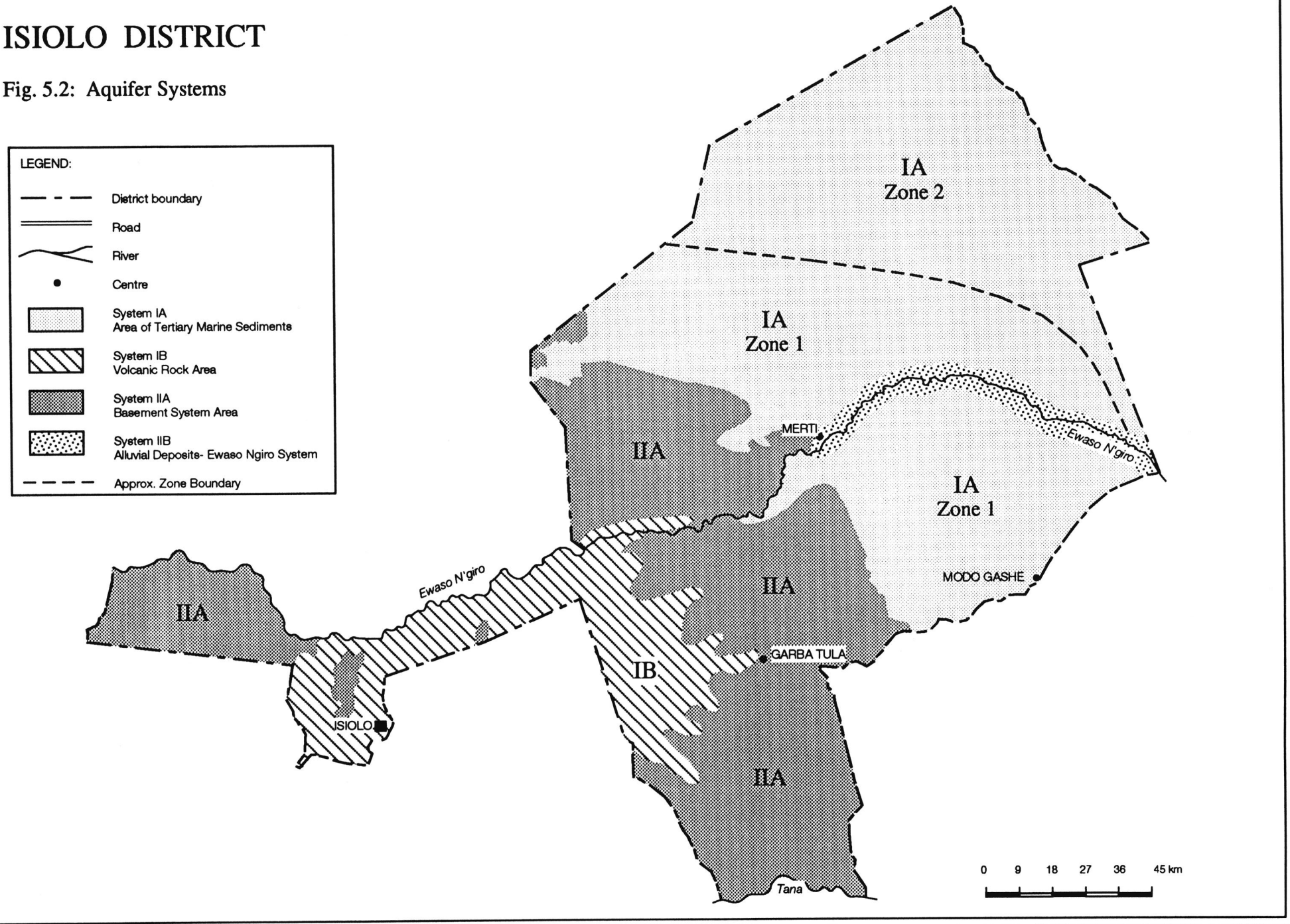
To the *regional aquifer systems*, classified as category I, belong:

- System IA - Tertiary Marine Sedimentary
  A system composed of pervious sedimentary rocks (sands, gravels, pebbles, sandstones and basalts). These rocks cover the Basement Rocks in a large part of east Isiolo. They are sporadically overlain by volcanic rocks.

- System IB - Volcanic Rocks
  A system comprising fissured and weathered volcanic rocks with interbedded sediments (old land surface deposits, lacustrine deposits and pyroclastic deposits) between lava flows. These rocks overly the Basement Rocks in the central western part of Isiolo District (see Figure 5.1 and Plate 1).

ISIOLO DISTRICT

Fig. 5.2: Aquifer Systems



To the *local aquifer systems*, classified as category II, belong:

- System IIA - Fissured and Weathered Basement
  These aquifer systems consist of local weathered and/or fissured pockets in the Basement System Rocks containing isolated groundwater bodies. The unweathered, unfissured rocks surround these pockets, fully separating them from the other aquifer systems. The pockets are found scattered over the Basement Areas and also occur at the interface between the Basement Rocks and overlying sedimentary or volcanic rocks.

- System IIB - Local Sedimentary Deposits
  Aquifer systems of a local size, composed of fluviatile (river) deposits, lacustrine (lake) deposits, and deposits of other origin. The groundwater in these deposits is isolated from that in other aquifer systems by impervious rocks or thick clay layers. Important systems in Isiolo District are the fluviatile deposits along the Ewaso Ngiro and the limestones at Gorba Tula.

In the following sub-chapters a more detailed description is given of each of these aquifer systems.

5.4.2 System IA - Area of Tertiary Marine Sediments

Tertiary/Jurassic marine clays, sands and conglomerates, the so-called Merti Beds occupy about half the District and cover the whole eastern area, extending also to Marsabit, Wajir and Garissa. The deposits have a thickness of upto hundreds of metres. Sands and conglomerates form extensive aquifers. Their hydraulic characteristics depend on the average grain size and may vary from moderate to very good.

The borehole inventory shows that 34 boreholes have been drilled in this area. The aquifer is confined as indicated by the difference between the water struck and water rest levels (Appendix 5.1).

Most of its water is fossil, a remnant of the early sea which covered most of the area. Local recharge conditions have, however, improved water quality in some areas. On the basis of water quality, this system can be sub-divided into two zones (Figure 5.2).

Zone 1 occupies the south western part of the system. Its lithological composition is predominantly clayey. Consequently, there is a very low groundwater flow rate and recharge capacity. The water is also highly mineralized.

Zone 2 covers a fairly extensive area north of the first zone. Groundwater recharge is more pronounced due to it's sandy nature, as is also confirmed by the high groundwater flow rate and the presence of good water quality (EC < 1,000 micro-Siemens/cm). Recharge originates mainly from the Marsabit volcanic highlands and to some extent probably also from the Yamicha Plateau. In this zone, the infiltrating fresh water replaced the connate sea water completely.

Towards the east the salinity of the groundwater increases. However, near Habaswein, the water quality improves probably due to more groundwater recharge from the perched aquifers along the Ewaso Ngiro River, facilitated by an east-west fault and also by a paleo channel-like northwest-southeast running sandy structure which intercepts the course of the River.

Transmissivity, Specific Capacity and Yield

From 34 boreholes in the area pumping tests could be conducted in 7 boreholes only. The data obtained is of poor quality and could not be interpreted in detail. As such the yields shown in Appendix 5.1 and Plate 5 are based on the capacity of the pump.

As it was impossible to interpret the pumping test data the transmissivity values have been estimated from the specific capacity values by the use of their discharges and the resultant drawdowns, using Logan's equation [T=1.22 Q/s]. Borehole yields at a 5 metre drawdown have also been calculated (Table 5.2).

Table 5.2 Calculated Hydrogeological Parameters, System IA

Borehole Number	Locality	Transmissivity Calculated from T=1.22 Q/s m^2/d	Specific Capacity Q/s m^2/d	Yield at 5m Drawdown m^3/h
C3655	Habaswein	39	32	6.70
C3830	Diri	15	12	2.50
C4176	Arba Jahan	195	160	33.30
C4586	Boji	28	23	4.80
C4643	Urura	30	25	5.20
C4699	Yamicha	124	124	21.20

Considering the data presented in Appendix 5.1 and Table 5.2, boreholes sunk in this system have yields varying from 1 to 30 m^3/h.

Groundwater Levels

The water struck levels listed in Appendix 5.1 and indicated on Plate 5 range between 11.3 and 130 metres below ground level. But in 81% of the boreholes, water has been encountered at less than 100 metre depth. In several boreholes, water has been struck at two levels (52%) and even three different levels (8%).

The water rest levels vary from 7.3 and 128 metres below ground level (Appendix 5.1 and Plate 5). In the majority of the boreholes (81%) water rest levels do not exceed 85 metre depth.

Groundwater Flow

Groundwater movement from recharge area to discharge area depends on the available recharge, the aquifer characteristics and the mode of discharge. In the area under consideration, these conditions are not uniform, mainly due to variations in precipitation in different recharge areas of the same system and geological conditions of the underground.

Groundwater flow is in two directions as it can be seen on Plate 5. In the northern part of the system, groundwater flow is in a south-eastern direction while in the south it flows eastward. The groundwater flow rate has been estimated separately for the two zones.

For the southern zone (Zone 1) the groundwater flow was calculated for the section along the 110 m piezometric line. The only transmissivity value available is that from borehole C3830 of 15 m^2/day. The hydraulic gradient (i) calculated from the groundwater contours (Plate 5) is 2.54×10^{-3}. The average width (W) is 63 km. Hence, groundwater flow rate (Q) is in the order of:

$$Q = T.i.W. = 15 \times 2.54 \times 10^{-3} \times 63 \times 10^{3}$$
$$= 2{,}400\ m^3/day\ (0.44\ l/s/km\ width)$$
$$\text{or}\quad 0.88 \times 10^{6}\ m^3/year$$

For the northern zone (Zone 2) the groundwater flow was calculated at the section following the 150 m piezometric line. The average value of transmissivity obtained from boreholes C3655, C4176, C4586, C4643 and C4699 is 80 m^2/day. The average hydraulic gradient (i), determined from the groundwater contours (Plate 5) is 1.66×10^{-3}.

Assuming an average width (W) of 50 km, the groundwater flow rate (Q) is calculated by the application of Darcy's Law as:

$$Q = T.i.W. = 80 \times 1.66 \times 10^{-3} \times 50 \times 10^{3}$$
$$= 6{,}640\ m^3/day\ (1.5\ l/s/km\ width)$$
$$\text{or}\quad 2.4 \times 10^{6}\ m^3/year$$

Groundwater Quality

Most of the groundwater in the marine sedimentary rocks is fossil and saline, but a part of it has been replaced by fresh water infiltrating into the aquifers.

Based on the groundwater quality two zones can be distinguished:
Zone 1 with highly mineralized water (EC values up to 8,000 S/cm) covering the south-western part and
Zone 2 with good water quality (EC values less than 1,000 S/cm) covering the northern part of the area.

In *Zone 1* of the Sedimentary Rock Area the WHO-recommended maximum permissible limit of 1,500 mg/l of TDS for drinking water is exceeded in all 8 cases analyzed (100%), while the WHO-recommended fluoride content limit of 1.5 mg/l for drinking water is exceeded in 7 cases out of 8. The WHO-recommended iron content limit of 1 mg/l in drinking water is exceeded in 2 cases (25%) out of 8.

High fluoride content values are given by water samples from boreholes C3805 (20 mg/l), C3814 (12 mg/l), C3822 (37 mg/l), C3830 (7.6 mg/l), C3853 (12.5 mg/l) and C4424 (8 mg/l).

High iron content is given by water samples from boreholes C4424 (1.8 mg/l) and C4475 (2.96 mg/l).

The bicarbonate and the chloride anions predominate while the sulphate anion is in quite high concentrations ranging between 800 and 1,630 mg/l in groundwater encountered in Modo Gashe, Sericho and Habaswein areas. The sodium cation predominates. And as such groundwater in this zone is mainly of Na-HCO_3 and Na-Cl types (Figure 5.3).

In *Zone 2* of the Sedimentary Rock Area water is generally of good quality. The WHO-recommended maximum permissible limit of 1,500 mg/l of TDS in drinking water is exceeded in 2 cases out of 6. The area with high salinity is around Boji - Hadado - Diri. Here the water is quite saline, TDS ranging between 1,500 and 4,800 mg/l. The fluoride content is slightly above the recommended level of 1.5 mg/l drinking water only around Habaswein.

Groundwater within the northern zone is generally of Na-HCO_3 type (Figure 5.3), but around Hadado on the boundary with Wajir District, groundwater of Na-Cl type is encountered in borehole C3915.

5.4.3 System IB - Volcanic Rock Area

The Volcanic Rocks comprising fine to coarse pyroclastic debris, intermittently deposited with lava flows, cover the central western part of the District. Coarse pyroclastics and weathered or fractured basalts have good hydraulic characteristics and form extensive aquifers.

A total number of 30 boreholes has been drilled in this system. The aquifer is confined as indicated by the difference between the water struck and water rest levels (Appendix 5.1). The aquifer is mainly recharged in the mountainous areas of Mount Kenya and the Nyambeni Hills with rainfall of over 1,200 mm annually and partly locally (local rainfall varying from 300 to 650 mm annually). Part of the percolated water is discharged by springs (Plate 2).

Transmissivity, Specific Capacity and Yield

The borehole yields indicated in Appendix 5.1 and Plate 2 are based on the capacity of the pump. Drawdown measurements were conducted in 17 boreholes only, and pumping test data from 10 boreholes could be interpreted. The calculated hydrogeological parameters are listed in Table 5.3.

Considering the data presented boreholes sunk in this system can yield 50 m^3/h and even more.

Groundwater Levels

The water struck levels indicated in Appendix 5.1 and Plate 2 range between 3 and 83 metres below ground level.

The water rest levels in the boreholes vary from 2 to 64 metres below ground level, while near the Ewaso Ngiro River the rest levels are at the surface at the spring outlets.

Groundwater Flow

Groundwater recharged in Mount Kenya and Nyambeni Hills, flows in northern, north-western and north-eastern directions. Part of it is discharged as springs in the low lying areas.

Table 5.3 Calculated Hydrogeological Parameters, System IB

Borehole Number	Locality	Transmissivity	Specific Capacity	Yield (m^3/h) at Drawdown of	
		m^2/day	m^2/day	5m	10m
C3665	Garba Tula	328	183	38	76
C7406	Isiolo	300	202	42	84
C7925	Northern Grazing Area	264	180	37	75
C7926	Northern Grazing area	307	252	52	105
C7927	Northern Grazing area	130	67	14	28
C8976	Ngare Mara	450	370	77	154
C9577	Bibi	140	110	23	46
C9578	Kinna	374	97	20	40
C9641	Kula Mawe	37	14	3	6

The average value of transmissivity has been calculated from Table 5.3, excluding the values obtained from the limestone deposits in Garba Tula which are believed to represent local aquifer properties. The average transmissivity value is taken as 260 m^2/day. The hydraulic gradient determined at the position of the 820 m piezometric line is 8.8×10^{-3}.

Taking an average width (W) of 72.5 km, the application of Darcy's Law yields a total groundwater flow (Q):

$$Q = T.i.W. = 260 \times 8.8 \times 10^{-3} \times (52.5 + 20) \times 10^3$$
$$= 166{,}000\ m^3/day\ (26.4\ l/s/km\ width)$$
$$\text{or}\quad 60 \times 10^6\ m^3\ year$$

As the groundwater flows from recharge to discharge areas, approximately 30,000 m^3/day is discharged in numerous springs (Table 5.1 and Plate 5). The groundwater discharged in the springs is roughly 20% of the total groundwater flow in System IB.

A further loss of groundwater occurs through evaporation along the numerous seepage zones on the right bank of the Ewaso Ngiro River.

Groundwater Quality

From the results of the chemical analyses, the WHO-recommended maximum permissible limit of 1,500 mg/l of TDS in drinking water is exceeded in 2 cases (8%).

The high values of salinity are given by water from wells W3 and W4 at Garba Tula (Appendix 5.3) drilled in local limestone deposits. Well W3 is the water source for Garba Tula water supply whilst W4 belongs to Garba Tula Catholic Mission.

It should be noted that groundwater from System IB has a high level of hardness. Groundwater from this system is of the type ($Na\text{-}HCO_3$) sodium bicarbonate (Figure 5.3).

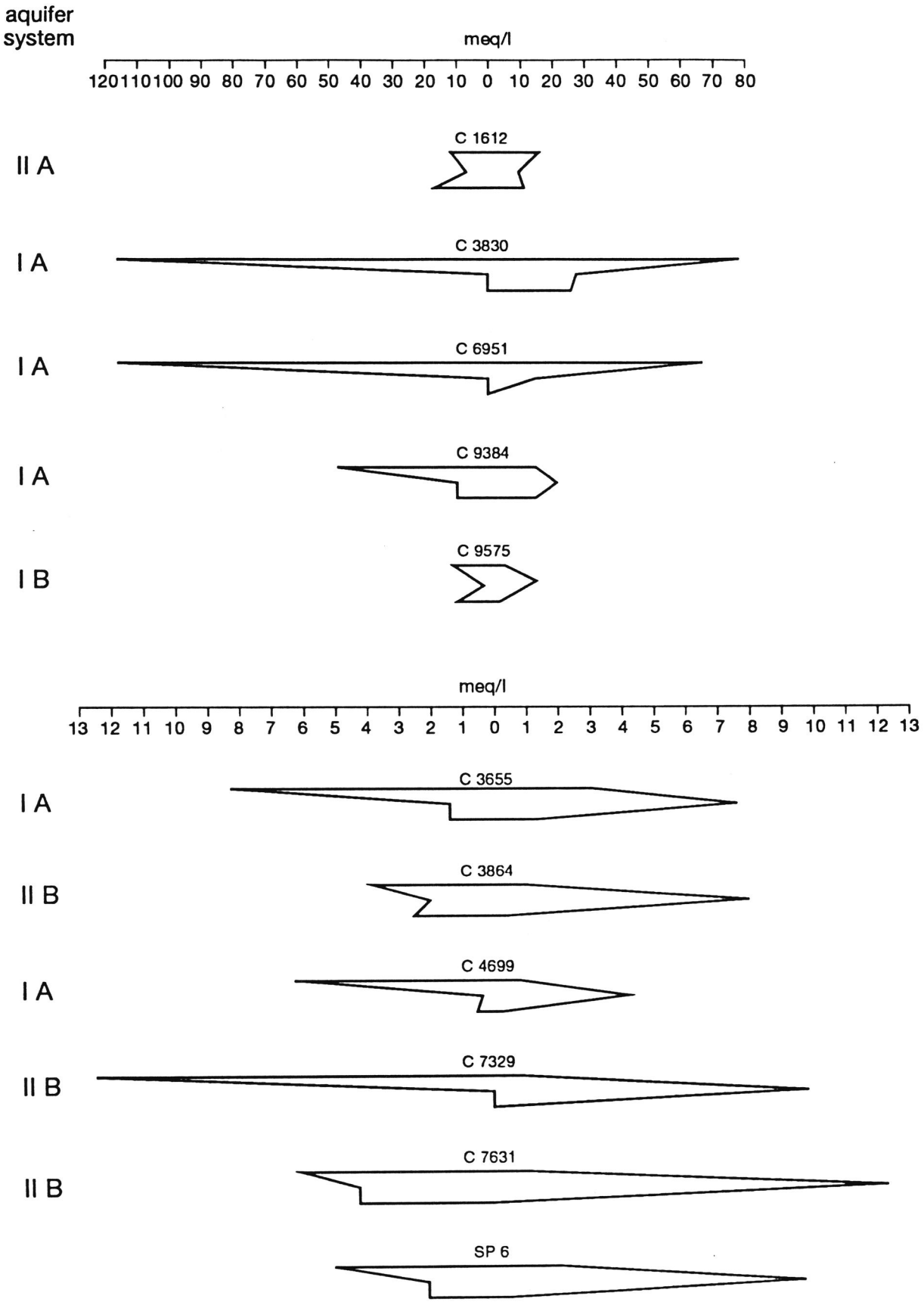


Figure 5.3 Stiff Diagrams of Groundwater Samples from Aquifer Systems IA, IB, IIA and IIB

5.4.4 System IIA - Fissured and Weathered Basement Zones

Isiolo District is wholly underlain by the precambrian Basement System, consisting of metamorphic gneisses and intrusive granitoid rocks. By their nature, these rocks are impervious, i.e. not suitable for the conduction or storage of groundwater.

During several periods of tectonism (crustal movements), however, they underwent severe faulting. Along these faults and their peripheral fracture zones, surface water could penetrate and was stored. Moreover, the Basement rock surface was exposed to weathering, facilitating the infiltration and accumulation of water.

Basement rocks surface in the utmost western part of the District (Oldo Ngiro, Kipsing) and in the central northern and eastern part (see Figure 5.2).

These fissured and weathered rocks contain isolated groundwater pockets. The recharge is either by direct infiltration of rainwater along the fissures, cracks and weathered zones of the metamorphic rocks or by indirect infiltration of the run-off along river courses.

Transmissivity, Specific Capacity and Yield

The transmissivity and specific capacity values have not been estimated due to lack of pumping test data from the 9 boreholes sunk in this system. But according to the data listed in Appendix 5.1, boreholes drilled in System IIA may have yields in the range from 1-20 m^3/h, but are usually below 3 m^3/h.

Groundwater Levels

The difference between the water struck and rest levels indicates that the aquifers are generally confined. The confinement is probably due to the weathering of the Basement System rocks into clayey material which forms an impervious layer above the aquifer.

Groundwater is struck at depths between 20 and 90 metres and measured water rest levels vary from 15.9 to 79.3 metres below ground level (Plates 2A and 2B).

Chemical Composition of Groundwater

The results of the water analysis of the samples taken from C1612 and C6951 indicate very high levels of salinity (2,495 and 6,912 mg/l respectively). The iron concentration is also very high in groundwater around Bulesa (8.8 mg/l).

5.4.5 System IIB - Local Sedimentary Deposits

These local sedimentary deposits can be found scattered all over the District on top of other systems. To this type of aquifer systems belong the fluviatile (river) deposits, the lacustrine (lake) deposits and local deposits of other origin. They have in common that they have limited sizes from a hydrogeology point of view. These systems composed of coarse alluvial deposits (sands, grids and gravels) and/or limestone deposits form perched aquifers isolated from their surroundings by silt and clay layers. The width of the aquifers may be from very small (some metres) to rather large (some kilometres).

Transmissivity, Specific Capacity and Yield

Eleven boreholes have been drilled in the local alluvial systems. A properly tested borehole is C9380 at Merti drilled by the project. According to the data analysis (Appendix 5.1), the transmissivity value calculated from the recovery phase by use of Theis recovery method is 836 m^2/day. At 1 m drawdown this borehole will yield 20 m^3/h. For the other boreholes without test pumping data yield estimates were based on the pump capacity. The measured yields range from 1 to 13.6 m^3/h.

The limestone deposits at Garba Tula yield high amounts of water against very low drawdowns. A limited pump capacity and time constraints did not allow WRAP to test these aquifers extensively, so that the sustainability of the high yields is not knows.

Groundwater Levels

The difference between the water struck and rest levels indicates that these perched aquifers are generally confined.

Groundwater in the alluvial deposits is encountered between 30 and 45 metres deep (Merti Area) and between 18 and 20 metres (Sericho - Habaswein area). The water rest levels are between 11 and 12 metres below ground level.

Chemical Composition of Groundwater

Groundwater samples collected from C3864, C4543, C7325, C7327, C7329 and C9380 indicate that the water is fresh (Appendix 5.3).

Fluoride content ranges between 1.8 and 2 mg/l in the Sericho area while at Merti it is within the WHO-recommended content of 1.5 mg/l in drinking water.

The WHO-recommended TDS of 1,500 mg/l in drinking water is exceeded in one case (Sericho - C7713).

6. WATER RESOURCES DEVELOPMENT POTENTIAL

6.1 Introduction

This chapter provides a concise description of the development potential of the water resources in Isiolo District. Three alternatives have been examined, viz. surface water, groundwater and rainwater.

A rough analysis of the data existing at the beginning of the project already revealed that the potential of these resources in Isiolo District is very limited. The major part of the District has an arid to very arid climate, with low rainfall, very high evaporation and relatively little surface water discharge. The major stream, the Ewaso Ngiro, is shared with neighbouring districts where the water seems to be fully consumed in drought periods. The geological formations in the District have relatively poor water bearing properties, with exception of the Volcanic Areas which cover a relatively small part of the District. Rainfall storage via roof catchment, dams or pans may provide some relief but rainfall is extremely low.

Hence the WRAP assessment study was focused on further analysis of the relatively poor resources, in particular the groundwater resources. In continuation WRAP has also undertaken local pre-feasibility studies to provide a basis for removing some of the most urgent water supply problems of rural centres in the District.

6.2 Surface Water Development Potential

The surface water availability in the District depends on rainfall and is highly variable in time and space. Average annual rainfall varies from 400 - 640 mm around Isiolo Town, to 300 - 350 mm in the areas around Barsalinga, Archer's Post and Garba Tula, and to 150 - 250 mm in the eastern and northern parts of the District (Figure 4.3).

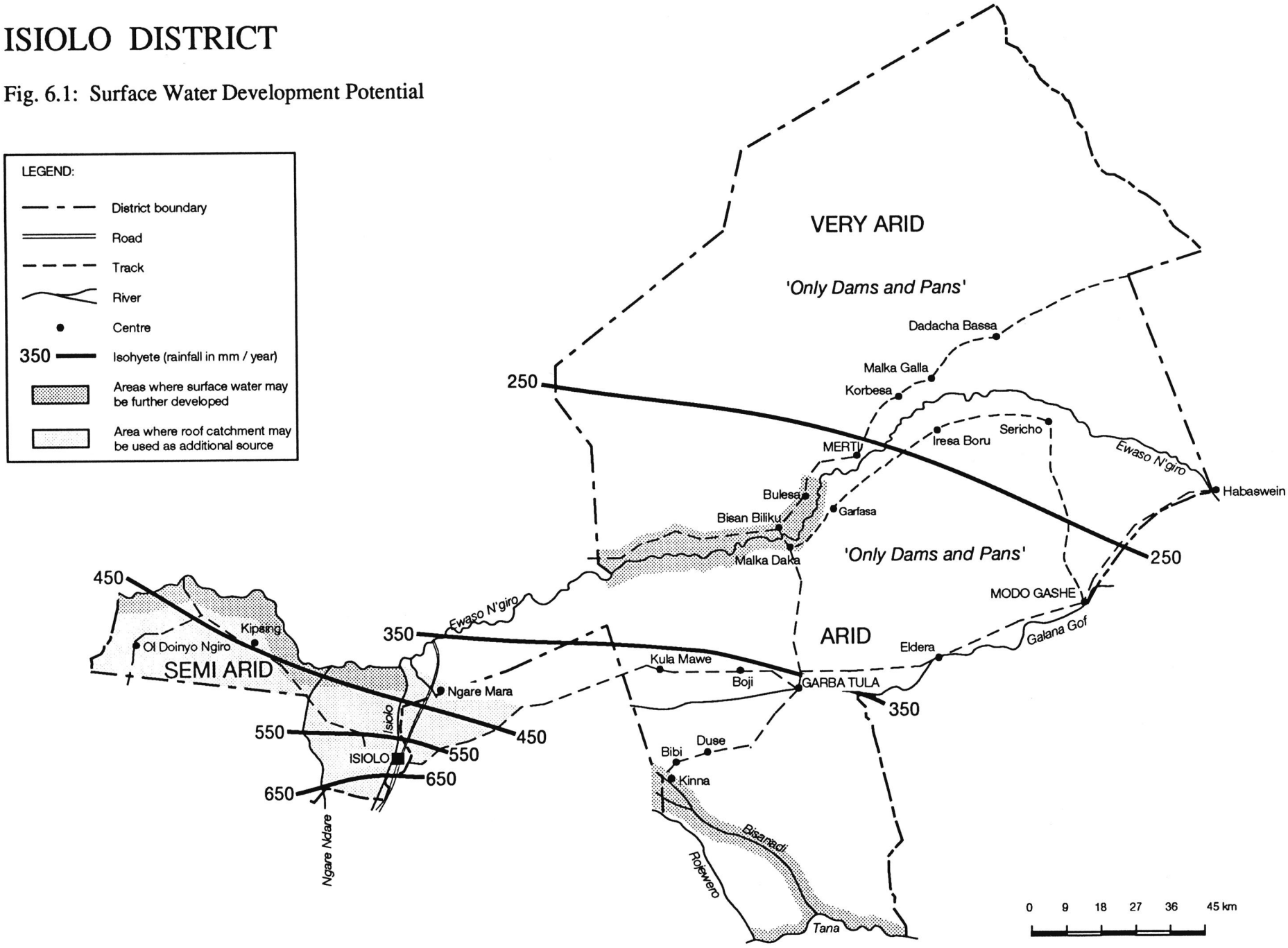
In Isiolo District rainfall occurs in two distinct seasons with two peaks in April and November. The two seasons contribute about 80 - 95% of the total annual rainfall.

Surface water from the main rivers in Isiolo District is already extensively used for domestic water supply and irrigation. Further development possibilities are limited but could be improved through regional water management supported by monitoring. Lack of data, especially of the intermittent streams, makes it difficult to assess their development potential in more detail. The discharges estimated on the basis of the few discharge measurements indicate that the streamflow of some big streams could be used more optimally, but more exact data would be needed to prove that this is true. Considering the high evaporation rates storage of water in river banks should be preferred above open storage behind dams or in pans, but the short flow durations usually do not allow this.

A more definite answer on the possibilities and the feasibility of alternative solutions requires further detailed studies. Also minimum discharges required to avoid pollution of the river beds should then be considered. Such detailed studies were beyond the scope of WRAP. Conclusions as regards the surface water development potential of the rivers should, therefore, be considered preliminary.

ISIOLO DISTRICT

Fig. 6.1: Surface Water Development Potential



Ewaso Ngiro River

The main perennial river in the District is the Ewaso Ngiro. The river originates in the Aberdare Mountains and the north-western slopes of Mount Kenya and is perennial until Bulesa, except in drought years (see Figure 6.1 and Plate 2).

The mean annual flow of the Ewaso Ngiro at Archer's Post amounts to about 630 million m^3 with a minimum of 163 million m^3 recorded in 1952 and a maximum of 2,780 million m^3 recorded in 1961. The low flows of the river have gradually decreased due to an increase of water use in Laikipia District. In 1985 and 1986 the Ewaso Ngiro dried up in a reach of about 50 km upstream of Archer's Post, clearly showing the limitations for further development potential.

The use of the Ewaso Ngiro upstream in Laikipia District affects the development possibilities of this river for Isiolo District. For domestic supply purposes the river is not a reliable source. For irrigation further development is possible by using the flood water. However, due to the high flood levels and changes in the course of the river, siting of surface water intakes is very critical and very expensive structures are required.

Isiolo River

Isiolo River originating from Mount Kenya is the source of water for Isiolo Town. The mean annual flow of the Isiolo river at R.G.S. 5D8 amounts to 6 million m^3 (16,400 m^3/day) with a recorded minimum of 950,000 m^3 in 1987 and a recorded maximum of 110 million m^3 in 1971.

The Isiolo River provides domestic water for Isiolo Town at approximately 2,000 m^3/day. Irrigation at present uses about 8,000 m^3/day and because the flows during the dry season are already very much reduced, the possibilities for more irrigation are limited.

Ngara Ndara River

For the short period of the study (March 1989 - September 1990) the Ngara Ndare river was observed to have a lowest flow of 8,000 m^3/day, a highest flow of 50,000 m^3/day and an annual average flow of 5 million m^3 (14,000 m^3/day).

The water use along this river is not known and therefore more detailed information is needed to determine it's development potential.

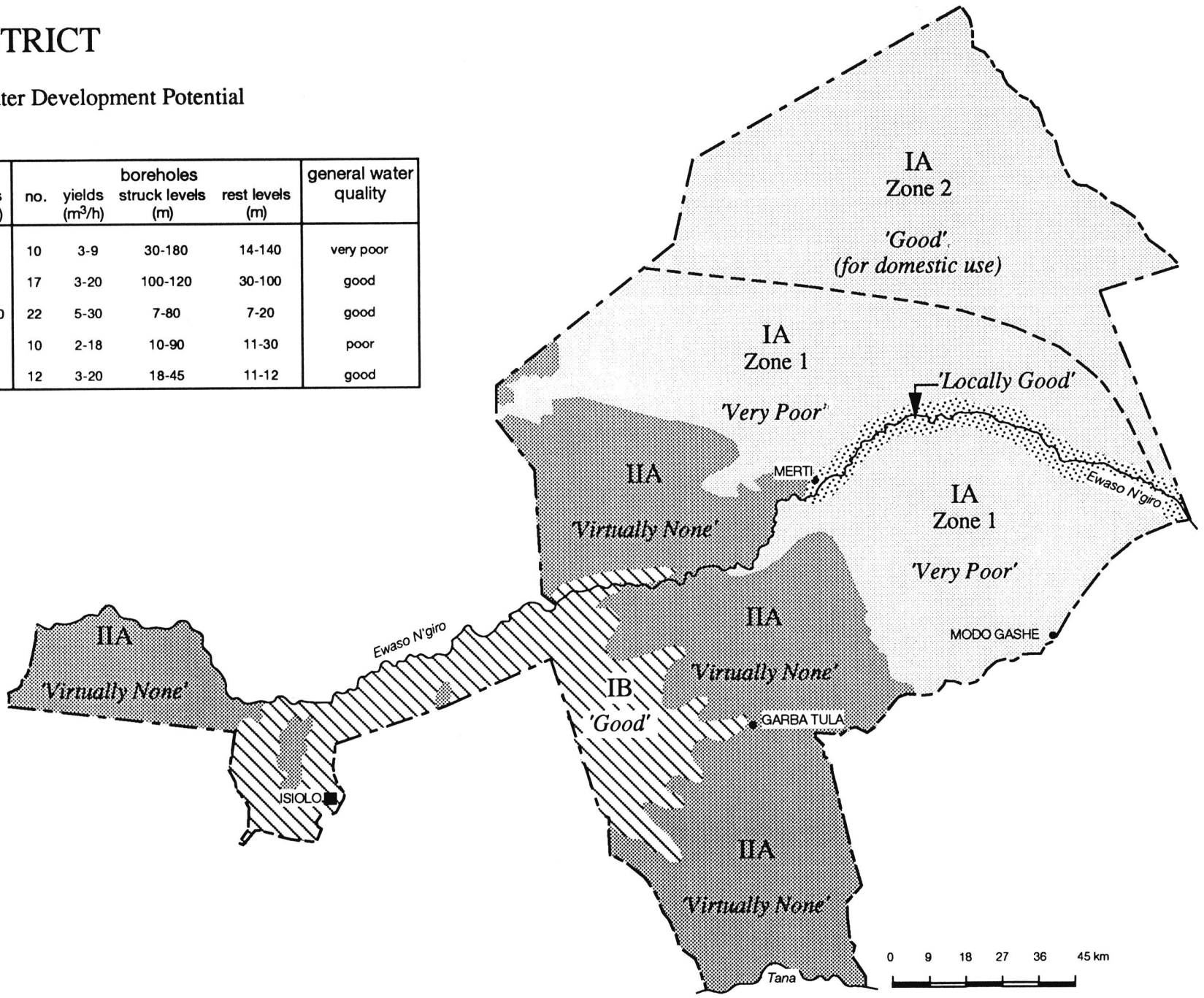
Ngara Mara River

For Ngare Mara only miscellaneous current meter gaugings are available. The lowest and highest discharge measured was 2,300 and 24,000 m^3/day respectively. The average flow is about is 12,000 m^3/day of which around 80% is used for irrigation. Further development is not recommended, also because the river is dry nowadays during part of the year.

ISIOLO DISTRICT

Fig. 6.2: Groundwater Development Potential

aquifer system	springs no.	springs yields (m^3/h)	boreholes no.	boreholes yields (m^3/h)	boreholes struck levels (m)	boreholes rest levels (m)	general water quality
IA-zone 1	---	---	10	3-9	30-180	14-140	very poor
IA-zone 2	---	---	17	3-20	100-120	30-100	good
IB	23	3-360	22	5-30	7-80	7-20	good
IIA	1	2	10	2-18	10-90	11-30	poor
IIB	---	---	12	3-20	18-45	11-12	good



Bisanadi and Kinna Rivers

The Bisanadi and Kinna Rivers originate from the Nyambeni Range and drain to Tana River in the south of the District. These rivers are used for irrigation in the Kinna and Rapsu irrigation schemes. Their development potential has not been assessed due to lack of data.

Laggas

Laggas flow intermittently during the rainy seasons, usually only for very short periods. The lagga flow can reach large volumes, due to high rainfall intensities and small storage capacities of the catchments. It is estimated that they contribute about 50% of the total flood flow in the area.

The laggas can be developed for temporary storage by construction of earth dams and pans. The feasibility of subsurface dams should be investigated.

6.3 Groundwater Development Potential

The description of the groundwater development potential in Isiolo District follows the classification of the aquifer types as described in Chapter 5.4. The distribution of the different aquifer systems coincides with the geological formations surfacing in the District as shown in Figure 5.2 and Plates 1A and 1B. The regional aquifer systems occupy large areas of the District and as such can be shown on the maps (Plates 2A and 2B).

The local aquifer systems occupy areas too small to be shown individually on the maps. The weathered and/or fissured pockets of Basement Rocks (system IIA) can be found within the Basement Area boundaries. The fluviatile and lacustrine deposits (system IIB) are scattered all over the District, except for the sediments along the Ewaso Ngiro River.

The overall picture is that the groundwater development potential in the District is limited because of lack of good aquifers, and the presence of saline water in large parts of the District (Figure 6.2). The volcanic areas covering roughly 10% of the District form a positive exception.

Recharge conditions are especially critical for the potential of isolated local aquifers. The sustainability of the often considerable yields should be the subject of more detailed studies.

System IA - Area of Tertiary Marine Sediments

The northern zone of this area (Zone 2) offers a good groundwater development potential for domestic use.

The groundwater in the area is generally of a good quality (less than 150 mg/l TDS) except for the area around Boji - Hadado - Diri where the salinity of the water is higher.

Groundwater aquifers are expected at depths ranging from 100 to 120 m on average and groundwater levels may vary from 30 to 100 m. For more detailed information the maps should be seen. WRAP experience shows that borehole yields may range from 3 to 20 m^3 per hour.

The total groundwater flow in the area is in the order of 2.4 x 10^6 m^3/year (6640 m^3/day). If 30% of this amount is taken as a safe yield for a first phase of development then about 2,000 m^3/day can be withdrawn. This means that 100 wells with a daily production of 20 m^3 could be installed in this zone.

The southern zone of this area (Zone 1) offers no good chances for groundwater development as the groundwater is highly mineralized.

System IB - Volcanic Rock Area

The volcanic rock area offers a good groundwater development potential.

The groundwater may be found at the surface (near springs) to depths less than 70 m below the surface. In most cases groundwater levels are less than 20 m deep.

The groundwater quality is generally good.

The yield of the inventoried wells varies from 2 m^3/h to over 30 m^3/h with an average of about 10 m^3/h.

The total groundwater flow in the area amounts to an estimated 60 x 10^6 m^3/year (roughly 166,000 m^3/day). Assuming that the average recharge is of the same magnitude and taking 30% of the recharge as a safe yield for withdrawal, then 50,000 m^3/day can be gradually developed. This means that a large number of wells can be drilled at suitable, well distributed, locations.

System IIA - Weathered and Fissured Basement Zones

The Basement areas in Isiolo District offer limited possibilities for groundwater development. The weathered and fissured zones are usually small and thin and the groundwater in these zones is mainly saline. Borehole yields are seldom higher than 3 m^3/h but usually even lower.

As a result the groundwater potential in these areas may be sufficient to permit a minimum level of living but does not support any substantial development of the areas.

System IIB - Local Sedimentary Deposits

Important alluvial aquifers are those along the Ewaso Ngiro. Many of these aquifers have a limited extent and depth. Despite their limited sizes these aquifers may offer substantial amounts of water for the dry seasons. Borehole yields of up to 15 m^3/h are possible. The water quality is acceptable for human consumption.

The limestone deposits at Garba Tula hydrogeologically have been classified as local aquifers. Such aquifers may yield significant amounts of water at very low drawdowns.

The sustainability of the yields depends on the recharge of the aquifers which can be determined only through local studies. The water quality is usually very good. These systems are rather vulnerable to contamination due to lack of a protecting toplayer.

6.4 Rainwater Development Potential

Rainwater may be used as additional source for domestic water by using roof catchments. However, due to low frequency and quantity, rainwater can not be relied upon as the only source for domestic water supply in Isiolo District. The situation is a little better for the area around Isiolo Town where annual rainfall exceeds 400 mm/year.

Rock catchments have limited potential in Isiolo District due to the small number of rock outcrops with suitable surfaces.

The storage of rainwater in dams and pans has already proved a feasible solution especially for the supply of livestock. The development potential of these structures has not been studied in detail by WRAP as this is already covered by other projects in the District.

6.5 Conclusion

The development potential of water resources in Isiolo District is rather marginal.

The perennial surface water resources have already been exploited to a considerable extent. Floodflow of the rivers could be used more optimally by constructing dams or intakes. But the feasibility of such solutions requires more detailed studies taking into account that the costs of the required structures will be very high.

The groundwater development potential is equally limited and does not support extensive development programmes with exception of the groundwater resources in the Volcanic areas that might be exploited more intensively. However, these areas only cover an estimated 10% of the District.

The collection of rainwater in dams and pans provides an important source of water for livestock, but rainwater serves only as an additional source for domestic use.

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APPENDIX 3

GEOPHYSICAL SURVEYS

APPENDIX 3

GEOPHYSICAL SURVEYS

3.1 Bisan Biliko

3.2 Bibi

3.3 Kinna

3.4 Kula Mawe

3.5 Bulesa

3.6 Merti Aquifer - Regional Study

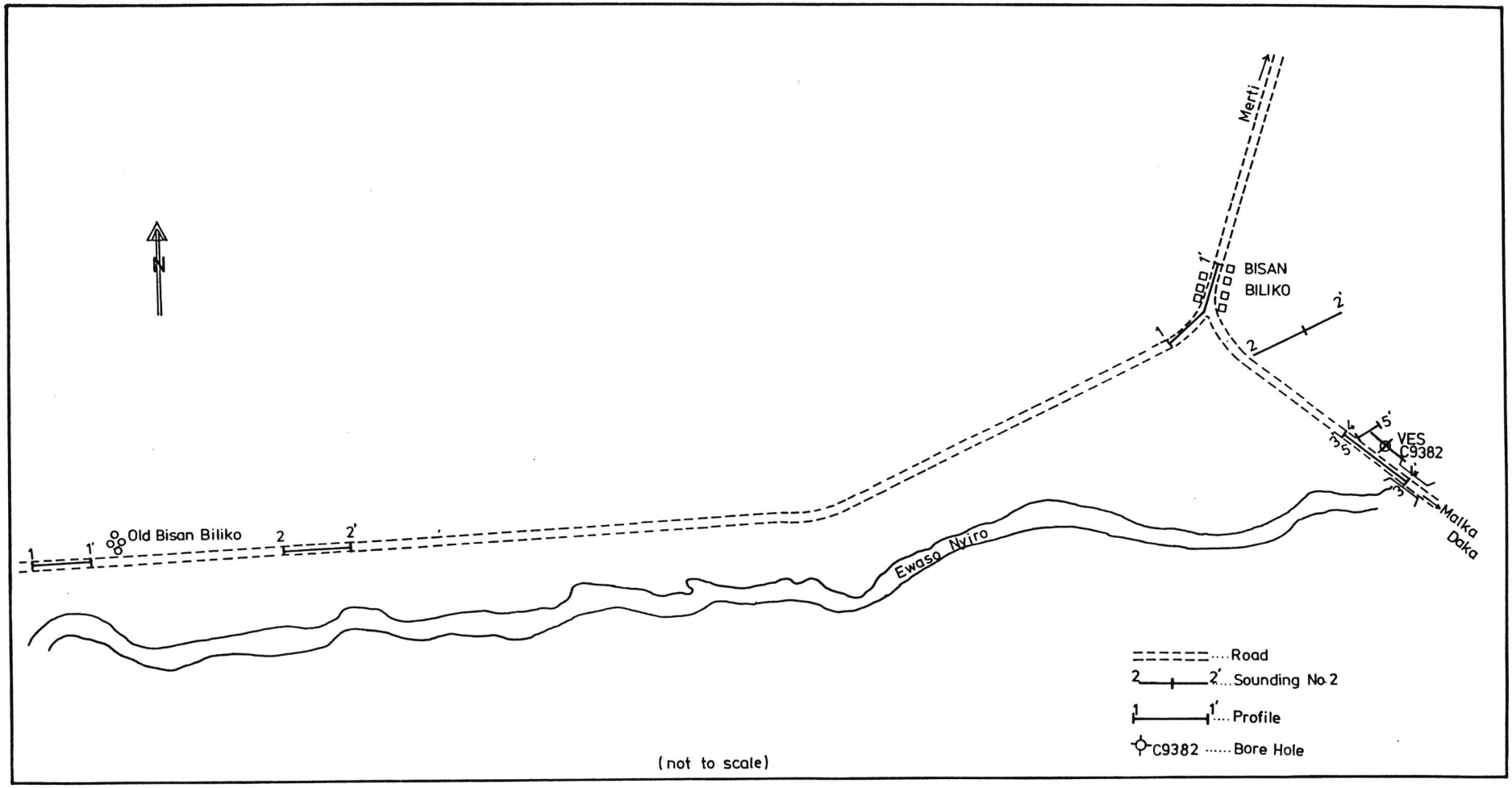
3.7 Garba Tula

3.8 Duse

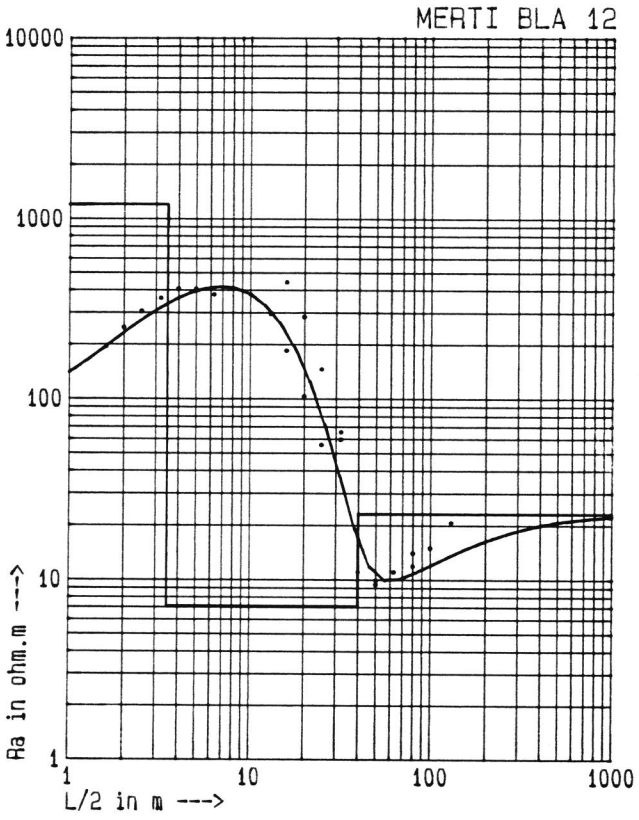
3.9 Boji

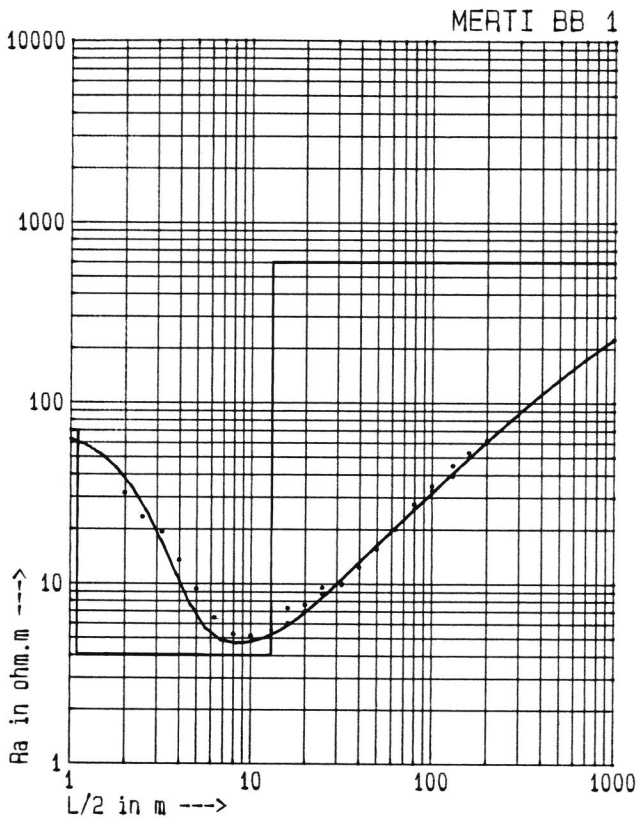
Appendix 3.1

Bisan Biliko



Appendix 3.1.1





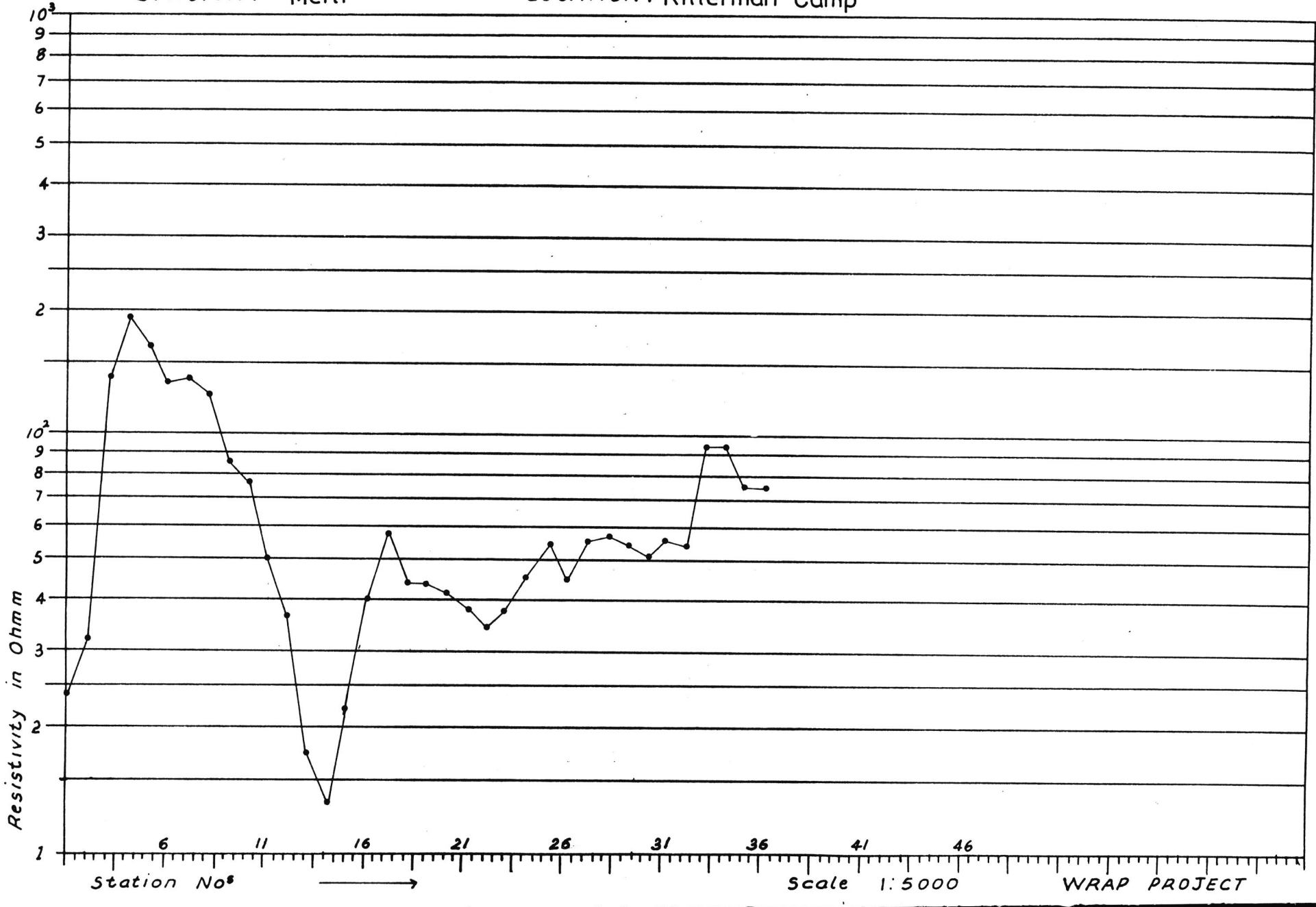
Appendix 3.1.2

Appendix 3.1.3

DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION: Kitterman Camp

EM - Profile No: 1-1

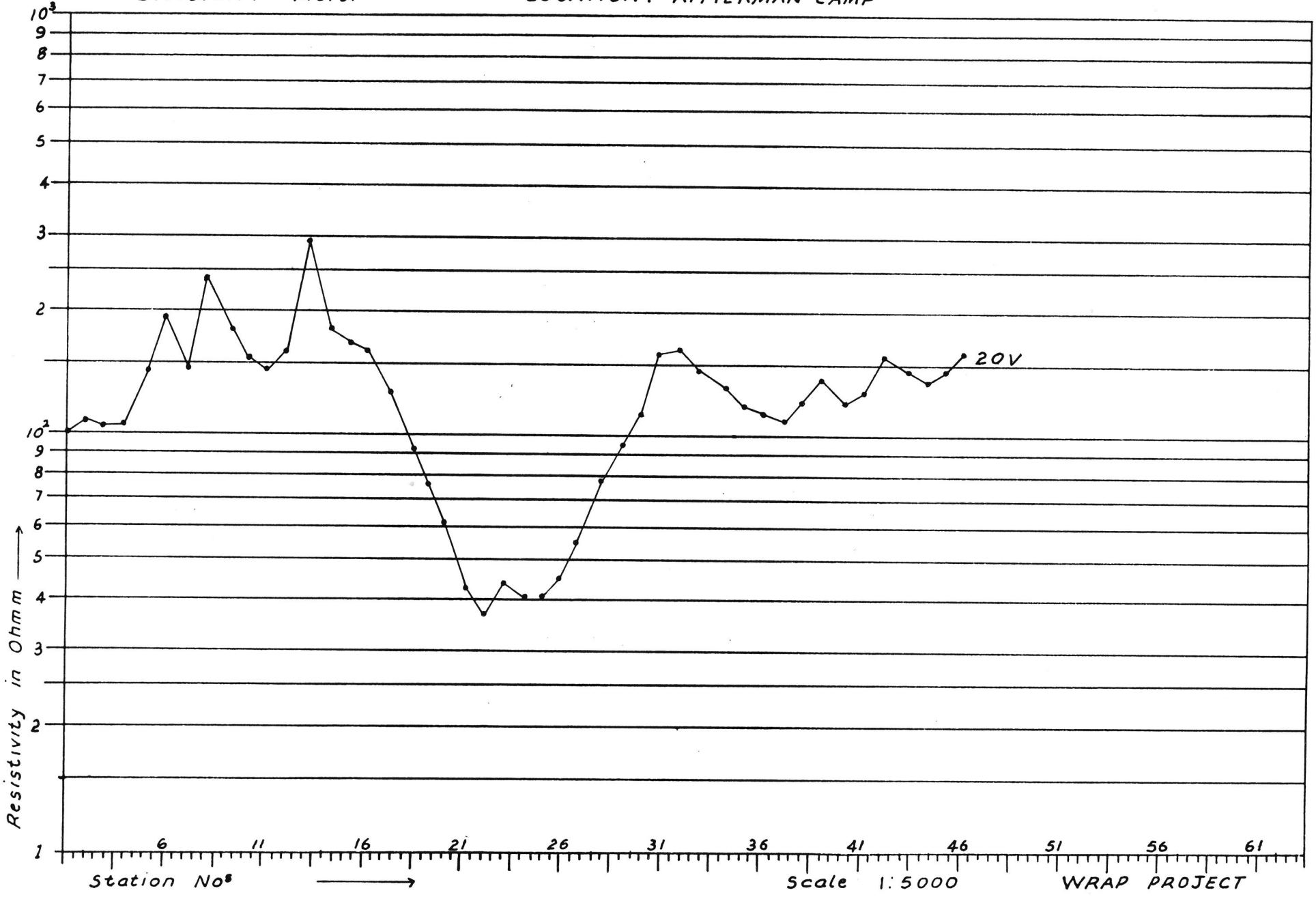


Appendix 3.1.4

DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION :- KITTERMAN CAMP

EM - Profile No: 2-2'

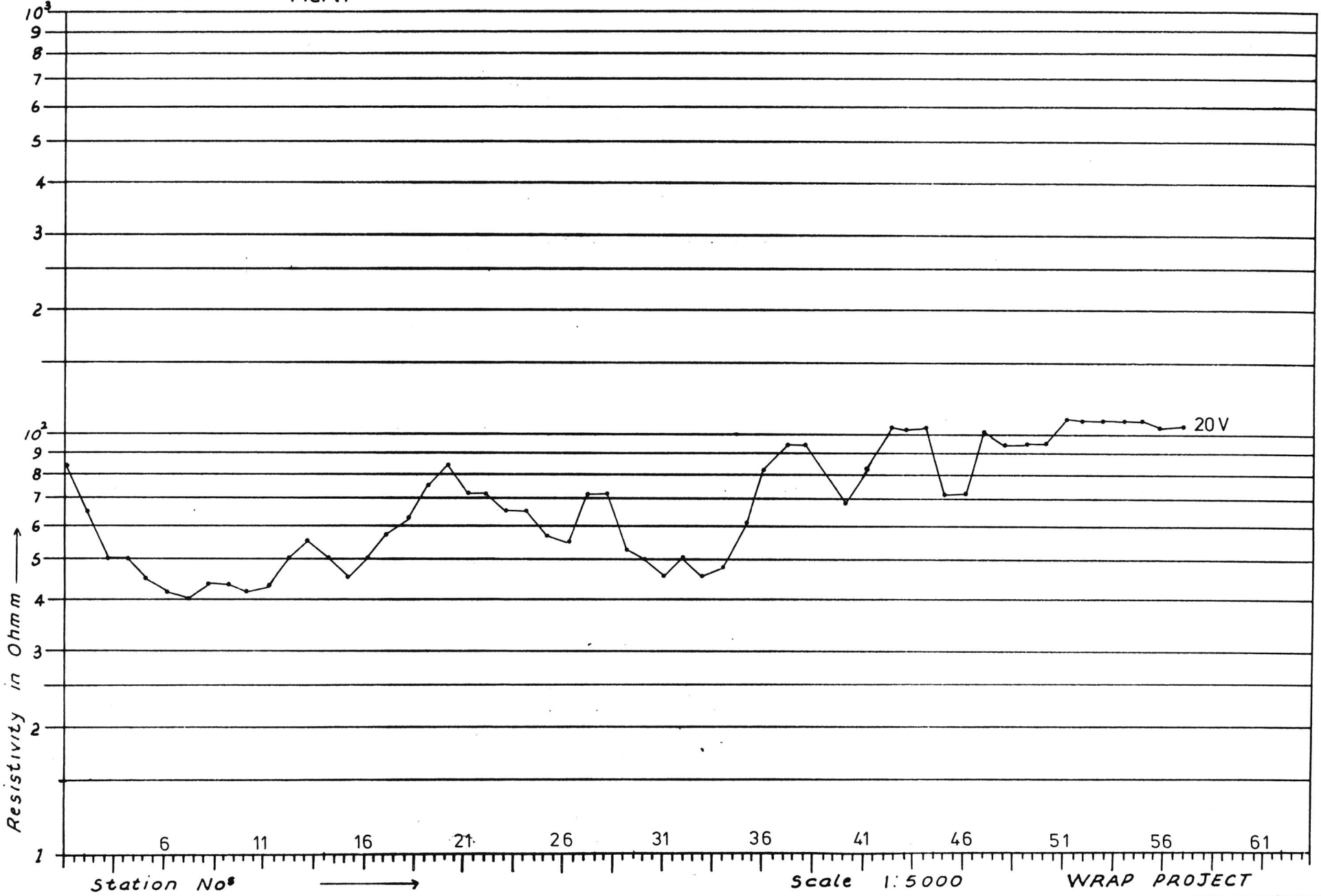


Appendix 3.1.5

DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION: Bisan Biliko

EM - Profile No: 1 - 1'

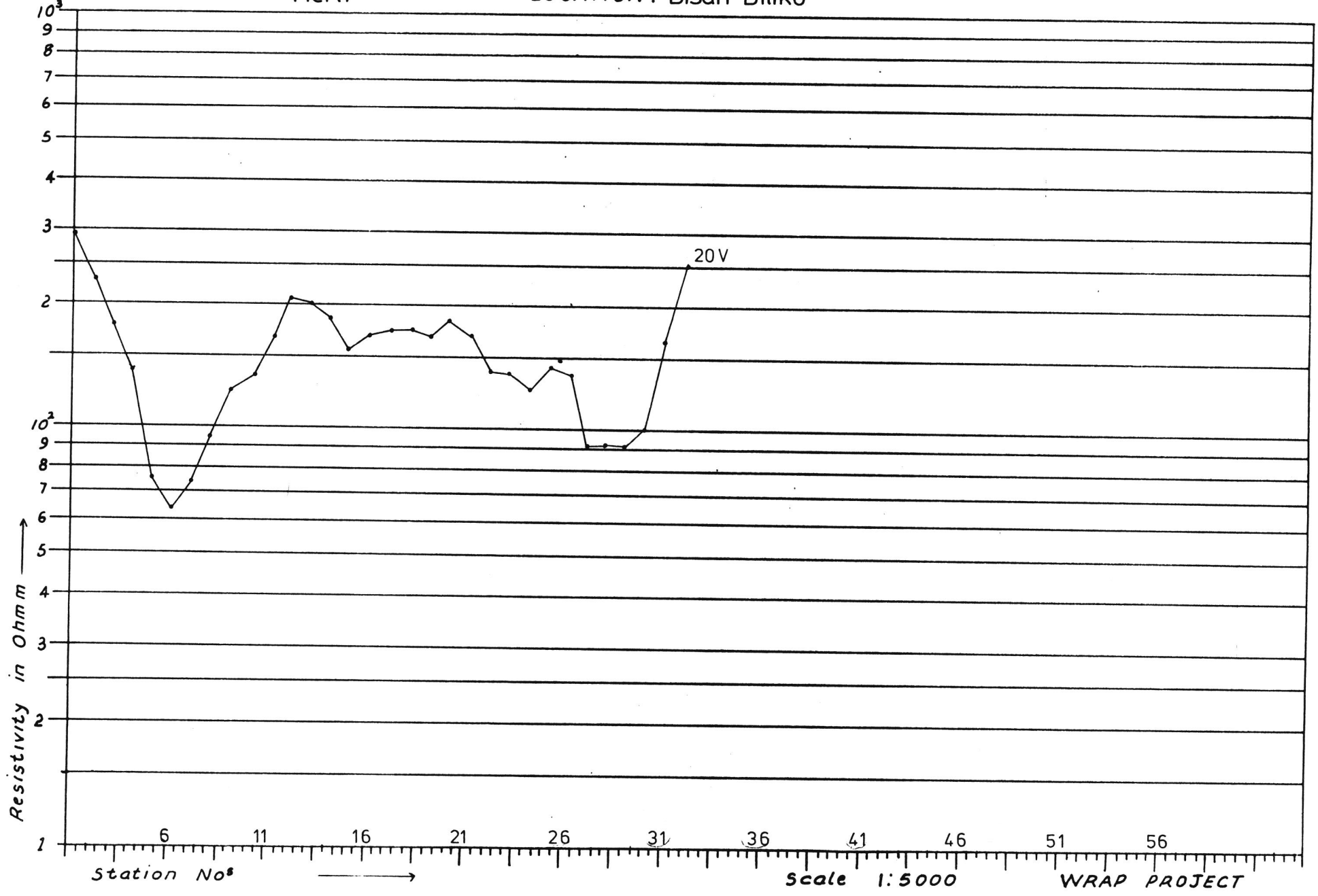


Appendix 3.1.6

DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION: Bisan Biliko

EM - Profile No: 2 - 2'

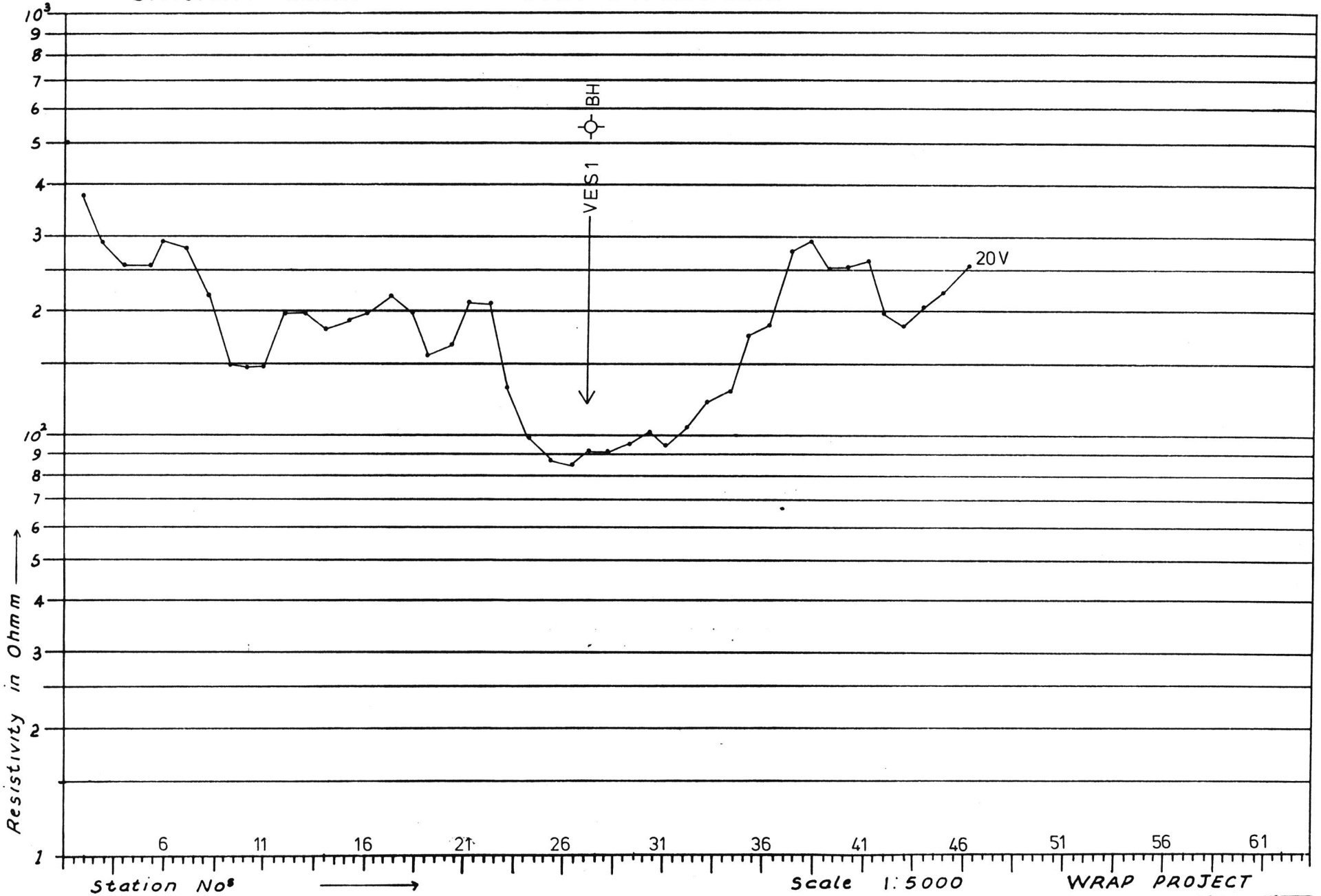


Appendix 3.1.7

DISTRICT :- Isiolo
DIVISION :- MERTI

LOCATION: BISAN BILIKO

EM - Profile No: 3 - 3'

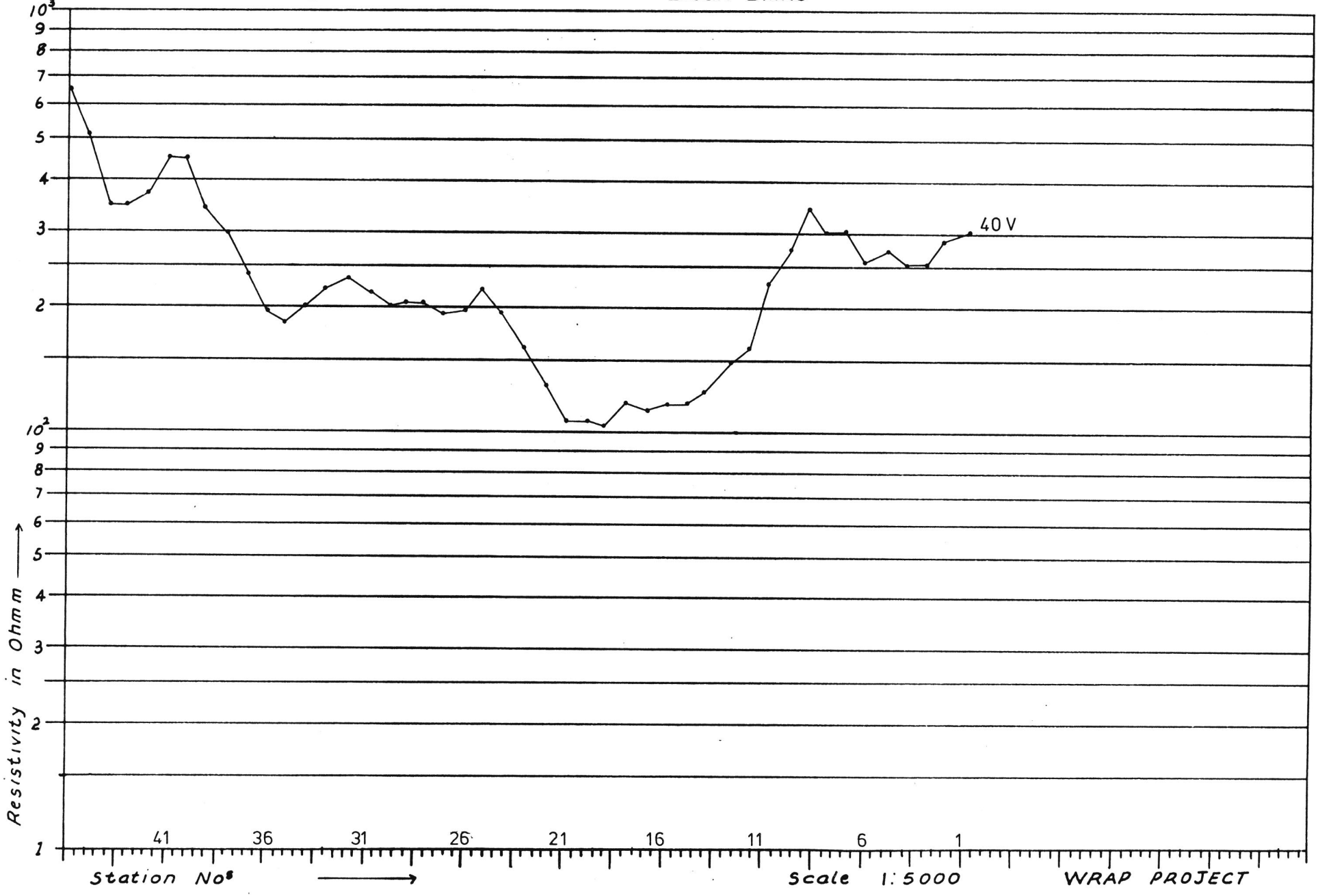


Appendix 3.1.8

DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION: Bisan Biliko

EM - Profile No: 4-4'

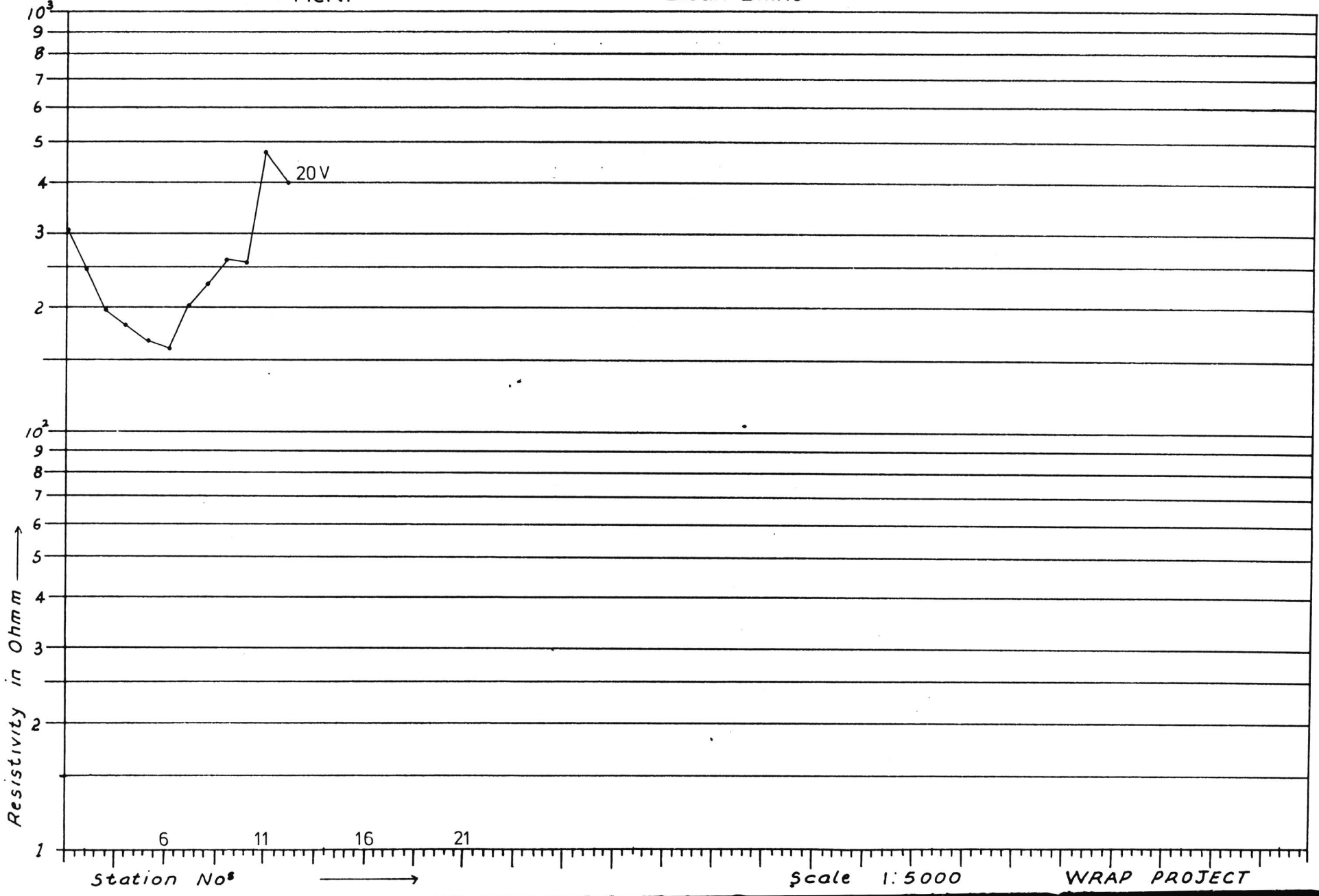


Appendix 3.1.9

DISTRICT :- Isiolo
DIVISION :- Merti

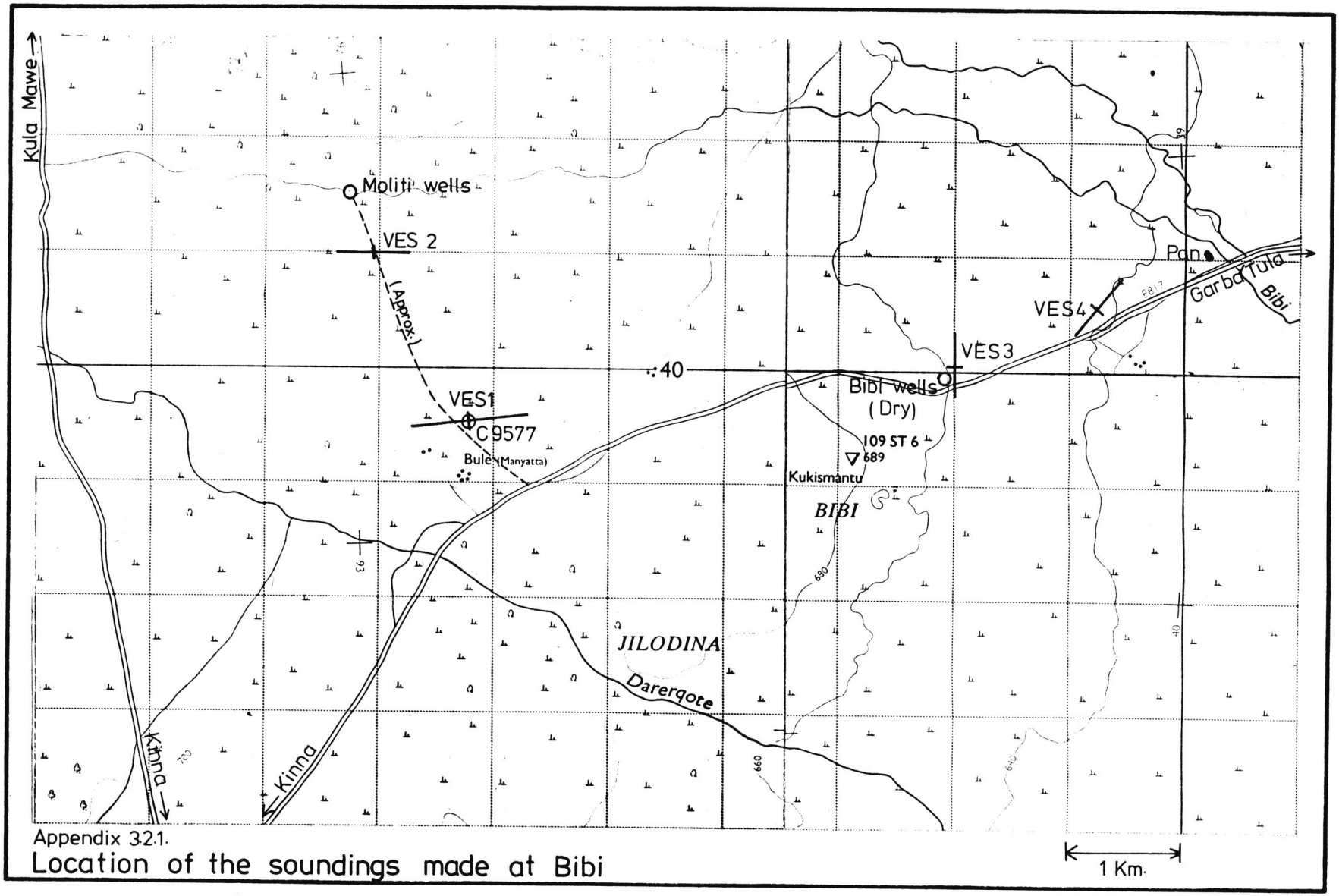
LOCATION: Bisan Biliko

EM - Profile No: 5 - 5'



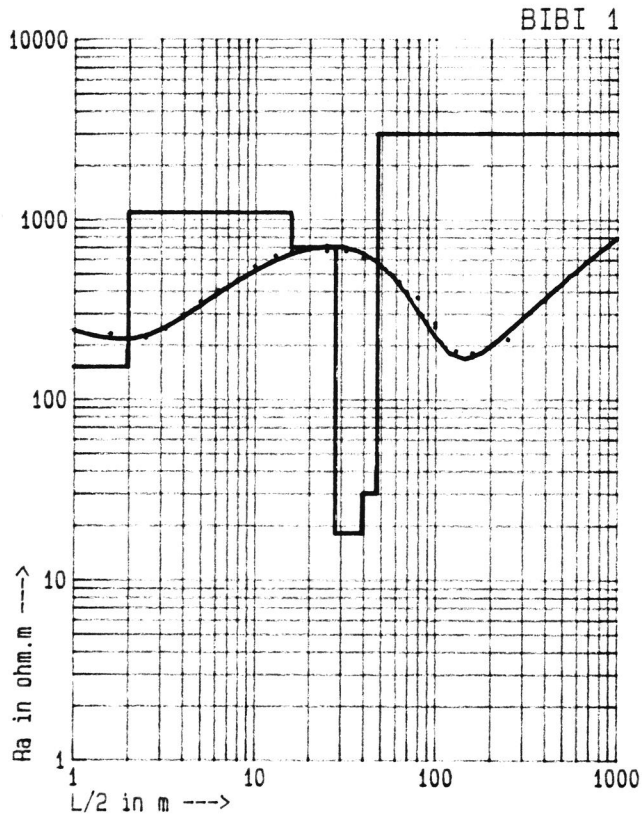
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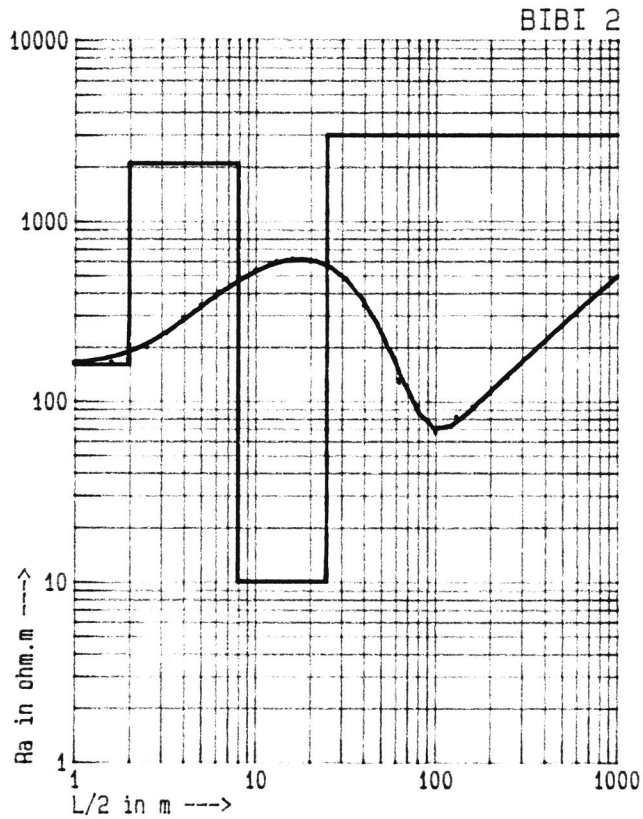
Bibi

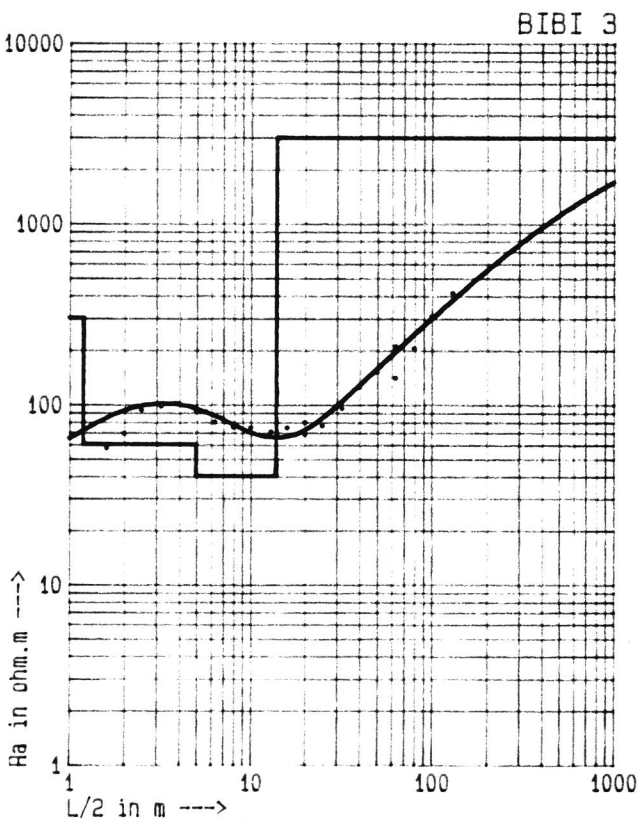


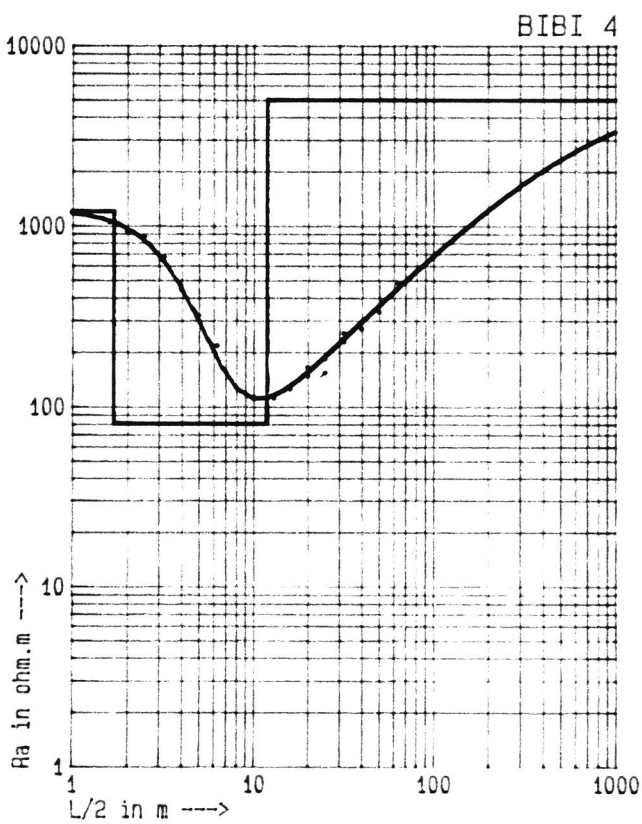
Appendix 3.2.1.

Location of the soundings made at Bibi





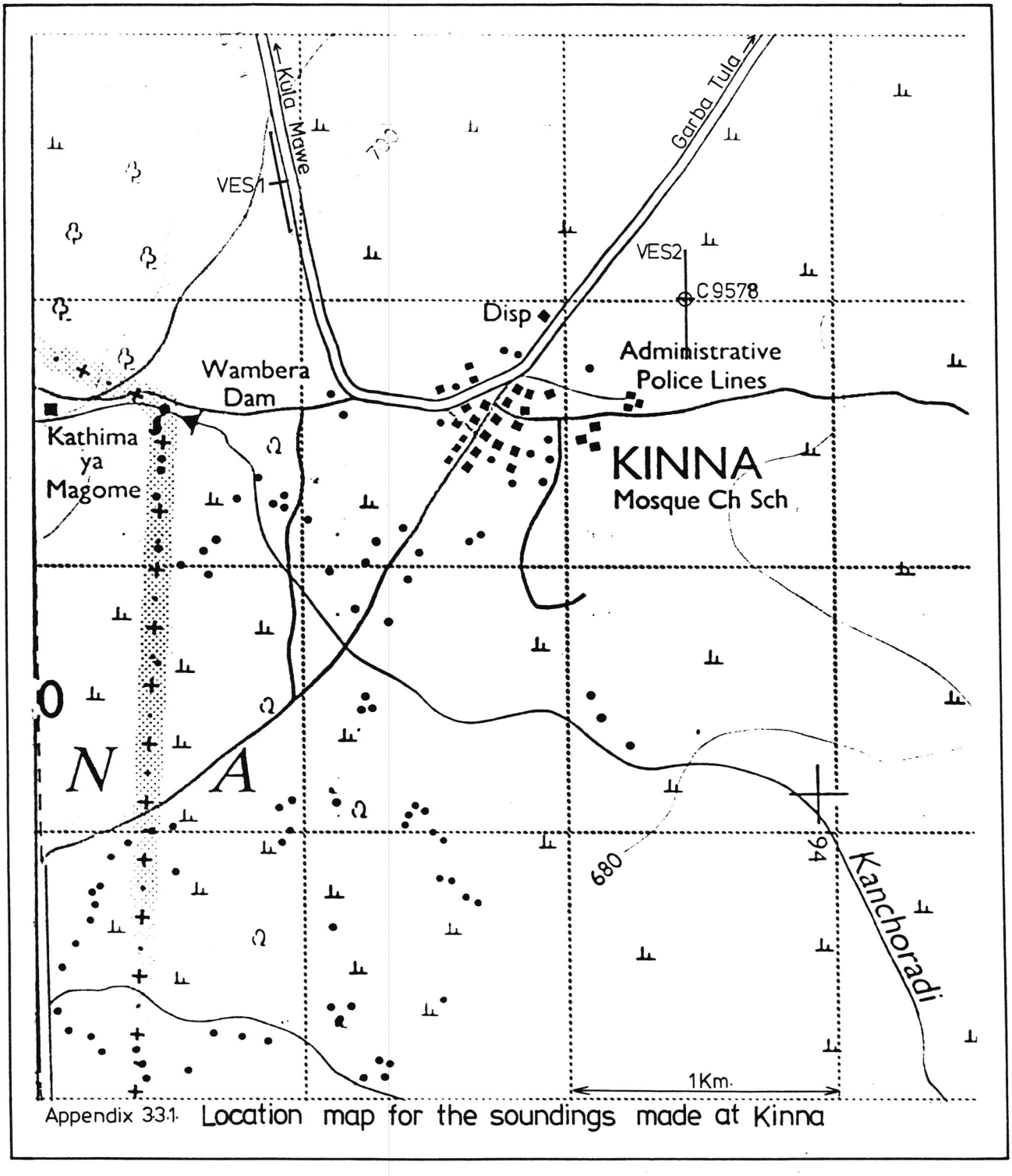




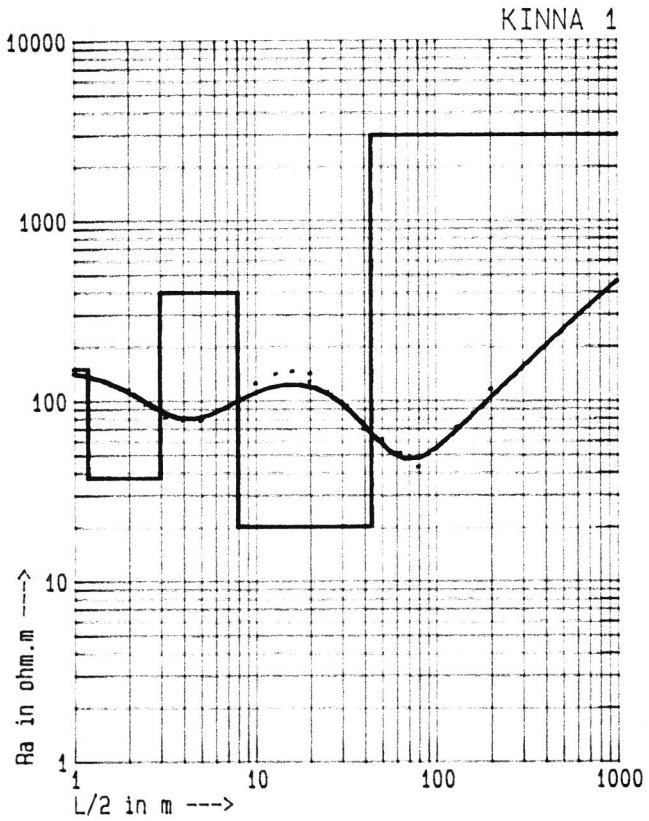
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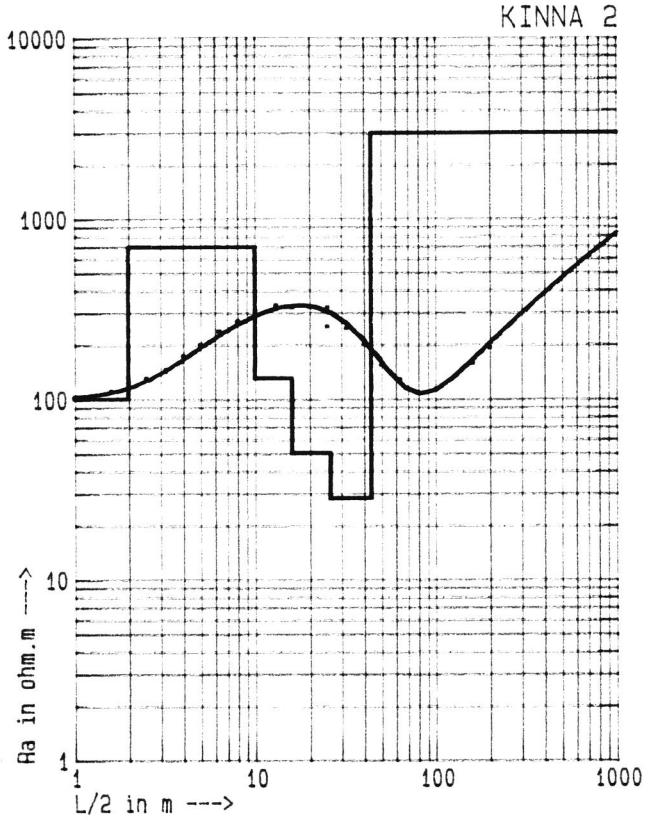
Appendix 3.3

Kinna



Appendix 33.1. Location map for the soundings made at Kinna





Appendix 3.3.2

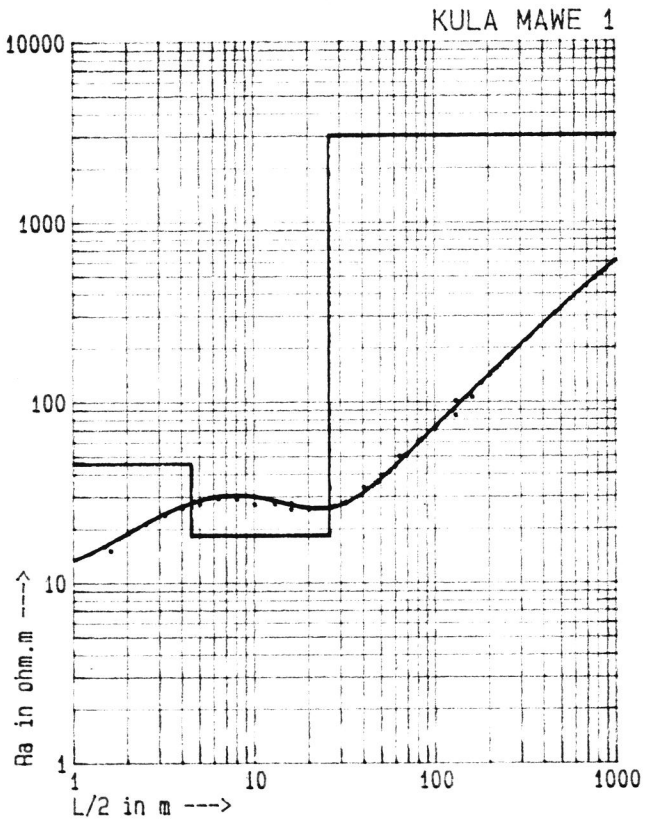
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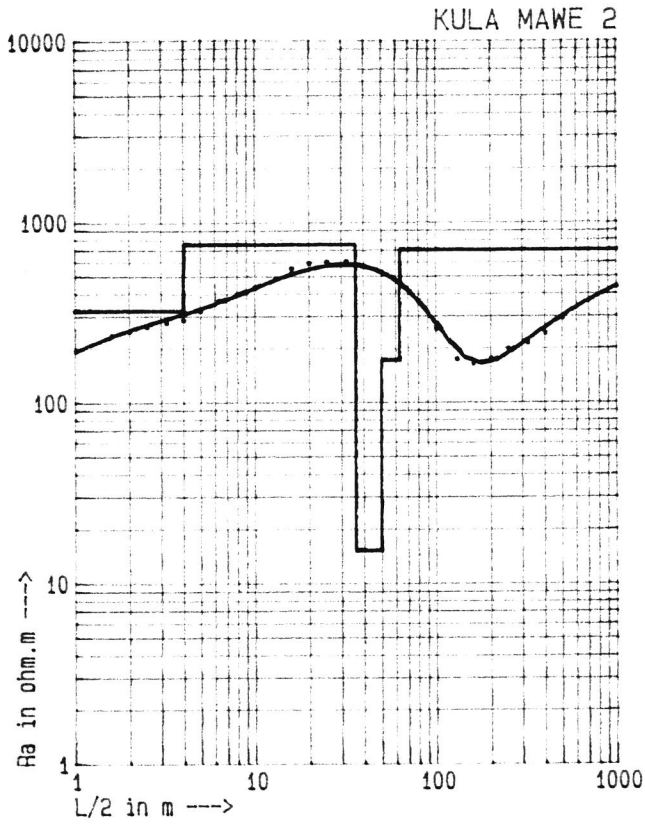
Kula Mawe



Appendix 3·4.1

Location of the sites of the soundings made at Kula Mawe

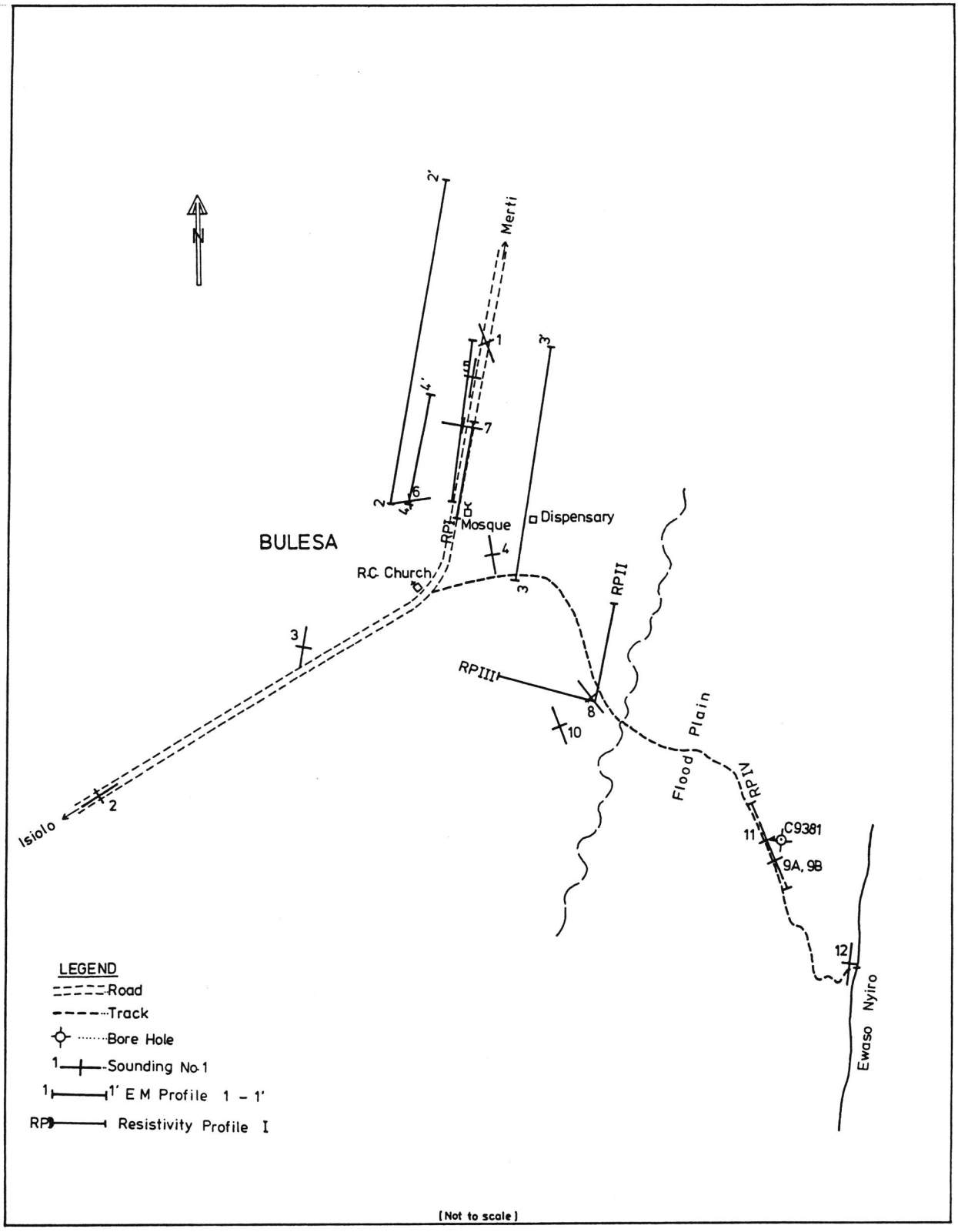




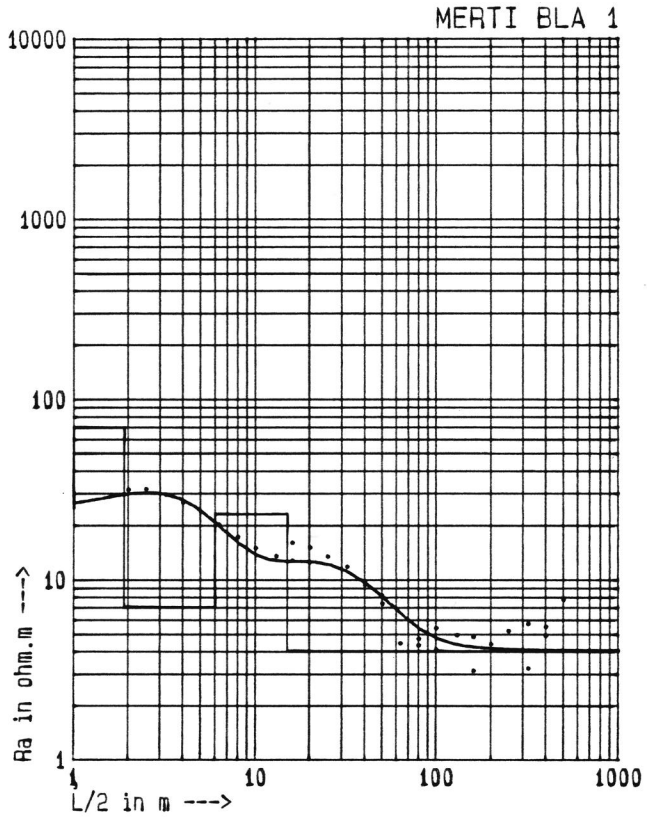
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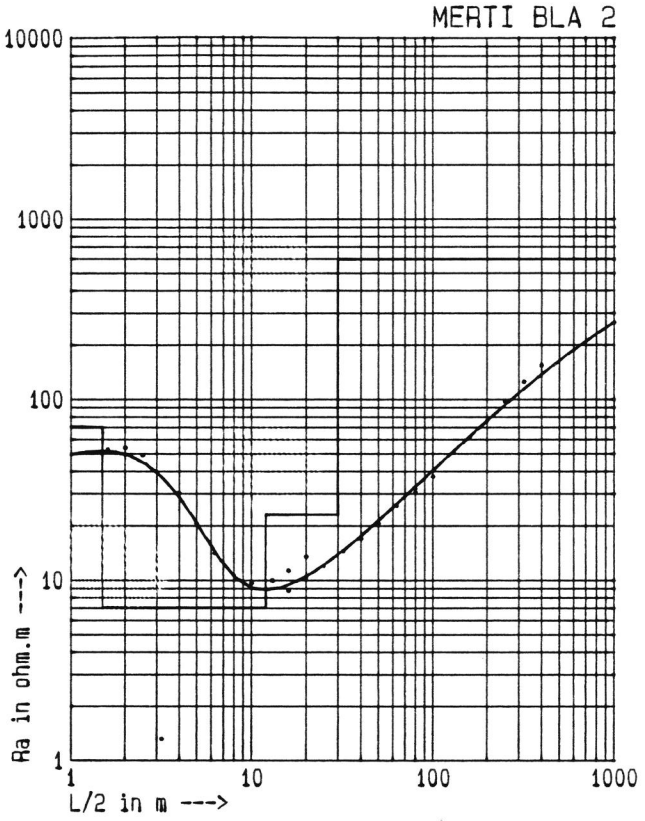
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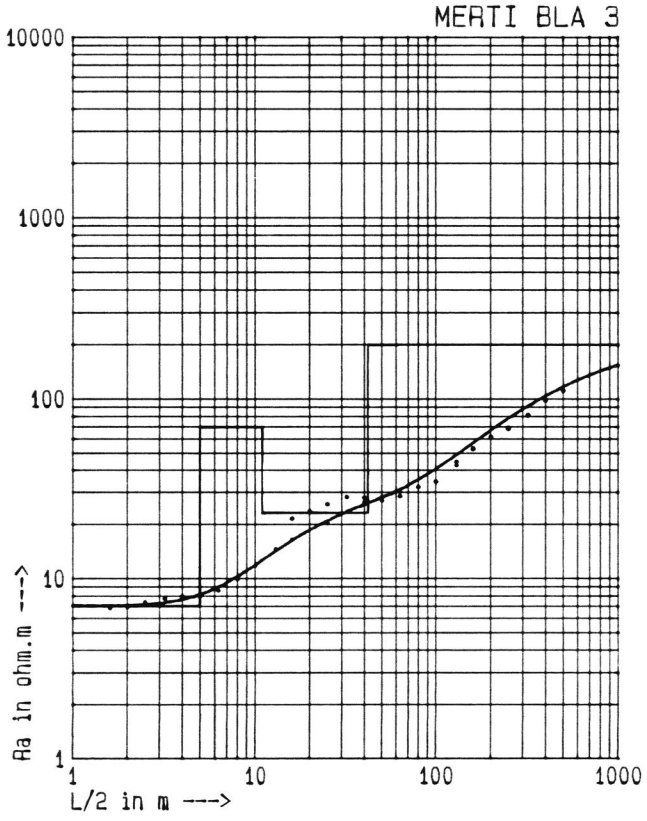
Bulesa

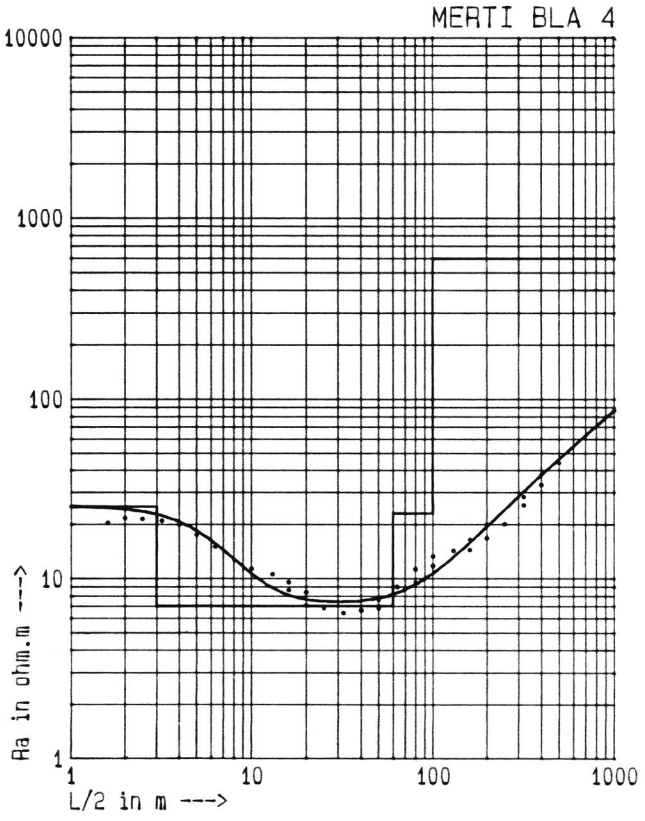


Appendix 3.5.1

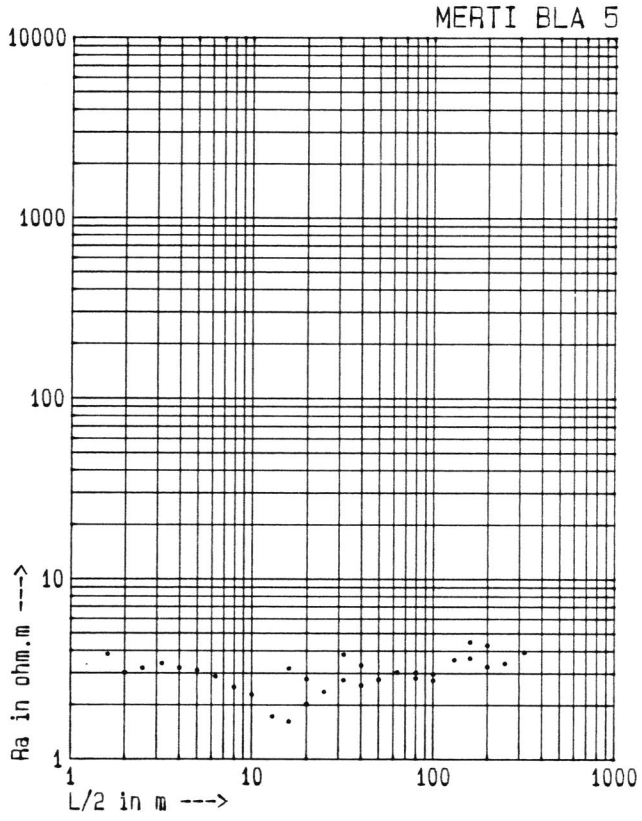


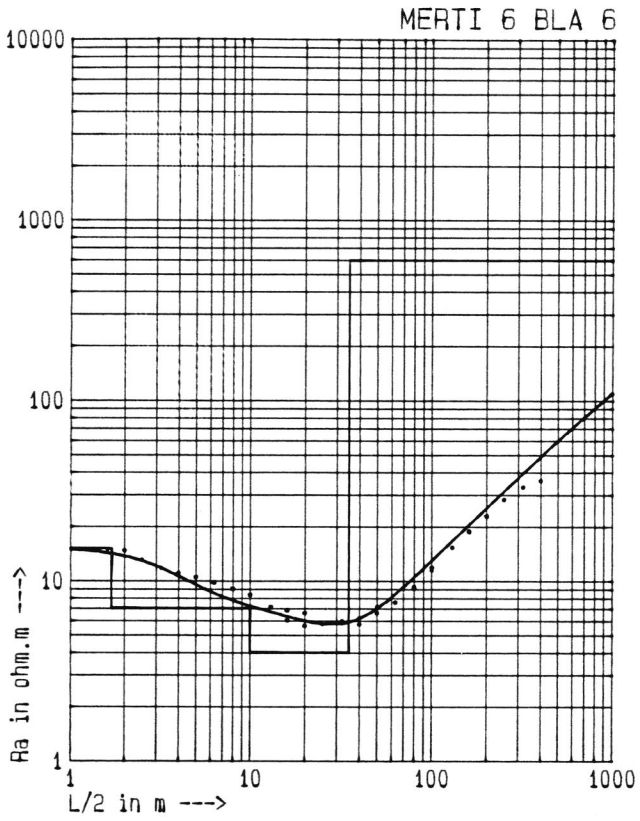


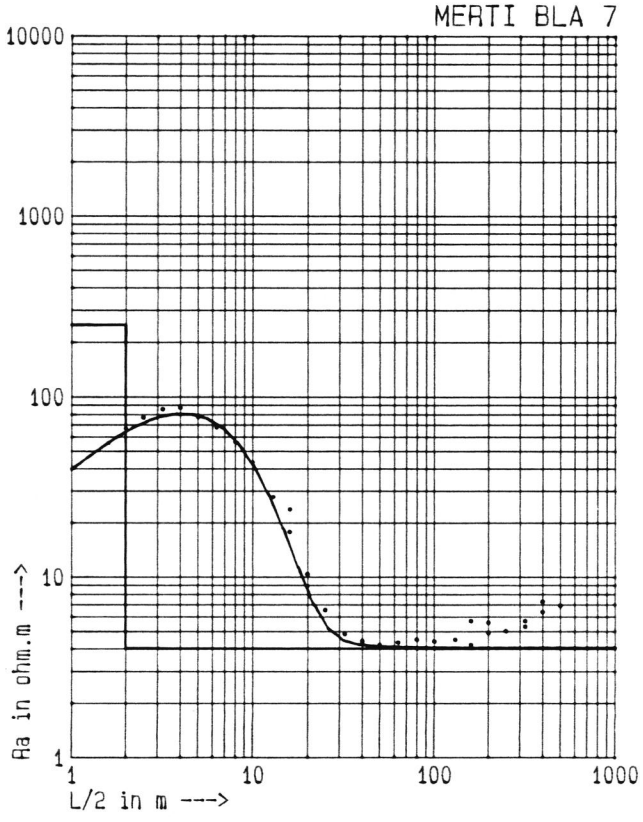


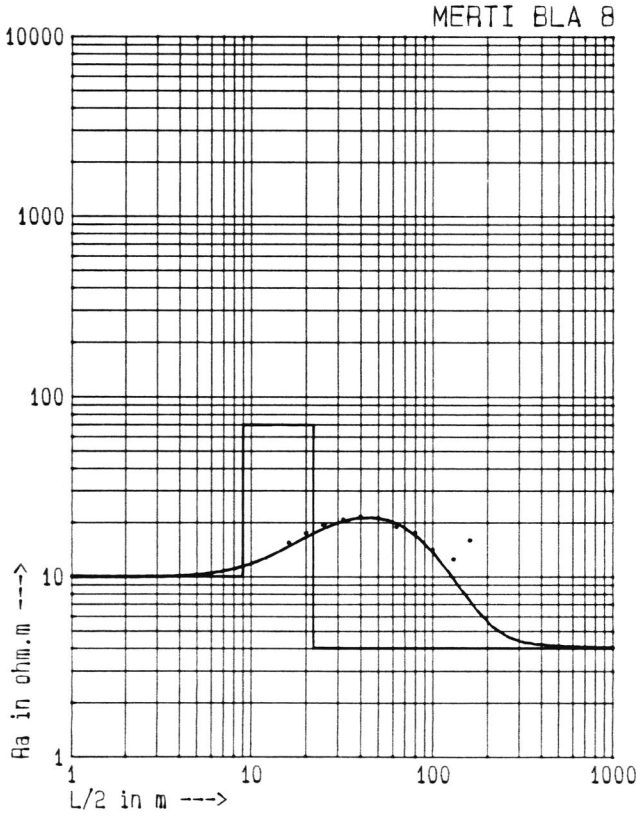


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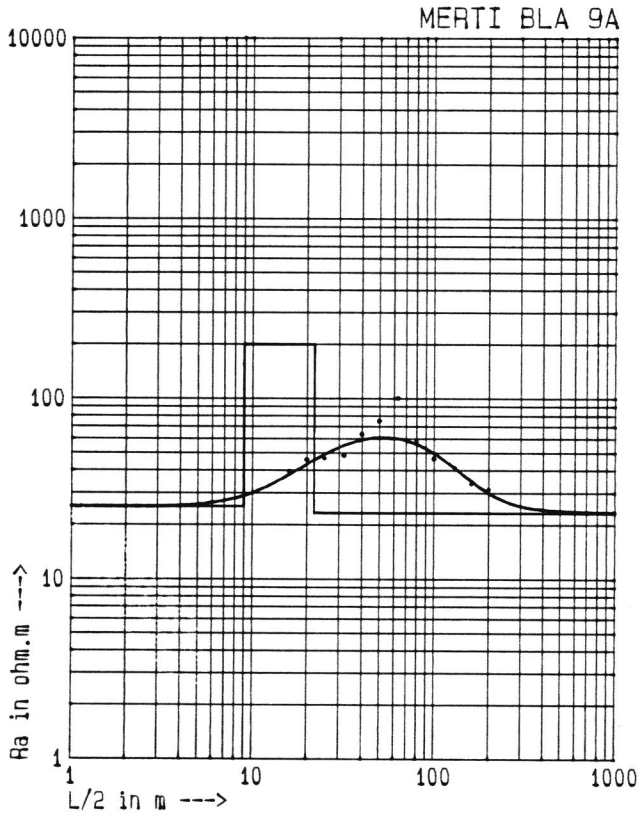


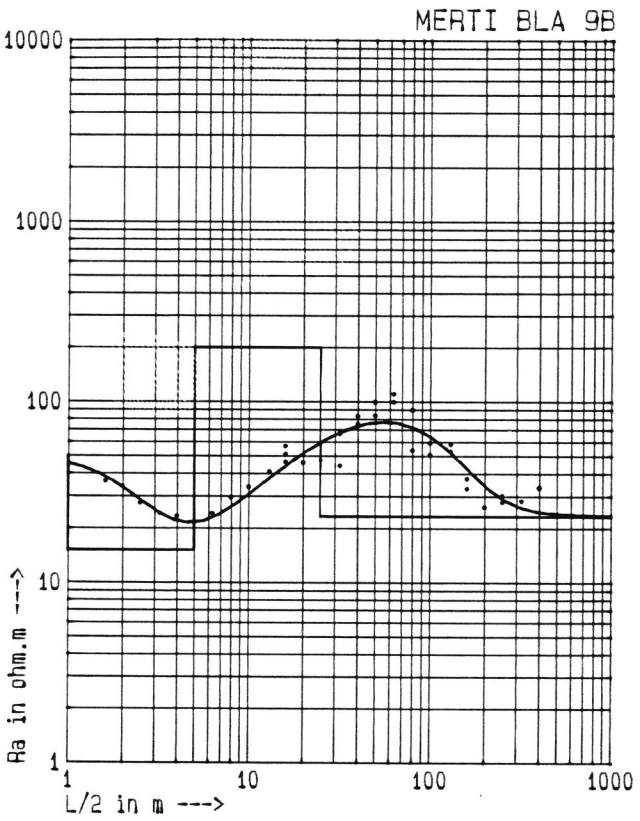


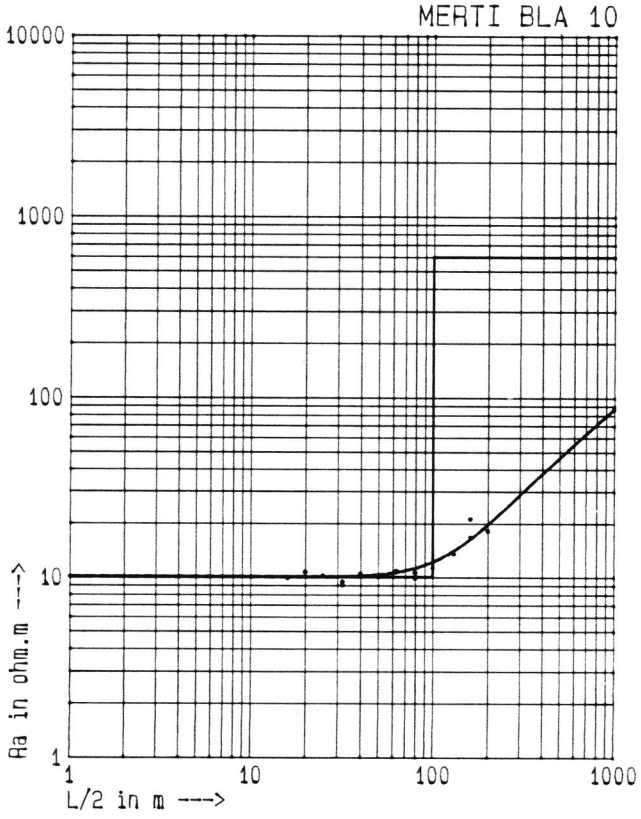


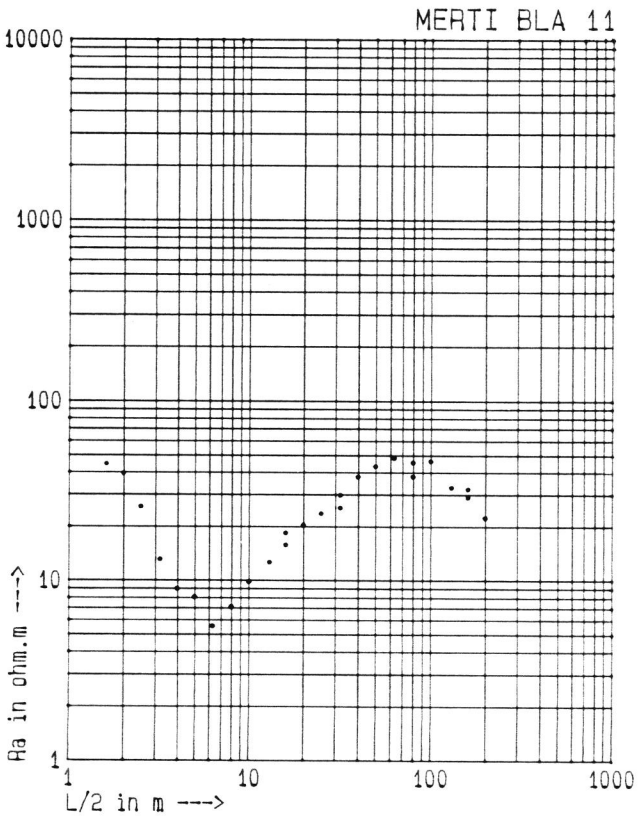


Appendix 3.5.3









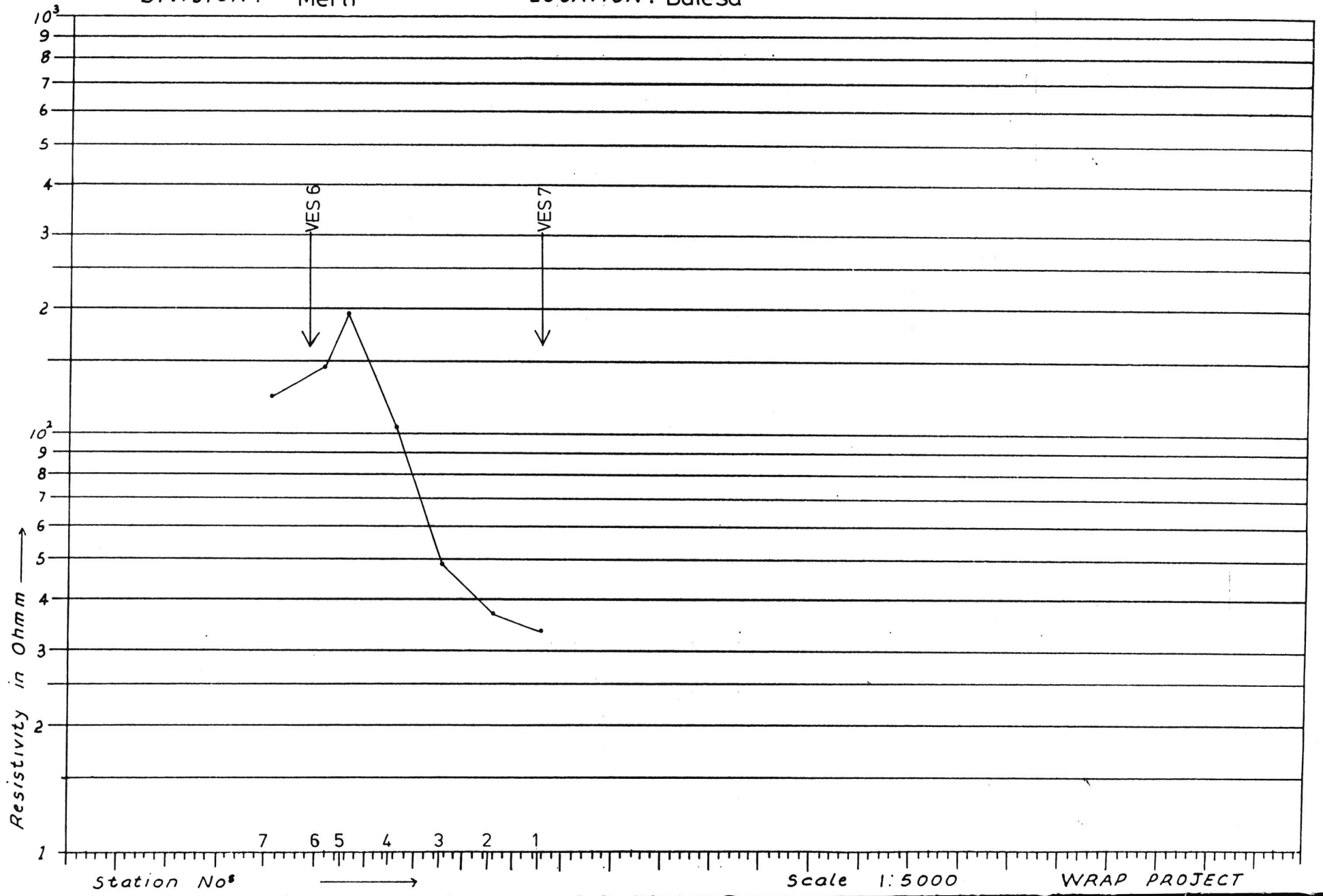
Appendix 3.5.4

Appendix 3.5.5

DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION: Bulesa

Resistivity - Profile No: RPI

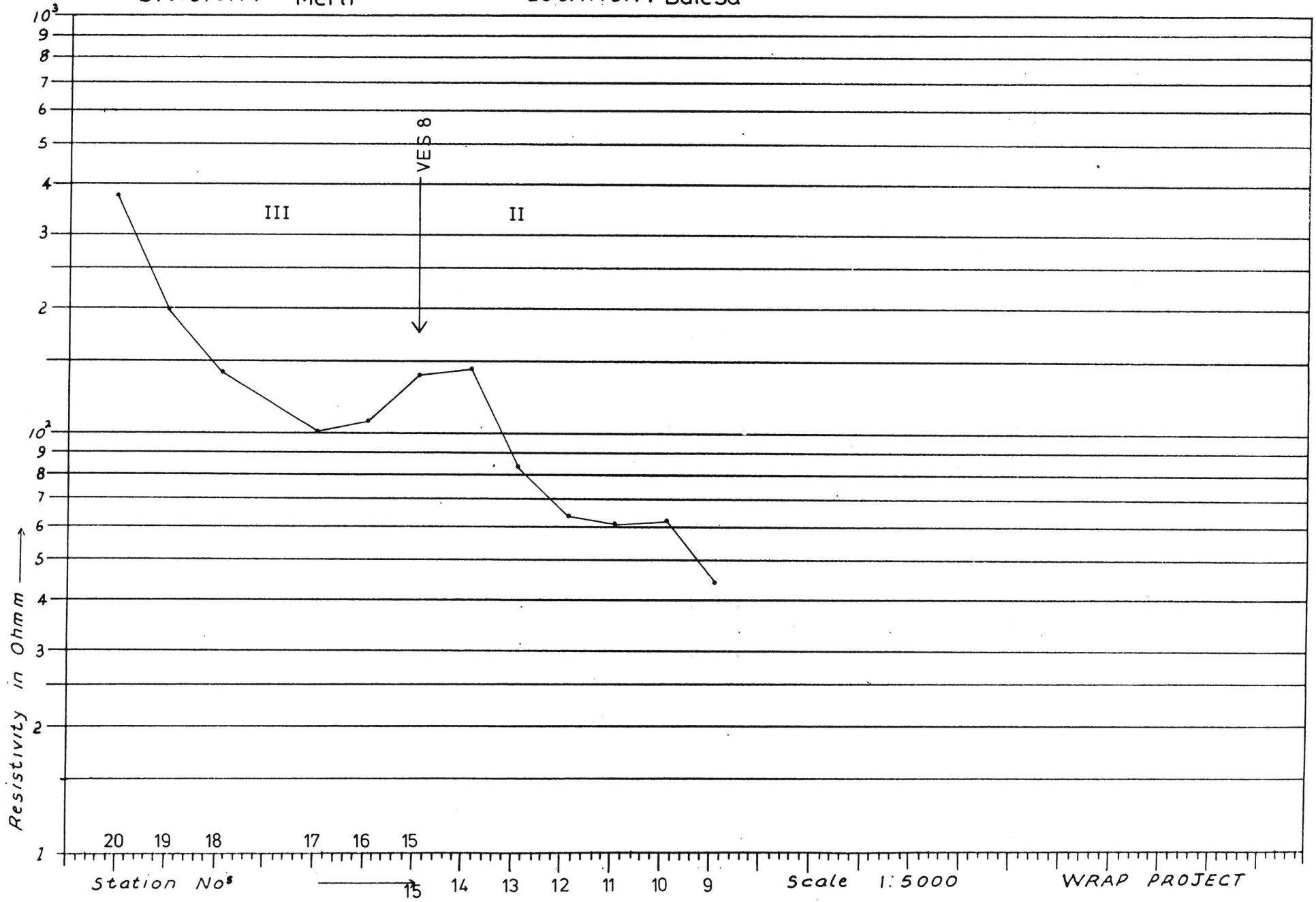


Appendix 3.5.6

DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION: Bulesa

Resistivity - Profile No: RP II, RP III

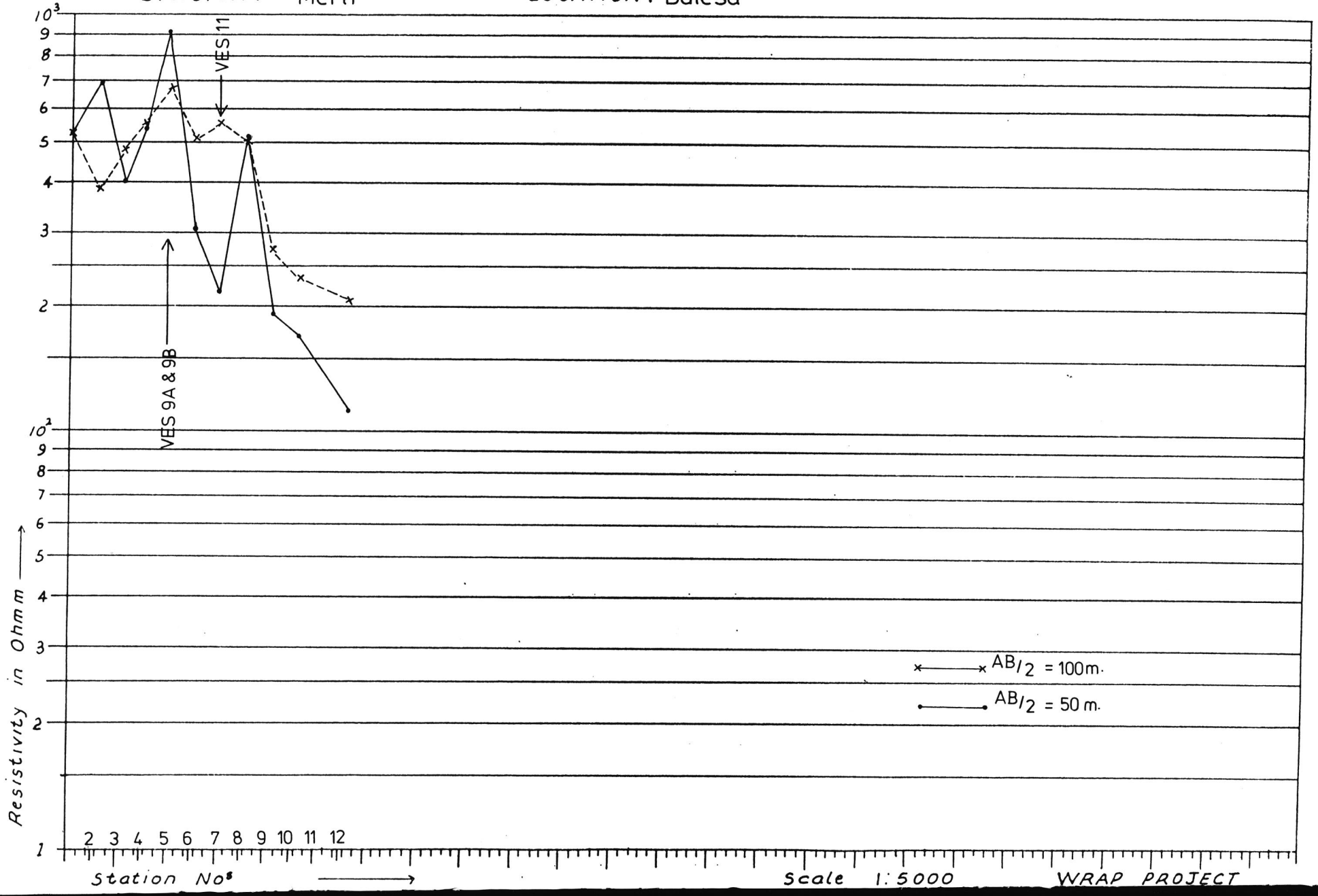


Appendix 3.5.7

DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION: Bulesa

Resistivity - Profile No: RP - IV

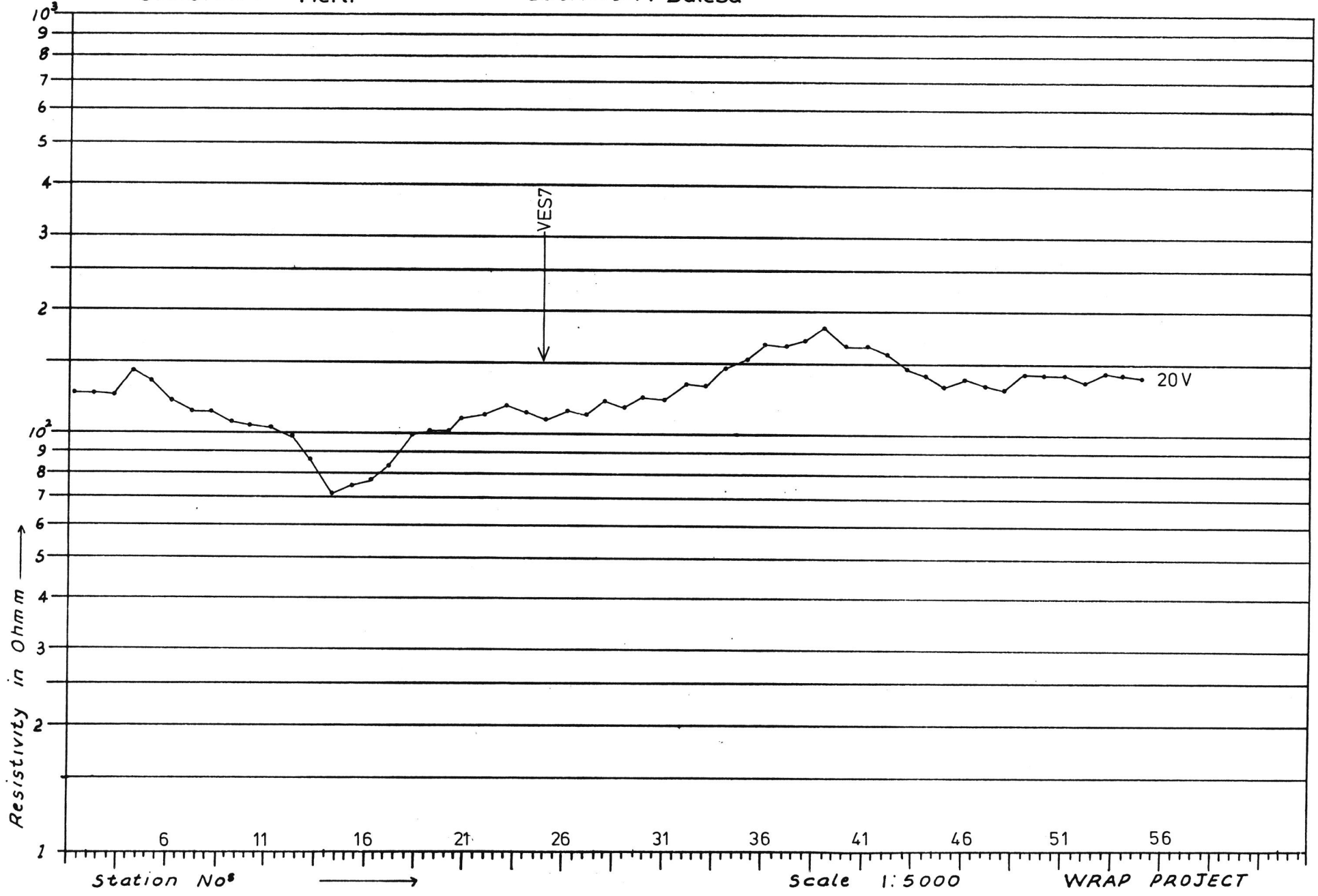


Appendix 3.5.8

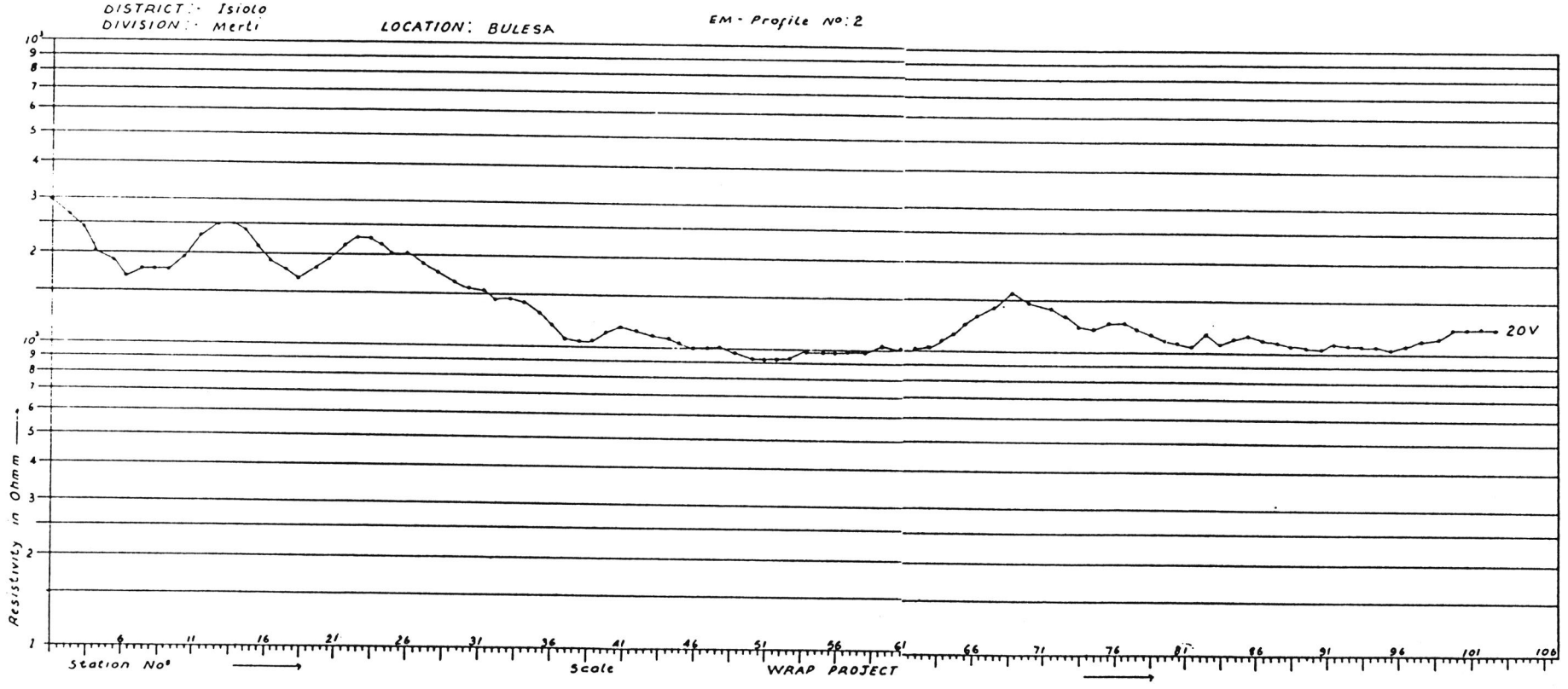
DISTRICT :- Isiolo
DIVISION :- Merti

LOCATION: Bulesa

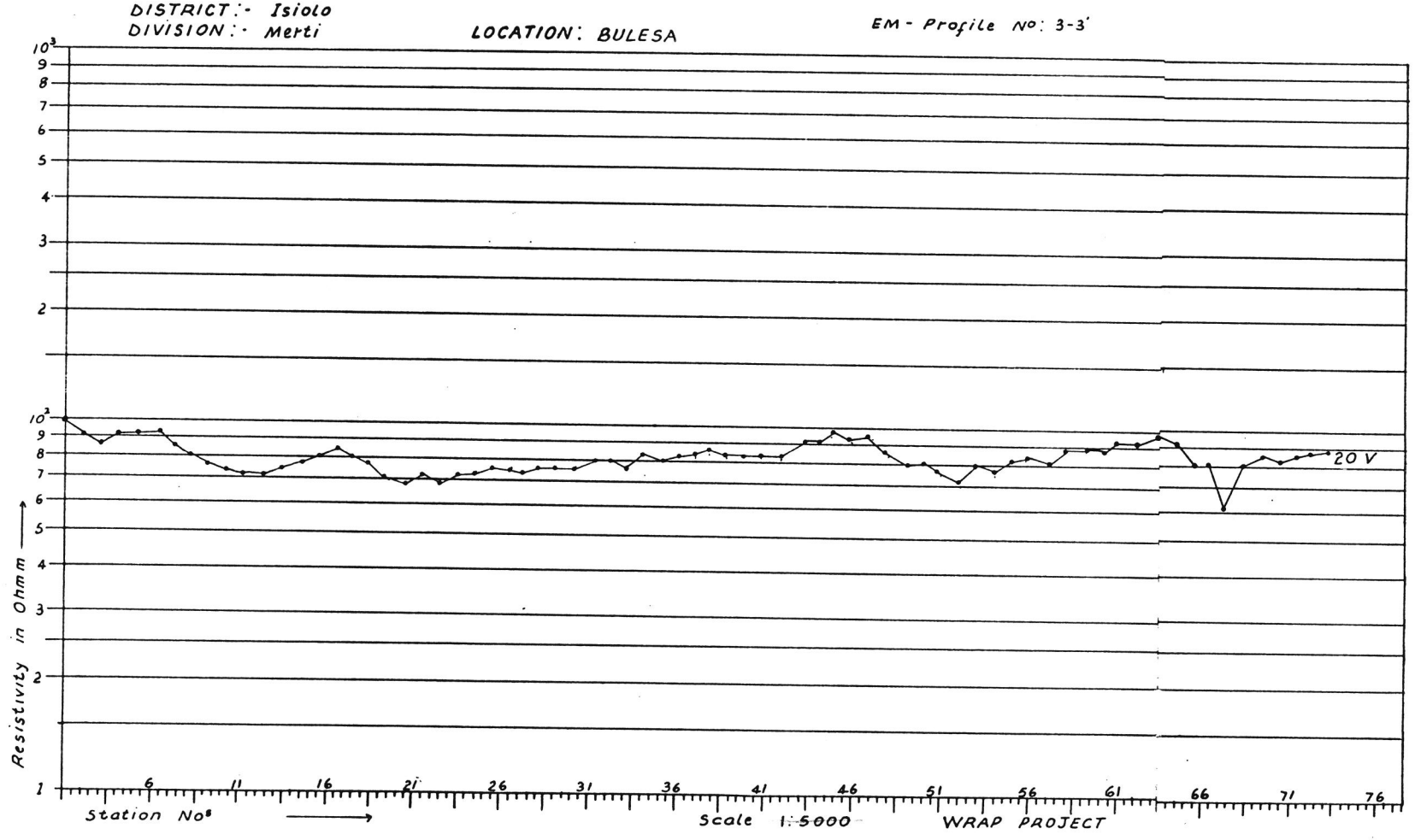
EM - Profile No: 1 - 1'



Appendix 3.5.9



Appendix 3.5.10

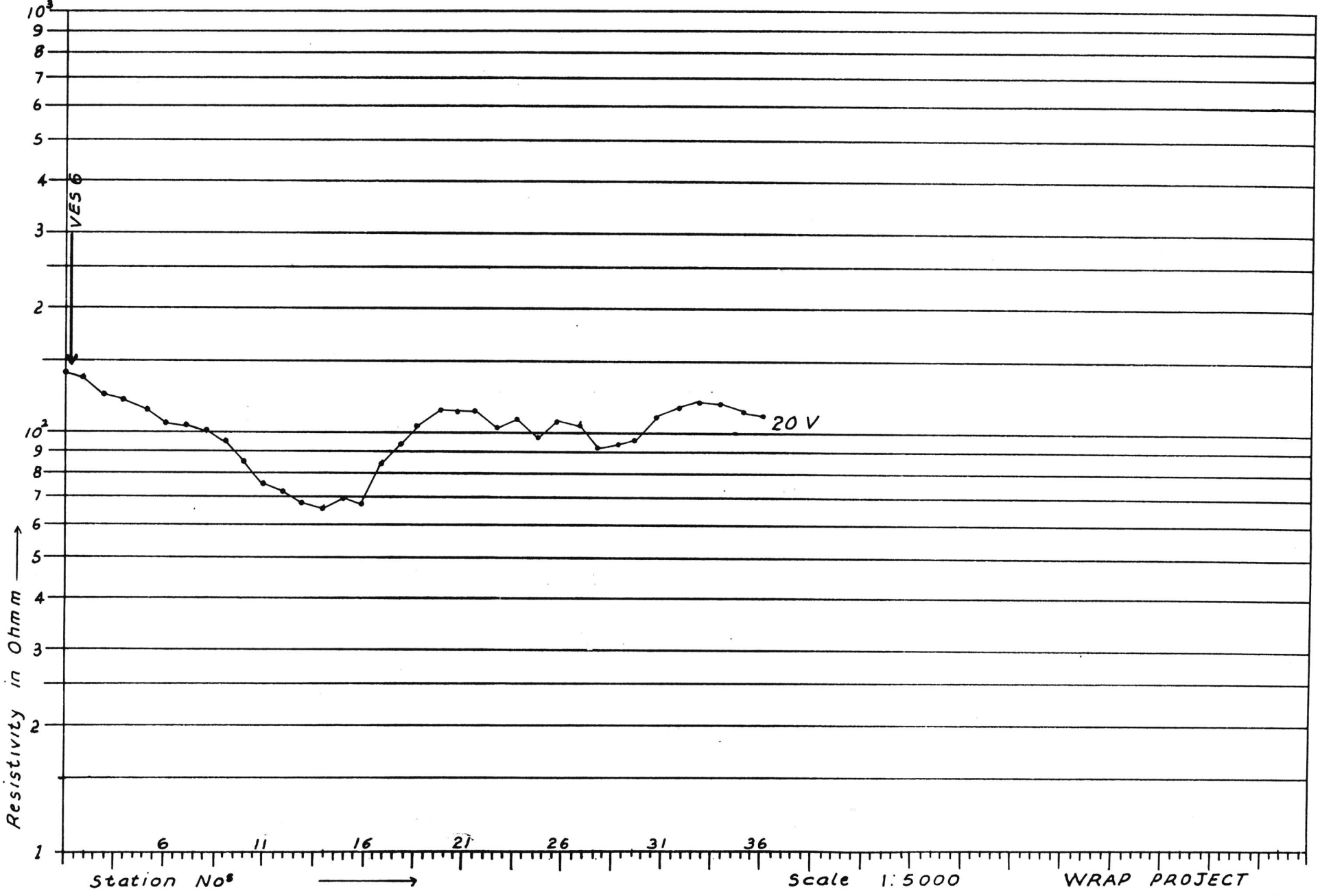


Appendix 3.5.11

DISTRICT :- Isiolo
DIVISION :- Merti

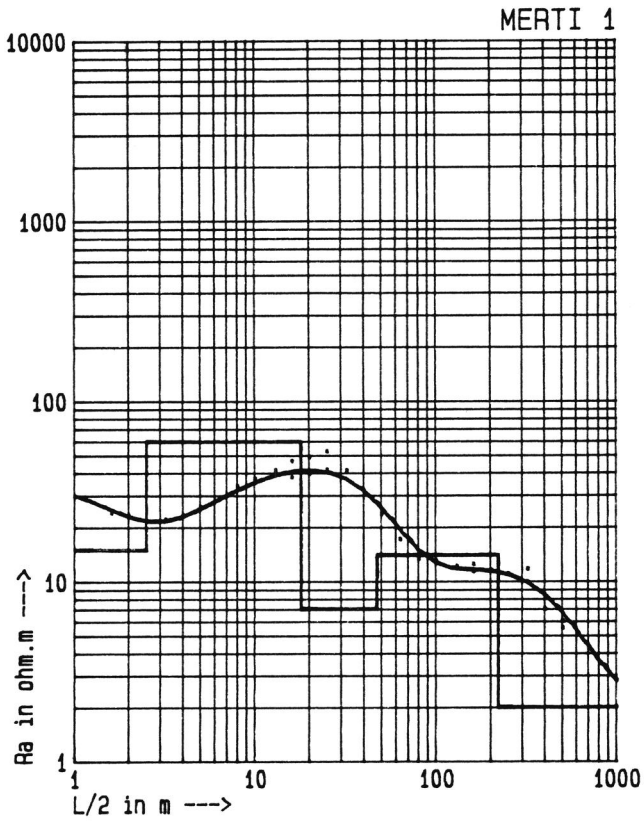
LOCATION: BULESA

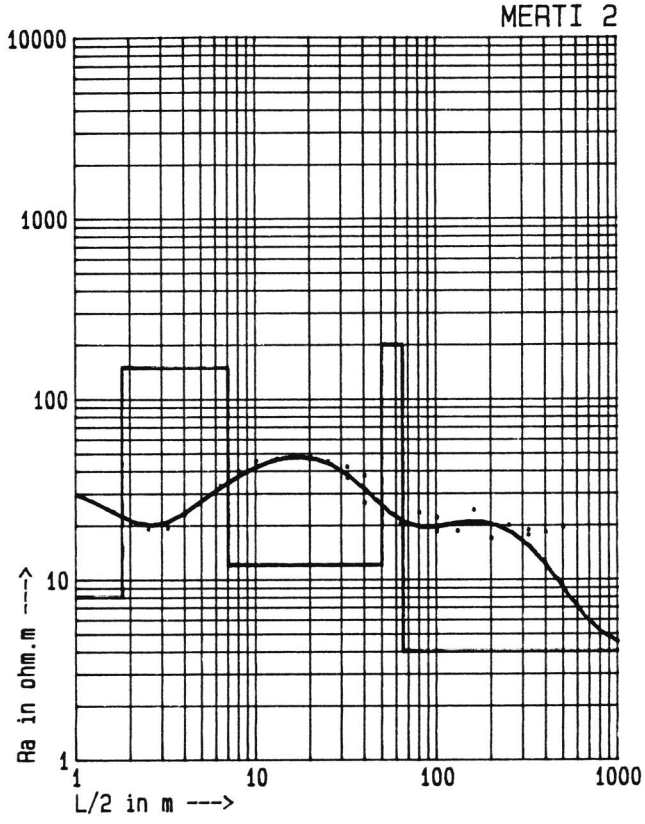
EM - Profile No: 4 - 4'

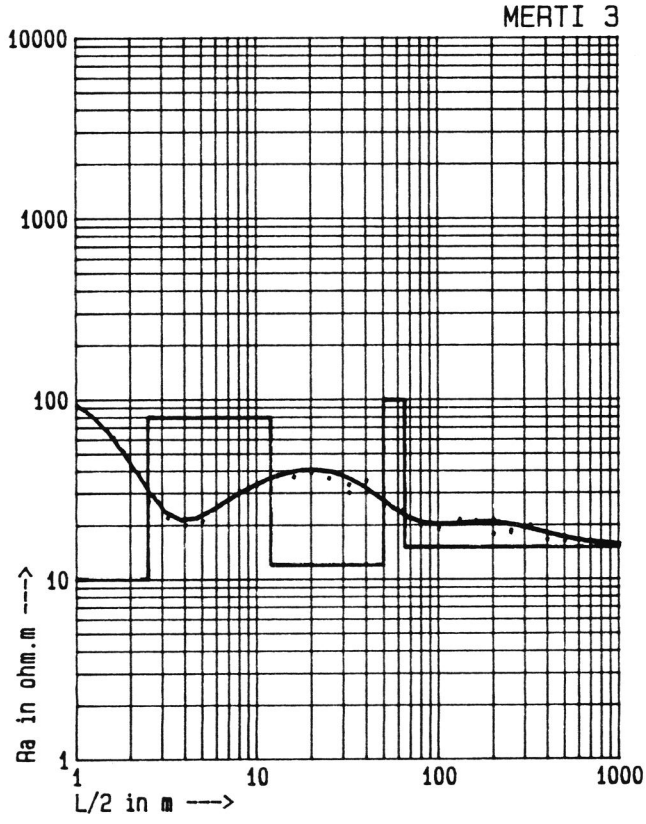


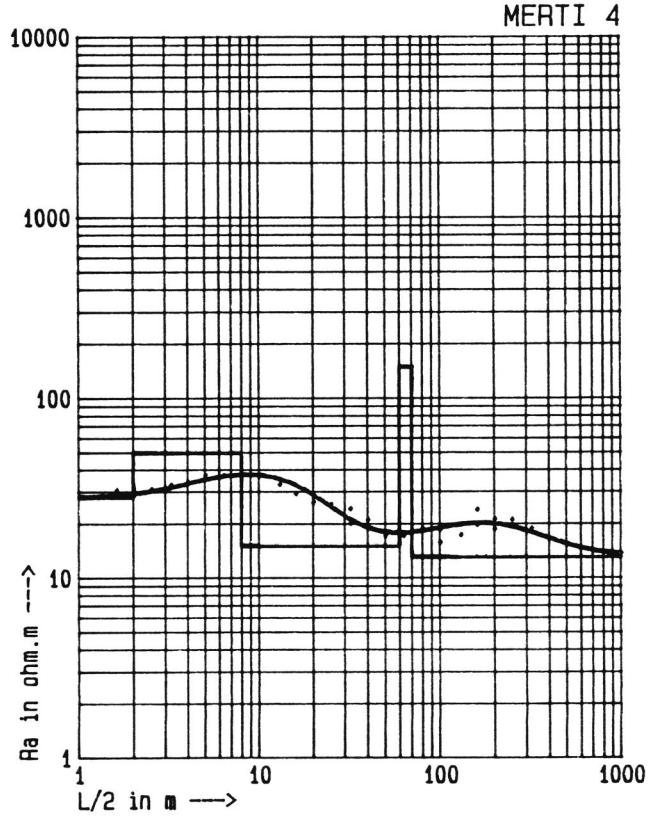
Appendix 3.6

Merti Aquifer - Regional Study

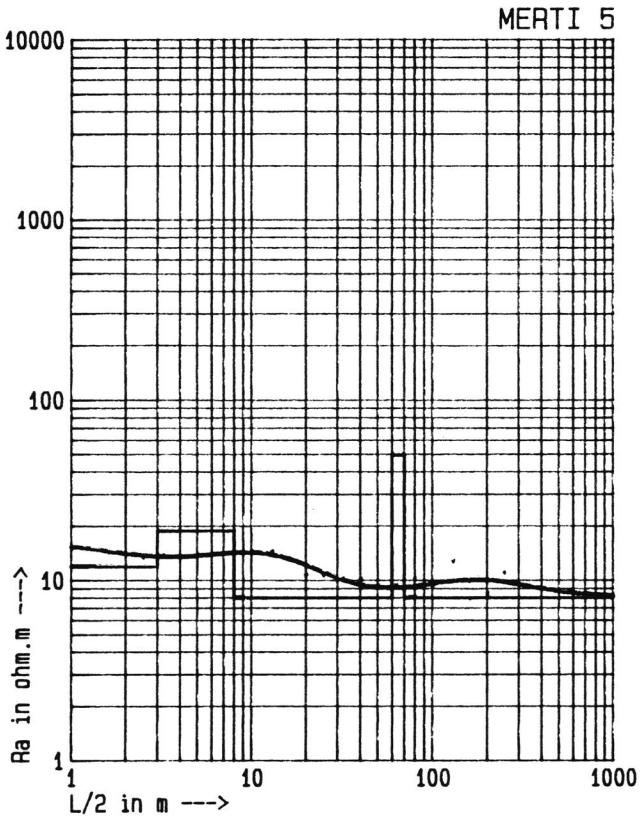


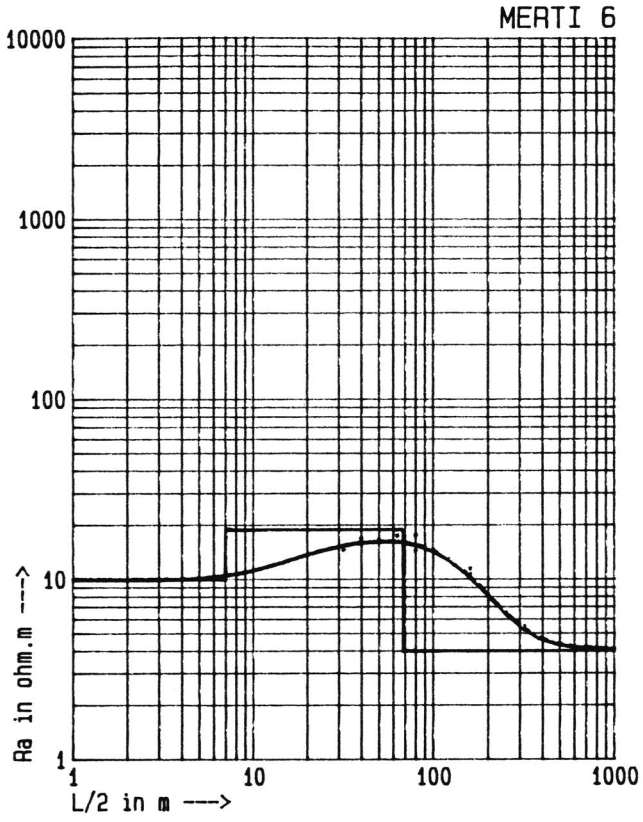


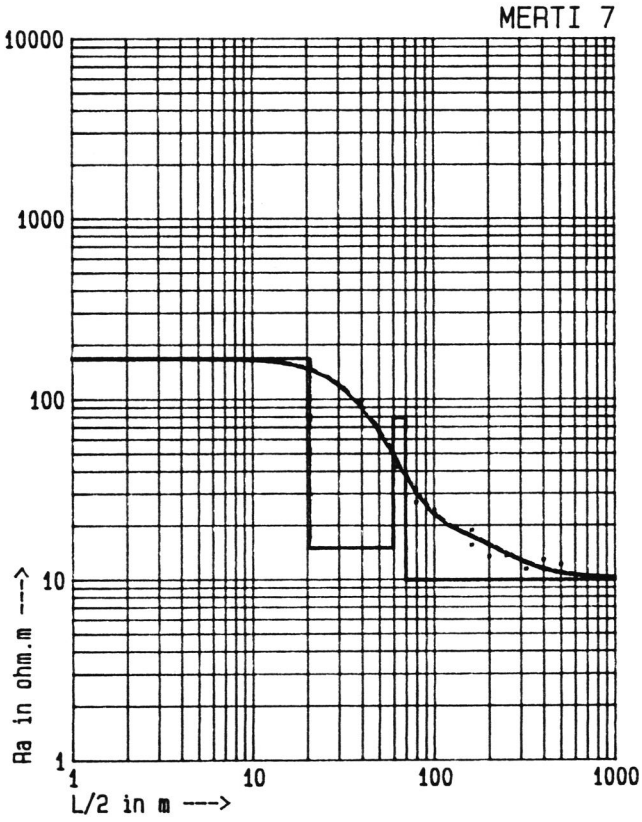


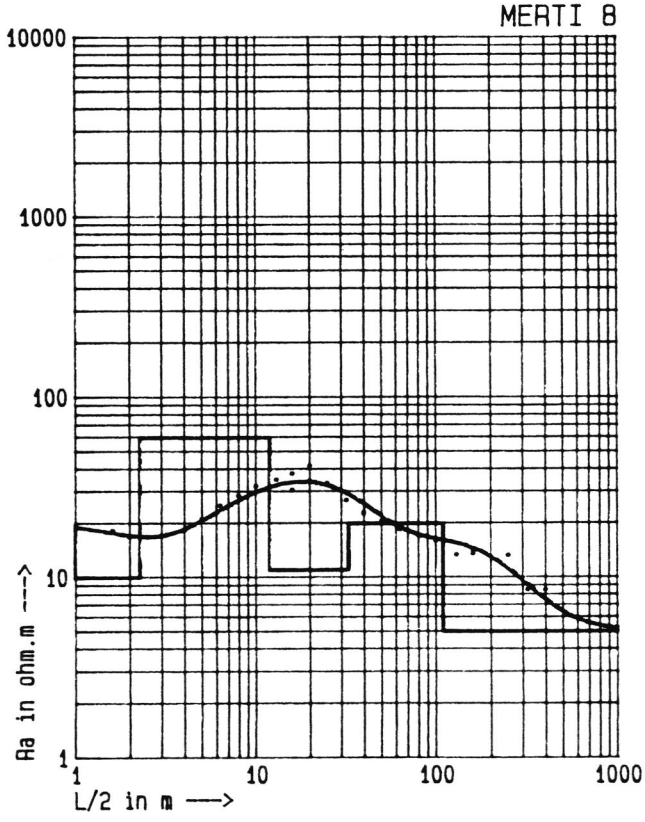


Appendix 3.6.1

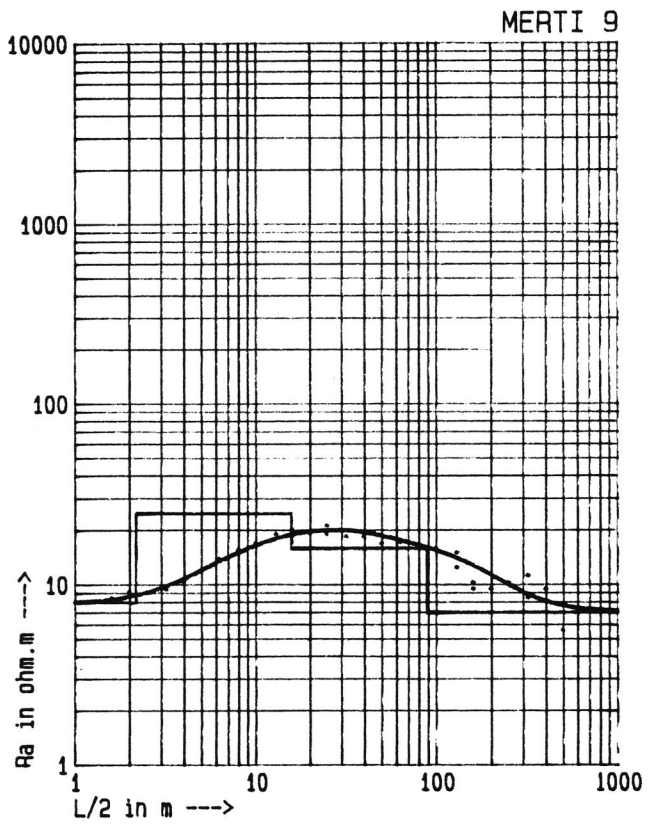


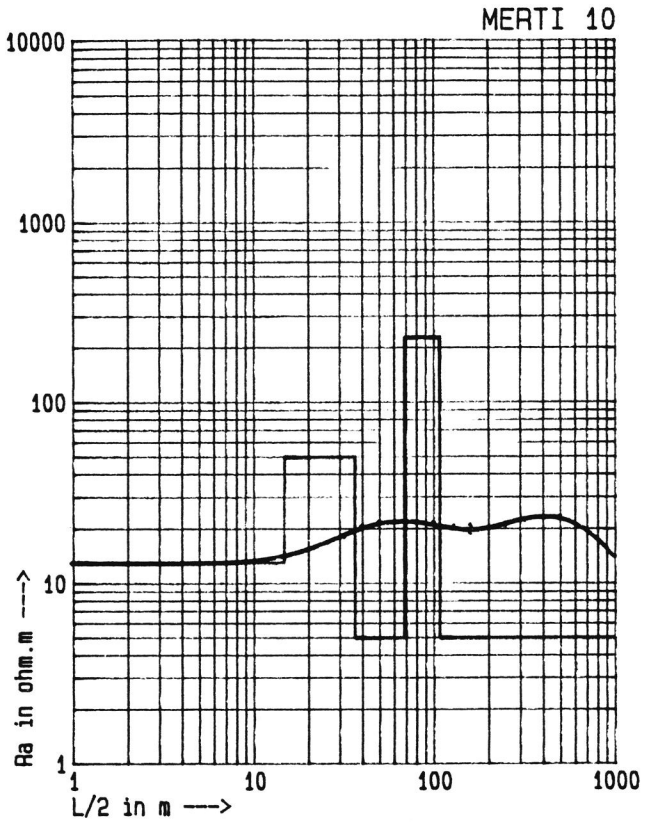


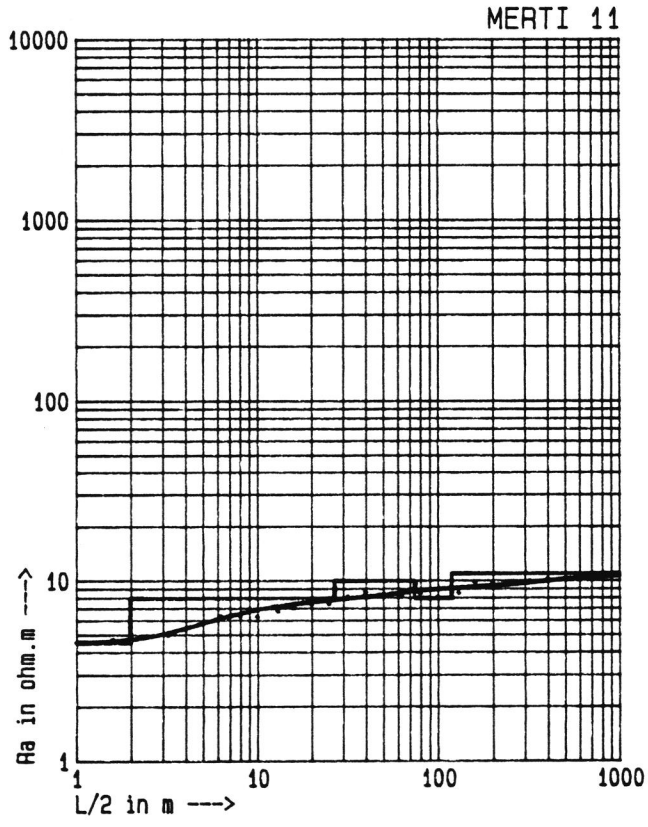


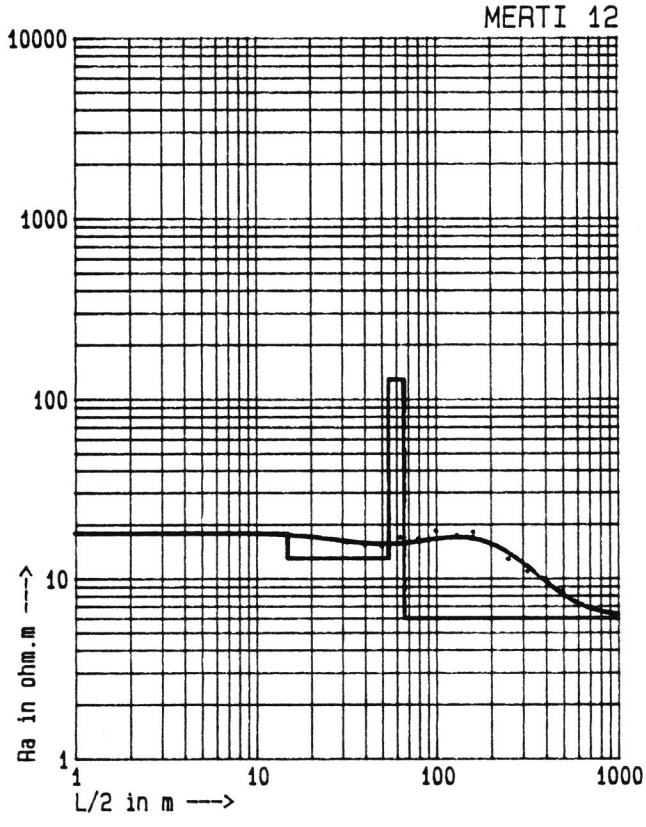


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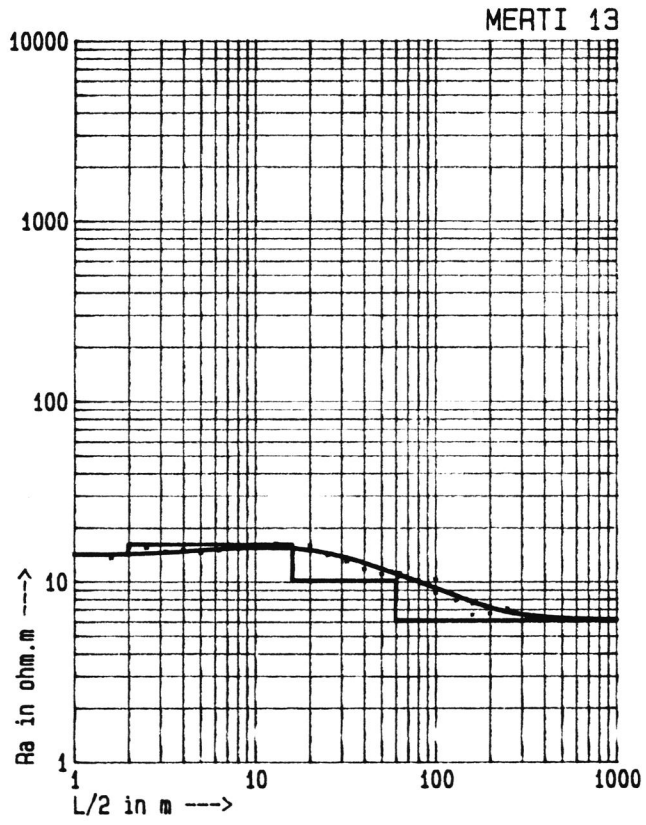


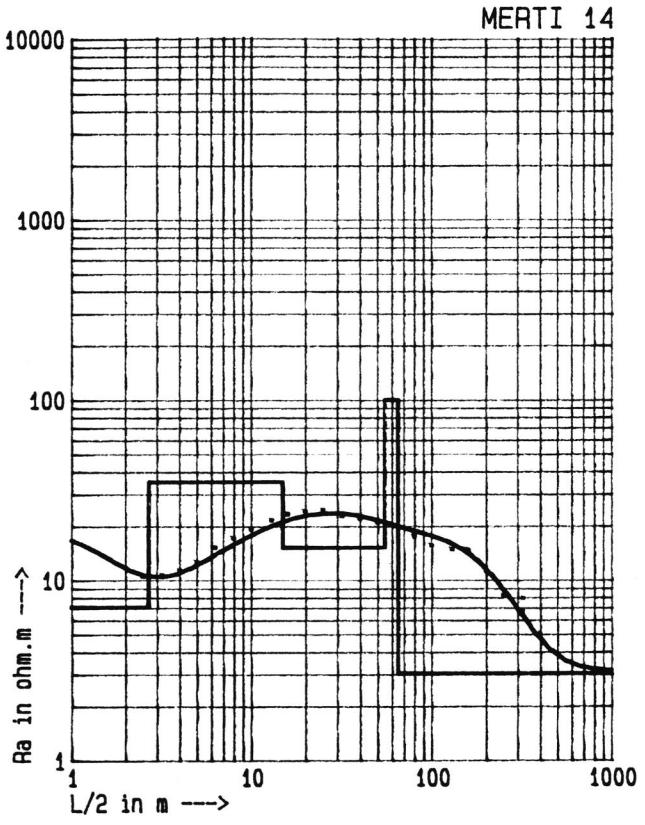


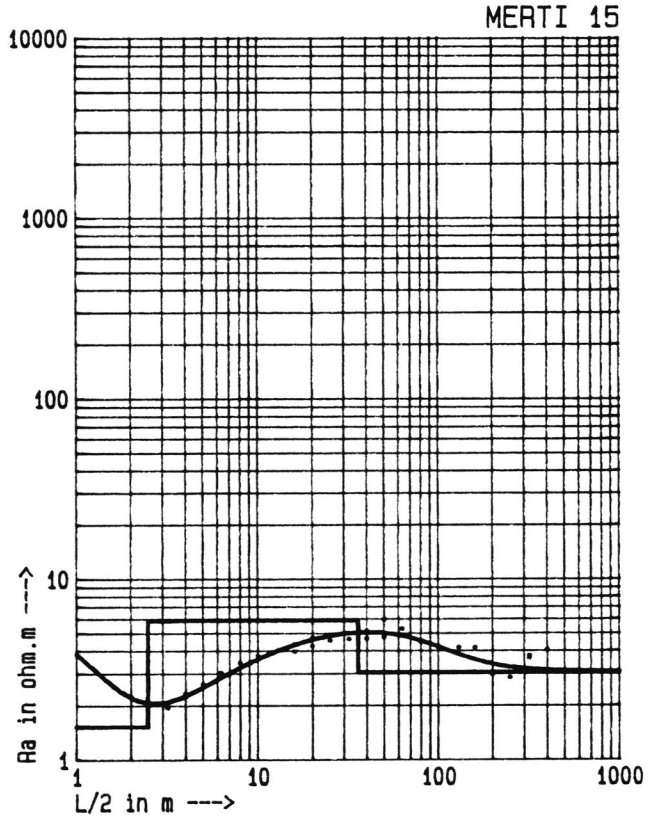


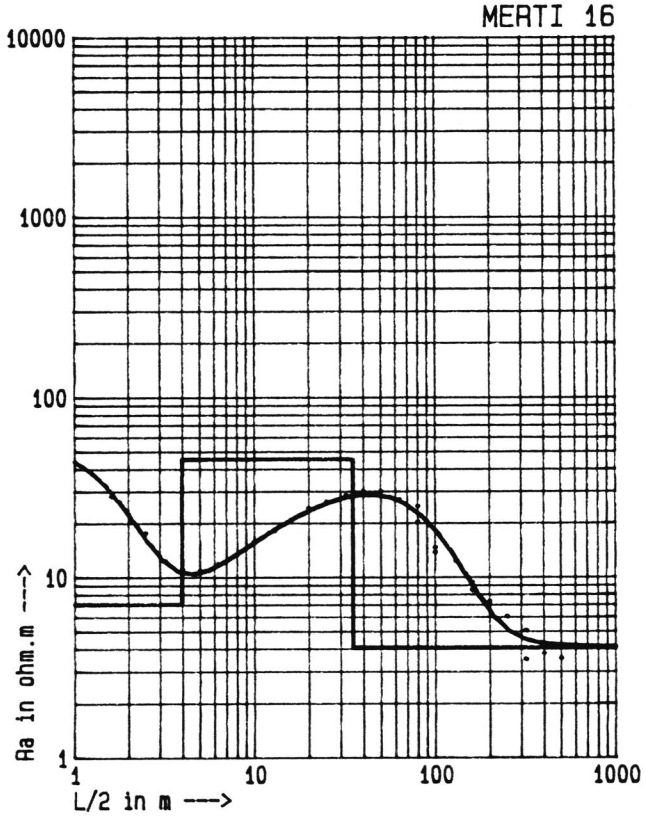


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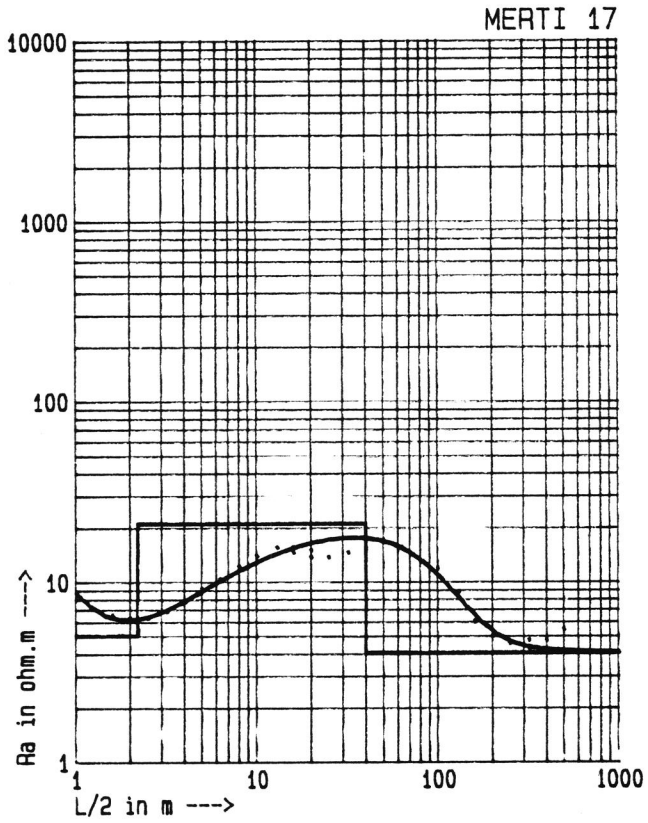


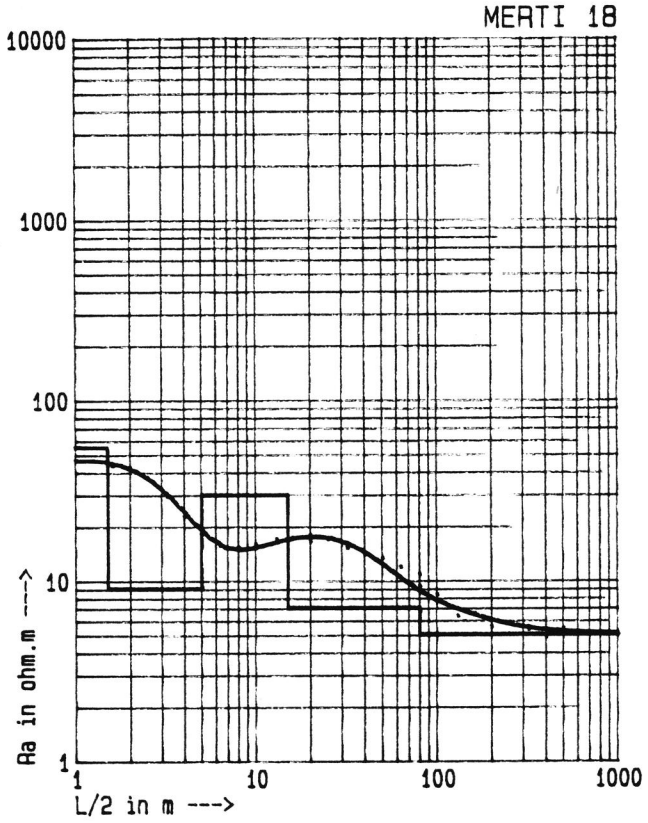


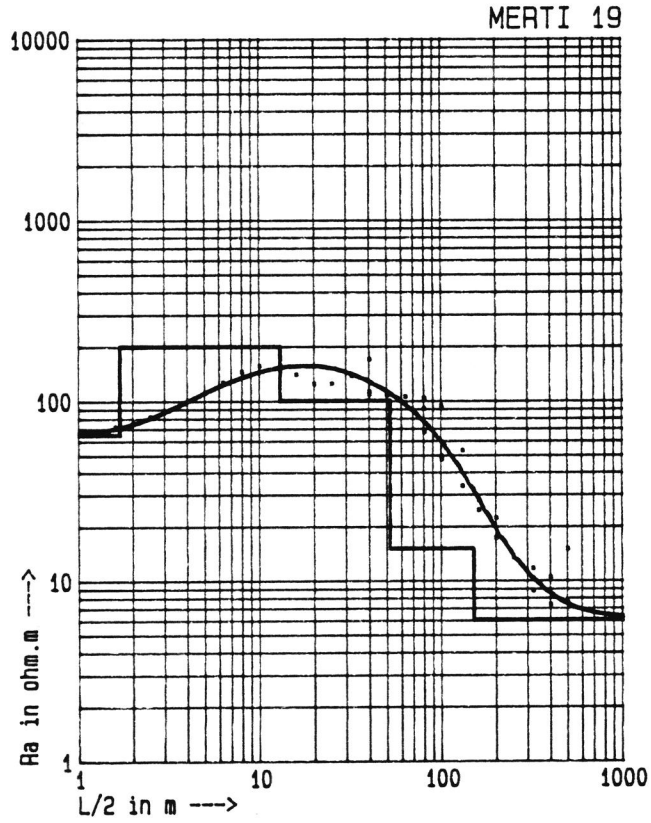


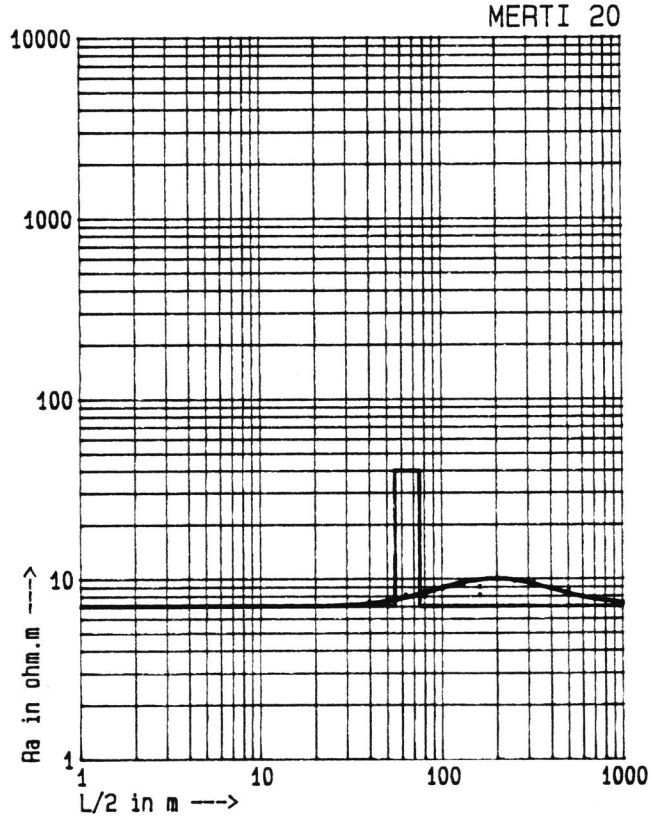


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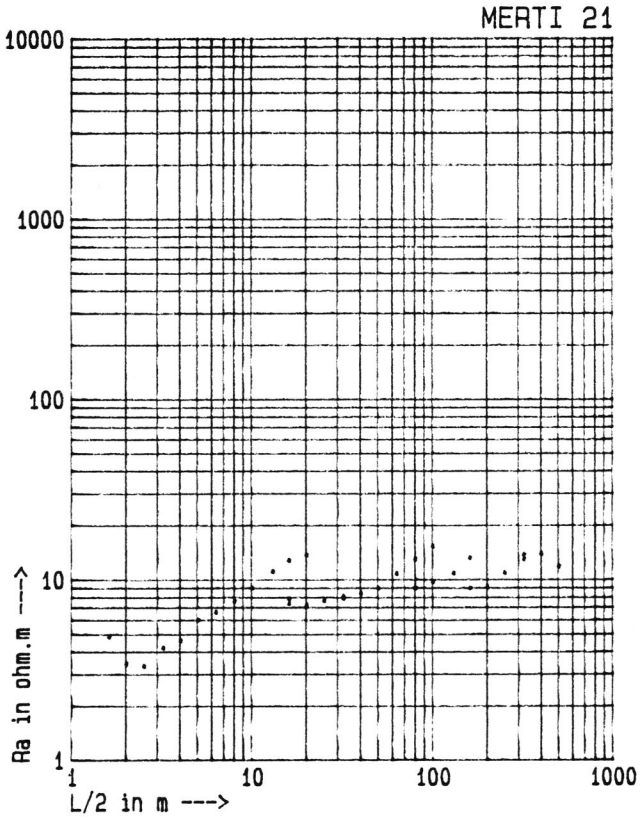


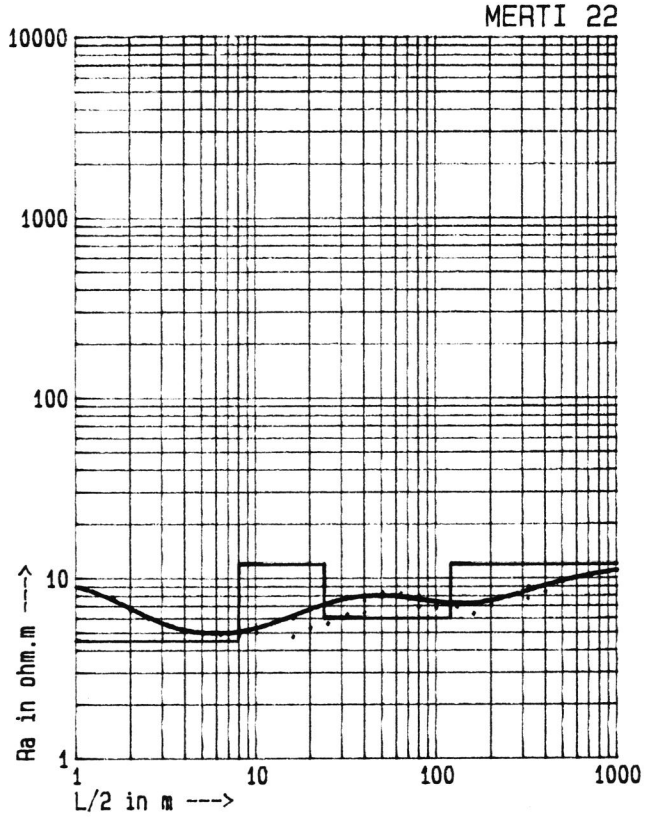


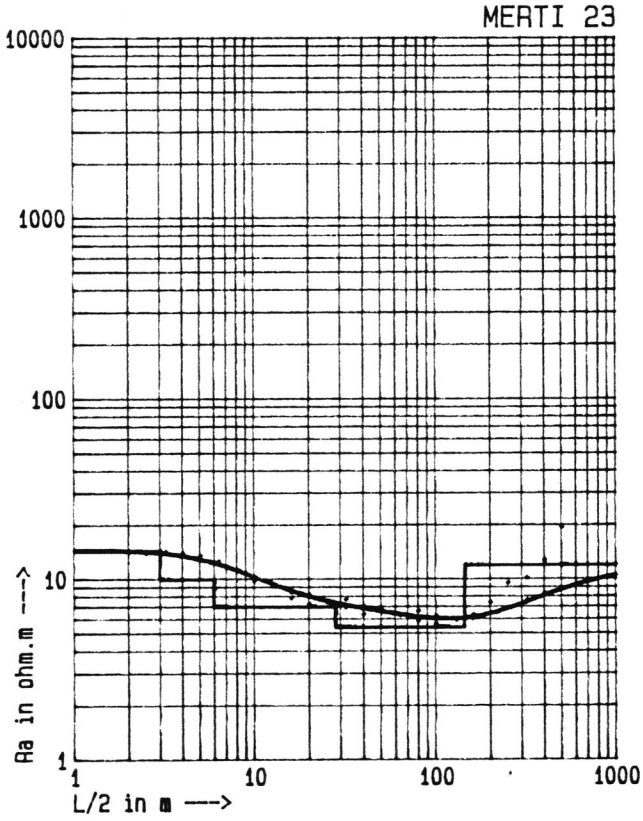


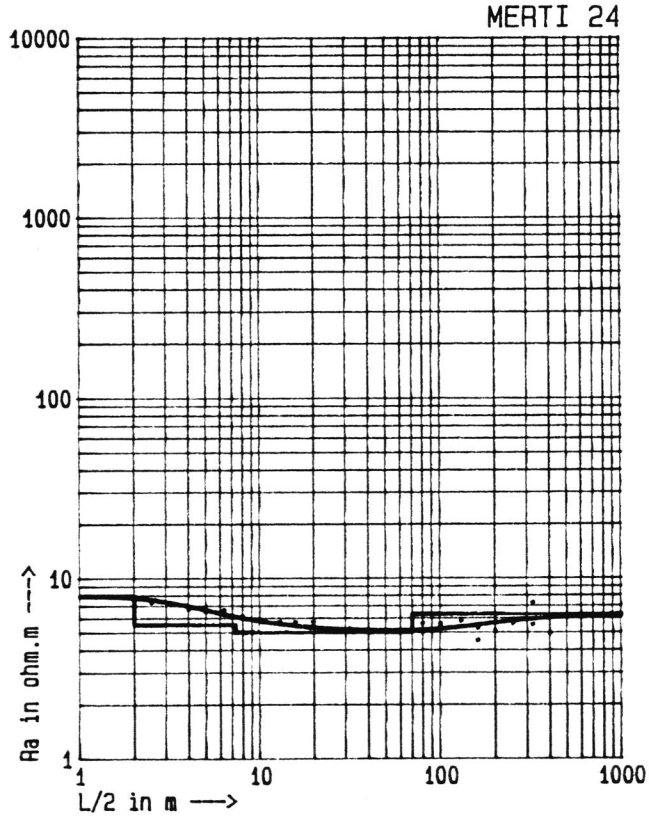


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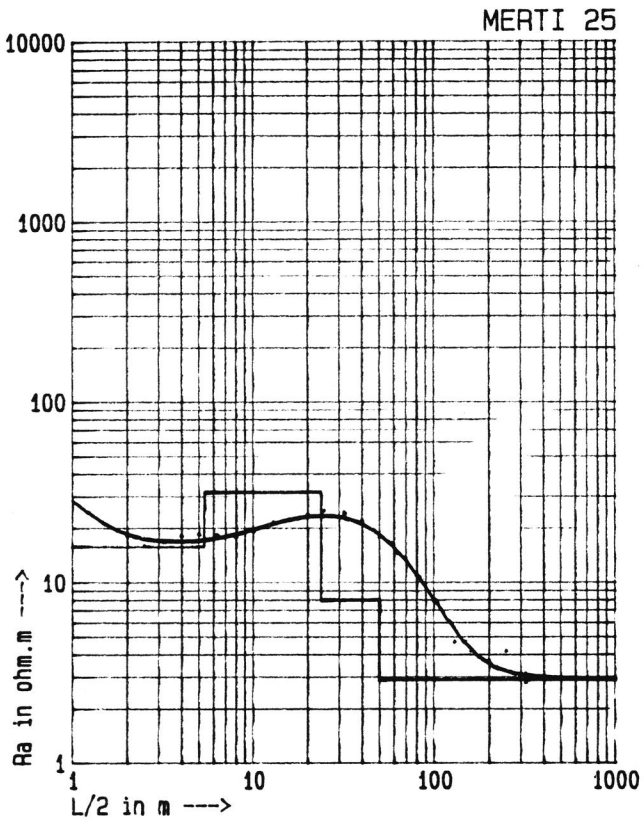


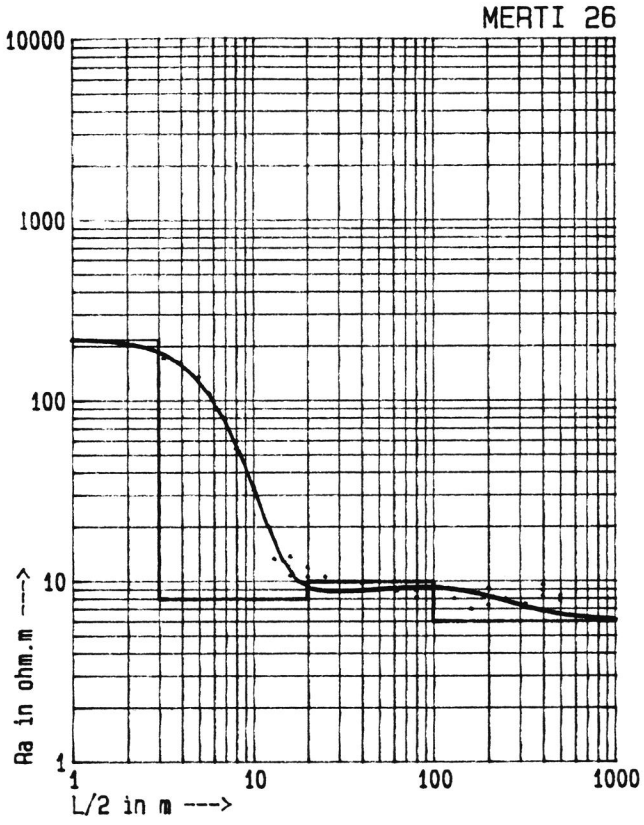


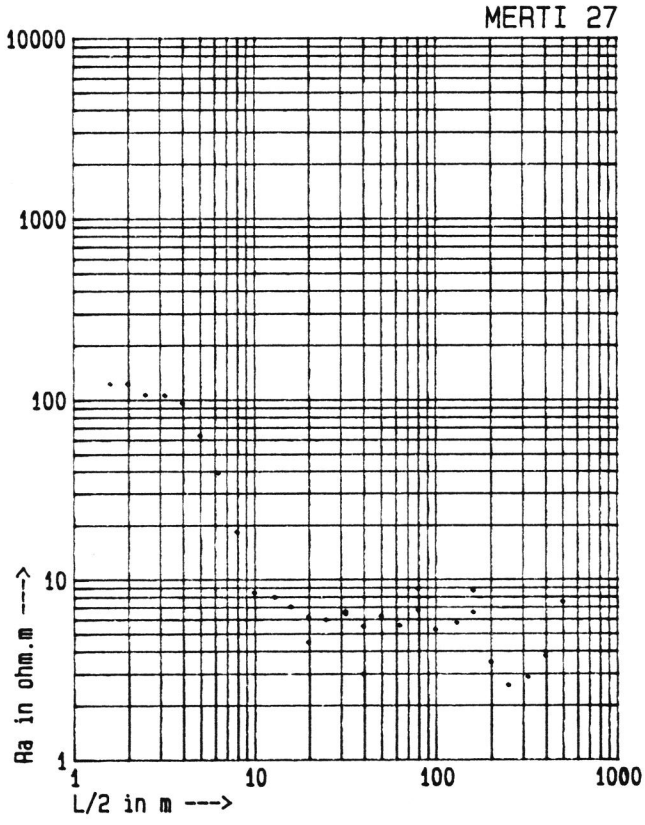


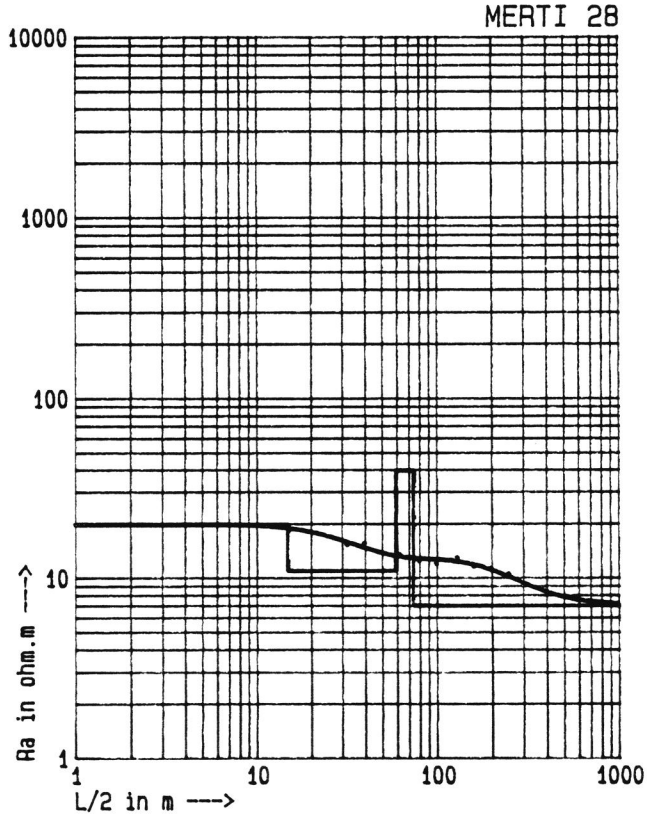


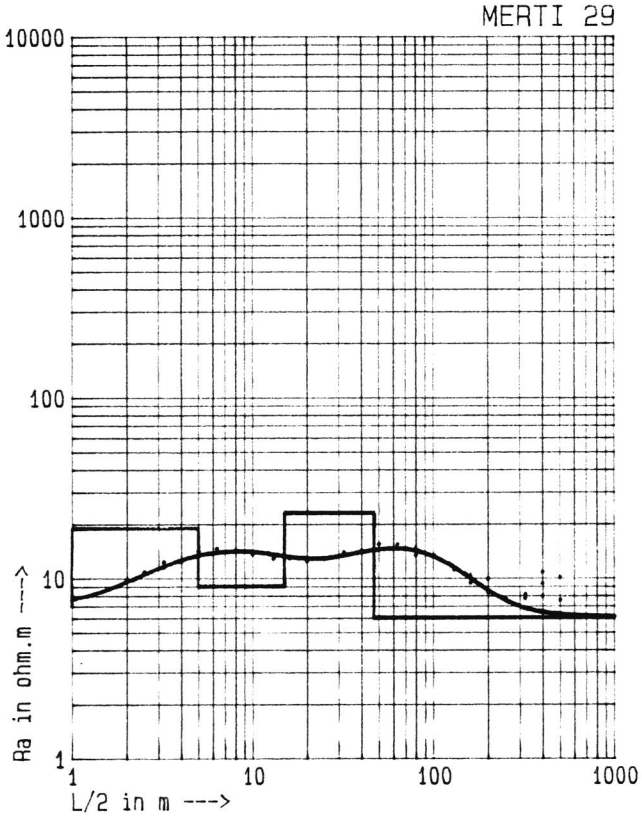
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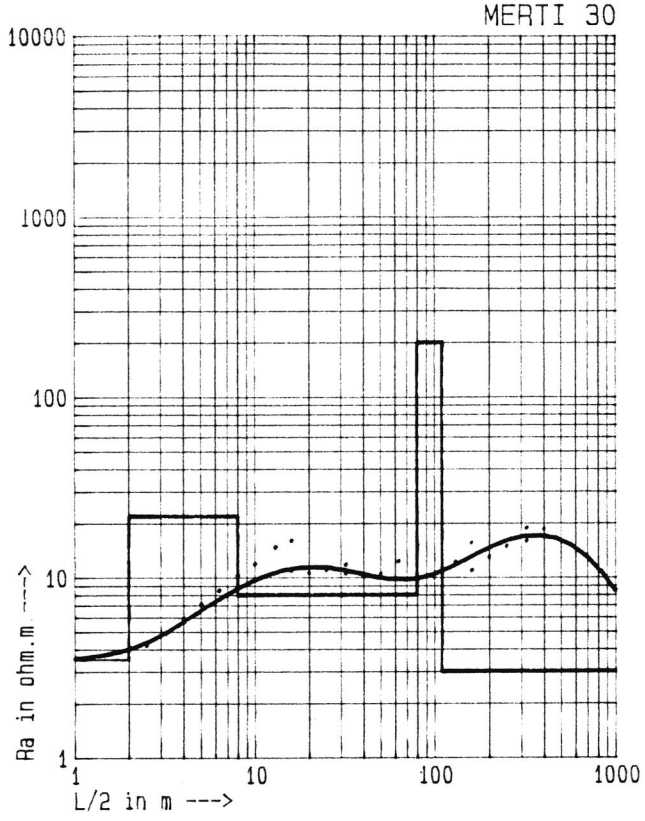

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10
100
1000
L/2 in m --->

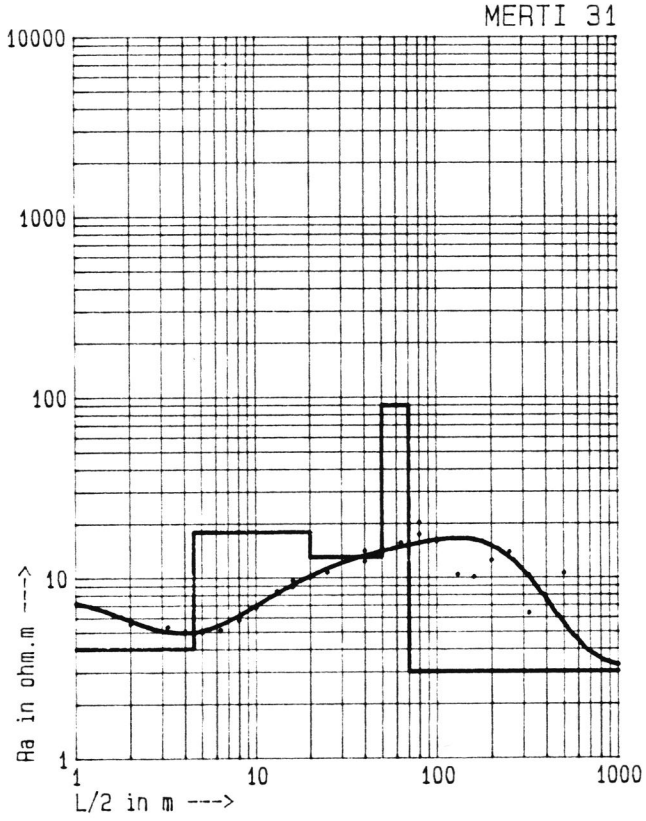

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1000
L/2 in m --->

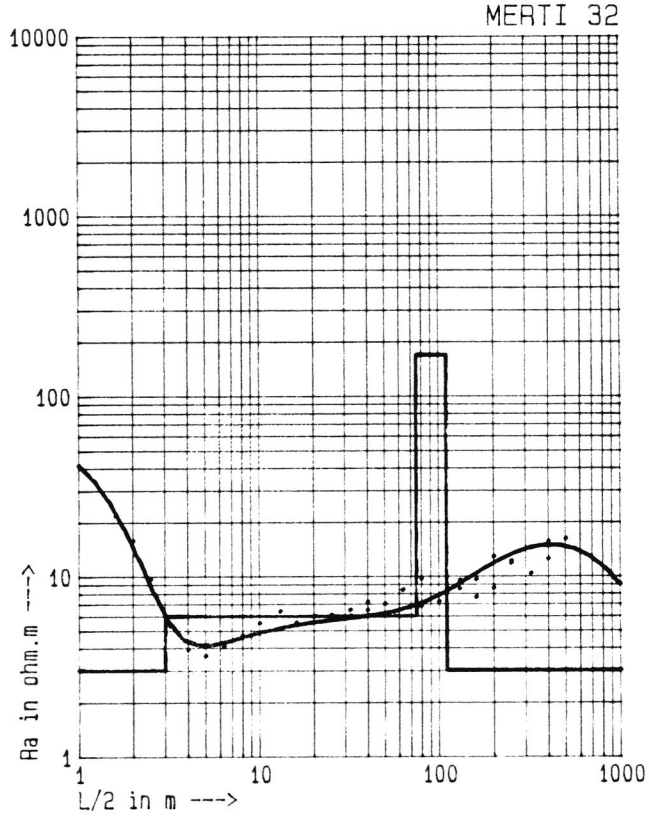

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10
100
1000
L/2 in m --->


MERTI 28
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Ra in ohm.m --->
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10
100
1000
L/2 in m --->

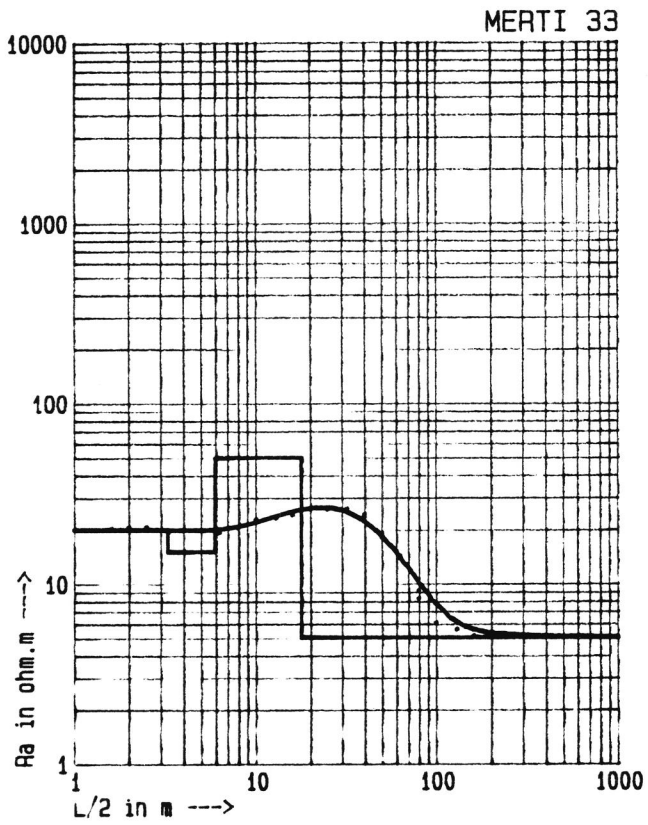


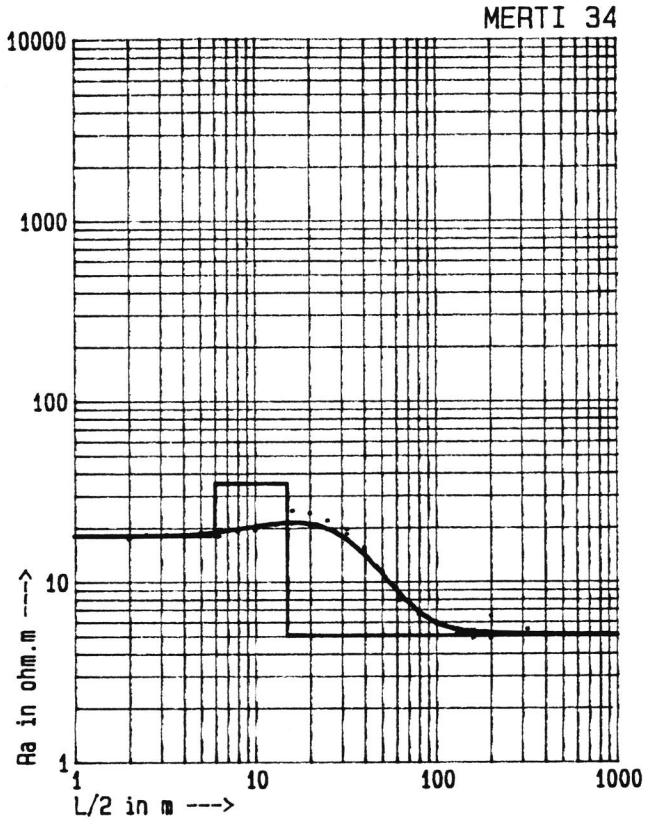


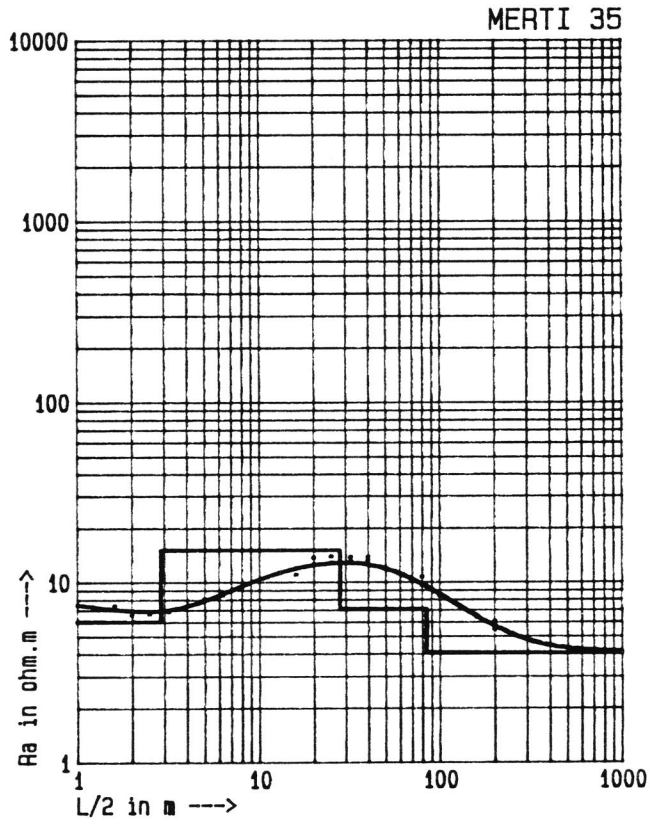


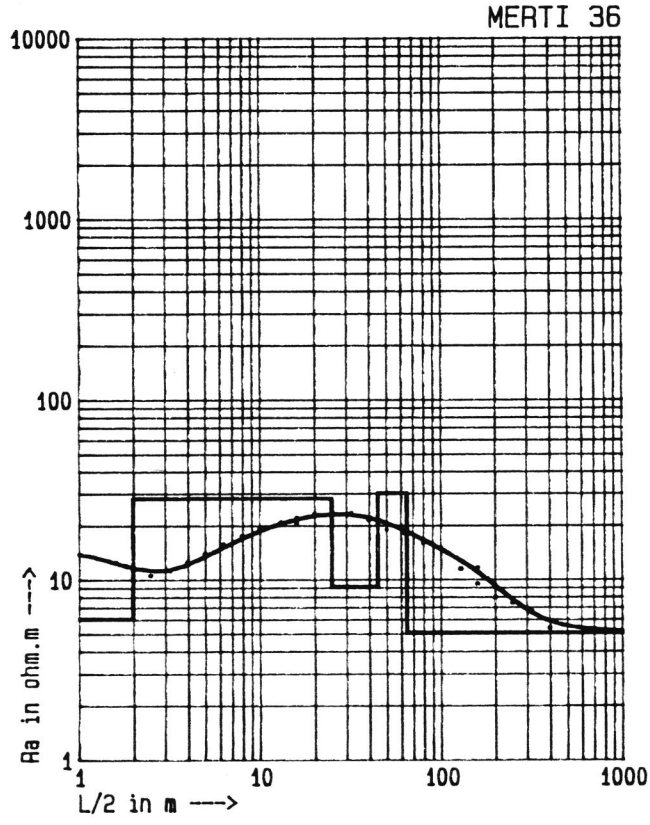


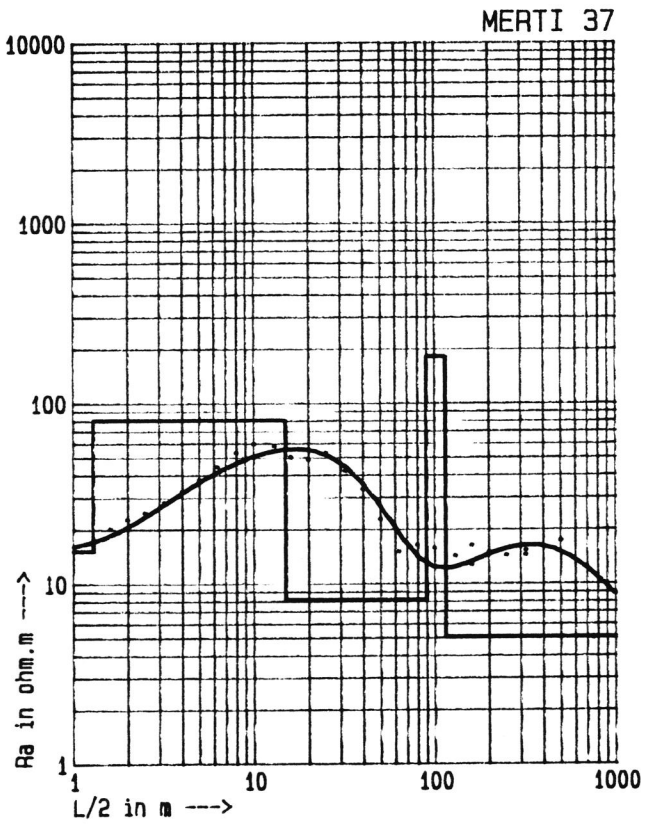
Appendix 3.6.8

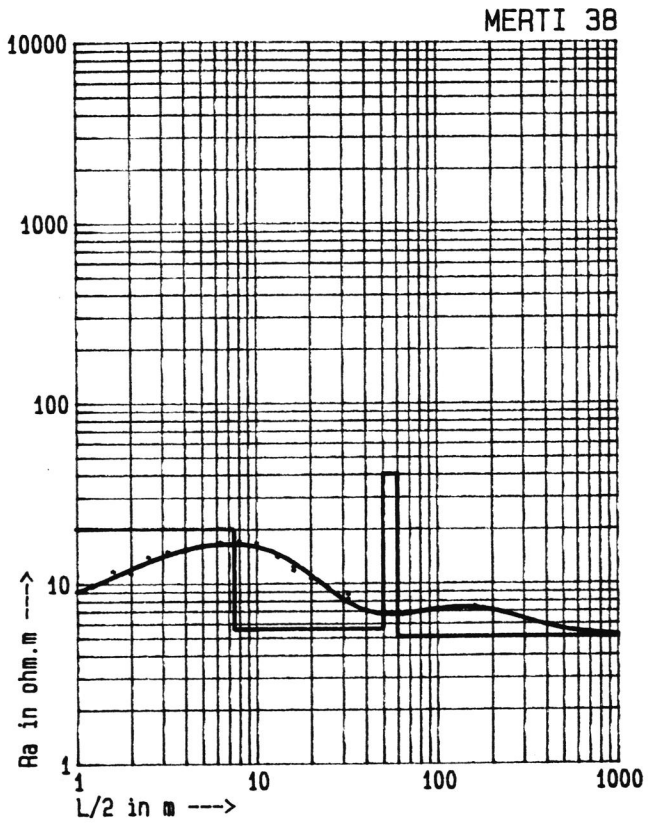

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10
1
Ra in ohm.m --->
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10
100
1000
L/2 in m --->

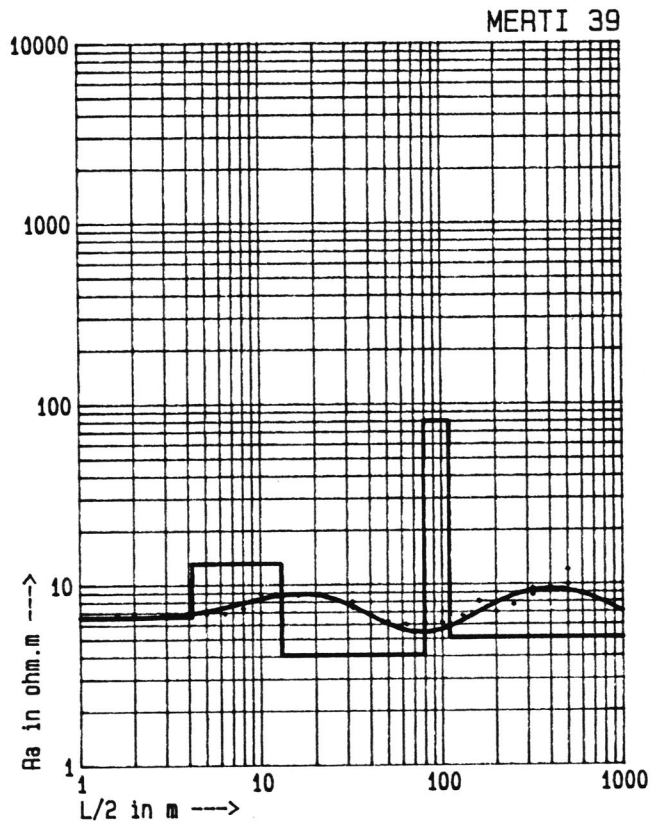

MERTI 34
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1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

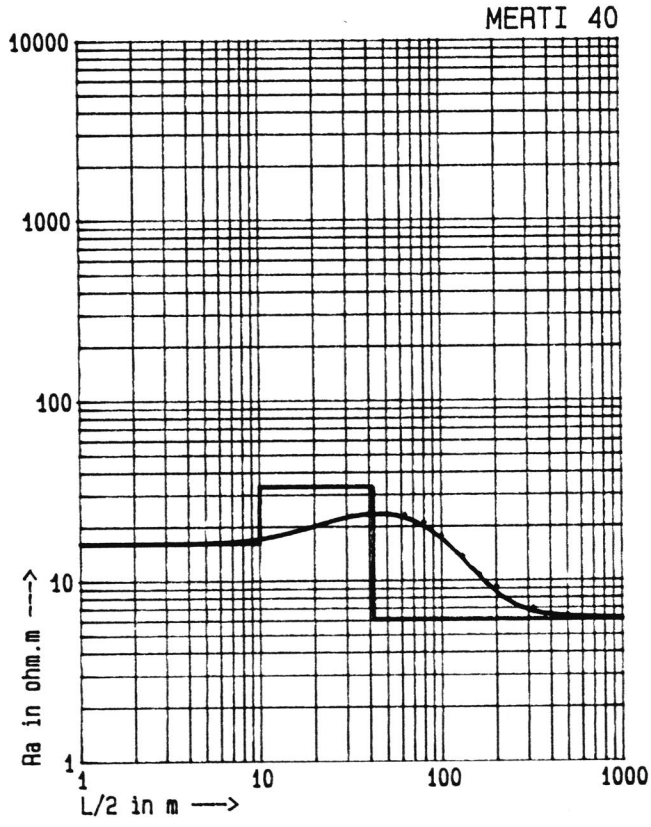

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1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


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1000
100
10
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Ra in ohm.m --->
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10
100
1000
L/2 in m --->

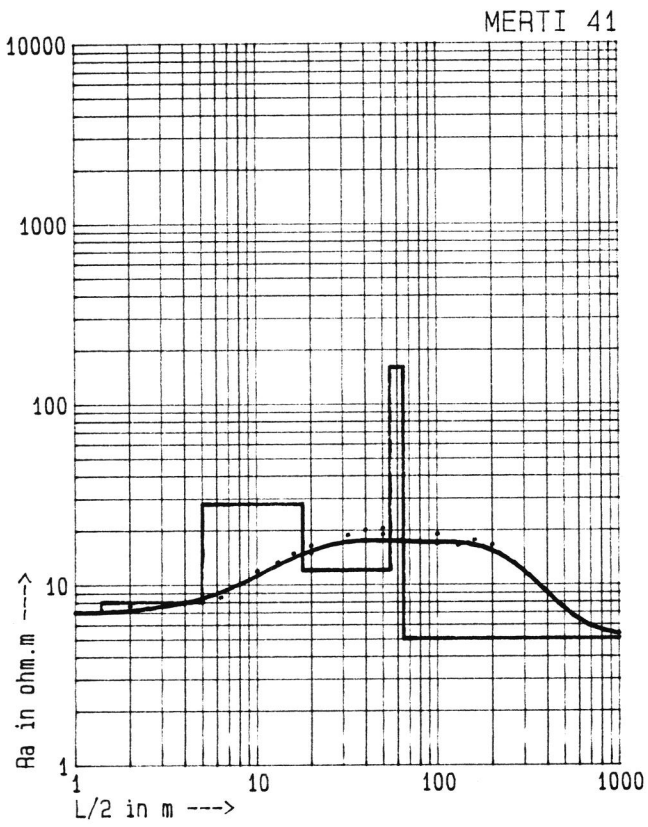


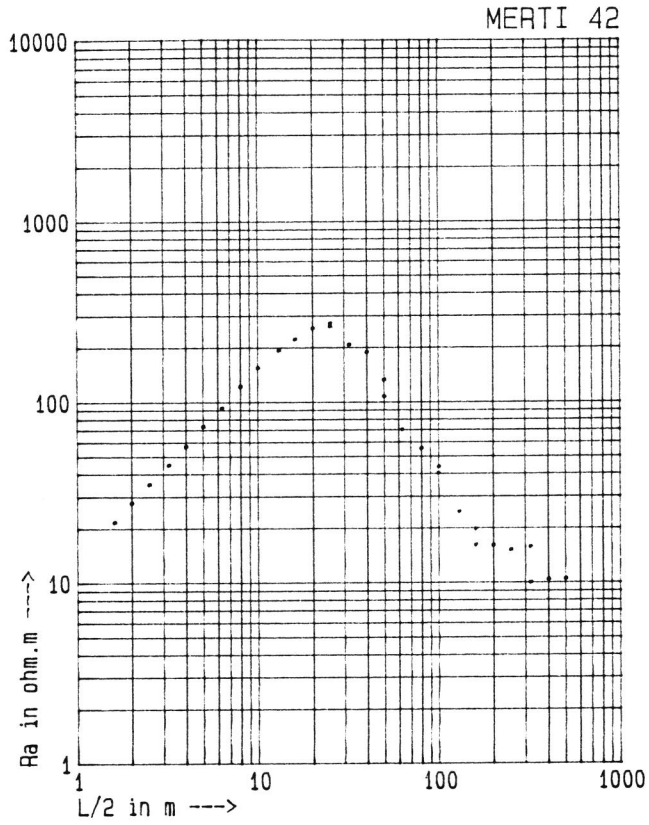


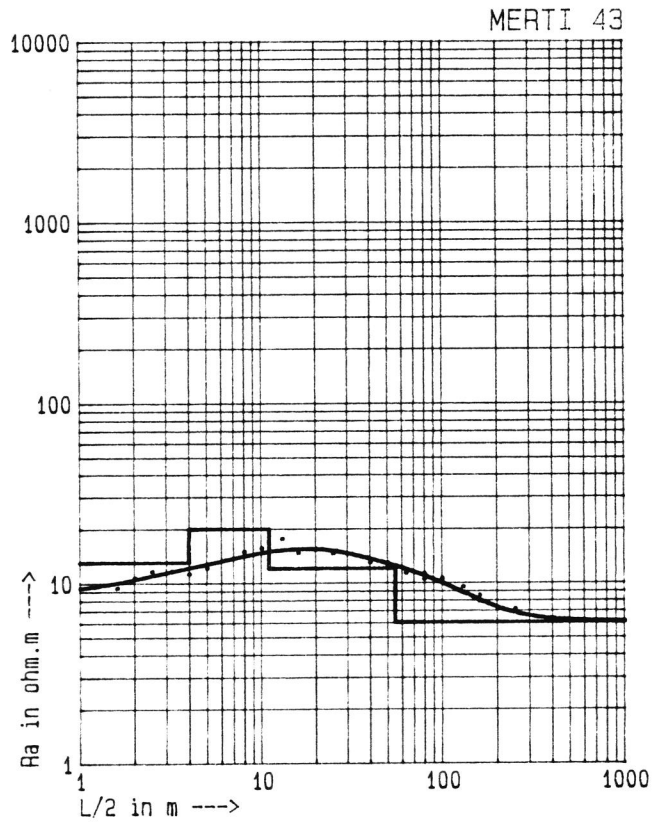


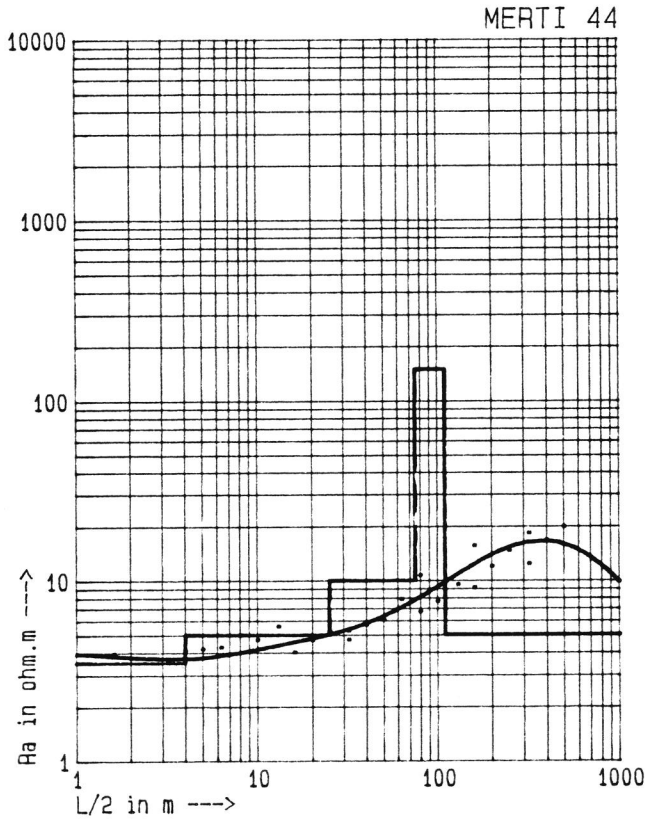


Appendix 3.6.10

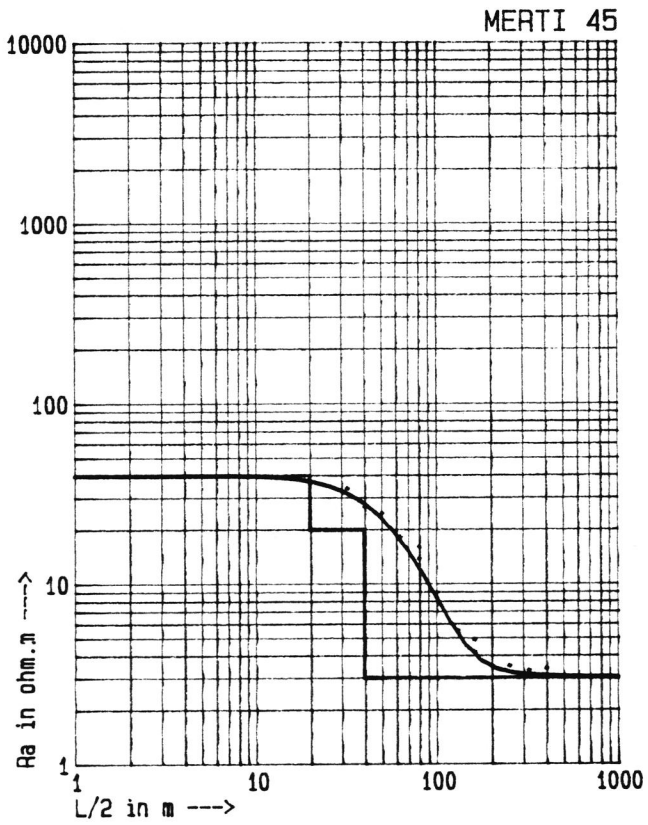


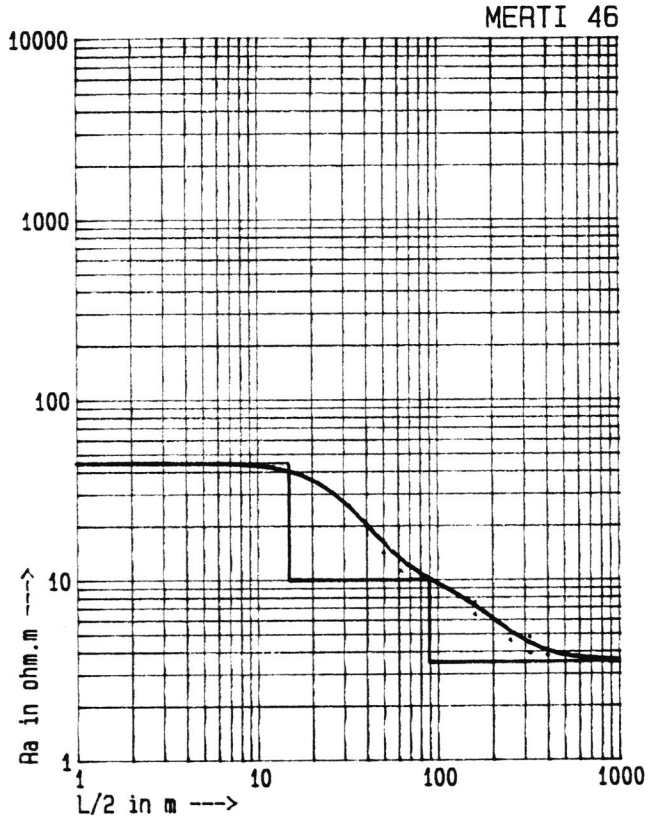


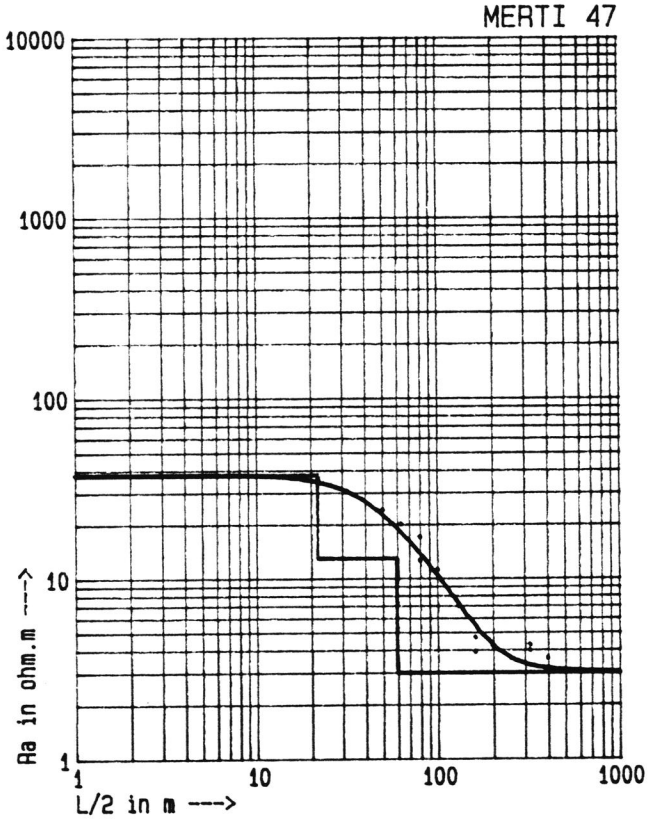


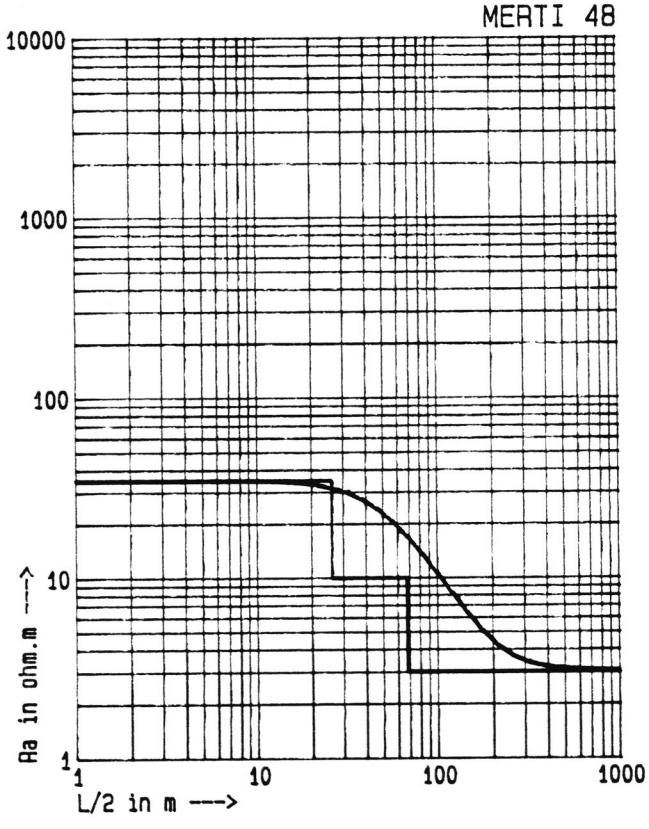


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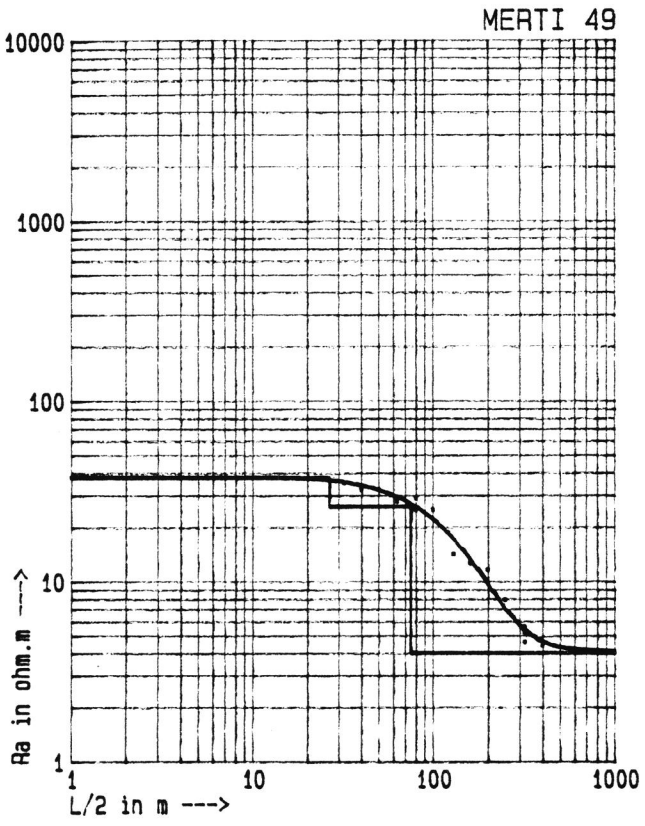


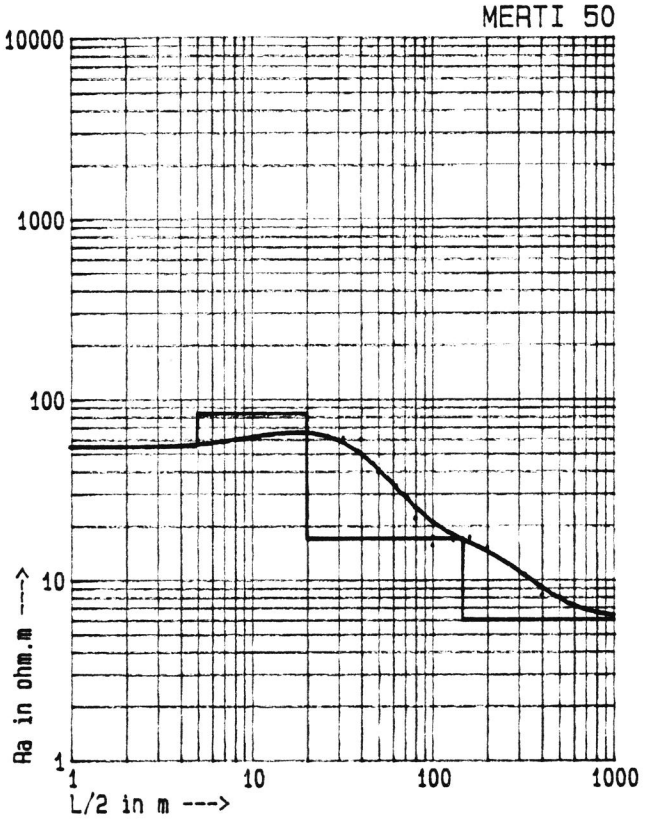


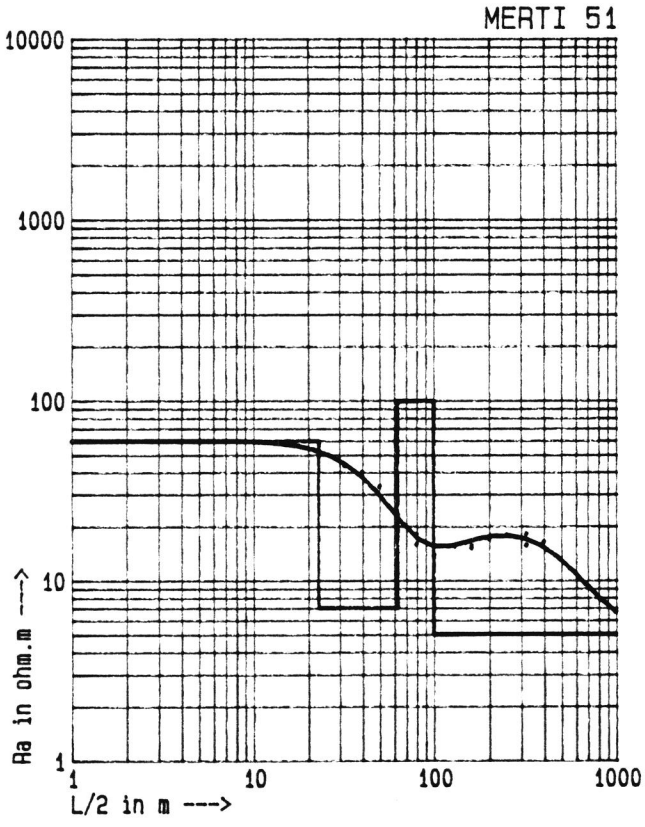


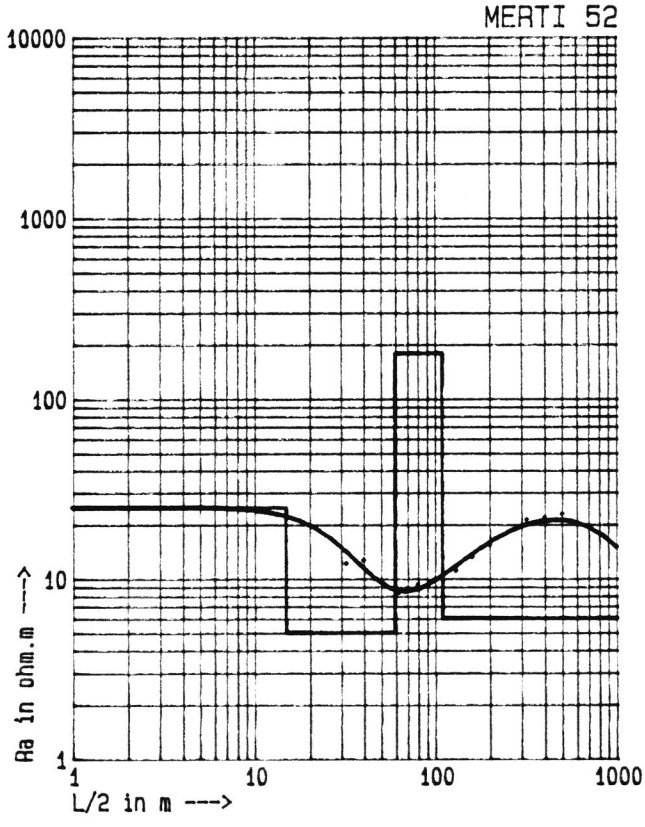


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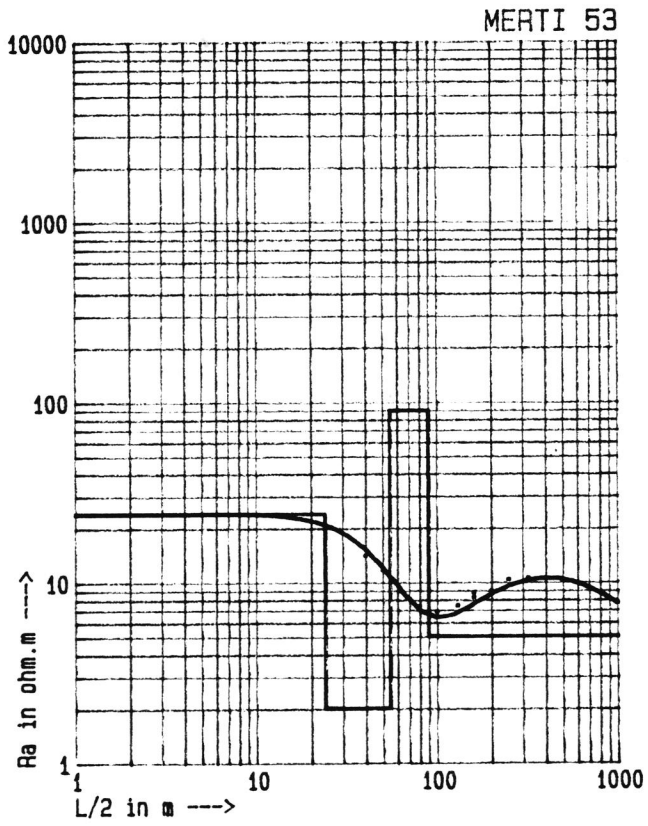


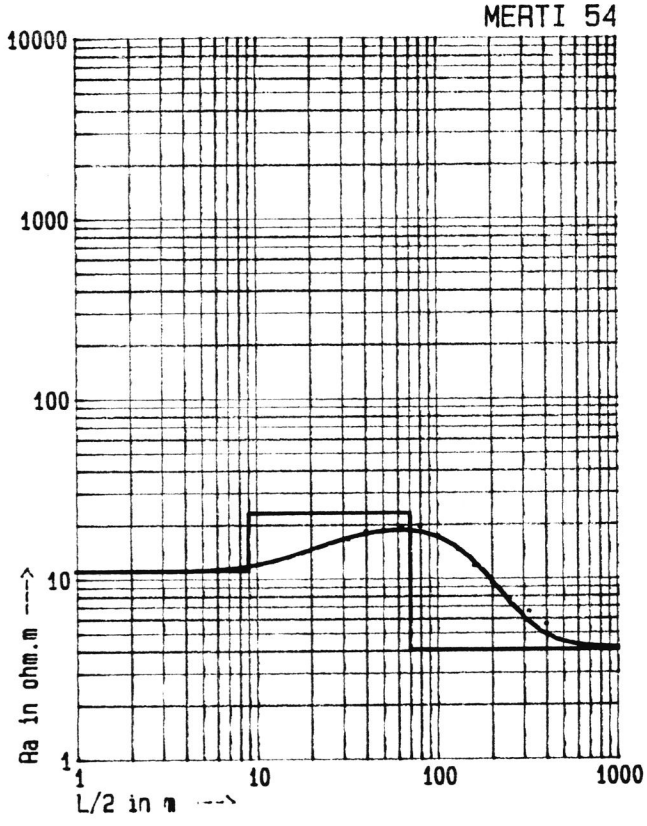


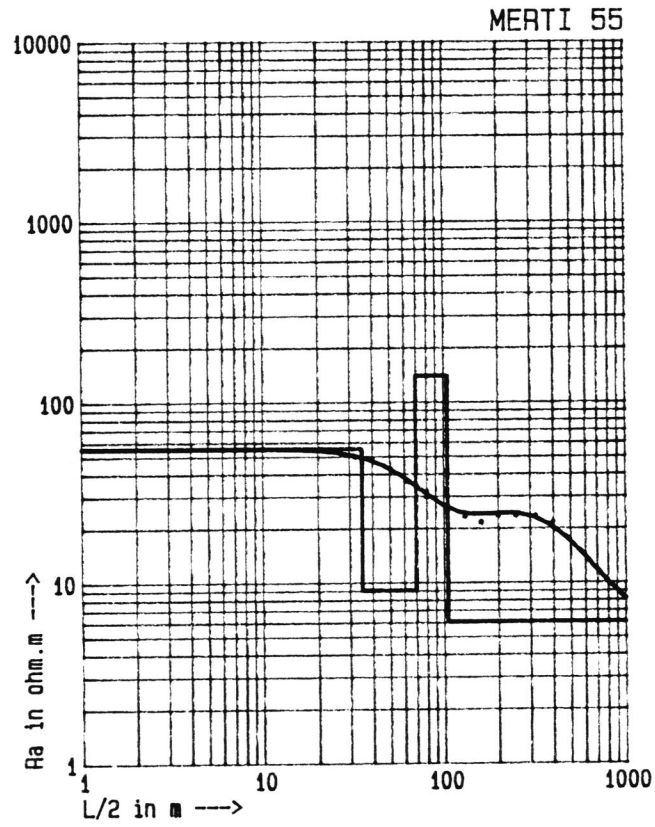


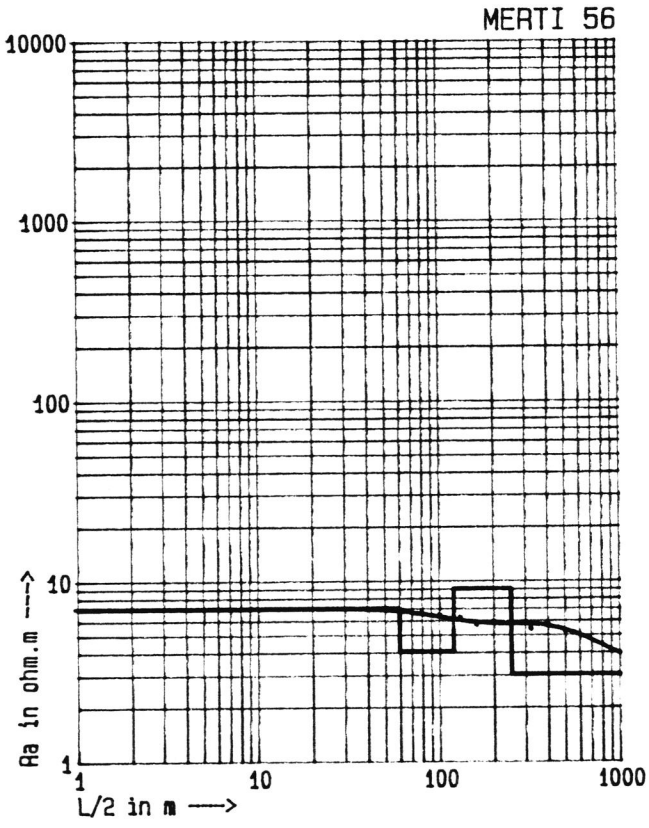


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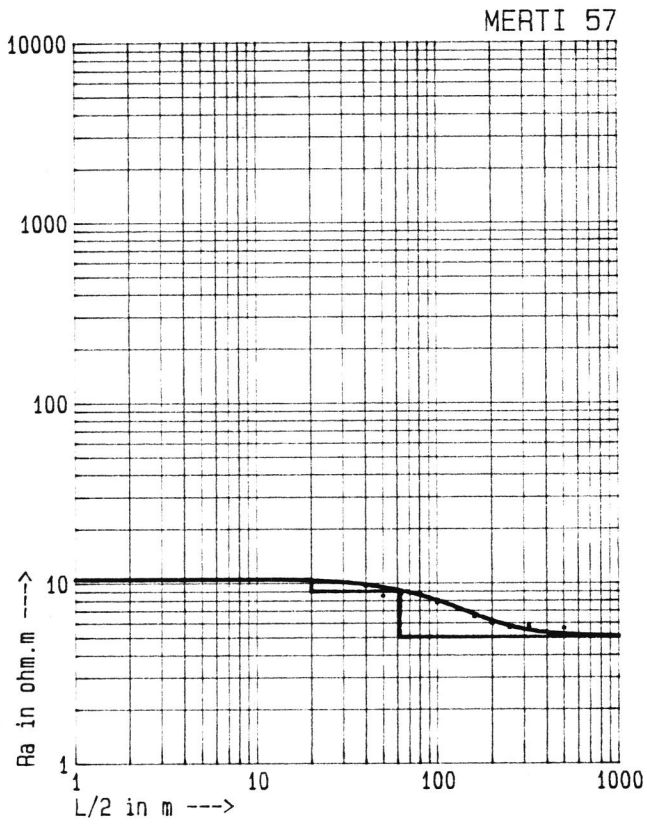


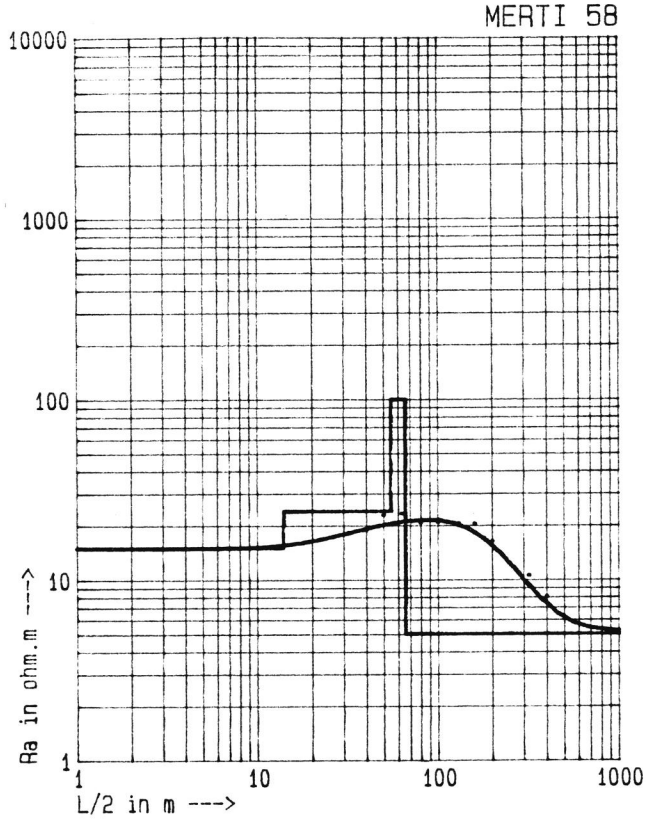


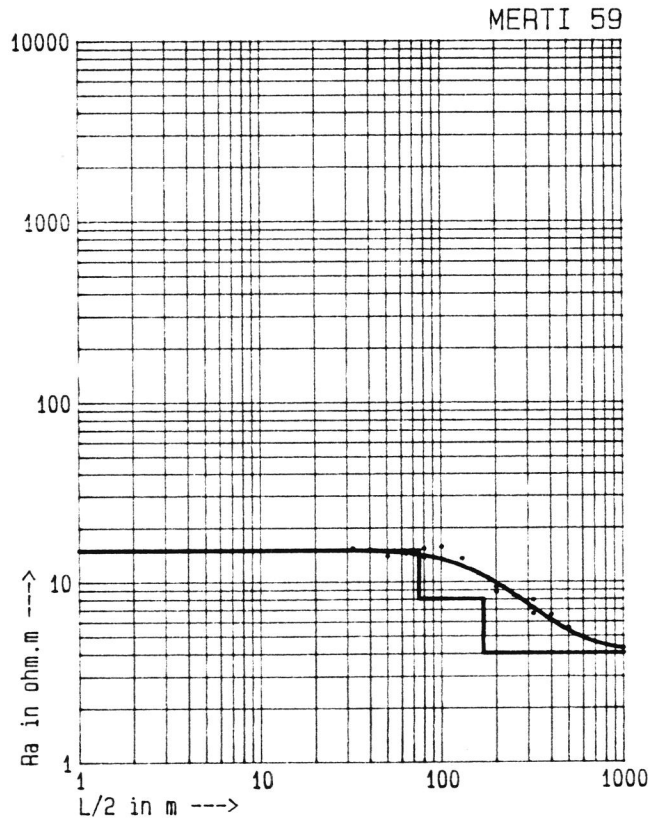


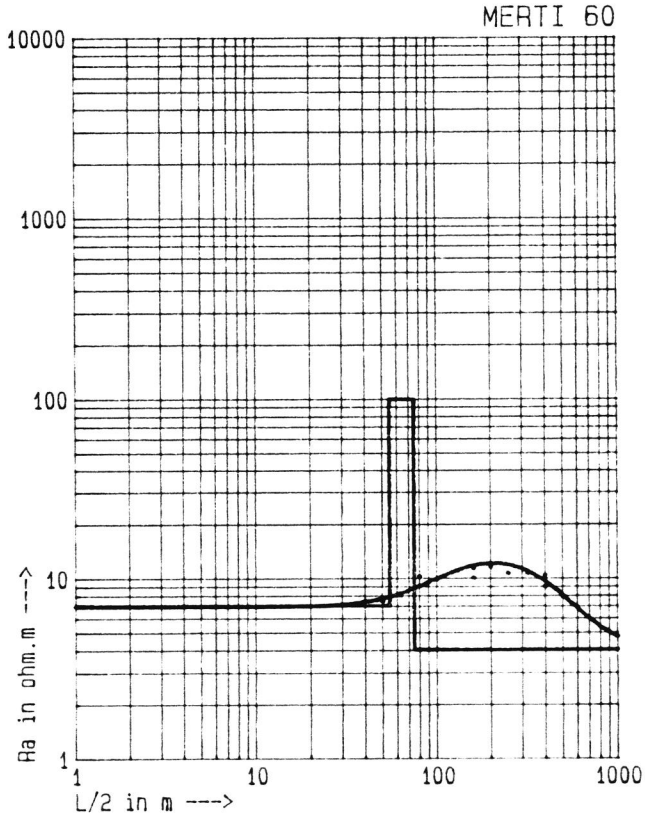


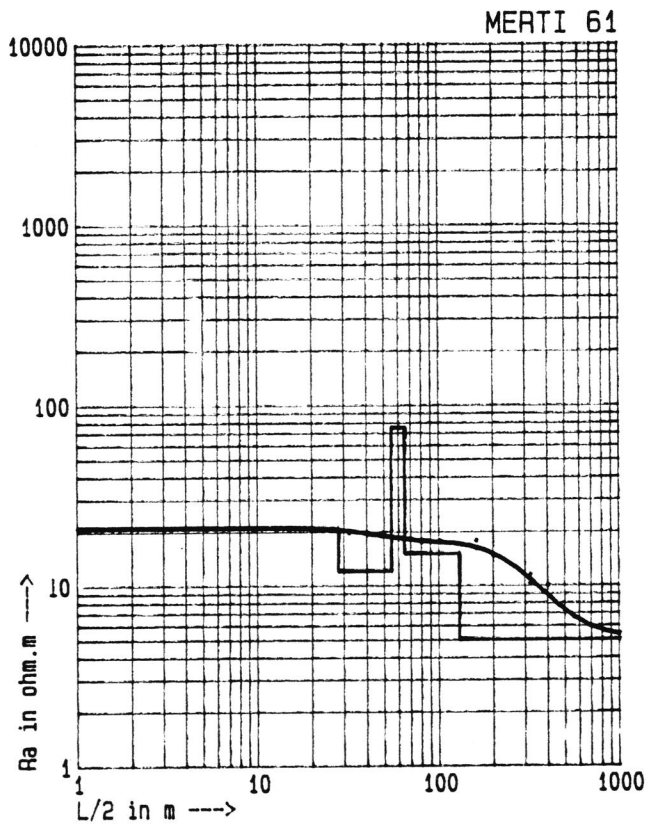
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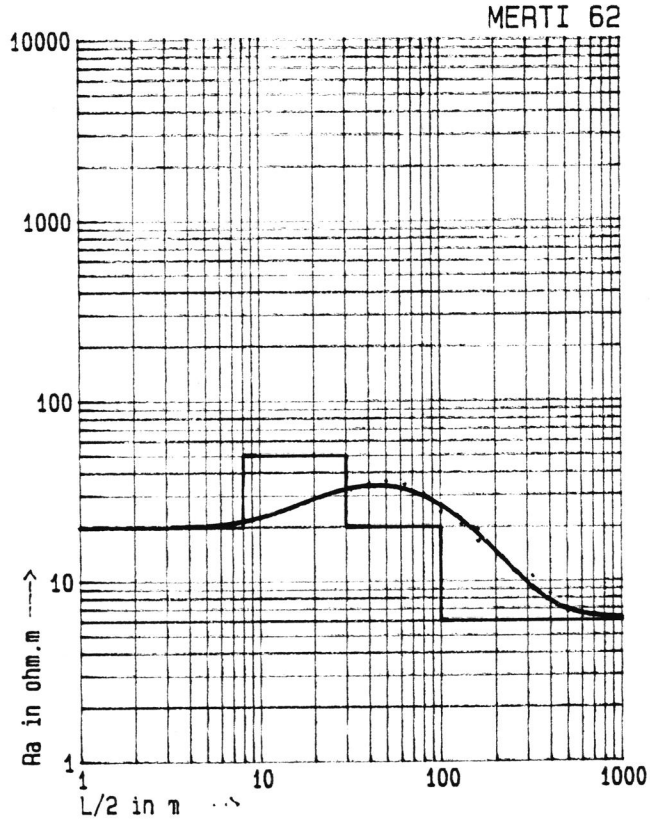

MERTI 57
10000
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

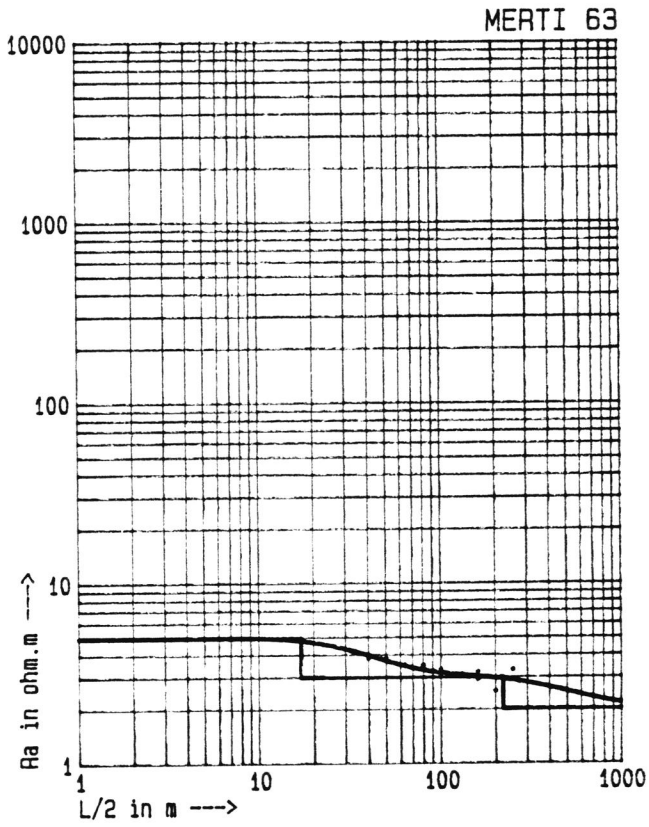

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10000
1000
100
10
1
Ra in ohm.m --->
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10
100
1000
L/2 in m --->

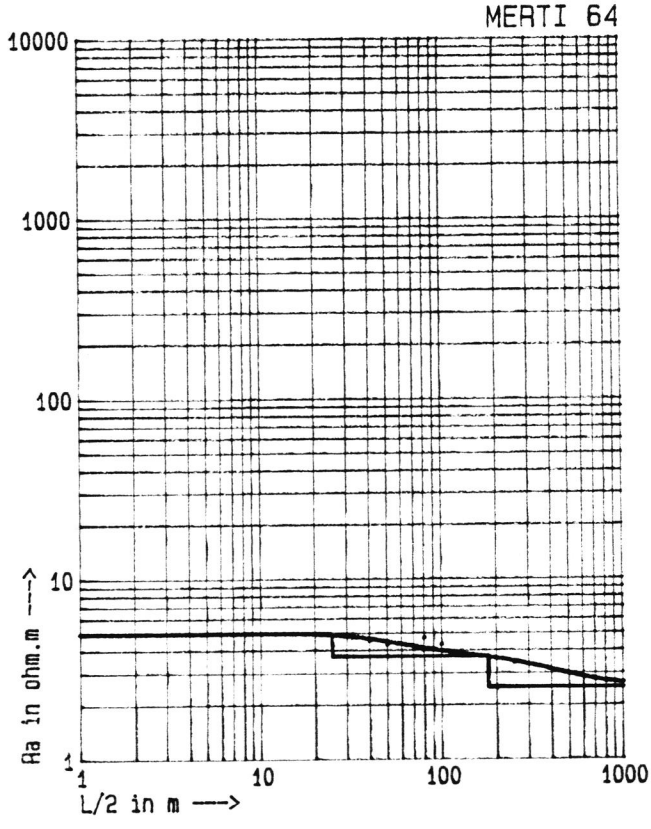

MERTI 59
10000
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


MERTI 60
10000
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

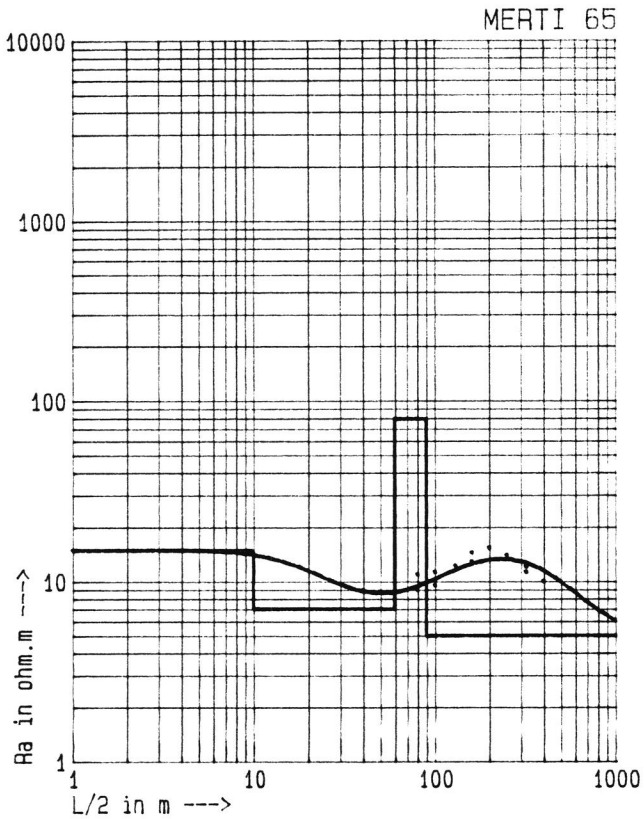


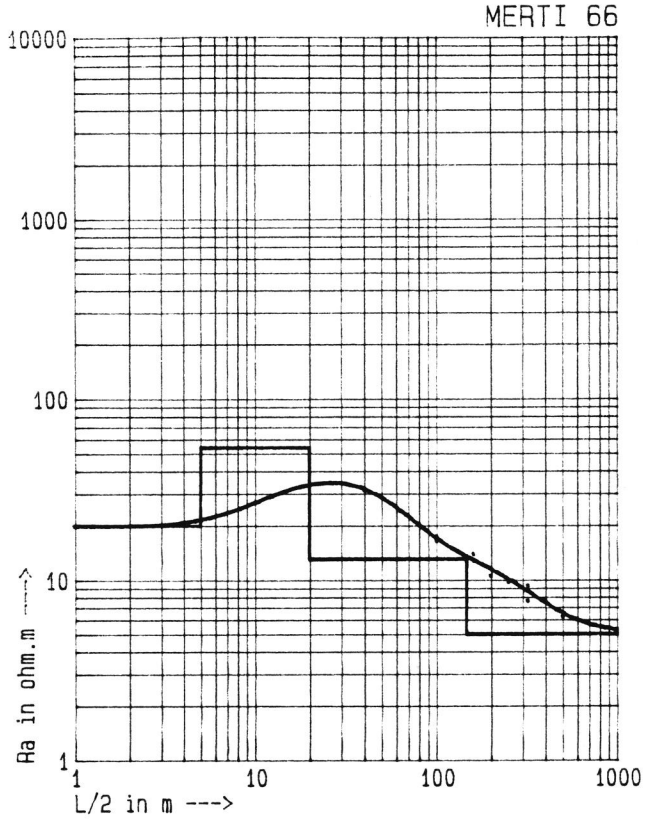


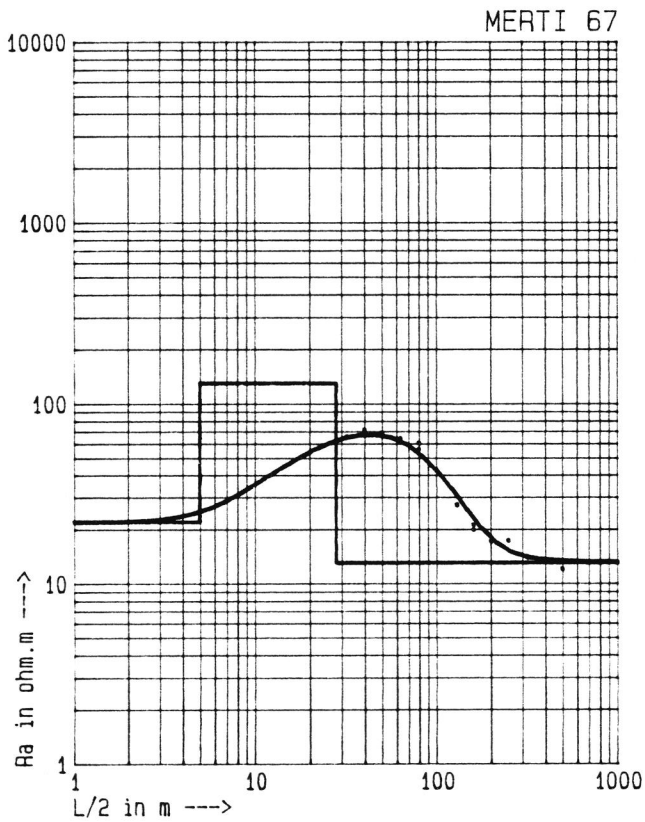


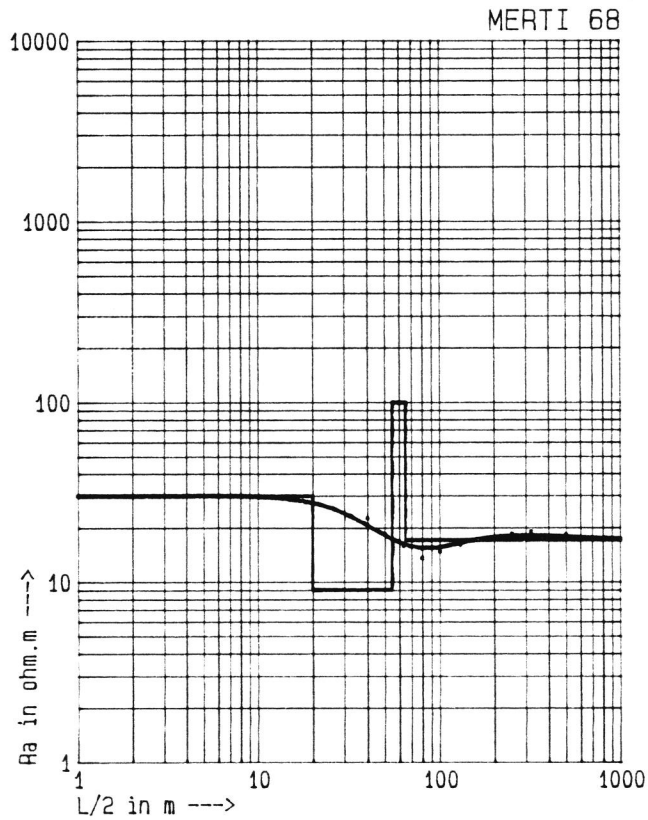


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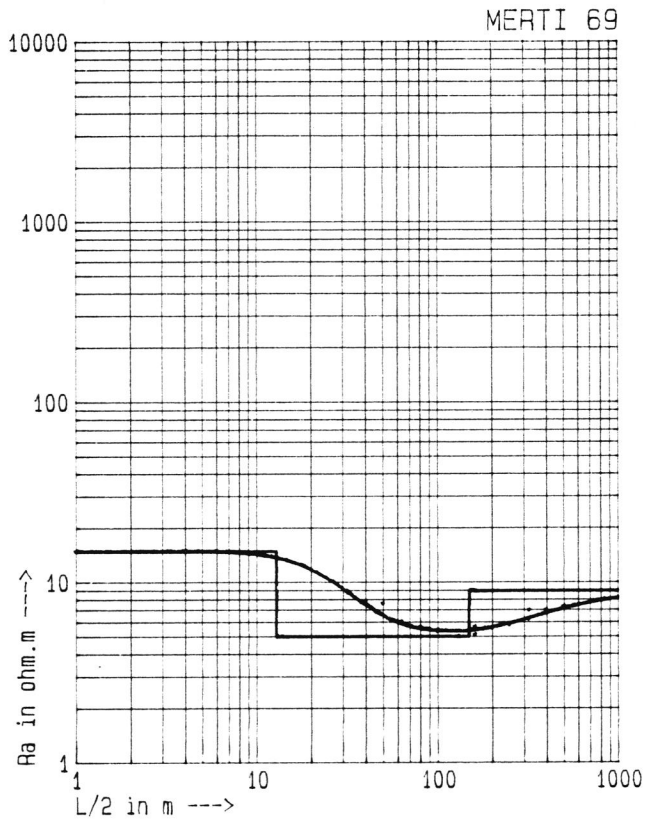


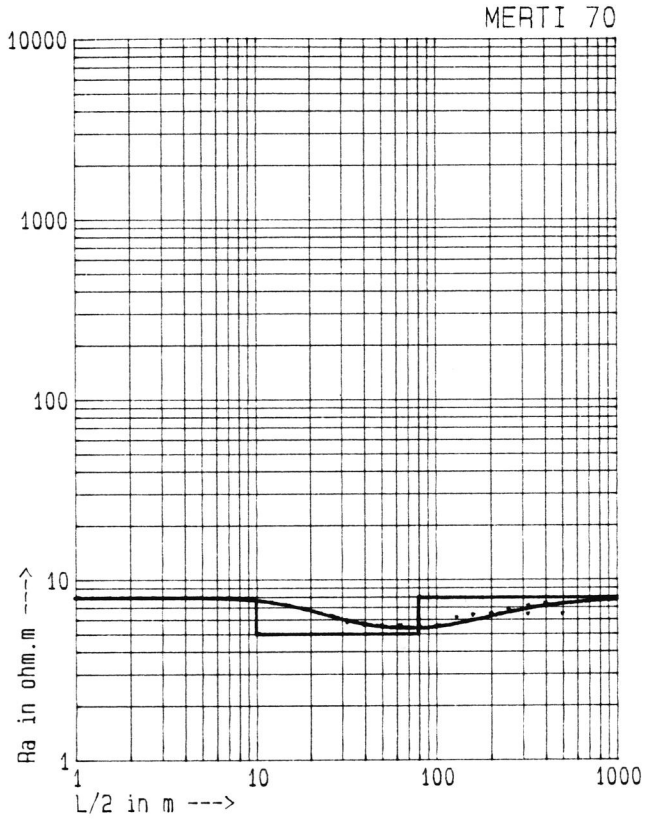


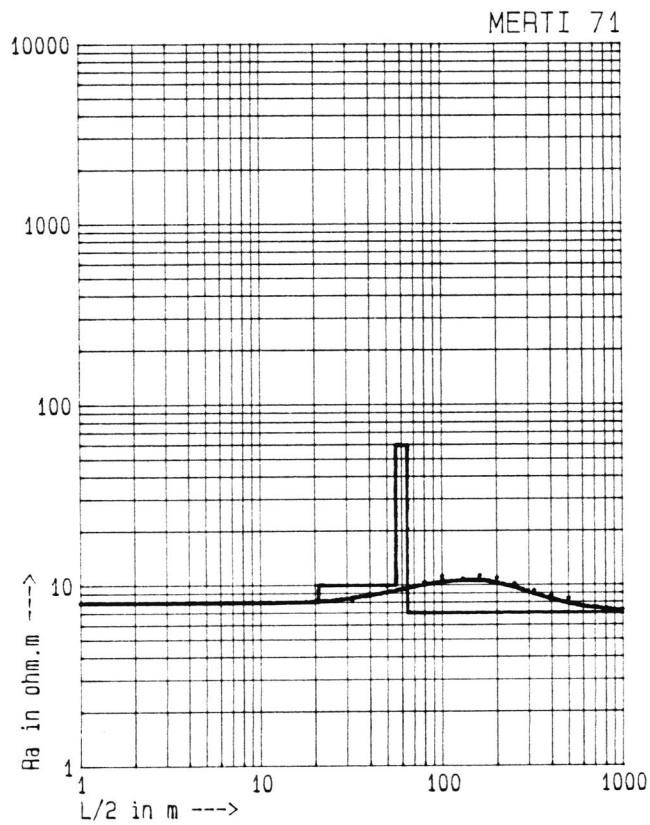


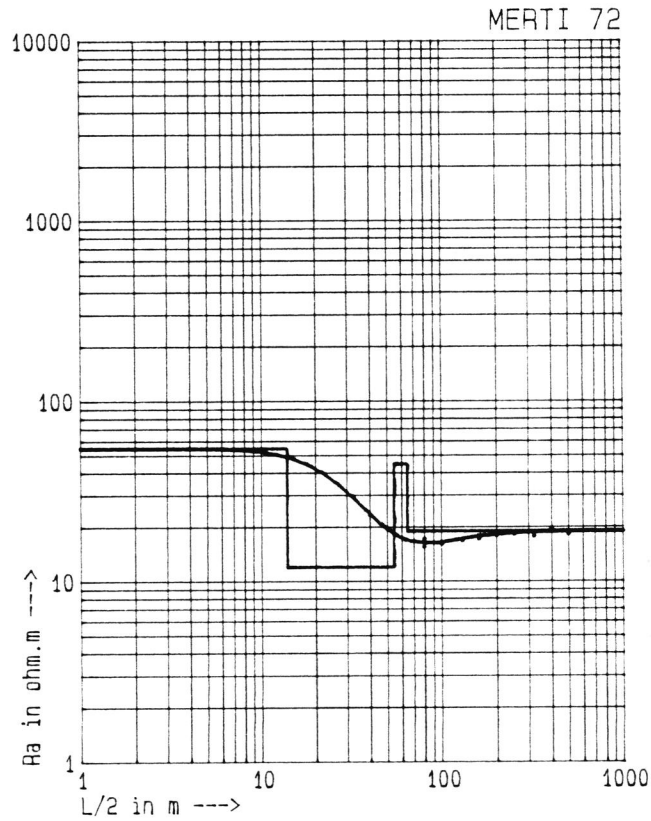


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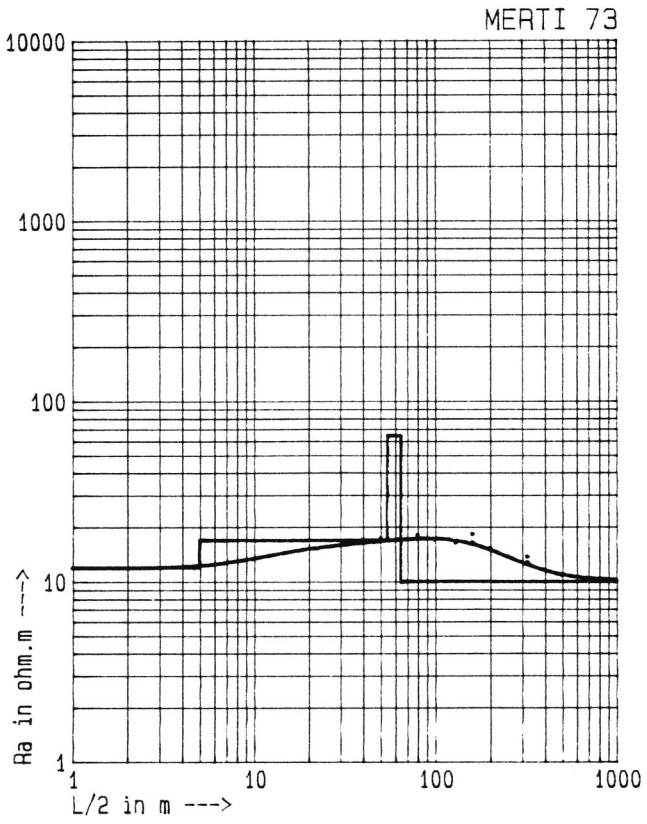


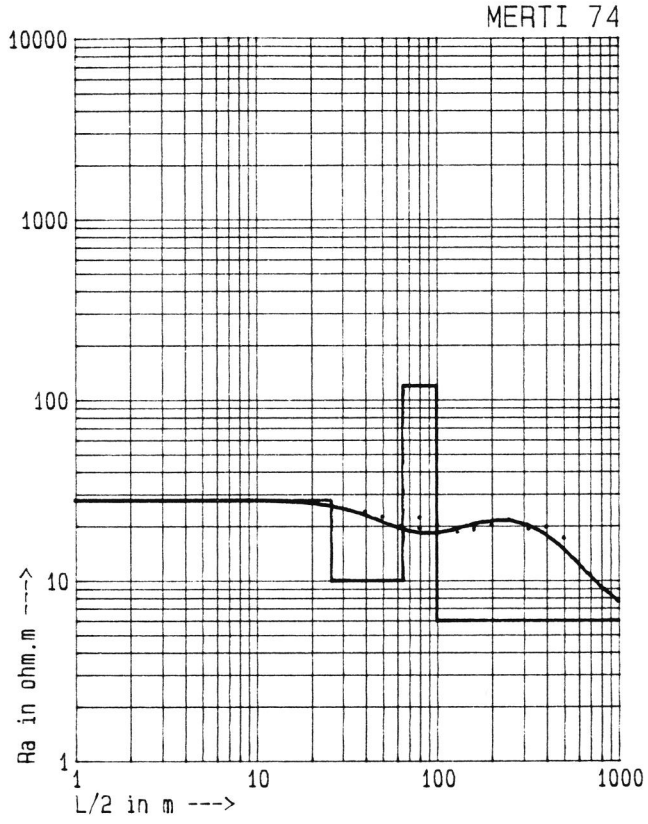


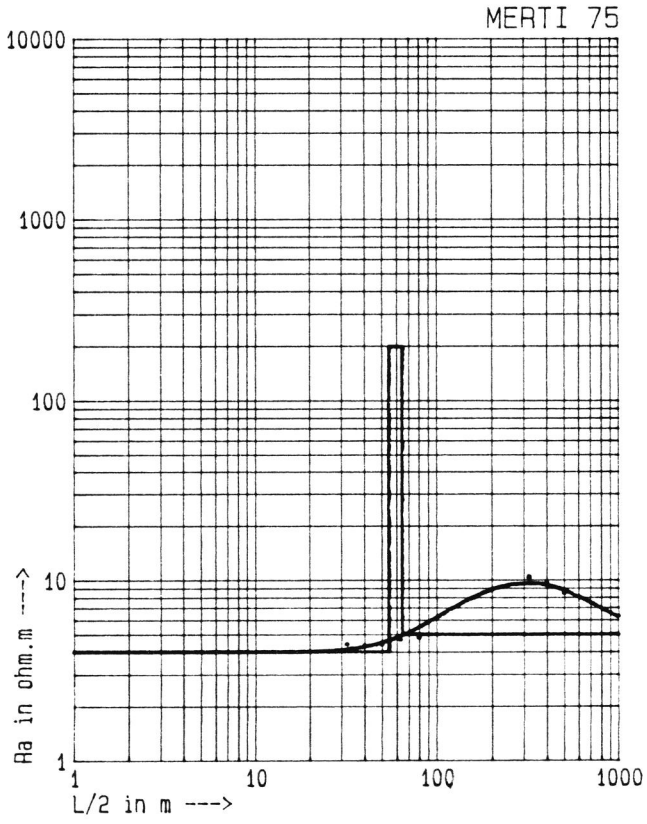


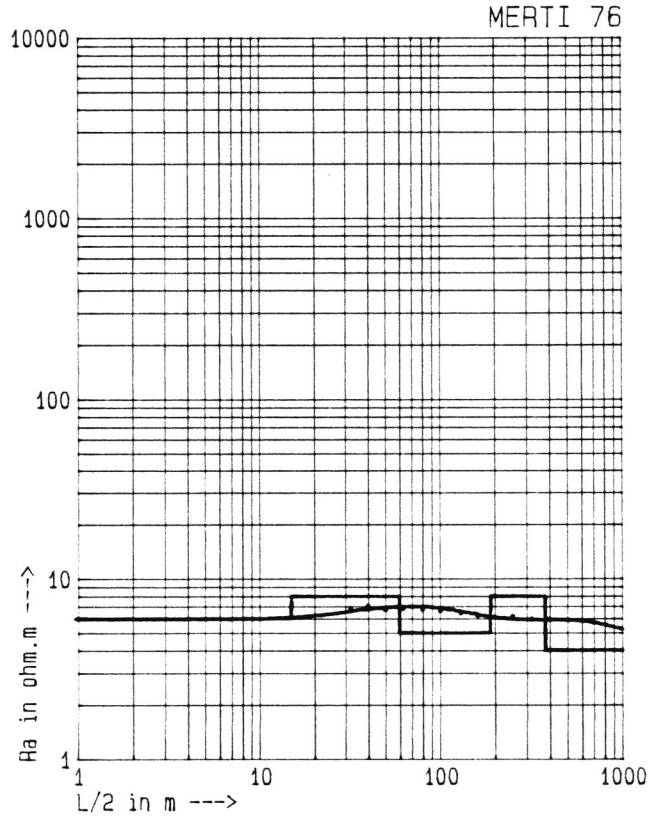


Appendix 3.6.18

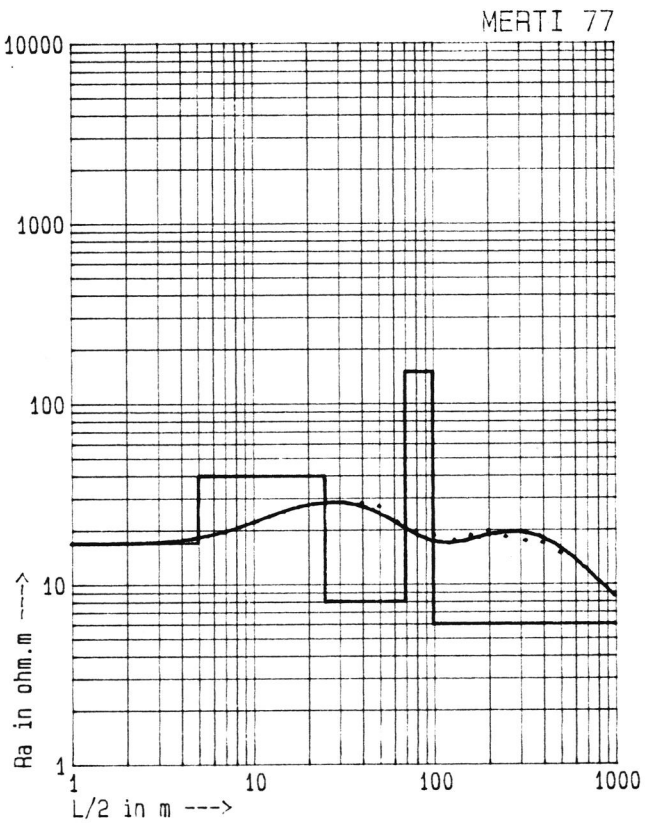


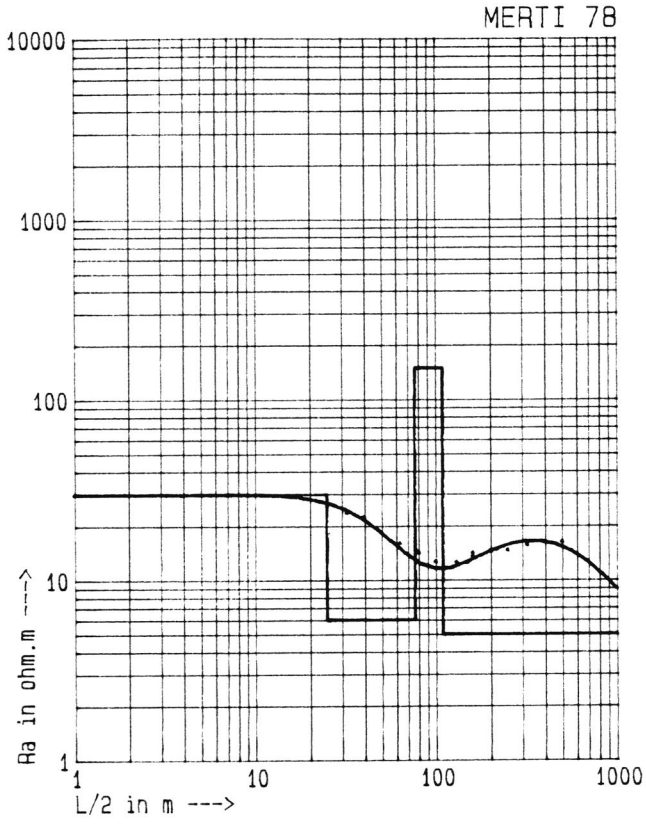


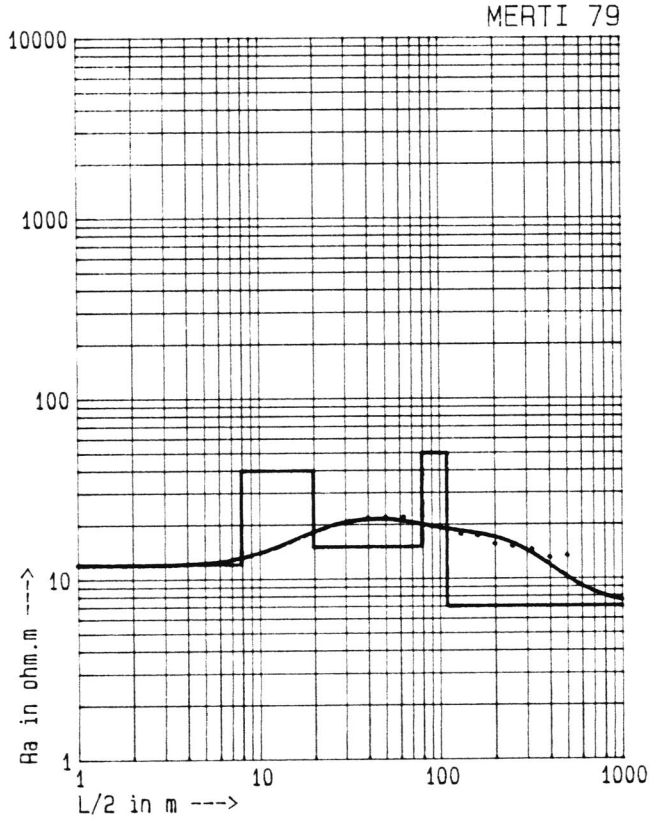


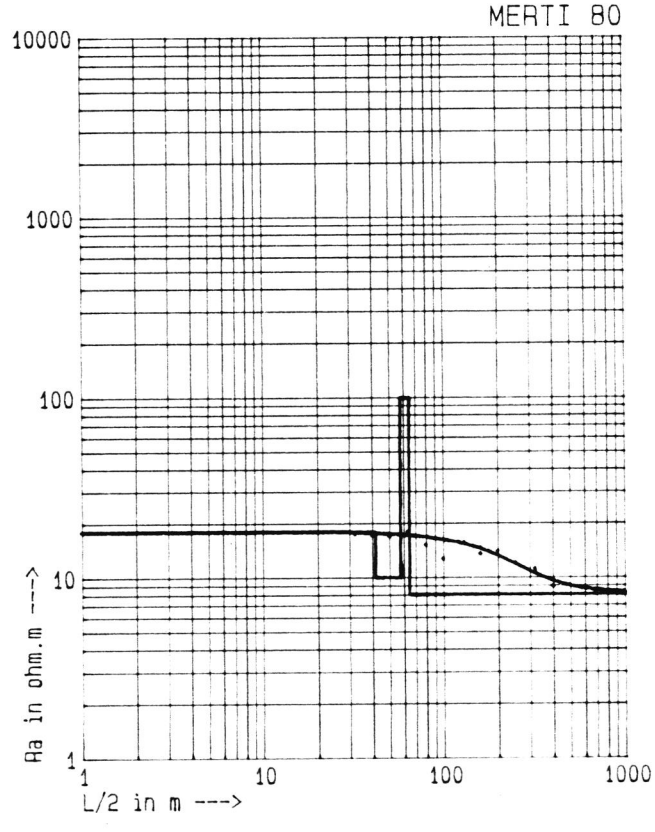


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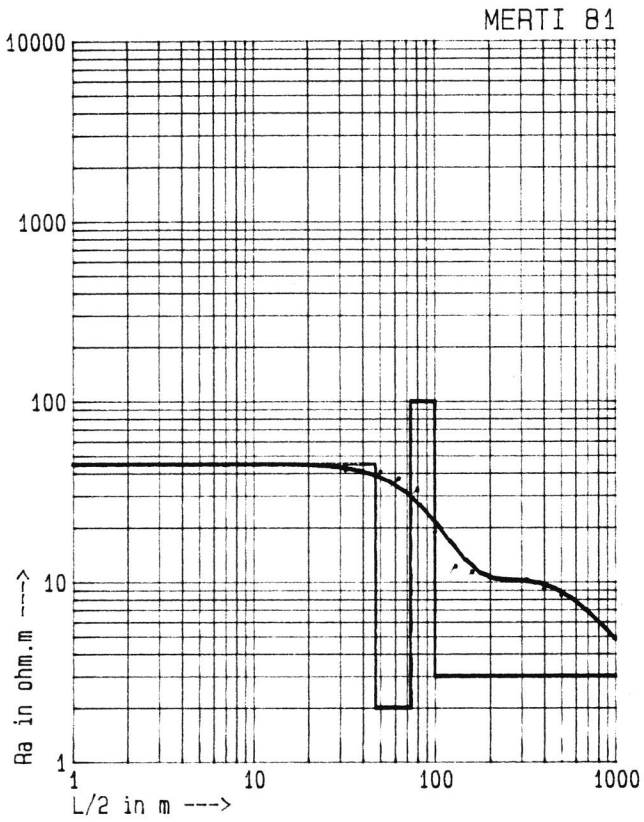








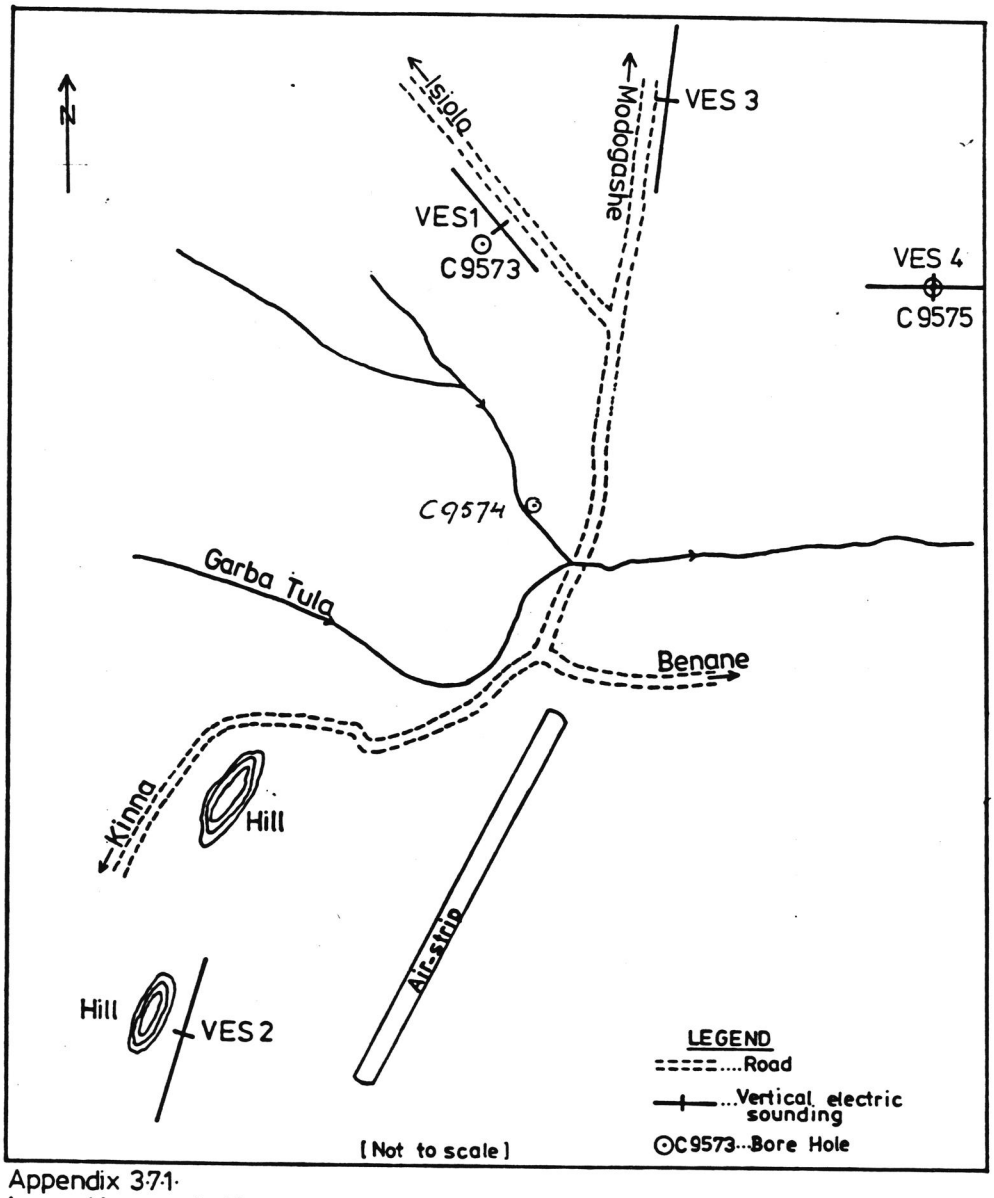
Appendix 3.6.20



Appendix 3.6.21

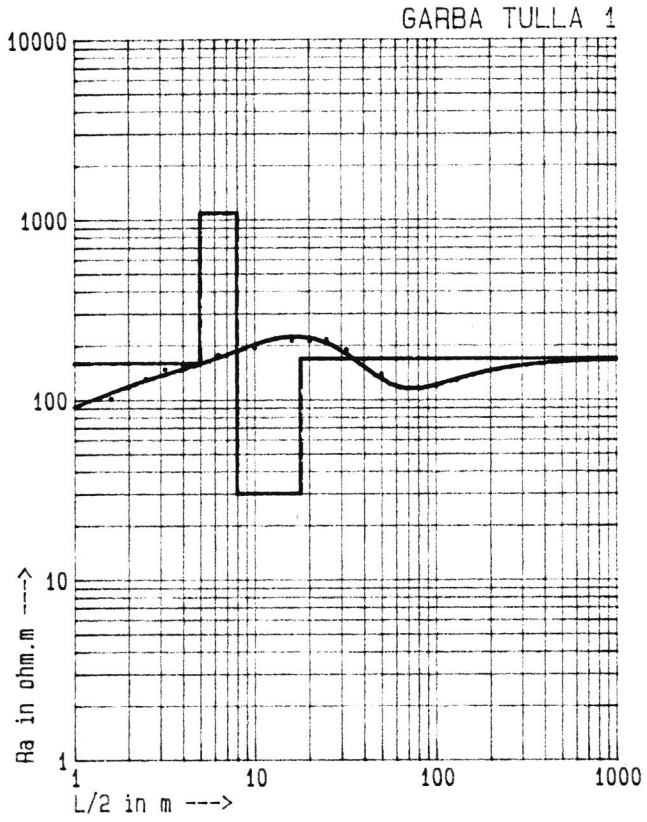
Appendix 3.7

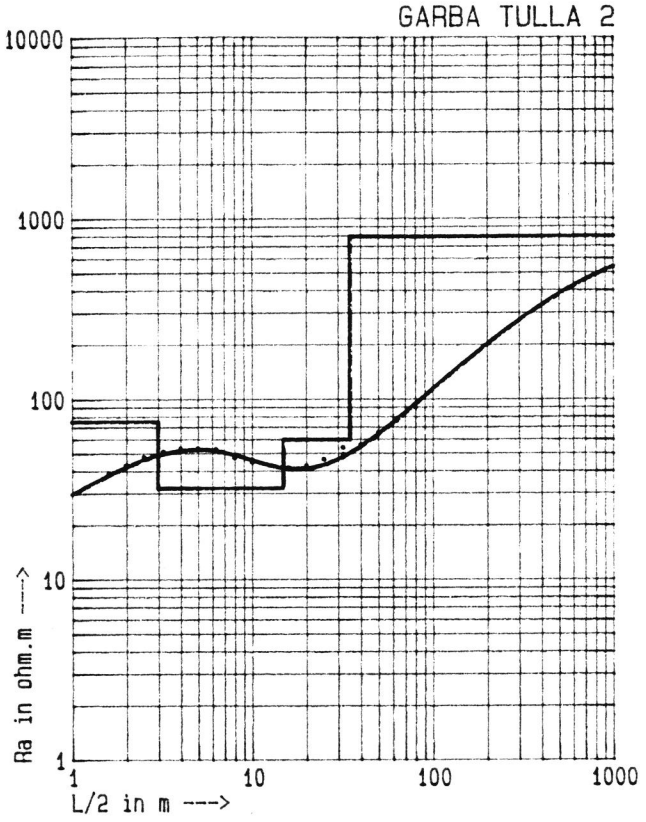
Garba Tula

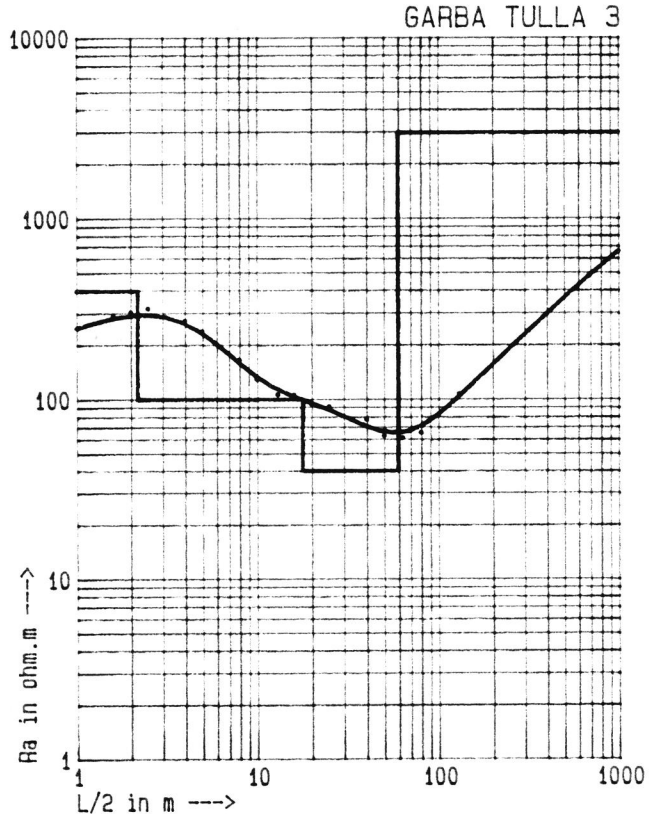


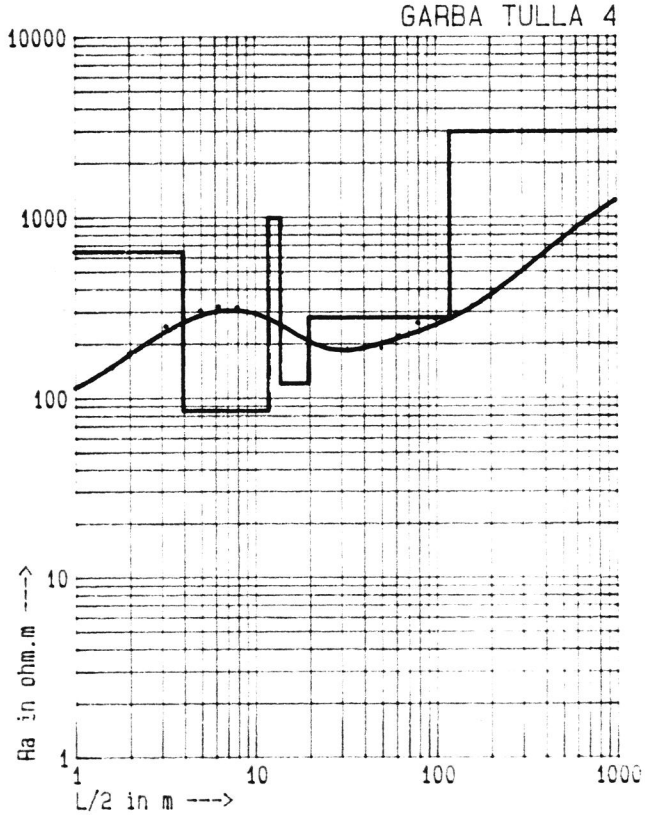
Appendix 3·7·1·

Location of the soundings made at Garba Tula





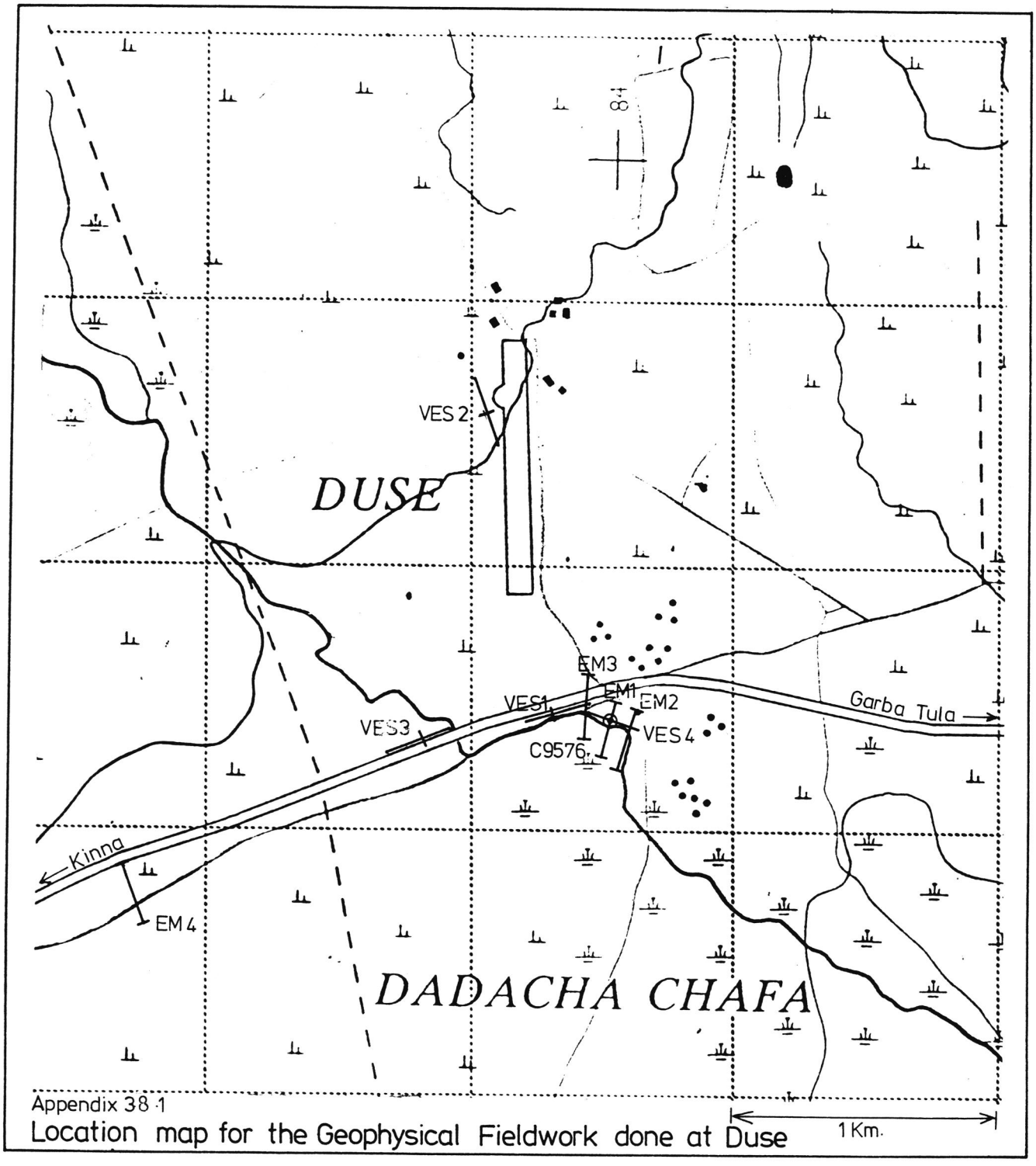




Appendix 3.7.2

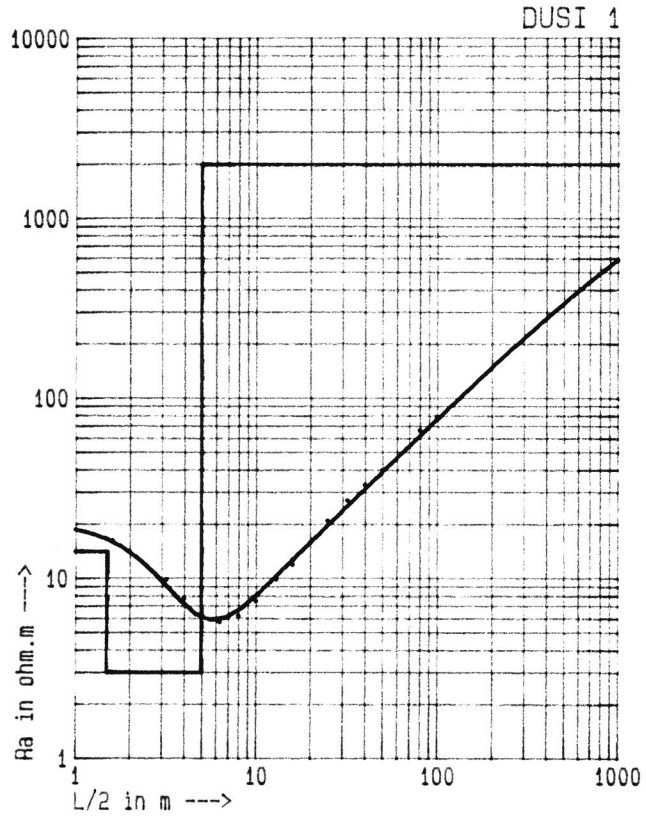
Appendix 3.8

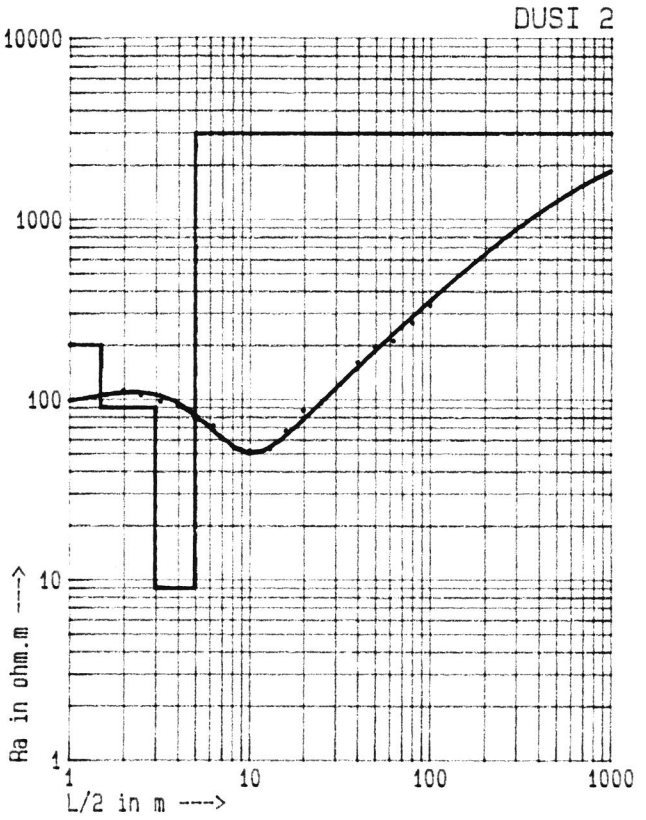
Duse

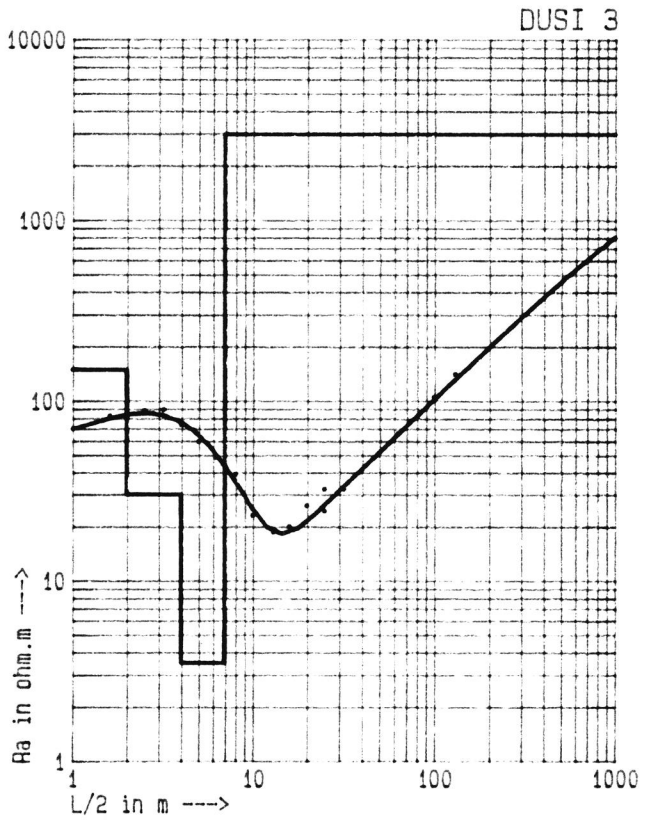


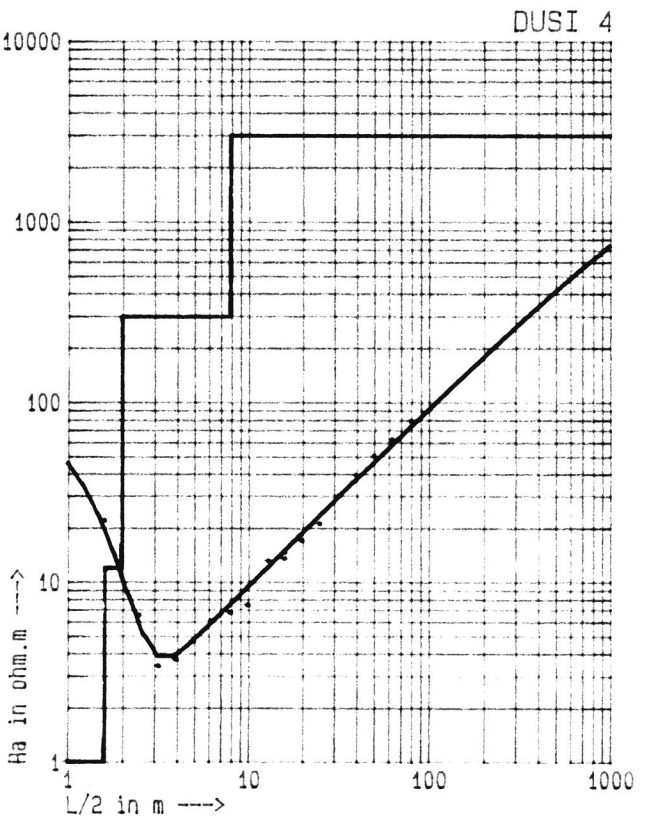
Appendix 38-1

Location map for the Geophysical Fieldwork done at Duse









Appendix 3.8.2

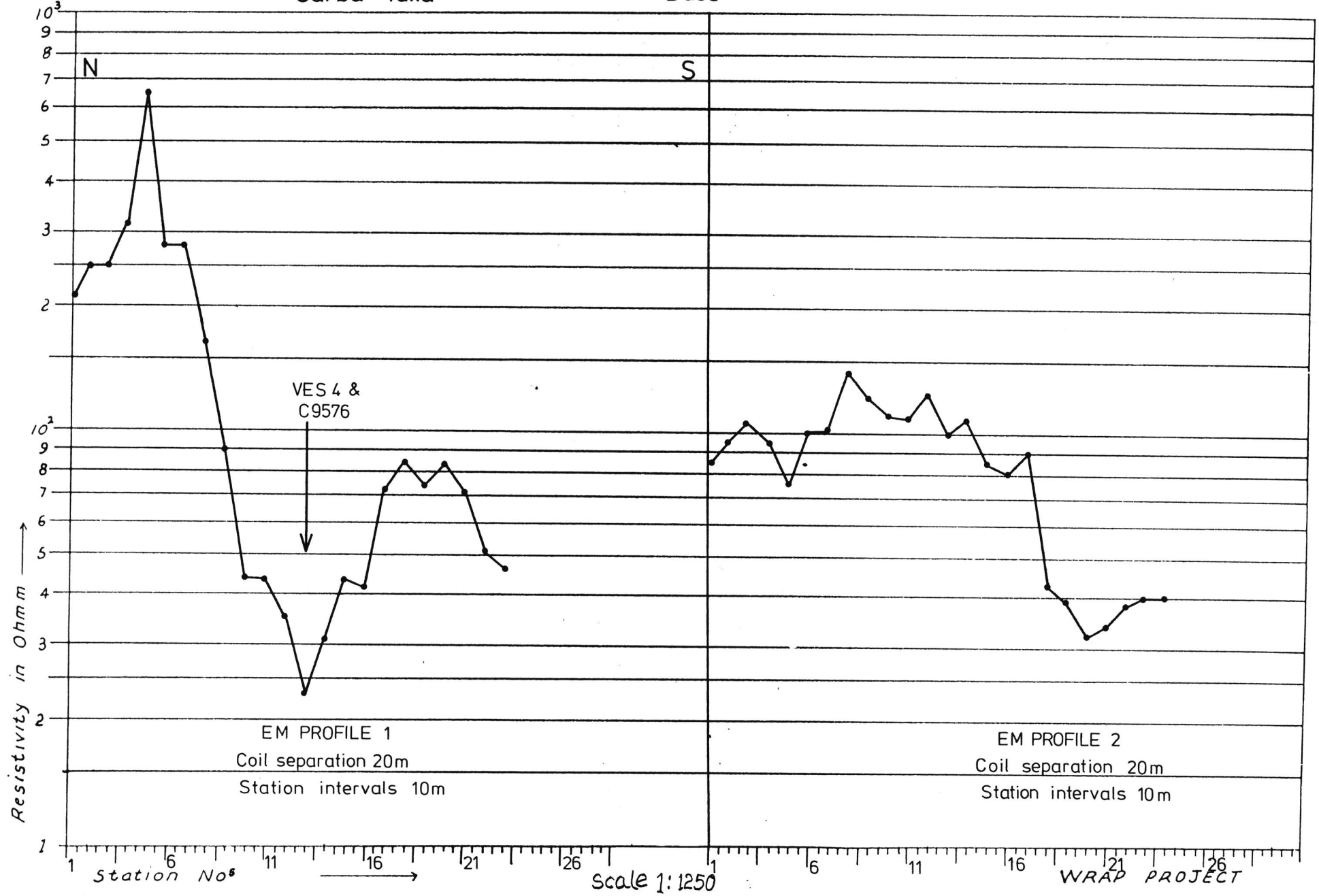
Appendix 3.8.3

DISTRICT :- Isiolo

DIVISION :- Garba Tulla

LOCATION : Duse

EM - Profile No: 1 & 2

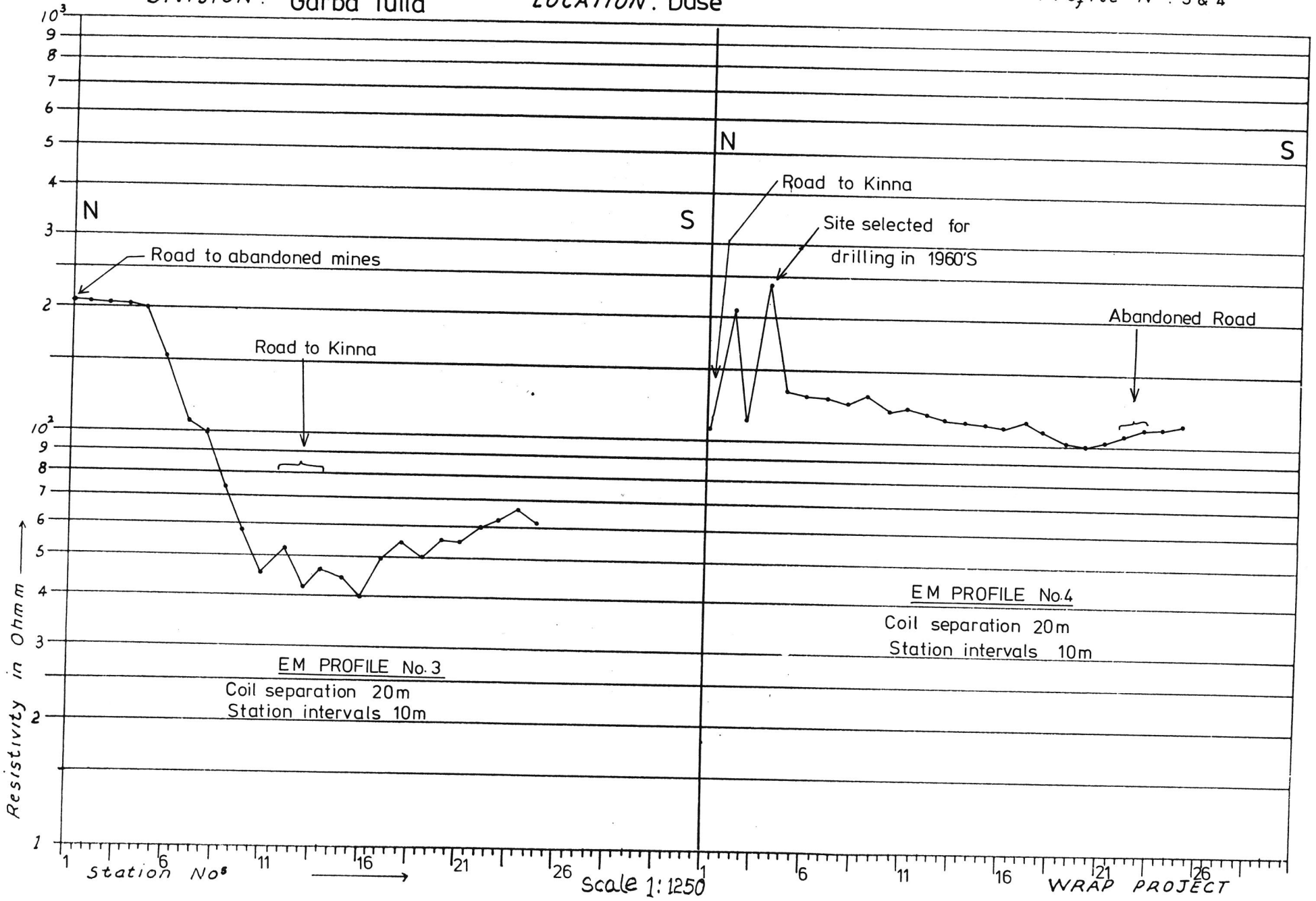


Appendix 3.8.4

DISTRICT :- Isiolo
DIVISION :- Garba Tulla

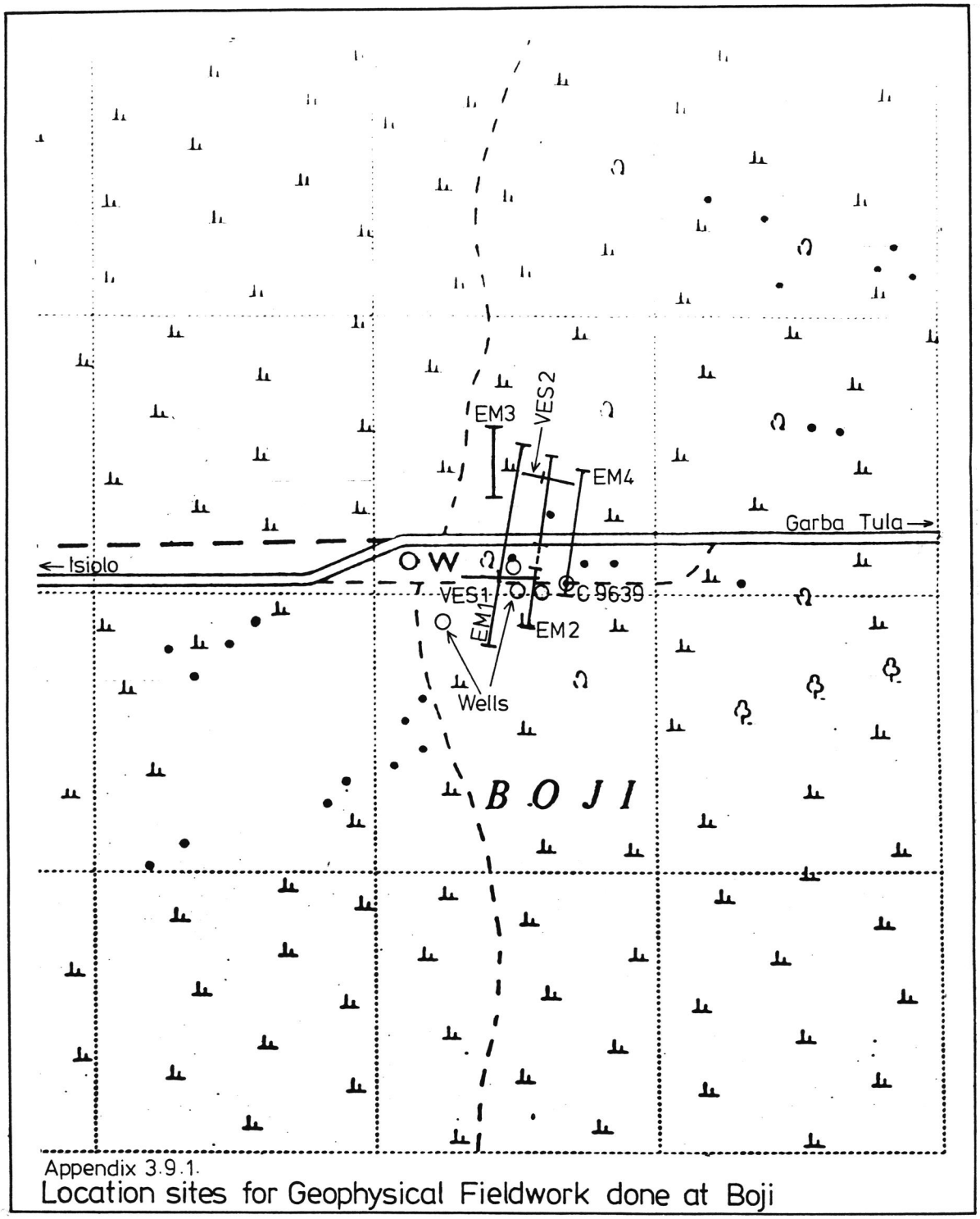
LOCATION: Duse

EM - Profile No: 3 & 4



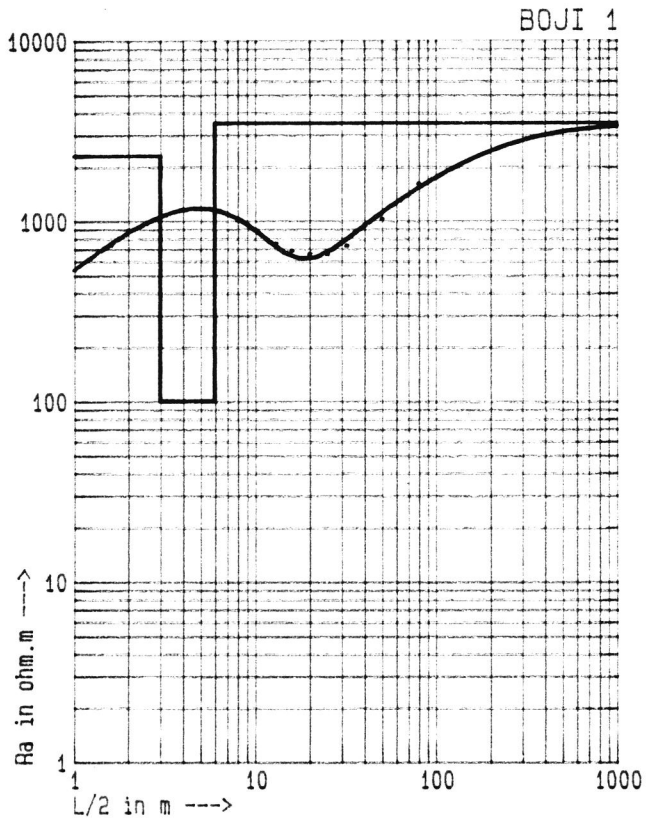
Appendix 3.9

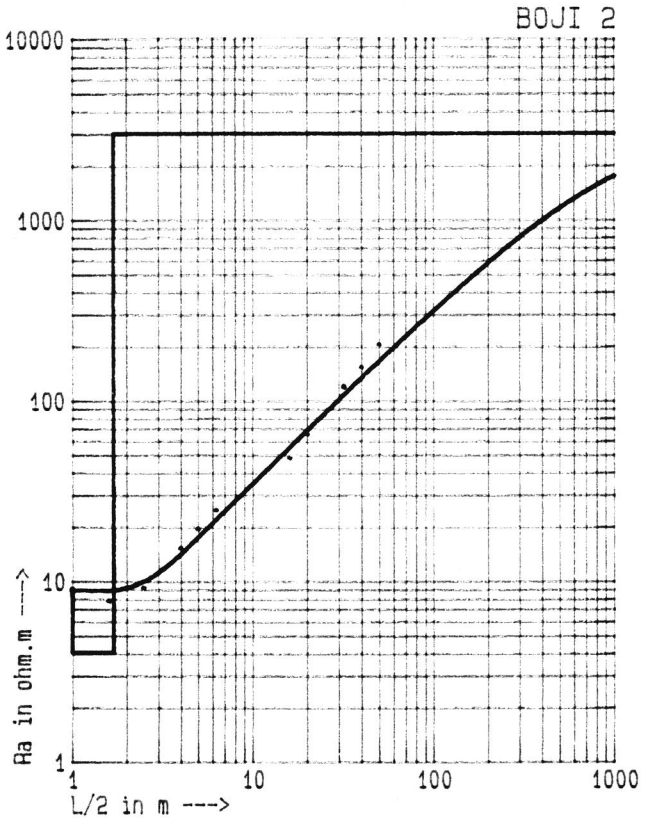
Boji



Appendix 3.9.1.

Location sites for Geophysical Fieldwork done at Boji





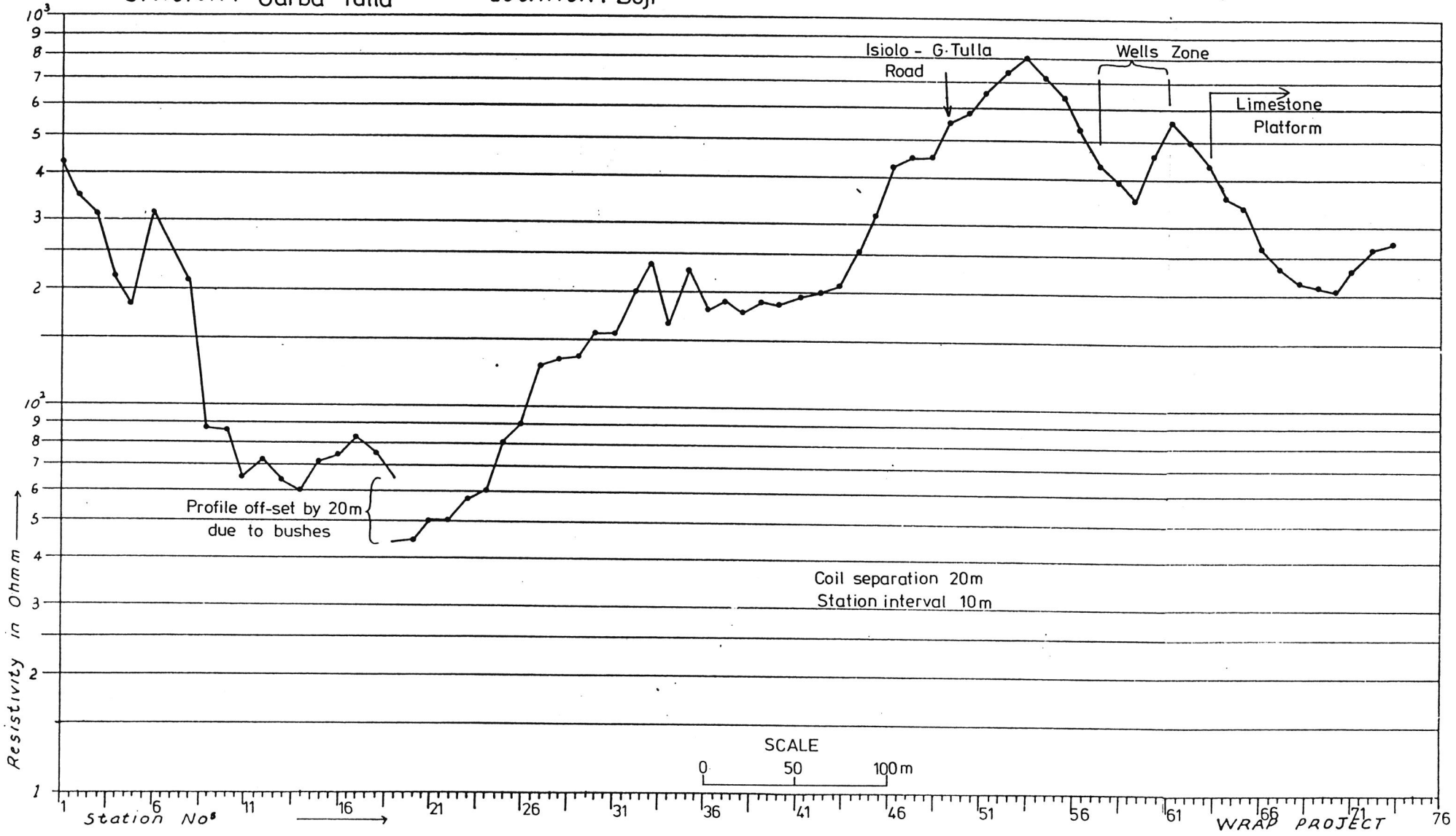
Appendix 3.9.2

Appendix 3.9.3 (a)

DISTRICT :- Isiolo
DIVISION :- Garba Tulla

LOCATION: Boji

Profile No: 1

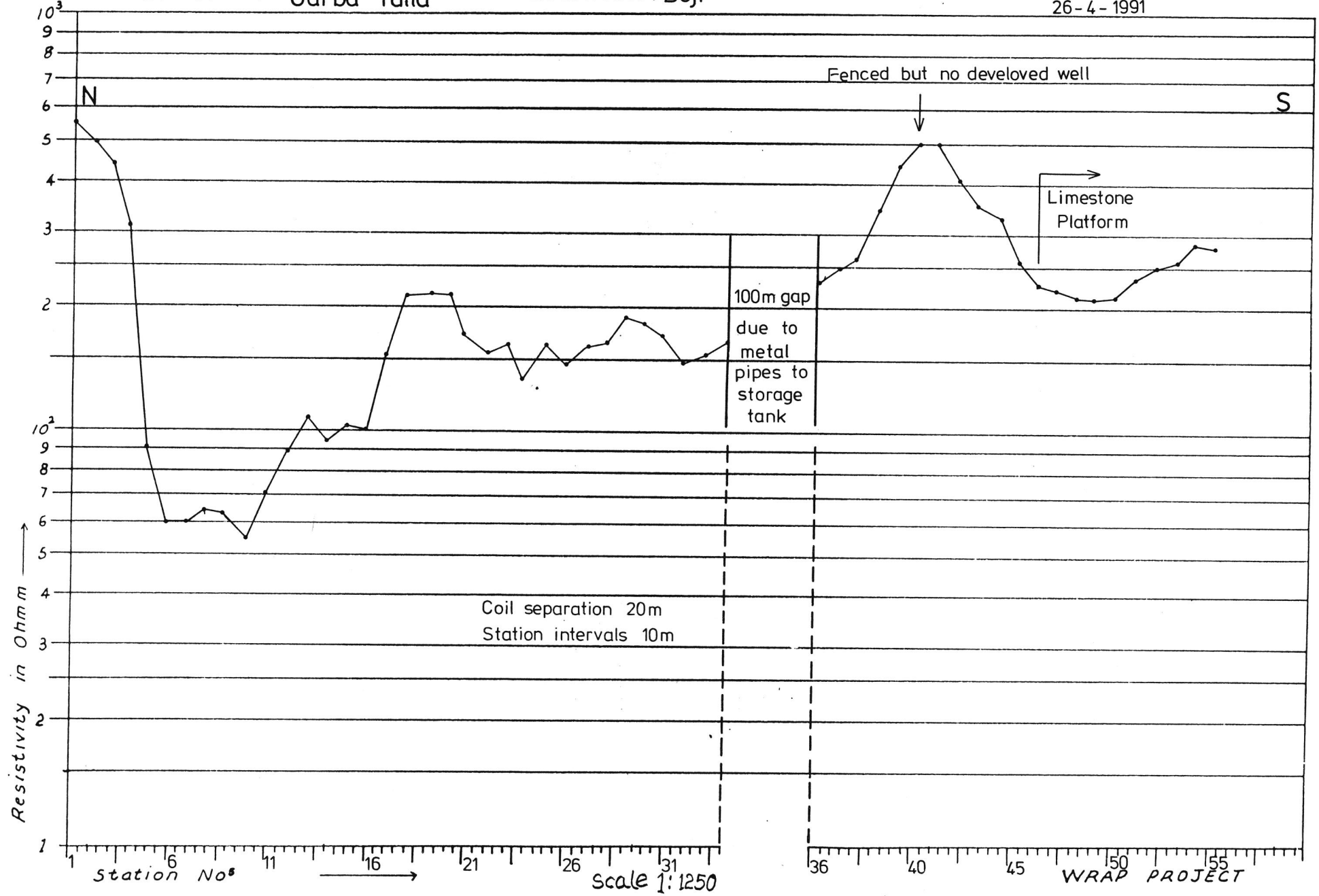


Appendix 3.9.3 (b)

DISTRICT :- Isiola
DIVISION :- Garba Tulla

LOCATION : Boji

EM - Profile No: 2
26-4-1991

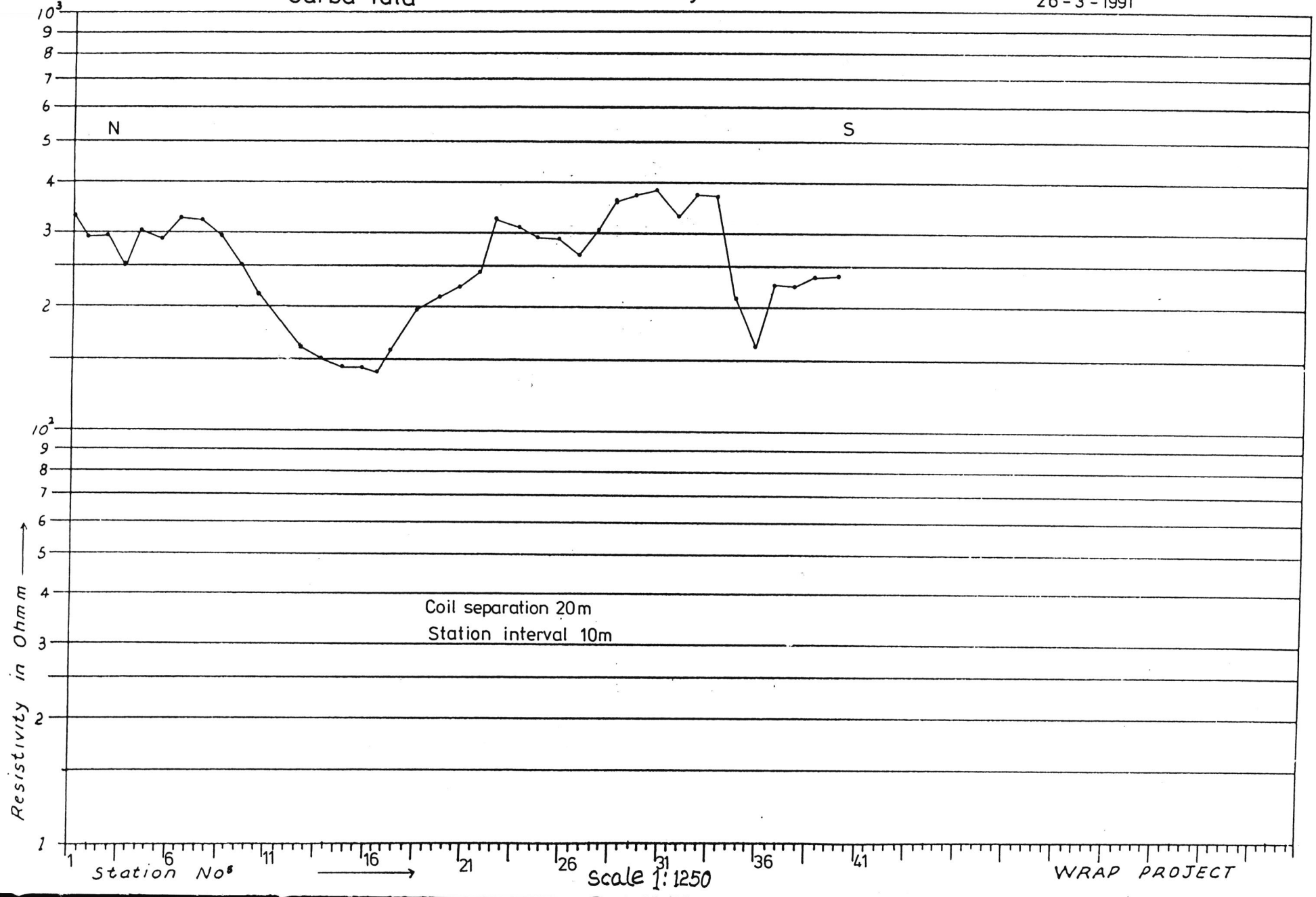


Appendix 3.9.3 (c)

DISTRICT : Isiolo
DIVISION : Garba Tula

LOCATION : Boji

EM - Profile No : 3
26 - 3 - 1991

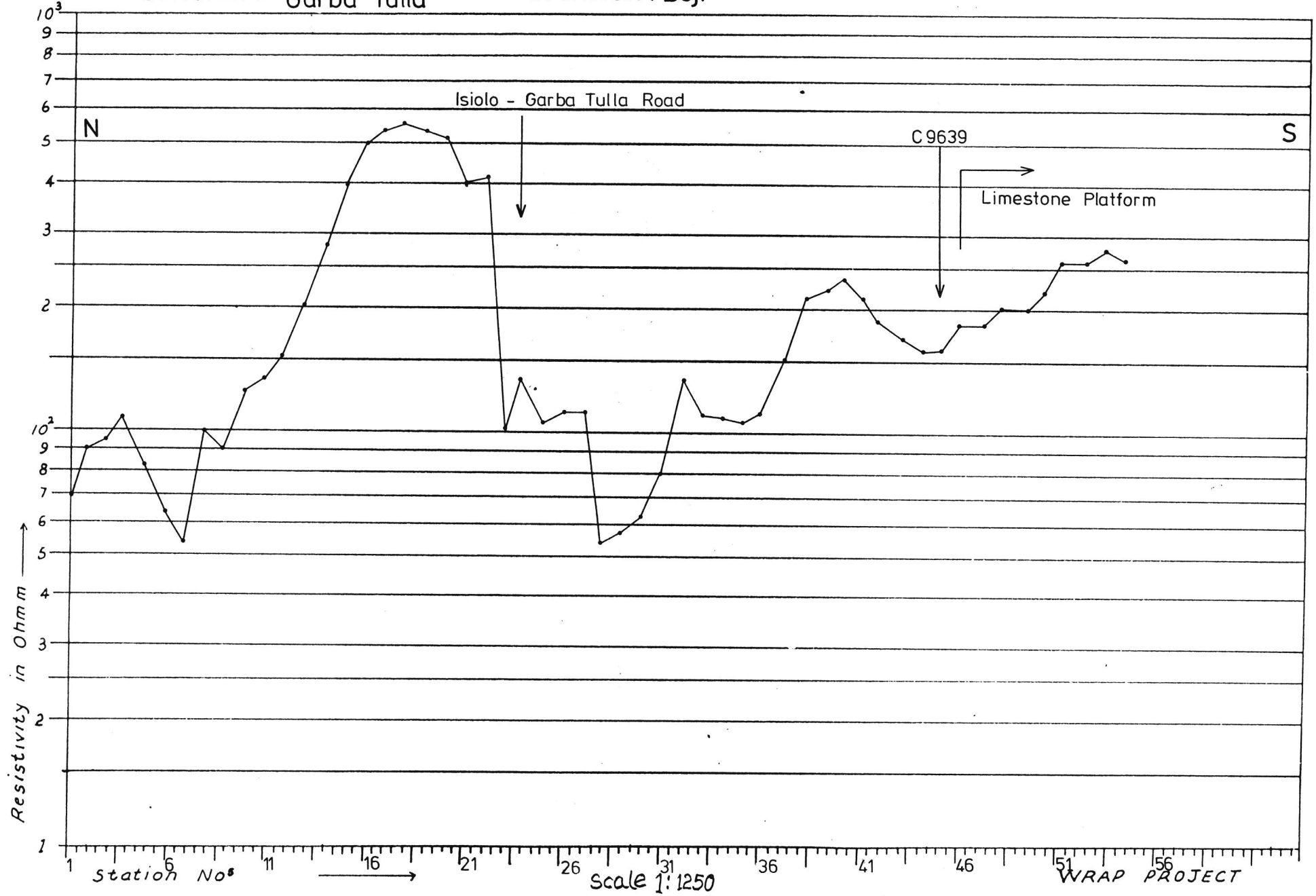


Appendix 3.9.3 (d)

DISTRICT :- Isiolo
DIVISION :- Garba Tulla

LOCATION : Boji

EM - Profile No: 4



APPENDIX 4

DATA ON RAINFALL, EVAPORATION AND SURFACE WATER

APPENDIX 4

DATA ON RAINFALL, EVAPORATION AND SURFACE WATER

4.1 List of Hydro-meteorological Stations

4.2 Mean Monthly Rainfall for Selected Stations

4.3 Annual Rainfall

4.4 Annual Rainfall Trends

4.5 Annual Rainfall Reliability

4.6 Annual Maximum Daily Rainfall Frequency

4.7 Pan Evaporation Data

4.8 Ewaso Ngiro River - Discharge Data

4.9 Isiolo River - Discharge Data

4.10 Ngare Ndare River - Flow Duration Rating Curves

Appendix 4.1

List of Hydro-meteorological Stations

Appendix 4.1 List of Hydro-meteorological Stations in Isiolo District

Rainfall Stations

Station No.	Name	Location	Altitude (m)	Record Period
88.38.000	Merti	1.04'N-38.40	320	1952-1957,73-76,79-83
88.38.001	Iresa Boru	1.06'N-38.57	244	1973
88.39.001	Sericho	1.08'N-39.05	259	1953-55, Feb. Oct. 1974
89.37.003	Isiolo District Office	0.21'N-37.35	1104	1930-1986
89.37.035	Archer's Post	0.38'N-37.40	863	1946-88
89.37.063	Samburu Lodge	0.35'N-37.33	879	1967-84
89.38.000	Garba Tulla	0.32'N-38.31	457	1950-1985
88.38.001	Kinna Scheme	0.19'N-38.12	840	1973-86
89.38.002	Benane	0.30'N-38.39	427	1973-1986
89.38.003	Bulesa Scheme	0.54'N-38.30	366	1973-1986
89.38.004	Kula Mawe	0.35'N-38.12	732	1973-1981
89.38.005	Rapsu Scheme	0.17'N-38.13	671	1973-1986
89.39.000	Modo Gashe Police Post	0.45'N-39.11	325	1952-57,1963-1980
89.37.102	Kipsing	0.31'N-37.22	316	1978-86
89.37.103	Longopito	0.42'N-37.08	350	1981-85
89.37.101	Isiolo L.M.D Headquaters	0.22'N-37.33	350	1974-1985

RGS Stations

River	RGS No.	Alt. (m)	Location	Record Length
Isiolo	5D8	1150	0.20'05"N-37.33'20"E	1976-88
E/Ngiro	5E3	823	0.38'30"N-37.40'40"E	1949-88
Ngare Ndare	New			

Evaporation Stations

Name	Station No.	Location	Altitude (m)	Record Length
Archer's Post		0.36'30"N-37.00'	864	1946-1988
Isiolo District Office		0.21'00"N-37.35'	1104	1946-1986
Kula Mawe		0.35'N-38.12'E	732	
Garba Tulla		0.32'N-32.00'E	518	1958-1960
Modo Gashe		0.45'N-39.11'E	325	
Merti		1.04'N-38.40'E	320	

Appendix 4.2

Mean Monthly Rainfall for Selected Stations

Appendix 4.2 Mean Monthly Rainfall for Selected Stations

Rainfall Station Name & K.M.D. Reg. No.		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual	Data Period
Archer's Post	X	9.3	9.1	33.8	84.1	4.6	3.4	3.8	3.3	3.4	29.8	89.6	39.4	313.6	1946-88
89.37.035	%	2.7	2.6	9.7	24.1	11.6	1.0	1.1	1.0	1.0	8.5	25.6	11.3		
	s	16.6	19.8	34.4	55.8	36.9	8.4	7.8	9.7	4.8	33.5	97.4	43.6		
	C.V.%	177.6	217.0	101.7	66.3	90.8	248.8	205.0	291.3	140.1	112.7	108.8	110.7		
Isiolo District Office	X	34.8	36.7	84.0	122.0	32.6	4.5	4.8	4.7	6.7	64.1	147.5	76.1	618.5	1930-86
89.37.003	%	5.6	5.9	13.6	19.7	5.3	0.7	0.8	0.8	1.1	10.4	23.8	12.3		
	s	31.0	37.4	52.6	54.3	33.9	10.3	12.4	10.9	11.4	55.9	80.7	51.5		
	C.V.%	89.2	101.8	62.7	44.5	103.7	228.1	258.5	232.2	170.7	87.3		54.7		
Samburu Lodge	X	19.5	28.2	42.3	104.0	41.6	2.1	2.7	4.0	6.2	40.8	96.6	35.9	423.9	1963-85
89.37.063	%	4.6	6.7	10.0	24.5	9.8	0.5	0.6	0.9	1.5	9.6	22.8	8.5		
	s	37.1	37.6	40.9	73.0	28.5	4.3	5.9	9.4	11.5	32.0	95.9	41.1		
	C.V.%	189.9	133.1	96.6	70.2	68.6	210.2	220.4	233.1	184.1	78.6	99.2	114.3		
Isiolo L.M.D	X	46.5	43.4	87.1	115.1	32.1	2.3	2.2	0.8	5.0	46.4	148.4	74.9	604.2	
89.37.101	%	7.7	7.2	14.4	19.1	5.3	0.4	0.4	0.1	0.8	7.7	24.6	12.4		
	s	63.7	51.3	59.4	39.8	40.8	4.9	4.8	2.8	5.7	47.4	77.6	58.8		
	C.V.%	137.2	118.0	68.1	34.6	127.1	217.1	220.2	331.7	114.4	102.2	52.3	78.5		
Garba Tulla	X	9.5	14.7	28.5	96.4	17.4	0.0	0.1	0.0	0.1	26.6	109.5	40.6	343.4	1950-85
89.38.000	%	2.8	4.3	8.3	28.1	5.1	0.0	0.0	0.0	0.0	7.8	31.9	11.8		
	s	28.3	40.0	38.1	79.4	30.5	0.0	0.3	0.0	0.7	49.8	100.8	41.9		
	C.V.%	299.0	272.7	133.8	82.4	175.2		565.7		547.7	187.1	92.0	103.1		
Kinna Scheme	X	15.2	7.1	28.0	104.6	28.9	0.0	0.3	0.2	1.3	79.2	121.1	65.7	451.6	1972-86
89.38.001	%	3.4	1.6	6.2	23.2	6.4	0.0	0.1	0.0	0.3	17.5	26.8	14.5		
	s	25.9	15.3	41.4	102.6	35.2	0.0	0.6	0.7	3.3	106.6	70.1	69.1		
	C.V.%	170.2	216.6	147.6	98.1	121.7		213.5	374.2	248.4	134.6	57.9	105.1		
Habaswein	X	8.1	6.0	21.9	87.4	9.5	0.3	0.5	0.3	1.3	21.8	64.6	27.2	248.9	1951-85
88.39.000	%	3.2	2.4	8.8	35.1	3.8	0.1	0.2	0.1	0.5	8.7	26.0	10.9		
	s	19.8	10.6	33.8	136.7	21.9	1.0	1.1	0.8	4.1	29.0	69.2	34.8		
	C.V.%	245.5	176.3	154.6	156.5	230.3	311.9	239.5	320.7	314.9	133.4	107.0	128.0		
Madogashe	X	7.0	5.8	31.1	75.7	16.6	0.2	0.9	0.0	0.8	20.4	58.2	38.0	254.7	1952-56, 1963
89.39.000	%	2.8	2.3	12.2	29.7	6.5	0.1	0.4	0.0	0.3	8.0	22.8	14.9		
	s	20.7	10.8	42.2	66.0	33.3	1.2	3.3	0.0	3.4	42.3	68.0	54.2		
	C.V.%	294.4	187.3	135.8	87.2	200.8	501.8	371.1		403.3	207.4	116.9	142.8		

X = Mean
% = Average Monthly Rainfall as Percentage of Annual Average
s = Standard Deviation
C.V.% = Coefficient of Variation in Percentage

Appendix 4.3

Annual Rainfall

Appendix 4.3 Annual Rainfall (in mm)

Station Name	Archer's Post	Isiolo District Office	Samburu Lodge	Garba-tulla	Kinna Scheme	Habaswein Police Post	Modogashe Police Post
Reg. No.	89.37.35	89.37.03	89.37.63	89.38.00	89.38.00	88.39.00	89.39.00
Elevation M.sl	263	1104	279	457	840	195	244
Years							
1930		886.5					
1931		576.3					
1932		583.4					
1933		651.8					
1934		375.2					
1935		541.5					
1936		642.4					
1937		533.1					
1938		493.3					
1939		424.4					
1940		434.3					
1941		519.2					
1942		602.7					
1943		466.3					
1944		459.2					
1945		419.4					
1946	144.3	514.9					
1947	357.6	697.2					
1948	317.8	576.6					
1949	180.1	472.2					
1950	227.6	484.9		235.6			
1951	668.5	1006.3		692.9			
1952	118.6	702.3		130.6			132.3
1953	170.7	653.5		120.7			206.0
1954	246.4	515.6		198.4		67.3	112.8
1955	169.9	594.6		257.8		70.1	79.8
1956	410.0	712.2		548.6		132.6	168.7
1957	422.4	854.5		382.3		135.1	
1958	316.7	580.1		274.1		310.1	
1959	445.8	664.0		226.8		149.1	
1960	242.6	588.3		241.6		332.7	
1961	847.3	1278.6		848.1		434.3	
1962	754.9	820.9		280.4		341.4	
1963	713.0	858.3		672.5		400.3	118.4
1964	366.0			360.2			304.8
1965	188.6			200.5			263.9
1966	478.4	711.6		362.6			
1967	539.0			515.9		168.3	180.3
1968	682.5	1242.5	771.2	1066		1218.9	769.7
1969	380.1	878.9	1024.3	591.9		385.6	133.7
1970	217.8	426	466.5	133.2		59.1	177.9
1971	287.8	314.8		289.8		137.0	130.4
1972	349.4	443.1		205.3	602.9	202.2	211.4
1973	276.4	475.4		273.2	268.7	66.1	101.2
1974	188.8	500.8	278.1	311.4	312.3	291.9	334.2
1975	276.1	475.1	96.1	287.2	476.4	205.0	413.3
1976	150.7	652.3	303.1	204.2	254.0	86.4	112.4
1977	403.7	615.5	254.3	557.2	605.3	260.2	443.9
1978	478.2	826.6	601.6	609.8	879.8	341.3	440.3
1979	264.2	726.4		531.1	510.9	263.3	321.1
1980	225.6	528.1	467.3	233.8	199.0		437.3
1981	341.9	472.5	205.3	332.0	209.2		455.8
1982	481.9	762.7	286.1	322.2	828.3	272.6	
1983	195.8	555.4	401.4	174.1	38.0	84.1	9.6
1984	222.7	535.2	300.5	246.8	401.3		234.1
1985	272.2	641.3	169.4	197.7	523.0		340.1
1986	319.8	657.9			664.4		158.8
1987	304.1						75.5
1988	389.4						286.9
Mean	349.7	622.7	401.8	364.3	451.6	256.6	251.6
s	173.2	190.7	243.3	213.0	233.0	227.5	161.7
C.V.%	49.5	30.6	60.6	58.5	51.6	88.6	64.3

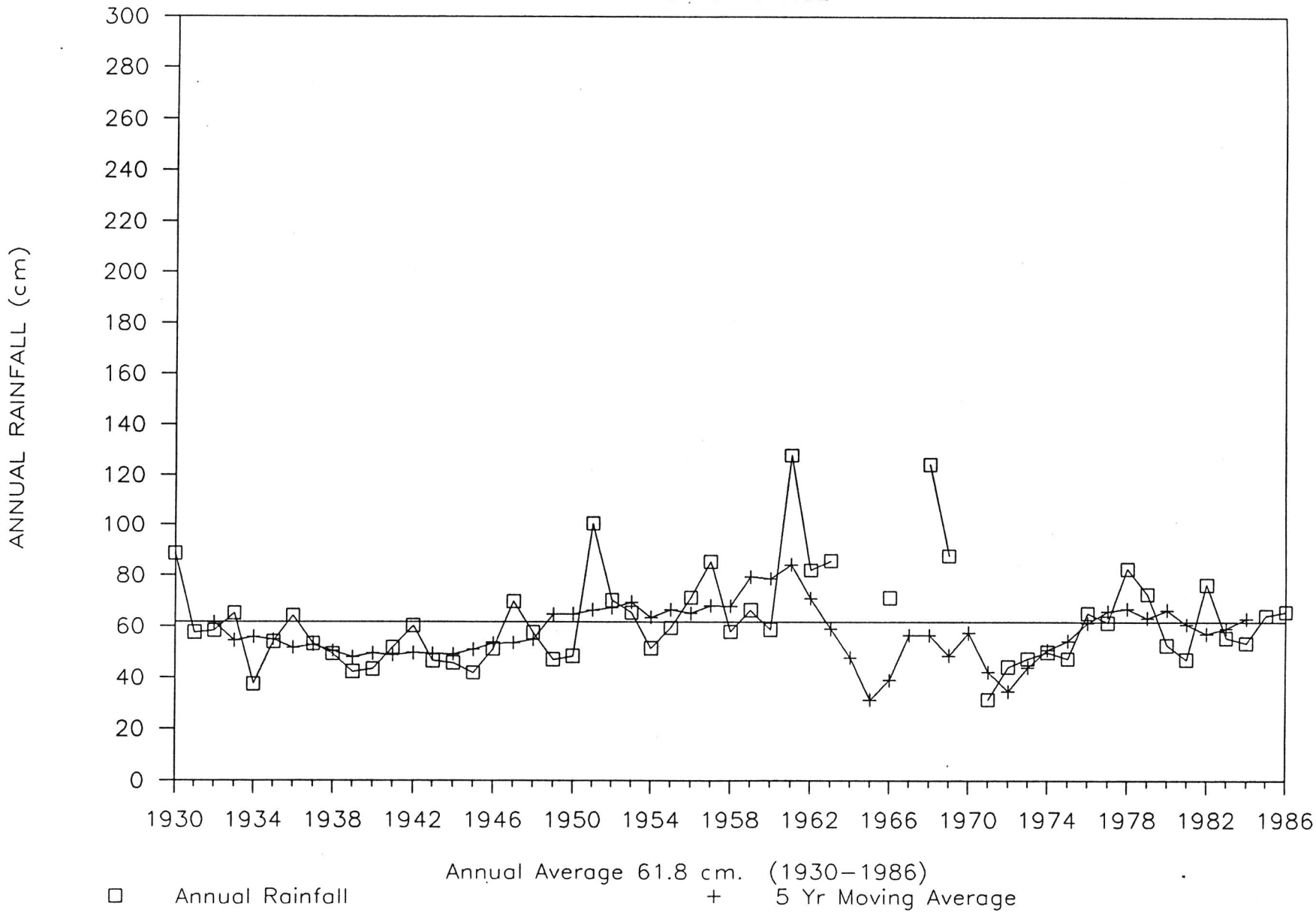
s = Standard Deviation
C.V.% = Coefficient of Variation in Percentage

Appendix 4.4

Annual Rainfall Trends

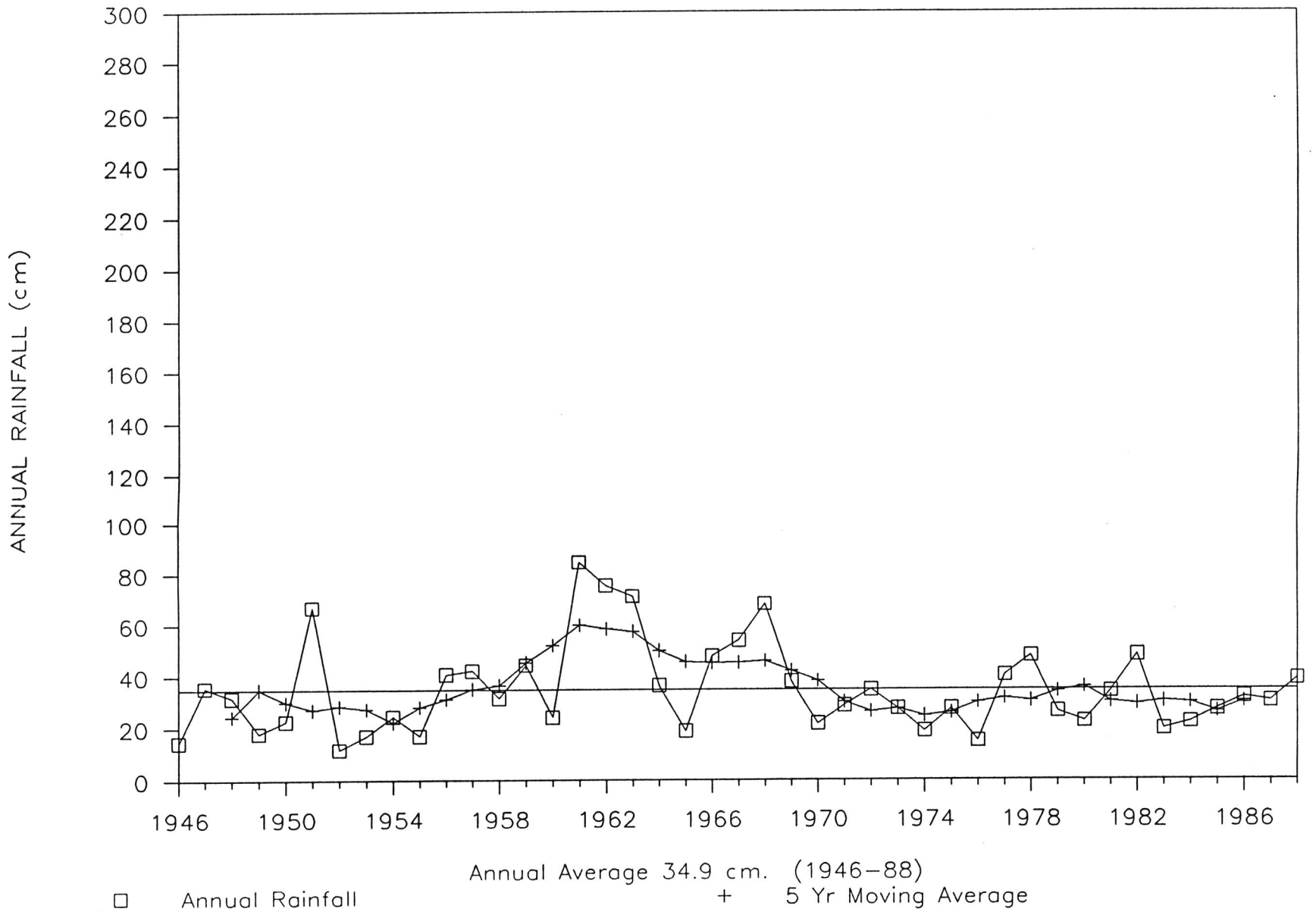
ANNUAL RAINFALL VARIATION at Station No. 89.37.003

ISIOLO DISTRICT OFFICE



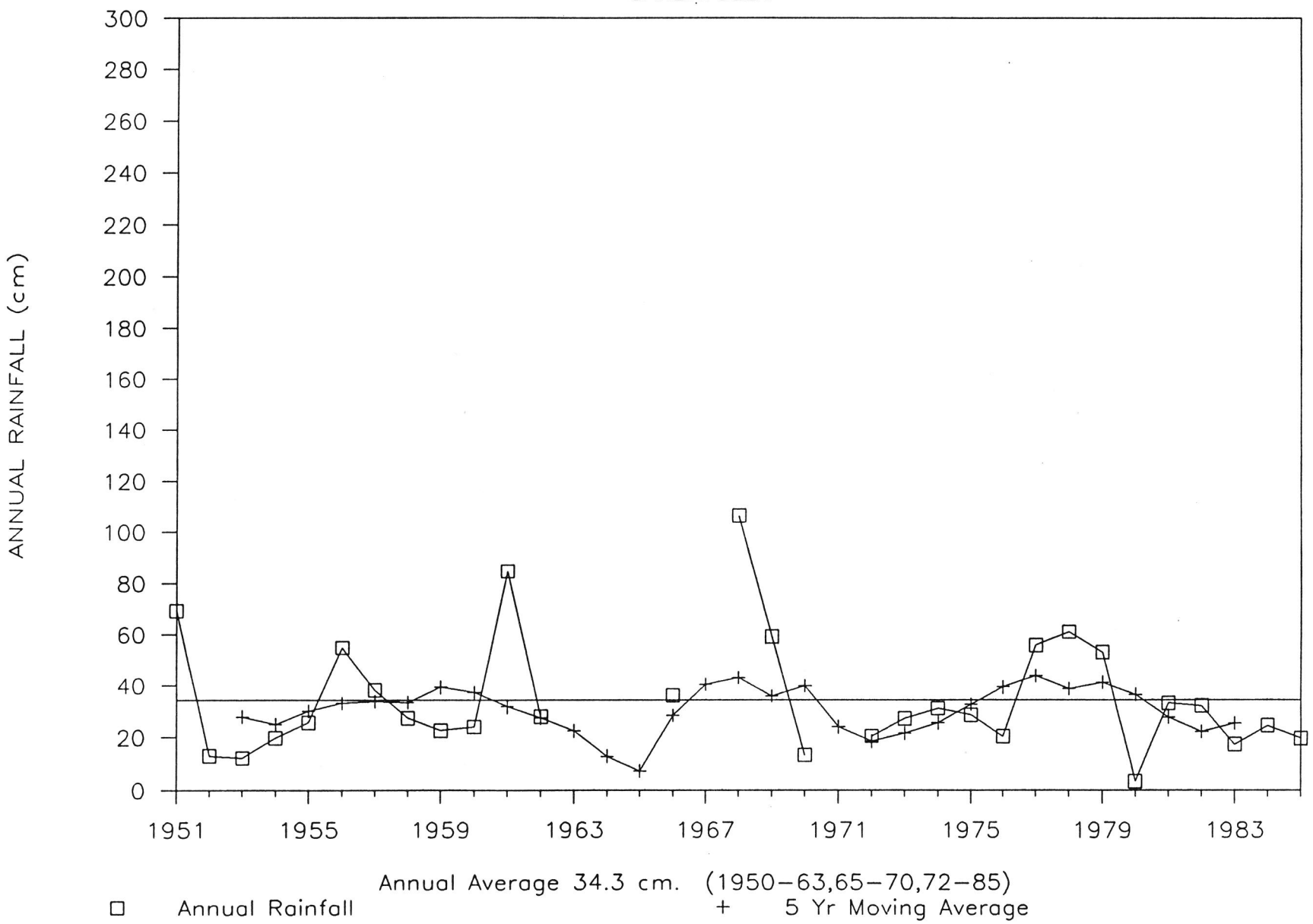
ANNUAL RAINFALL VARIATION at Station No. 89.37.035

Archer's Post



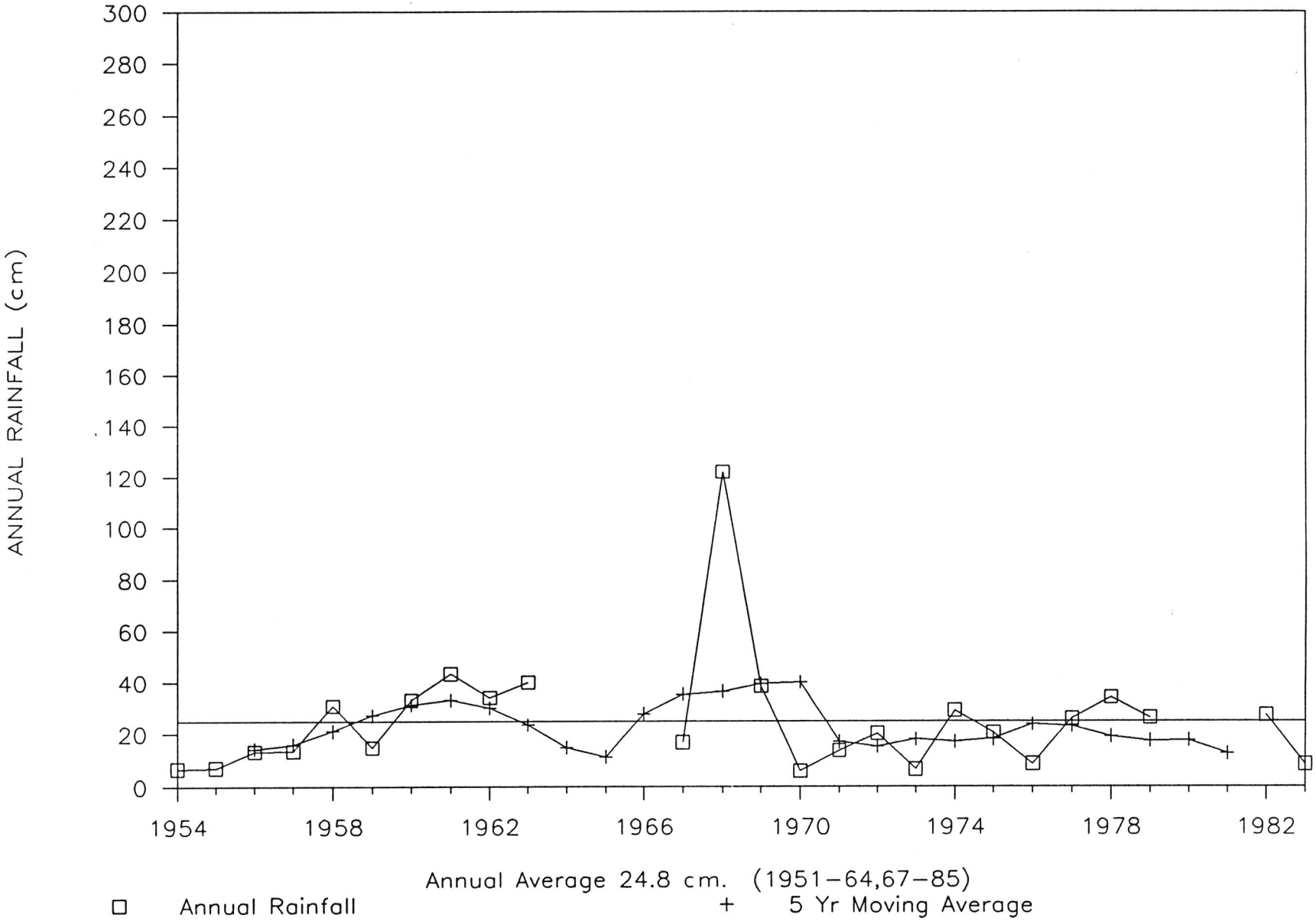
ANNUAL RAINFALL VARIATION at Station No. 89.38.00

GARBATULLA



ANNUAL RAINFALL VARIATION at Station No. 88.39.00

HABBASWEIN POLICE POST

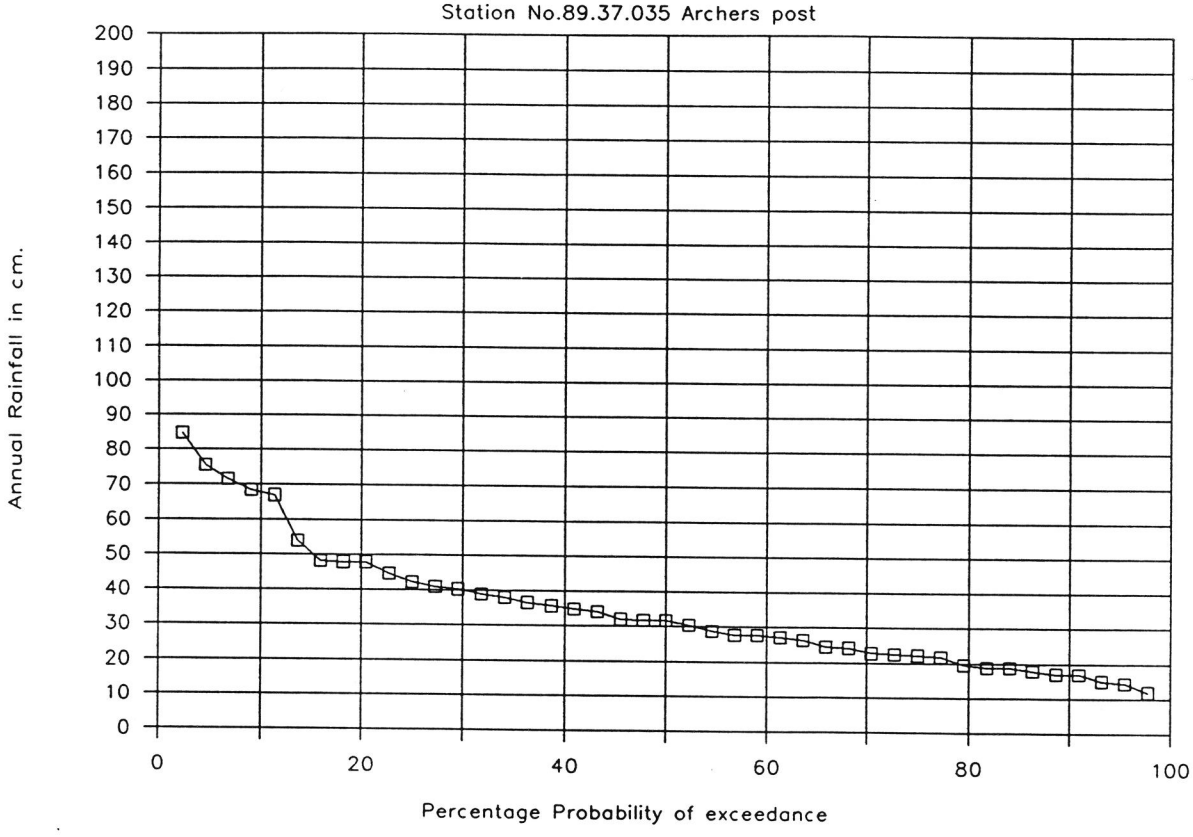


Appendix 4.5

Annual Rainfall Reliability

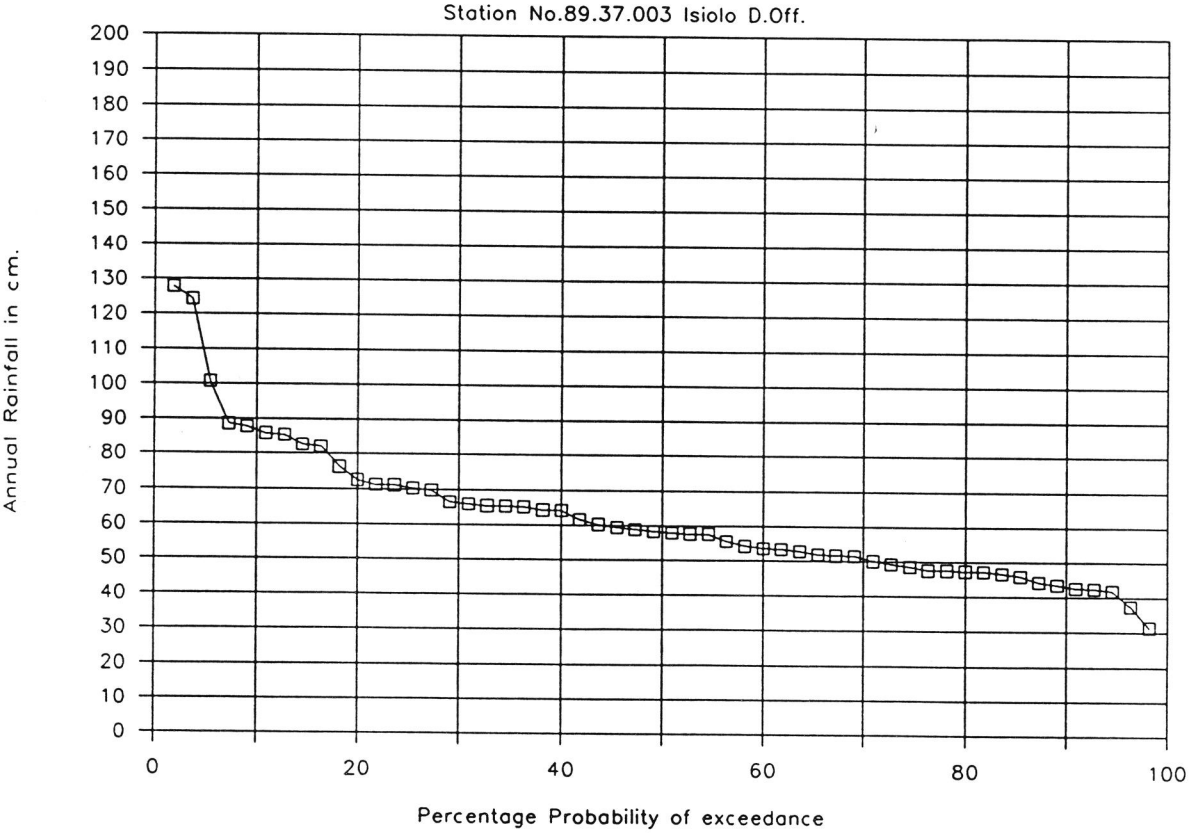
Annual Rainfall Distribution

Station No.89.37.035 Archers post



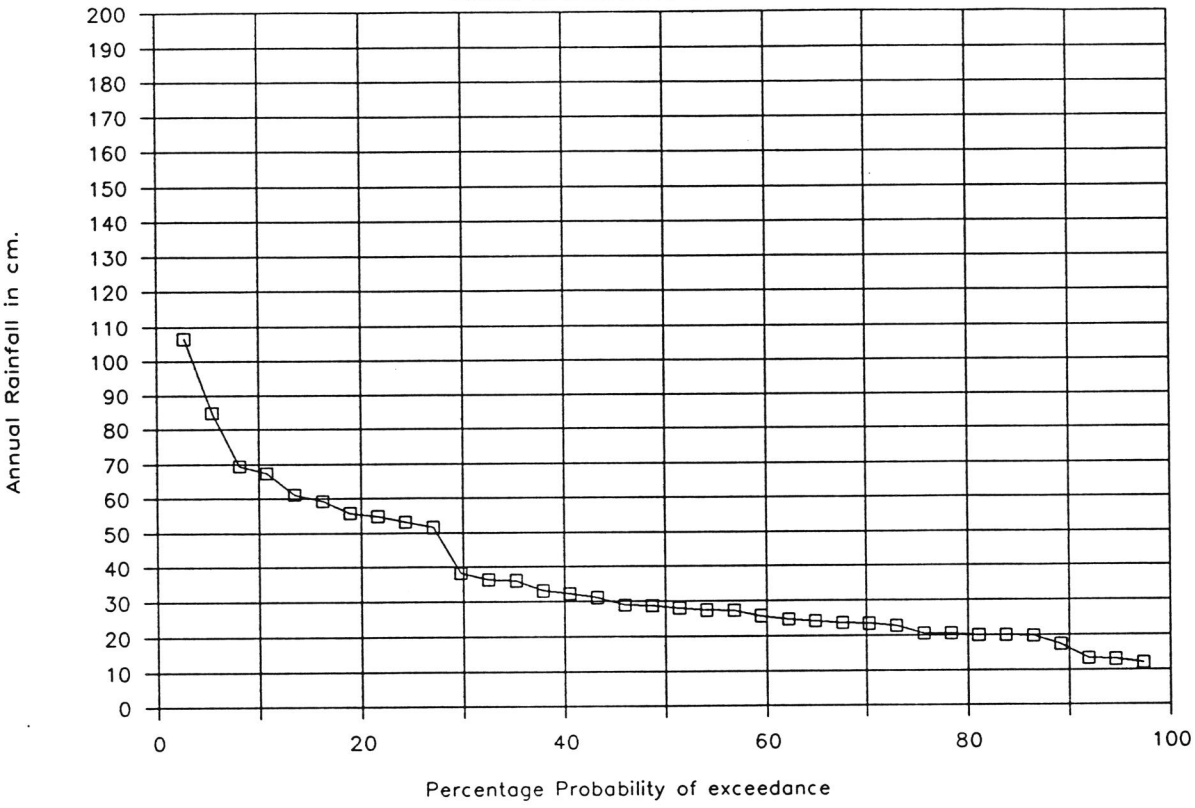
Annual Rainfall Distribution

Station No.89.37.003 Isiolo D.Off.



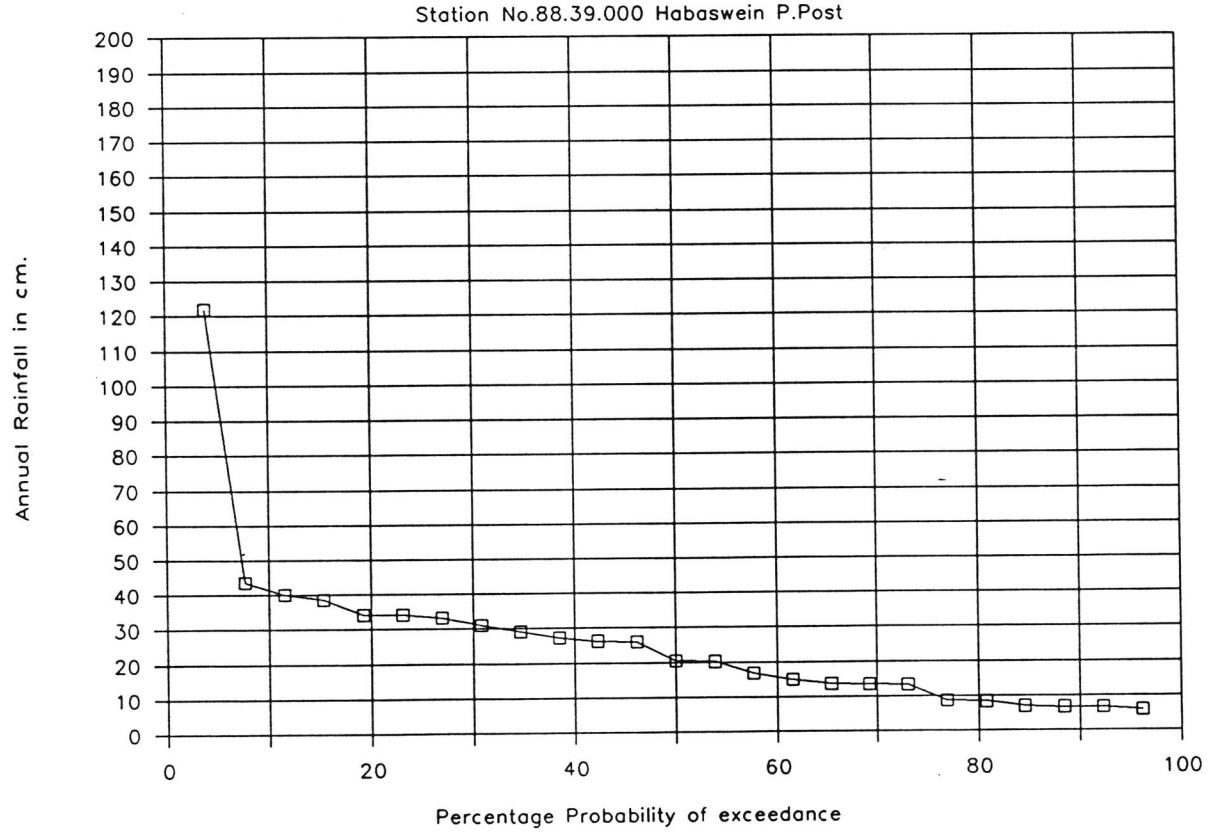
Annual Rainfall Distribution

Station No.89.38.000 Garbatulla



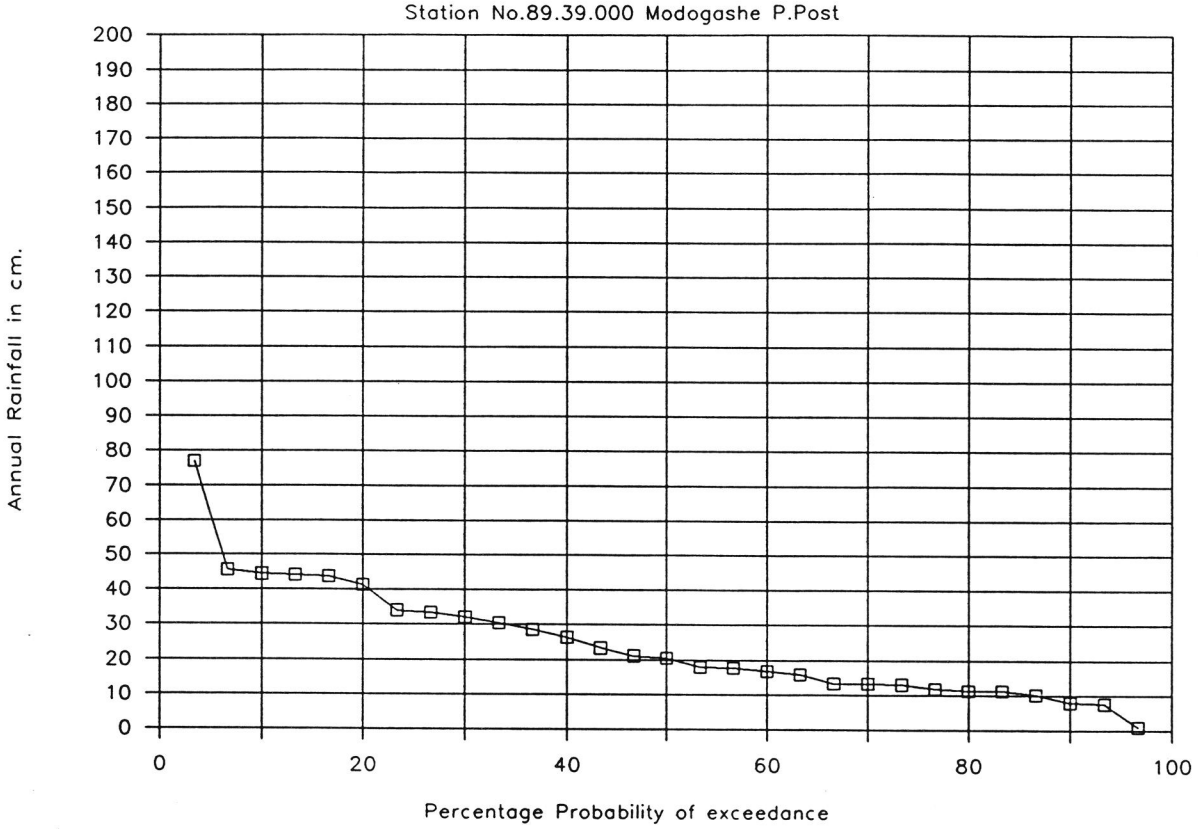
Annual Rainfall Distribution

Station No.88.39.000 Habaswein P.Post



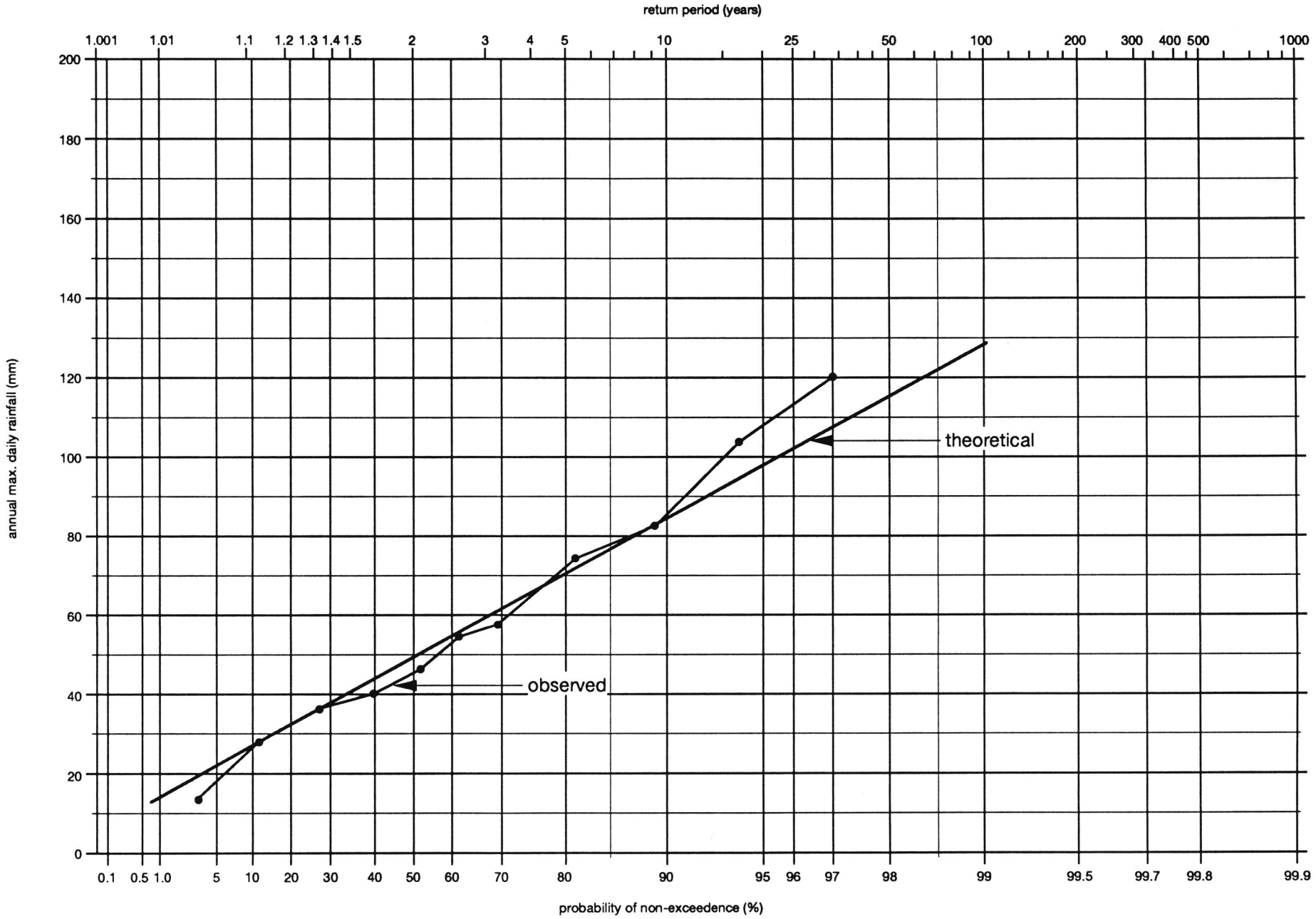
Annual Rainfall Distribution

Station No.89.39.000 Modogashe P.Post

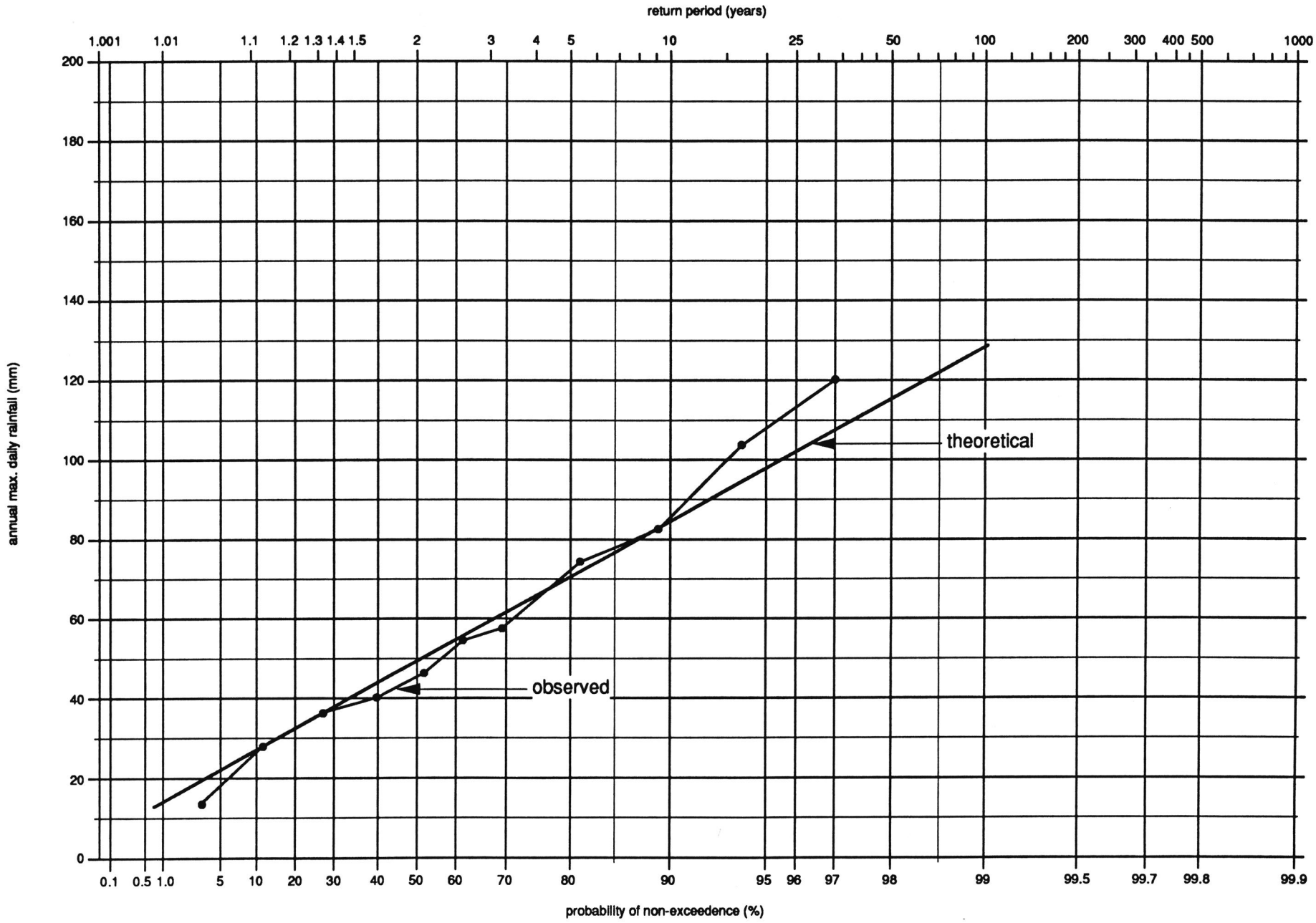


Appendix 4.6

Annual Maximum Daily Rainfall Frequency



App. 4.6, Fig. 1: Annual Max. Daily Rainfall Frequency, Isiolo District Office, Station no. 89.37.035



App. 4.6, Fig. 2: Annual Max. Daily Rainfall Frequency, Archers Post Rainfall Station no. 89.37.035

Appendix 4.7

Pan Evaporation Data

MONTHLY EVAPORATION DATA
(mm)
Source of data:

Station Name: ISIOLO
Number:
Record length: 1946-88
Coordinates: Lat. 00 21 40 N Long. 37 35 E
Altitude: 1104 m.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1946				212.6	302.3	346.5	372.4	400.8	392.7	310.4	152.9	225.8	2716.3
1947	237.5	251.7	196.3	168.4	231.6	287.0	316.5	277.4	336.8	311.2	176.0	139.7	2930.1
1948	220.5	279.9	207.5	233.7	281.9	303.8	323.3	356.6	335.8	312.9	158.8	170.9	3185.7
1949	232.2	254.8	261.4	242.6	327.4	333.8	337.8	362.2	379.5	355.9	242.3	219.2	3548.9
1950	300.2	279.4	249.2	190.8	256.0	290.1	306.6	329.2	348.0	386.3	165.6	261.1	3362.5
1951	280.4	342.4	378.2	108.0	249.9	286.8	366.5	402.3	364.7	261.6	141.0	107.4	3289.3
1952	290.6	356.1	364.0	306.1	278.1	476.0	518.2	535.4	477.5	228.6	164.6	140.0	4135.1
1953	186.9	199.4	193.8	192.3	254.8	326.1	334.8	333.2	350.8	272.8	139.7	155.7	2940.3
1954	218.9	206.2	262.1	155.2	230.1	309.9	259.3	336.3	327.7	256.5	130.0	165.4	2857.8
1955	216.4	223.8	276.1	200.2	265.7	272.3	345.4	281.2	387.6	359.7	214.4	247.7	3290.3
1956	177.0	247.4	220.0	190.5	314.5	433.3	390.7	321.1	312.4	302.3	137.2	156.7	3202.9
1957	224.5	247.4	209.0	188.0	234.4	217.9	272.5	324.1	290.1	244.6	153.4	126.7	2732.8
1958	173.0	172.2	220.2	214.9	221.7	264.2	217.2	276.9	295.4	255.0	200.4	204.2	2715.3
1959													
1960													
1961													
1962													
1963													
1964													
1965			228.6	189.5	222.0	261.6	264.2	273.1	255.5	228.6		170.2	2093.2
1966	224.8	183.4	184.9	179.6	214.6	206.8	229.1	199.6	220.5	211.8		201.2	2256.3
1967	203.7	203.2	208.5			220.2	250.4	260.1	201.9			214.9	1763.0
1968					194.1	188.0	200.7	207.3	204.7	214.6	160.3	167.4	1537.0
1969	166.9	155.7	152.4	202.4	196.3	186.4	193.0	262.6	246.9	193.0	161.5	181.6	2299.0
1970	173.2	196.3	228.6	167.9	239.3	239.8	247.9	252.0	250.4	245.1		185.2	2425.7
1971	190.8	242.8	339.1	214.6	130.6	185.4	217.4	235.5	215.9	324.4	163.3	177.5	2637.3
1972	186.2	185.7	267.5	286.8	273.8	274.6	338.6	351.0	353.6	293.1	165.6	195.6	3172.0
1973	207.5	225.8	274.6	239.0	311.4	319.5	297.4	343.9	337.1	341.9	145.0	180.1	3223.3
1974	228.1	203.2	194.1	153.9	199.6	217.4	244.6	231.4	243.6	212.1	139.4		2267.5
1975													
1976			237.5	172.7	211.1	218.2	229.6	217.4	231.9	261.1			1779.5
1977	163.6	161.0	147.1	129.3	194.6		188.0	224.5	198.4		124.5	124.7	1655.6
1978	157.2	146.3	143.8	160.0	165.6	178.1	155.4		182.9	168.7	141.7	165.6	1765.3
1979		106.7	145.8	109.7	135.4	161.5	176.0	197.6	252.5	237.5	114.6	148.3	1785.6
1980	183.9	191.3	209.6	143.8	147.1	179.1	192.0	217.9	205.5	207.3	128.3	142.0	2147.6
1981	192.8	182.6	144.3	124.7	87.1		168.9	208.5	221.5	199.9	177.0	140.5	1847.9
1982				130.6	181.4	181.6	177.5	237.5	218.9	188.2	96.8		1412.5
1983	154.2	187.2	168.4	172.2	187.5	212.6	196.1	224.0	198.6	145.5	149.4		1995.7
1984	187.5	195.1	201.4	145.8	216.9	217.9			190.5	175.5	92.7	141.2	1764.5
1985	149.6	162.3	137.7	135.1	159.5	156.5					125.2		1025.9
1986	157.2	153.2	159.5	119.4	135.4	149.6							874.3
1987	156.2	182.9	207.8	221.0	210.5	181.9	246.0	261.5	264.0	269.6	198.1	171.7	2571.2
1988	225.9	251.2	297.6	171.2	211.5	196.6	208.0	477.7	249.0	167.9			2456.6
1989	215.9	203.6	201.9	152.2	117.0	221.0	225.5	233.5	249.8	269.0	304.9	264.4	2658.7

Station Name: Archer's Post archers' post
Number:
Record length:

MONTHLY EVAPORATION DATA
(mm)

Coordinates: Lat. 00 38 20 N Long. 37 39 50 E
Source of data: Altitude: 864 m.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1946	278.9	294.4	334.0	205.7	267.0	280.9	306.3	286.3	271.5	286.0	233.4	281.4	3325.9
1947	304.3	304.0	229.9	158.8	202.2	246.9	258.1	267.2	281.4	299.5	179.1	201.9	2933.2
1948	285.0	313.7	312.9	220.0	243.1	276.9	273.8	306.6	308.4	280.7	191.0	237.7	3249.7
1949	290.6	287.0	322.6	282.7	254.3	242.3	241.6	247.4	256.0	241.8	218.9	166.9	3052.1
1950	228.6	231.1	228.1	228.3	172.0	224.5	216.4	242.3	251.0	262.9	249.2	235.2	2769.6
1951	255.0	249.9	256.0	122.7	142.7	196.6	206.2	240.8	258.6	217.2	169.9	143.0	2458.7
1952	204.2	236.2	286.0	189.7	243.6	276.4	262.6	260.6	280.4	264.2	184.4	206.0	2894.3
1953	240.0	243.3	278.9	219.5	208.3	247.1	303.5	304.8	294.1	254.0	178.1	207.8	2979.4
1954	266.7	268.2	302.0	155.7	198.9	218.9	231.1	265.4	268.5	249.2	178.6	222.8	2826.0
1955	242.3	229.1	285.5	223.0	242.1	242.3	263.1	258.3	264.9	232.4	224.0	218.9	2926.1
1956	193.0	251.0	225.8	170.9	216.2	237.2	243.3	265.9	266.2	276.4	176.0	182.9	2704.8
1957	231.9	239.3	229.4	183.1	195.3	223.0	245.4	261.4	266.4	275.8	164.6	141.0	2656.6
1958	207.8	215.9	256.5	206.5	184.7	222.8	187.7	277.4	276.4	270.5	224.0	210.1	2740.2
1959	236.7	218.9	283.5	232.9	200.7	236.2	266.7	290.3	296.4	308.9	210.6		
1960	238.8	262.4	225.0	178.8			270.8	283.2	290.1	238.3	202.7	199.6	
1961	269.0	259.1	306.6		244.1	260.1	288.3	233.4	274.8	195.8	133.1		
1962	193.8	240.8	260.1	168.9	160.8	232.7	253.5				211.6	212.1	
1963	238.8	285.0	273.8	181.9	166.1	230.6	291.4	286.3		310.9	201.2	117.9	
1964	186.4	237.0	239.5	189.7	256.0	275.3	264.2	286.5	324.6	292.4	289.6	189.2	3030.5
1965	253.5	292.6	350.5	264.2	279.1	284.0	301.2	349.5	351.5	292.1	199.4	267.5	3485.1
1966	313.2	279.4	281.7	239.5	272.8	306.3	337.8	320.5	340.9	326.9	211.6		
1967	298.2	310.9	322.8	187.2	184.2	247.4	274.1	299.0	327.7	290.6	148.6	209.3	3099.8
1968	260.1	236.7	178.3	142.0	194.1	241.6	297.7	271.0	299.5	257.3	157.0	175.0	2710.2
1969	224.0	184.9	227.8	243.1	239.8	274.3	288.5	299.7	309.4	323.6	211.3	248.9	3075.4
1970	301.8	307.3	286.3	272.5	304.8	326.9	327.9	340.9	316.5	344.9	231.6	308.4	3669.8
1971	349.5	308.6	352.6	252.0	244.6	301.5	305.1	282.2	287.3	299.5	252.2	251.5	3486.4
1972	294.4	264.7	326.9	308.1	254.3	269.0	333.5	358.9	343.7	267.2	189.2	293.9	3503.7
1973	273.8	273.6	326.9	301.2	283.7	281.4	292.1	304.0	287.8	283.0	254.5	294.9	3456.9
1974	298.5	284.0	284.5	239.5	271.5	254.0	279.9	295.9	298.5	299.0	260.1	296.4	3361.7
1975	290.1	300.2	341.9	256.3	245.9	264.2	293.4	305.8	295.1	294.9	253.0	325.1	3465.8
1976	334.0	293.1	339.1	257.8	299.7	302.3				323.9	284.2	248.4	
1977	293.9	296.9	309.9	234.4	267.2	294.9	291.1	307.1	285.5	287.3	185.9	210.8	3264.9
1978	273.3	258.3	247.4	253.0	295.4	297.4	285.8	294.4	304.8	271.3	210.8	231.6	3223.5
1979	261.6	265.4	291.3	213.6	218.2	0.0	290.1	283.0	299.7	296.4	246.9	285.2	
1980	304.8	271.5	343.9	290.6	250.4	272.5	284.0	284.7	322.6	332.0	252.7	321.8	3531.6
1981	360.4	305.6	281.2	188.0	221.0	254.0	260.1	285.5	287.0	293.9	192.8	198.9	3128.3
1982	288.5	273.1	311.9	189.0	240.8	276.6	314.5	295.9	304.0	255.3	204.7	217.7	3172.0
1983	319.0	283.7	307.3	288.8	289.8								
1984			316.0	259.3	287.5	239.5	231.9	235.7	265.9	303.0	204.7	223.0	
1985	250.2	247.9	288.3	250.2	244.6	271.8	278.9	297.4	291.6	306.1	264.4	274.8	3266.2
1986	316.2	275.5	261.8	262.3	267.9	276.5	289.0	302.8	303.0	277.4	244.5	247.4	3324.3
1987	288.8	277.5	307.7	222.2	293.6	252.2	285.5	316.5	248.0	315.8	281.6	281.5	3370.9
1988	287.5	294.0	294.4	240.1	287.1	270.4	251.2	288.5	266.7	297.5	248.8	267.3	3293.5
1989	272.0	287.5	325.3	263.3	253.0	315.5	320.6	328.0	311.2	290.9	226.5	266.2	3460.0

Appendix 4.8

Ewaso Ngiro River - Discharge Data

MINISTRY OF WATER DEVELOPMENT

Water Resources Assessment Project Documentation Section

MONTHLY AND ANNUAL DISCHARGE DATA

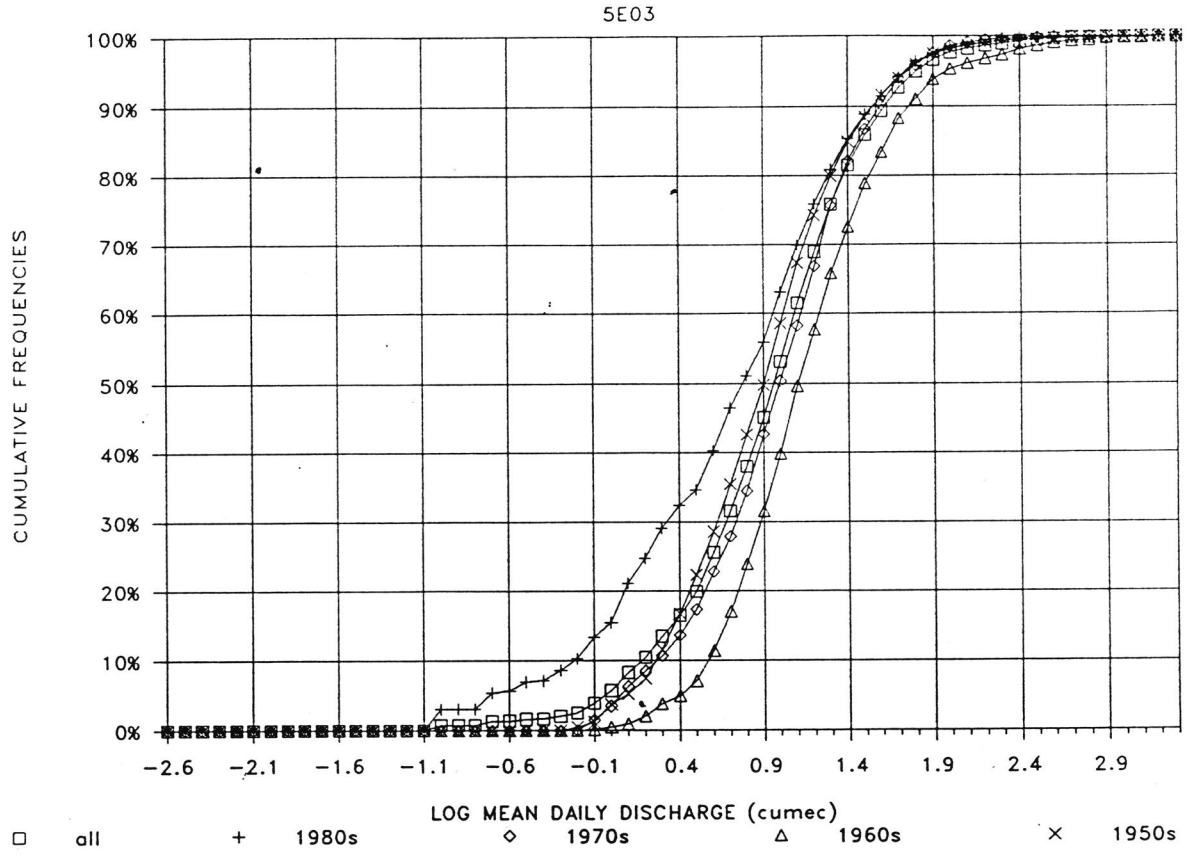
River: EWSO NGIRO RIVER
R.G.S: 5E03
Area : 15300 sq km

The flows are in: CUMEC

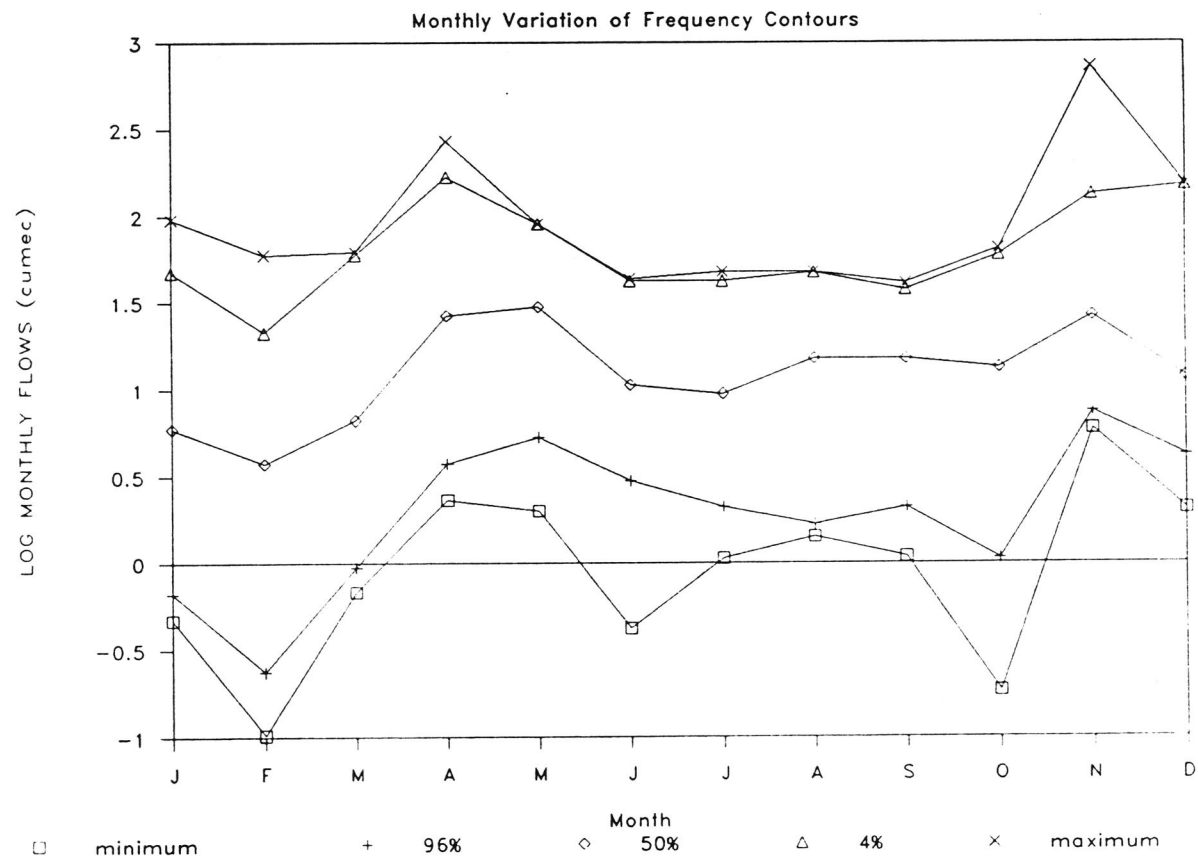
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Daily max	Daily min	Days without readings
1949				7.76	6.05	9.19	6.66	10.24	19.78	6.250	9.20	9.92				68
1950	3.88	2.193	9.32	41.00	11.51	7.23	10.60	11.55	14.07	5.344	5.98	4.52	10.60	210.8	1.010	1
1951	1.09	0.917	43.32	270.36	46.85	17.45	12.80	16.74	11.55	10.185	42.65	52.14	43.73	658.6	0.670	0
1952	12.17	2.859	1.74	3.18	12.83	2.68	1.96	2.47	3.88	3.871	7.38	7.05	5.20	28.2	1.180	5
1953	2.15	0.665	1.33	10.56	12.11	11.92	3.92	5.50	2.65	5.731	25.29	10.69	7.72	121.7	0.520	0
1954	2.24	1.005	0.80	26.66	28.46	8.44	30.80	23.76	39.28	16.937	12.13	25.72	18.12	178.3	0.521	0
1955	5.33	4.632	1.98	18.73	7.76	2.96	3.22	20.90	27.04	23.693	16.02	17.04	12.47	103.6	1.360	0
1956	19.14	7.682	7.35	26.30	25.94	7.71	9.20	22.39	24.65	13.491	18.86	10.29	16.09	128.0	2.600	0
1957	4.49	3.420	5.85	30.63	44.20	29.57	10.03	8.13	8.59	5.355	21.30	40.50	17.74	222.7	1.880	0
1958	7.54	21.738	12.30	14.59	37.53	14.11	47.72	44.92	21.61	12.615	9.69	22.42	22.31	126.5	3.310	0
1959	9.45	3.936	2.83	6.60	28.69	12.78	7.14	8.11	11.44	5.731	30.41	14.78	11.85	196.0	1.240	23
1960	4.49	2.185	16.00	23.91	8.18	4.36	5.44	5.74	13.20	7.235	22.95	11.15	10.39	267.0	1.210	35
1961	2.79	1.426	10.09	37.21	16.08	6.65	7.29	41.98	13.29	60.681	724.10	141.51	88.14	1836.0	0.702	35
1962	95.25	18.254	12.82	19.15	38.58	10.45	8.26	10.00	14.77	23.701	12.49	19.22	23.72	321.3	6.530	50
1963	13.41	4.870	5.37	34.76	56.67	28.39	8.40	16.24	12.37	8.030	59.10	151.13	33.46	390.2	2.780	66
1964	46.69	14.981	15.21	76.19	29.31	14.51	9.64	47.76	39.65	32.626	23.59	35.49	32.16	353.0	6.880	55
1965	20.56	9.342	6.01	17.89	14.72	5.84	5.23	4.10	4.62	16.789	30.14	10.92	12.18	84.5	3.310	54
1966	4.90	8.757	7.88	53.39	17.97	16.46	10.12	15.73	25.79	24.514	58.78	6.91	20.84	332.7	3.510	56
1967	2.29	1.534	8.65	43.43	89.95	28.77	29.69	27.92	17.96	22.259	86.54	35.40	33.00	485.9	1.070	58
1968	7.17	11.007	61.66	165.11	89.45	42.26	23.72	24.95	12.66	9.509	66.22	98.04	50.97	598.3	3.770	65
1969	18.24	17.819	28.43	17.21	28.16	8.64	6.31	5.65	10.25	6.000	19.98	10.85	14.78	87.2	4.140	58
1970	8.62	6.696	5.38	19.53	18.03	6.42	5.32	8.96	11.23	8.840	9.47	3.82	9.36	44.5	1.950	59
1971	2.18	1.149	0.82	31.22	26.13	14.37	18.39	39.90	30.51	17.235	17.26	16.73	18.07	165.7	0.655	57
1972	11.72	13.732	4.92	2.33	12.16	17.75	7.46	7.52	4.07	24.593	39.61	9.41	12.90	261.9	1.910	57
1973	11.60	2.575	1.82	4.36	4.60	6.47	4.04	14.63	11.79	9.630	26.93	4.93	8.62	165.4	1.010	57
1974	1.69	0.996	6.76	21.80	5.16	4.21	15.77	16.46	17.73	6.277	22.58	5.55	10.43	129.7	0.702	55
1975	1.86	1.029	0.83	52.34	21.55	16.38	41.67	47.51	41.02	27.170	24.73	7.22	23.68	350.4	0.702	51
1976	24.47	1.989	1.21	18.90	13.81	7.98	15.46	13.67	23.01	9.459	6.42	13.75	12.55	118.9	0.800	30
1977	16.01		7.81	85.07	66.44	10.05	27.63	25.45	14.32	14.582	132.38					31
1978		9.538	37.15	44.59	26.81	8.08	17.18	15.77	16.33	22.165	31.73	23.18				12
1979	20.30	59.610	18.22	24.16	26.46	16.77	7.87	6.50	3.80	4.348	20.84	3.93	17.40	129.6	2.730	3
1980	1.73			6.47	32.97	4.07	2.61	1.52	1.87	0.902	14.80	2.07				13
1981	0.57	0.260	60.29	93.45	38.75	7.35	8.96	25.86	15.75	12.552	12.46	5.23	23.55	390.1	0.098	0
1982	3.15	1.232	0.89	22.56	26.57	12.82	5.63	9.35	7.44	64.704	50.07	47.86	21.16	554.2	0.413	9
1983	11.32	4.072	1.80	12.28	14.72	5.35	6.91	29.51	28.27	16.282	13.67	26.07	14.26	114.2	1.230	0
1984	7.28	1.680	1.17	5.20	2.00	0.42	1.06	1.42	2.48	13.584	30.93	9.15	6.35	261.6	0.185	0
1985	1.37	21.121	5.55	36.86	23.60	8.76	7.95	8.99	7.19	6.059	18.45	5.88	12.52	224.8	0.098	0
1986	0.47	0.103	5.99	38.13	35.92	36.11	15.88	10.41	10.89	4.811	13.83	49.11	18.55	454.2	0.098	4
1987	2.76	0.518	0.68	7.95	8.08	43.22	4.82	2.10	1.08	0.185	10.11	5.87	7.24	187.4	0.098	2
1988	1.79	0.200	10.93	100.29	25.36	11.04	28.15	31.50	32.62	28.348	40.78	27.36	28.15	760.9	0.098	0
1989	12.85	12.813	5.78			4.16	8.94	4.40	10.99	14.748						98
1990		6.883	16.98	57.66	15.24	7.25	5.04									181
Max	95.2	59.61	61.7	270.4	90.0	43.2	47.7	47.8	41.0	64.70	724.1	151.1	88.1	1836.0	6.880	
Min	0.47	0.103	0.68	2.33	2.00	0.42	1.06	1.42	1.08	0.185	5.98	2.07	5.20	28.19	0.098	
Mean	10.90	7.318	11.35	39.75	26.72	12.84	12.26	16.98	15.65	15.293	46.00	25.71	20.29	306.78	1.694	
Runoff(mm)	1.9	1.3	2.0	7.0	4.7	2.2	2.1	3.0	2.7	2.7	8.1	4.5	3.6	53.7	0.3	

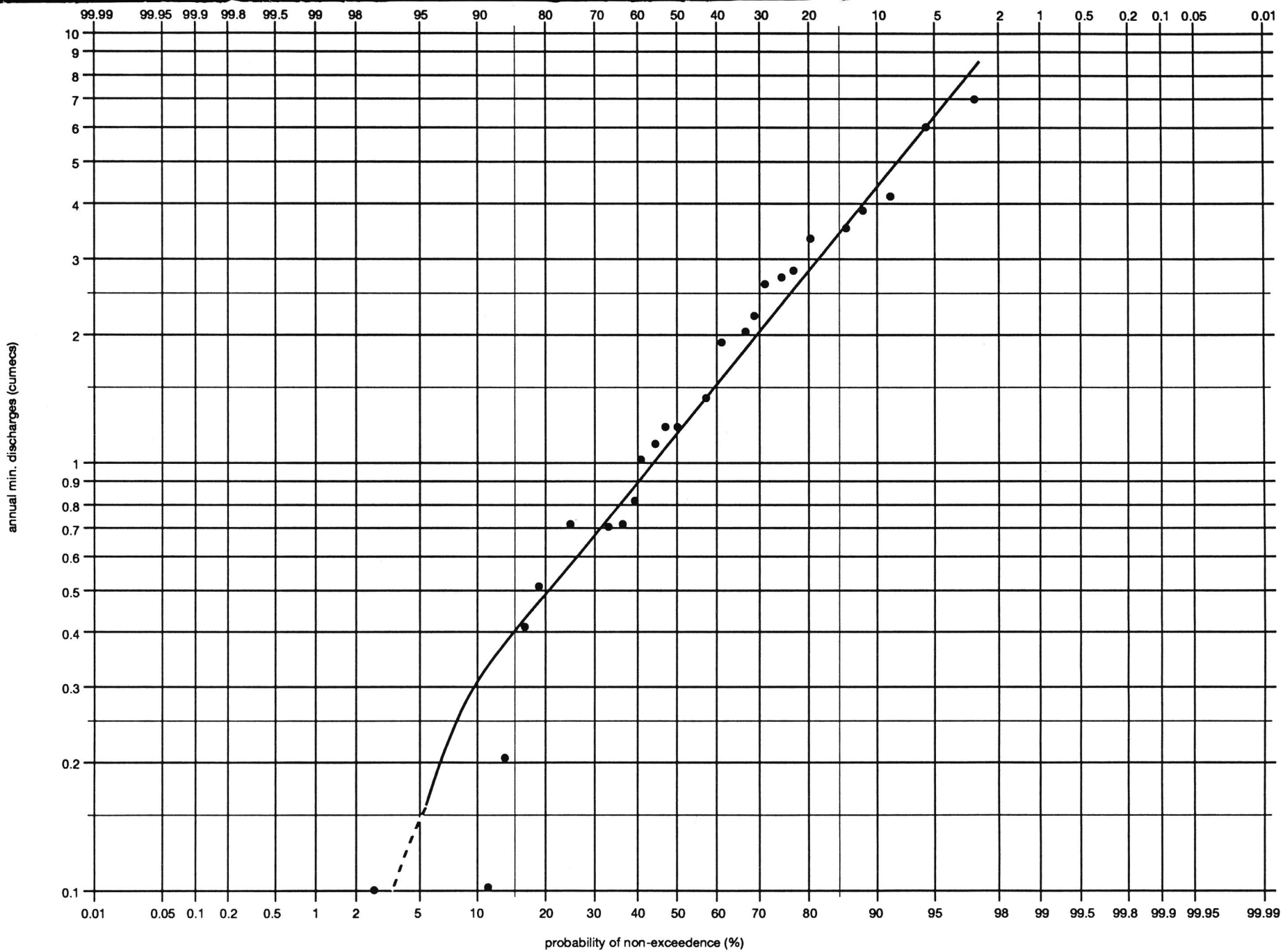
26-Oct-90

EWSO NGIRO RIVER

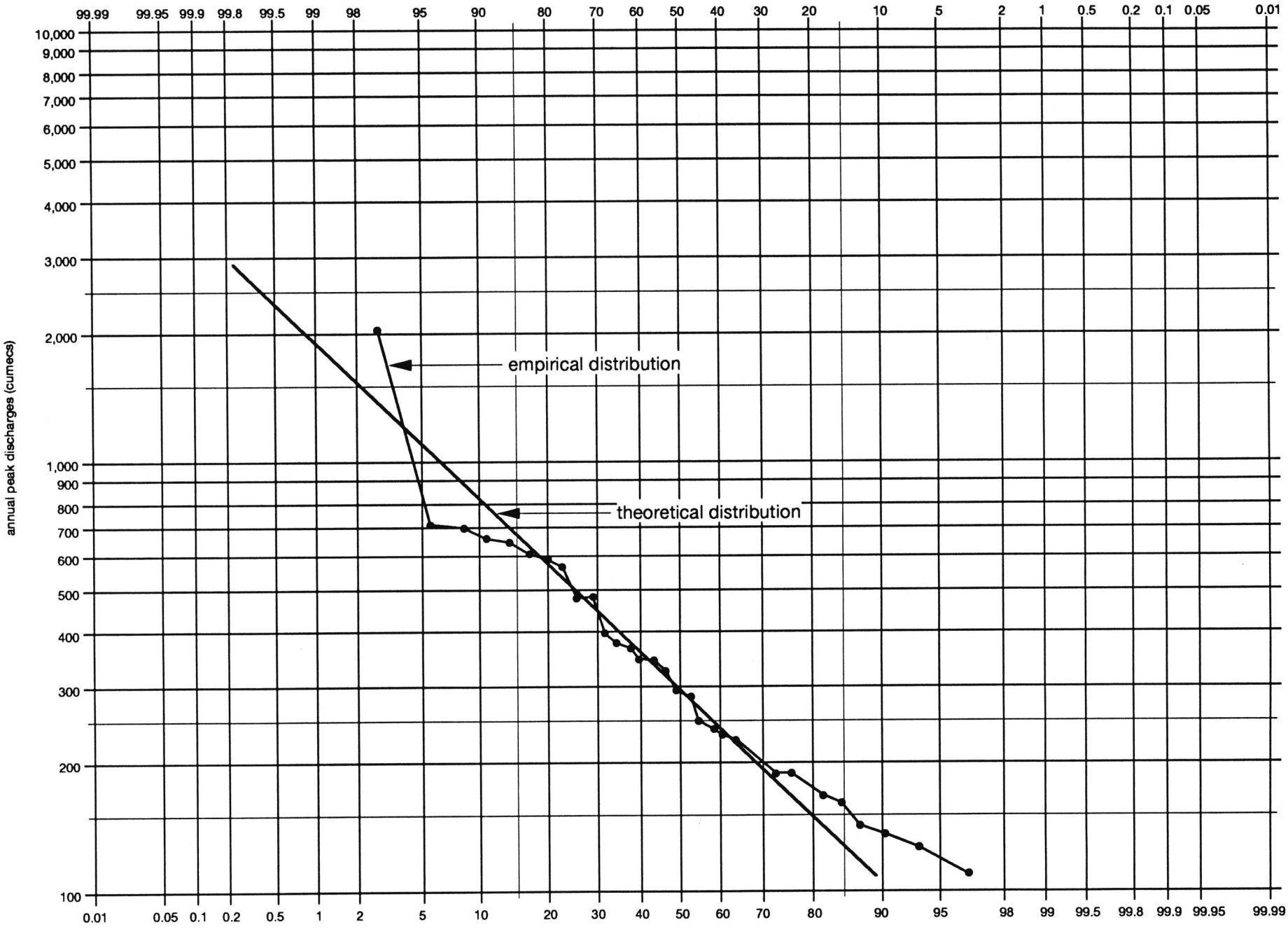


5E03





App. 4.8, Fig. 3: Annual Minimum Discharge Frequency Curve at RGS 5E 3



Type III Distribution of Annual Peak Flows at PGS 5 F 3

Appendix 4.9

Isiolo River - Discharge Data

Appendix 4.9 Isiolo River - Discharge Data

MINISTRY OF WATER DEVELOPMENT
Water Resources Assessment Project

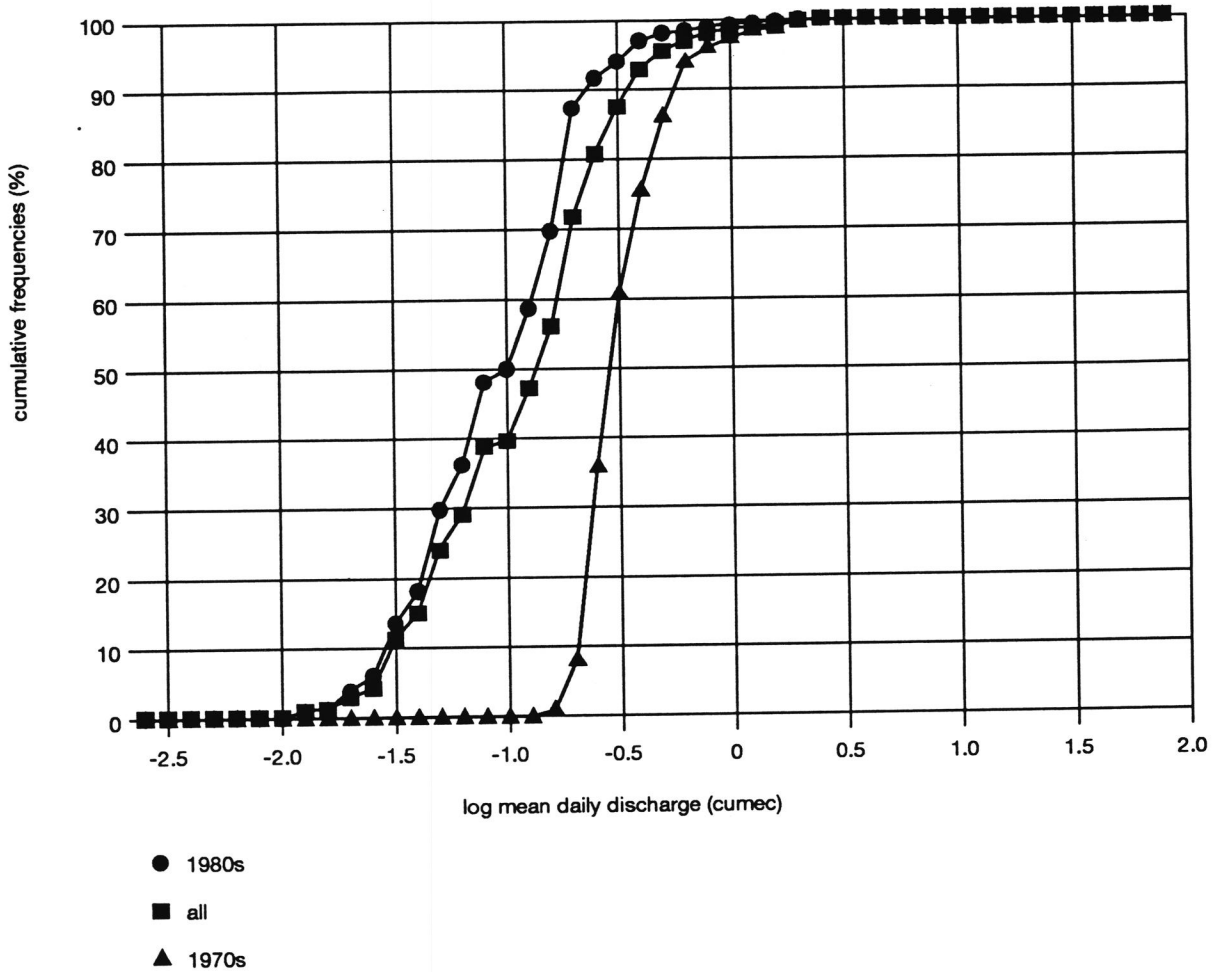
MONTHLY AND ANNUAL DISCHARGE DATA

River: ISIOLO RIVER
R.G.S: 5D08
Area : 229.5 sq km

The flows are in: CUMEC

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Daily max	Daily min	Days without readings
1976											0.451					310
1977	0.5787															300
1978						0.2356	0.2895	0.2639	0.2648	0.272	0.353	0.785				146
1979	0.3362	0.7136	0.352	0.410	0.308	0.1949	0.2037	0.2375	0.2247	0.237	0.493	0.228	0.325	3.500	0.159	5
1980	0.1965	0.1933	0.206	0.255	0.383	0.1802	0.1512	0.1735	0.1439	0.140	0.596	0.176	0.232	2.690	0.118	9
1981	0.1342	0.1202	0.570	1.053	0.592	0.1549			0.1776	0.146	0.161					23
1982							0.0258	0.0312	0.0254	0.435	0.446	0.412				183
1983	0.2142	0.1749	0.169	0.160	0.155	0.0548	0.0521	0.0760	0.1053	0.128	0.167	0.155	0.134	0.354	0.050	91
1984	0.0682		0.166	0.203	0.038	0.0191	0.0214	0.0142	0.0353	0.058	0.340	0.131				137
1985	0.0534	0.0549	0.078	0.144	0.046	0.0306	0.0306			0.067						154
1986		0.0352	0.125	0.095	0.125	0.0863	0.0632	0.0656	0.0404	0.062	0.091	0.107				108
1987	0.0877	0.0566	0.120	0.070	0.049	0.0432	0.0362	0.0489	0.0484	0.064	0.101	0.120	0.070	0.309	0.036	109
1988	0.0279	0.0176	0.043	0.124	0.070	0.0455			0.0310	0.039	0.063					138
Max	0.579	0.714	0.57	1.05	0.59	0.236	0.289	0.264	0.265	0.43	0.60	0.78	0.33	3.50	0.159	
Min	0.0279	0.0176	0.043	0.070	0.038	0.0191	0.0214	0.0142	0.0254	0.039	0.063	0.107	0.070	0.309	0.036	
Mean	0.1886	0.1708	0.203	0.279	0.196	0.1045	0.0971	0.1138	0.1097	0.150	0.297	0.264	0.191	1.713	0.091	
Runoff(mm)	2.2	2.0	2.4	3.3	2.3	1.2	1.1	1.3	1.3	1.7	3.5	3.1	2.2	20.0	1.1	

10-Jul-89

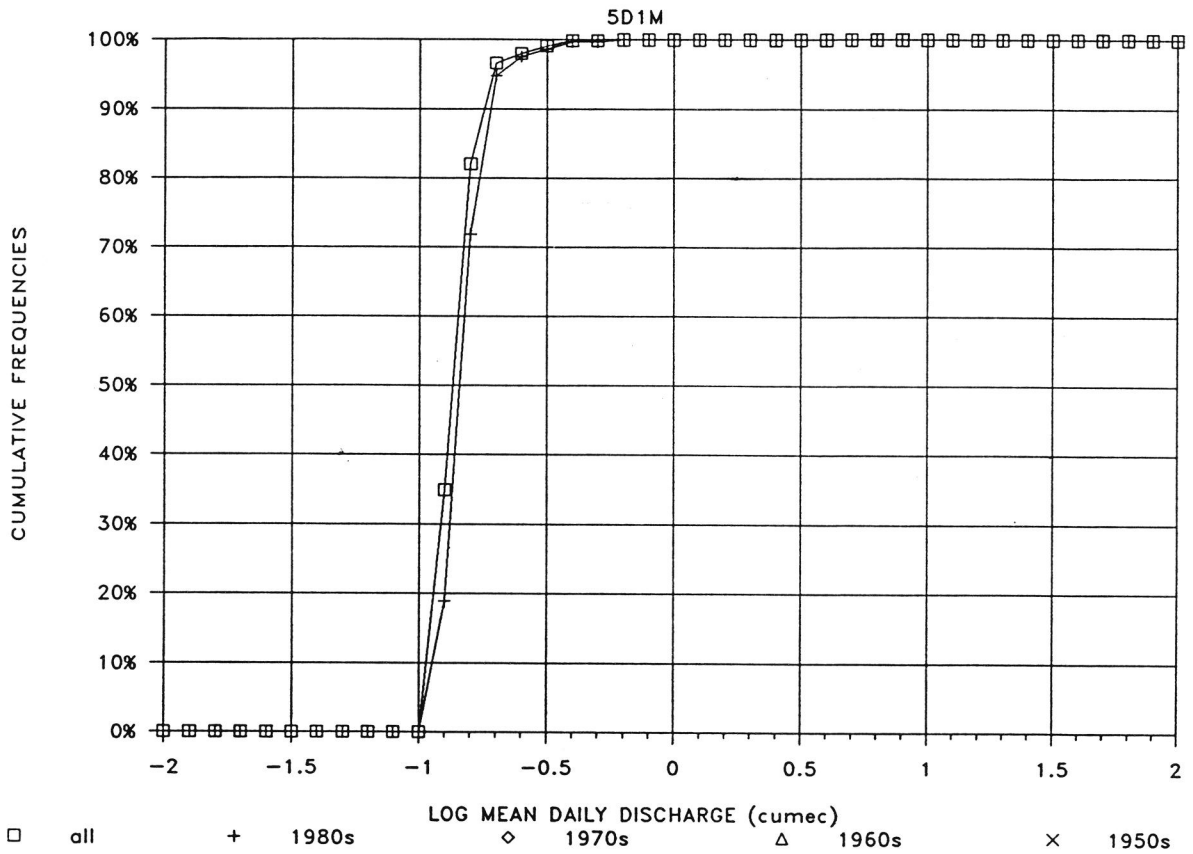


App. 4.9, Fig. 1: Cumulative Frequency Distribution of Daily Discharges-
Isiolo River, Station 5D08

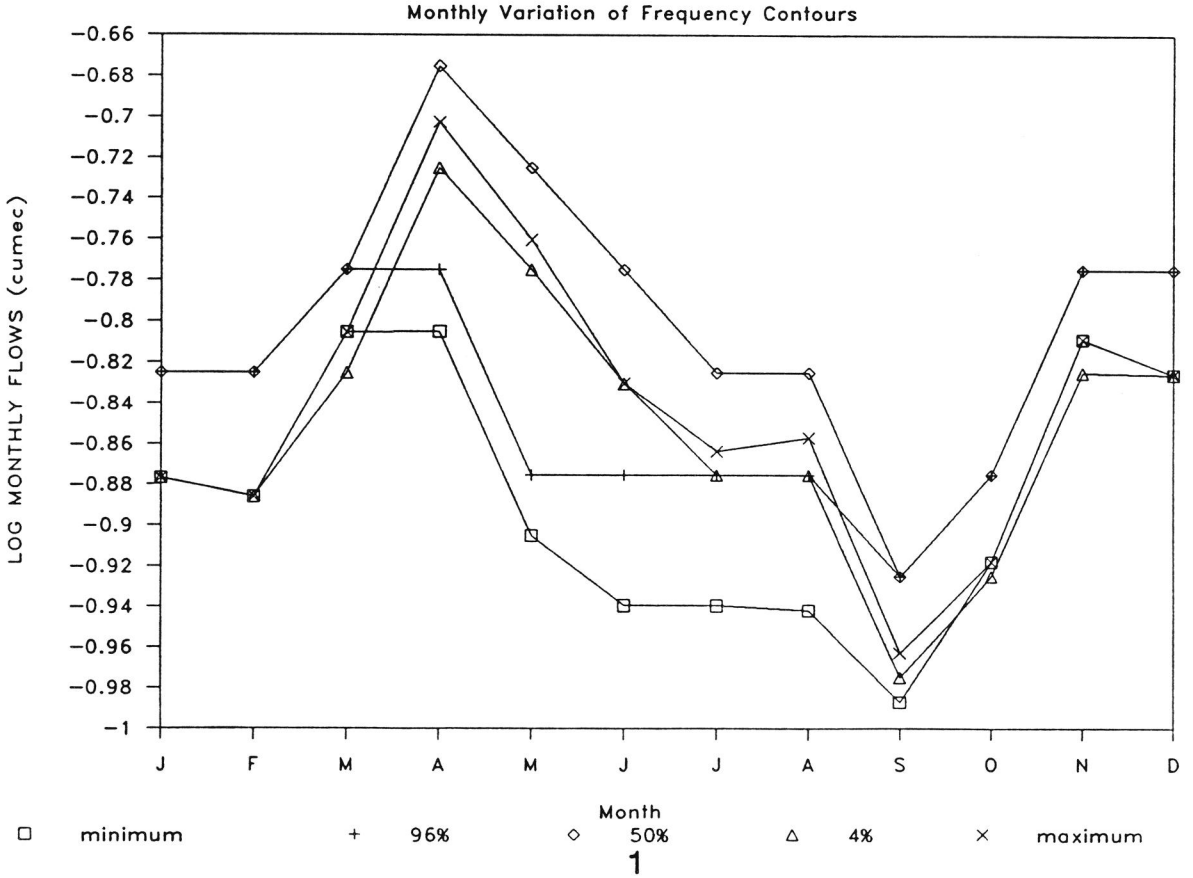
Appendix 4.10

Ngare Ndare River - Flow Duration Rating Curves

NGARE NDARE

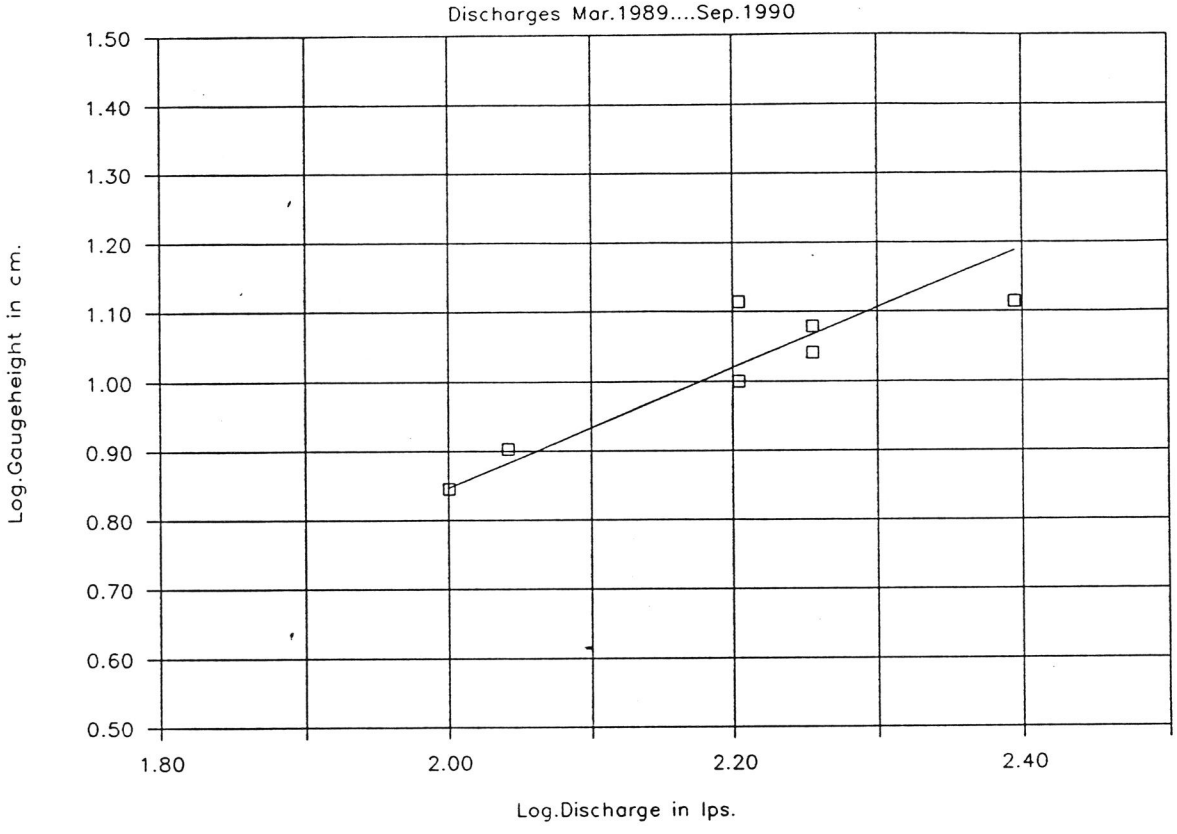


5D1M



NGARE NDARE RATING CURVE

Discharges Mar.1989....Sep.1990



APPENDIX 5

DATA ON BOREHOLES, WELL TESTS AND CHEMISTRY OF BOREHOLES, WELLS AND SPRINGS

APPENDIX 5

DATA ON BOREHOLES, WELL TESTS AND

CHEMISTRY OF BOREHOLES, WELLS AND SPRINGS

5.1 Borehole Data

5.2 Well Tests

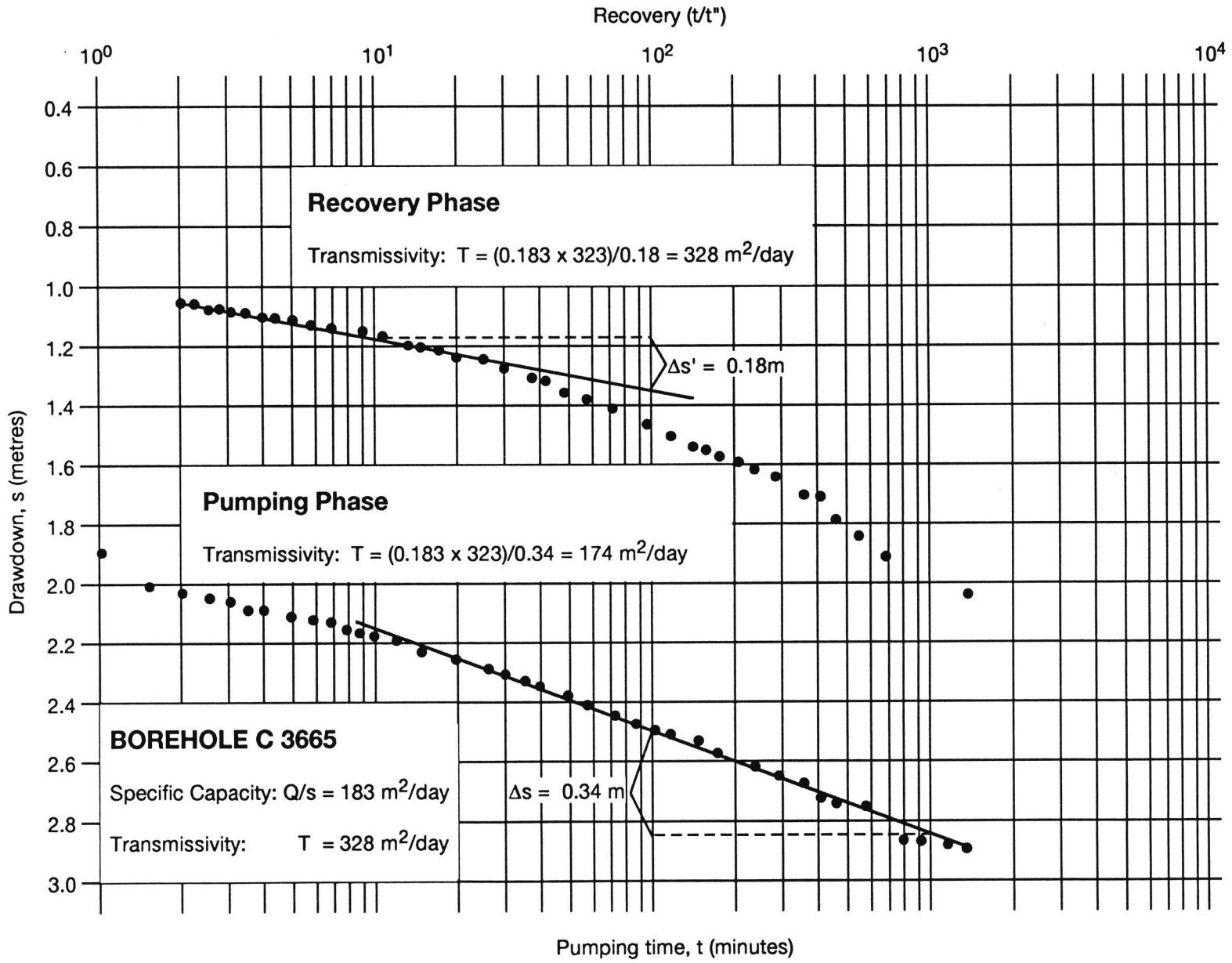
5.3 Chemical Data of Boreholes
Wells and Springs

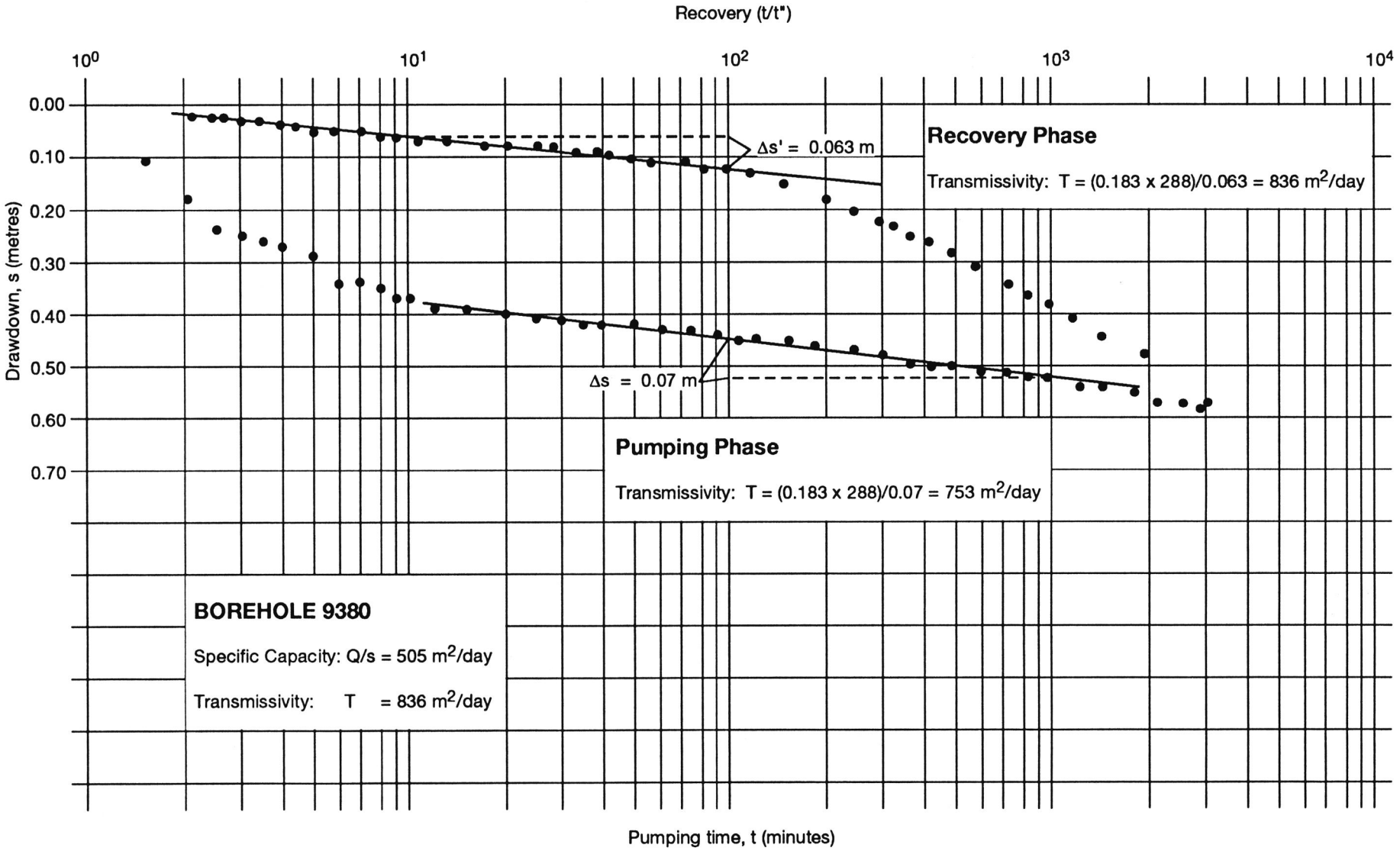
Appendix 5.1 Borehole Data

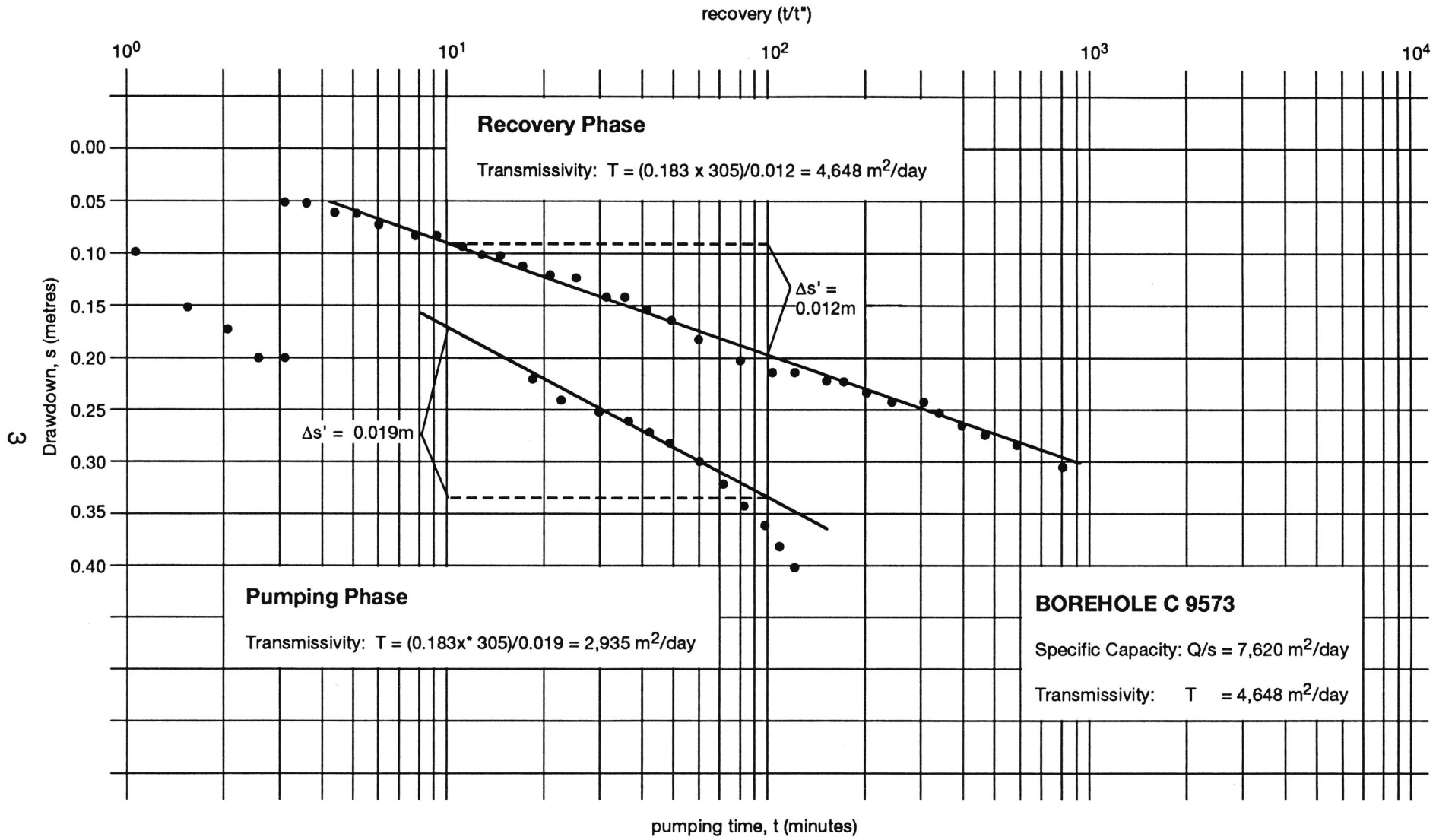
B.H No.	Locality	When Constructed	Elevation (m)	Total Depth (m)	W.S.L. Level (m)	W.R.L. Level (m)	Tested Yield (m^3/h)	Geo	Ch	TP	Present State
SA 10	Garba Tula	09/10/40	675	34.7	13.7	12.5	6.8	Yes	No	Yes	Not operating
SA 18	Garba Tula	14/10/40	600	19.5	12.5	11.9	9.1	Yes	No	No	Back filled
SA 32	Garba Tula	17/10/40	600	20.0	13.7	12.8	13.6	Yes	No	No	Abandoned
SA 37	Mado Gashi	23/11/40		108.0	-	-	-	Yes	-	-	Dry
SA 61	Hadado	03/12/40	300	62.5	-	-	-	Yes	-	-	Dry
SA 63	Hadado	20/12/40	300	74.7	-	-	-	Yes	-	-	Dry
SA 65	Mado Gashi	27/12/40		41.8	-	-	-	Yes	-	-	Dry
SA 66	Kula Mawe	05/02/41	770	91.4	59.0	48.8	6.7	Yes	No	No	Blocked
C 87	Isiolo	10/02/40		64.0	26.2, 30.5	13.4	4.6	Yes	No	No	Back filled
C 90	Isiolo	08/04/40		54.8	37.5	29.0	4.8	Yes	No	Yes	Operational
C 96	El Dera	03/07/40	400	124.4	108.2	-	3.3	No	No	No	Back filled
C 97	Isiolo	25/04/40		36.6	24.4	14.6	14.0	Yes	No	No	Not operating
C 98	Isiolo	01/06/40		62.0	30.5	24.4	15.9	Yes	No	No	Back filled
C 136	Kula Mawe	25/01/55	765	56.7	-	-	-	Yes	-	-	Dry
C1611	Kipsing	19/10/51	-	83.8	-	-	-	Yes	-	-	Dry
C1612	Longopito	22/11/51	-	106.7	54.9	27.4	2.5	Yes	No	No	Not operating
C1784	Kipsing	-	-	83.8	-	-	-	Yes	-	-	Dry
C2114	Isiolo	08/12/53	-	136.8	54.8, 82.3	64.0	0.6	Yes	No	No	Not traced
C2212	Isiolo	07/06/54	-	102 97.5	47.2, 82.3, 94.2	36.0	10.9	Yes	No	No	Not operating
C2324	Kula Mawe	12/02/55	765	52.0	40.8	36.0	5.5	Yes	Yes	No	Operational
C2502	Isiolo	30/04/56		213.4	65.5, 105, 167.6, 206.7	52.0	18.2	Yes	No	No	Operating
C2787	Ol Doinyo Ngiro	-	-	183.2	100.6	79.3	0.2	Yes	No	No	Back filled
C3129	Mlango	08/07/61	-	83.8	68.0	62.5	5.18	Yes	No	Yes	Not operating
C3636	Mado Gashi	24/11/69	300	188.0	181.4	135.0	-	Yes	No	No	Abandoned
C3645	Habaswein	11/12/69	270	38.7	-	-	-	Yes	-	-	Dry
C3655	Habaswein	29/06/70	280	169.0	108.2	105.5	6.8	Yes	Yes	Yes	Not operating
C3665	Garba Tula	18/04/70	600	18.3	11.3	8.7	11.2	Yes	Yes	Yes	Operating
C3689	Kuru Barata	28/05/70	565	152.4	20.4, 22.9, 41.2	15.9	1.6	Yes	No	No	Blocked
C3705	Ol Doinyo Ngiro	22/07/70	-	152.4	-	-	-	Yes	-	-	Dry
C3728	Longopito	19/03/71	-	152.4 74.7	51.2,	30.5	0.9	Yes	Yes	Yes	Back filled
C3729	Longopito	28/04/71	-	152.4	-	-	-	Yes	-	-	Dry
C3773	Ol Doinyo Ngiro	-		152.4	87.8, 111.3	61.6	0.2	Yes	-	-	Back filled
C3805	Sericho			91.4	19.8, 35, 50.3	22.3	4.6	Yes	Yes	No	Abandoned

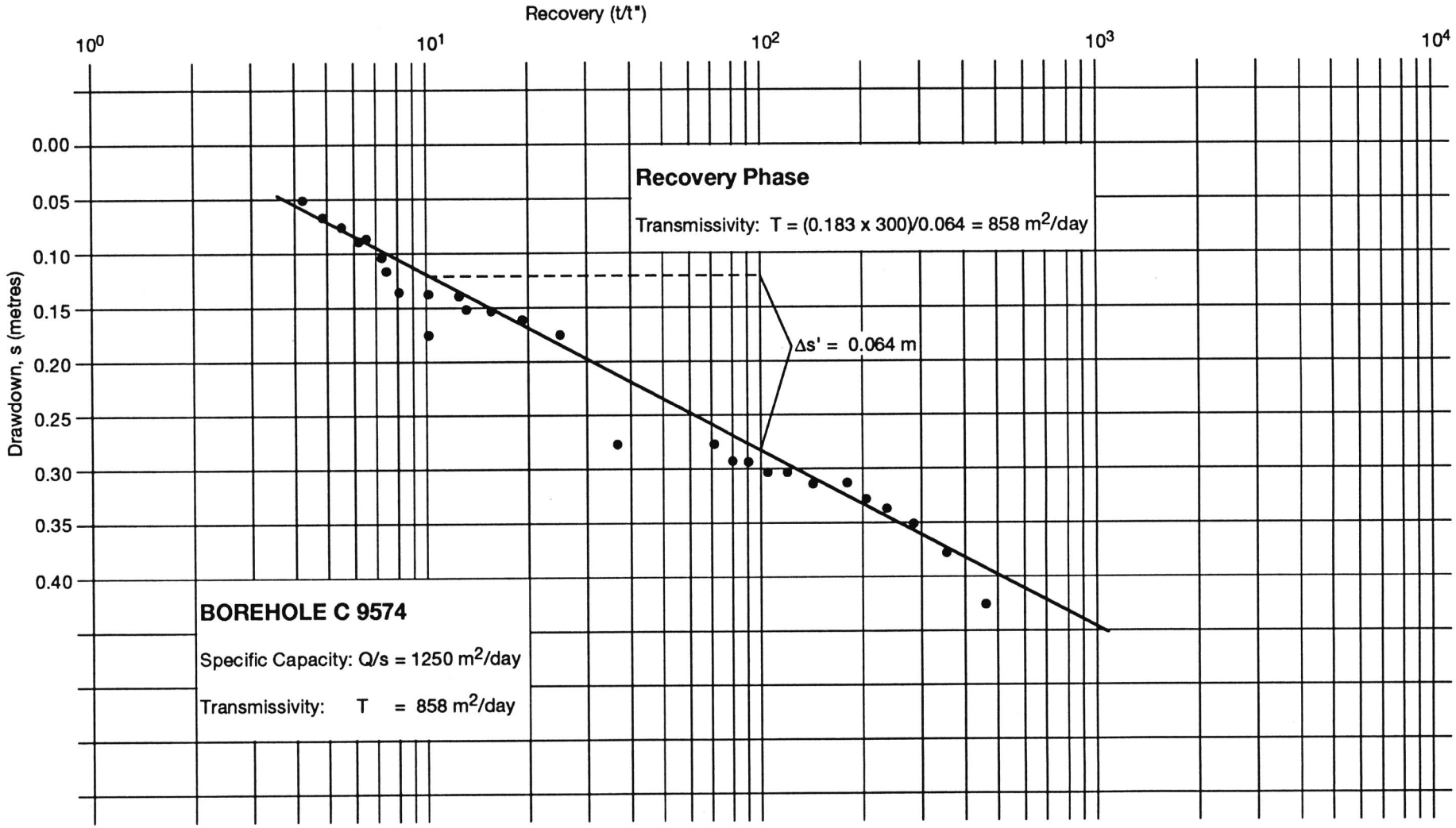
Appendix 5.2

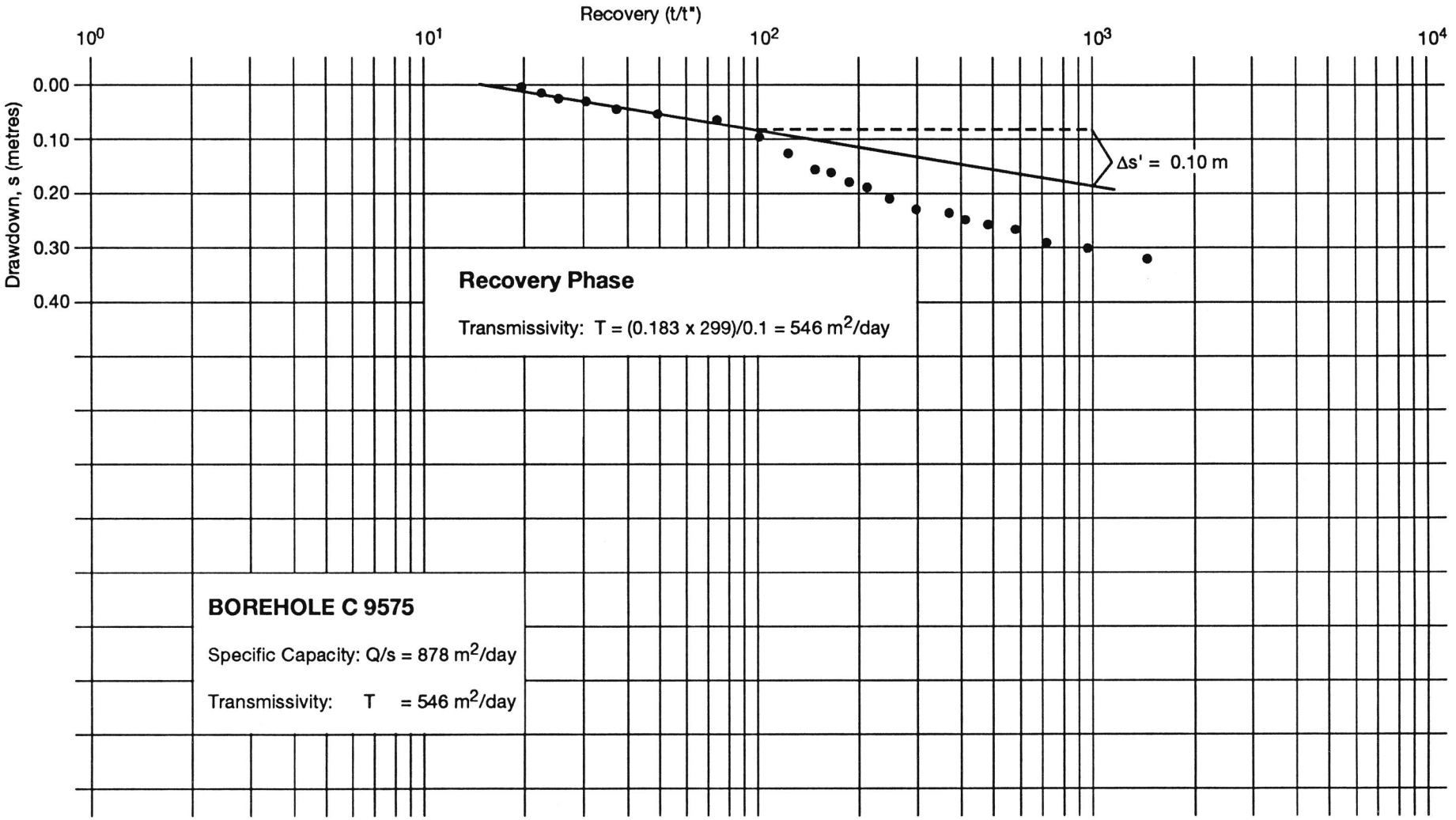
Well Tests

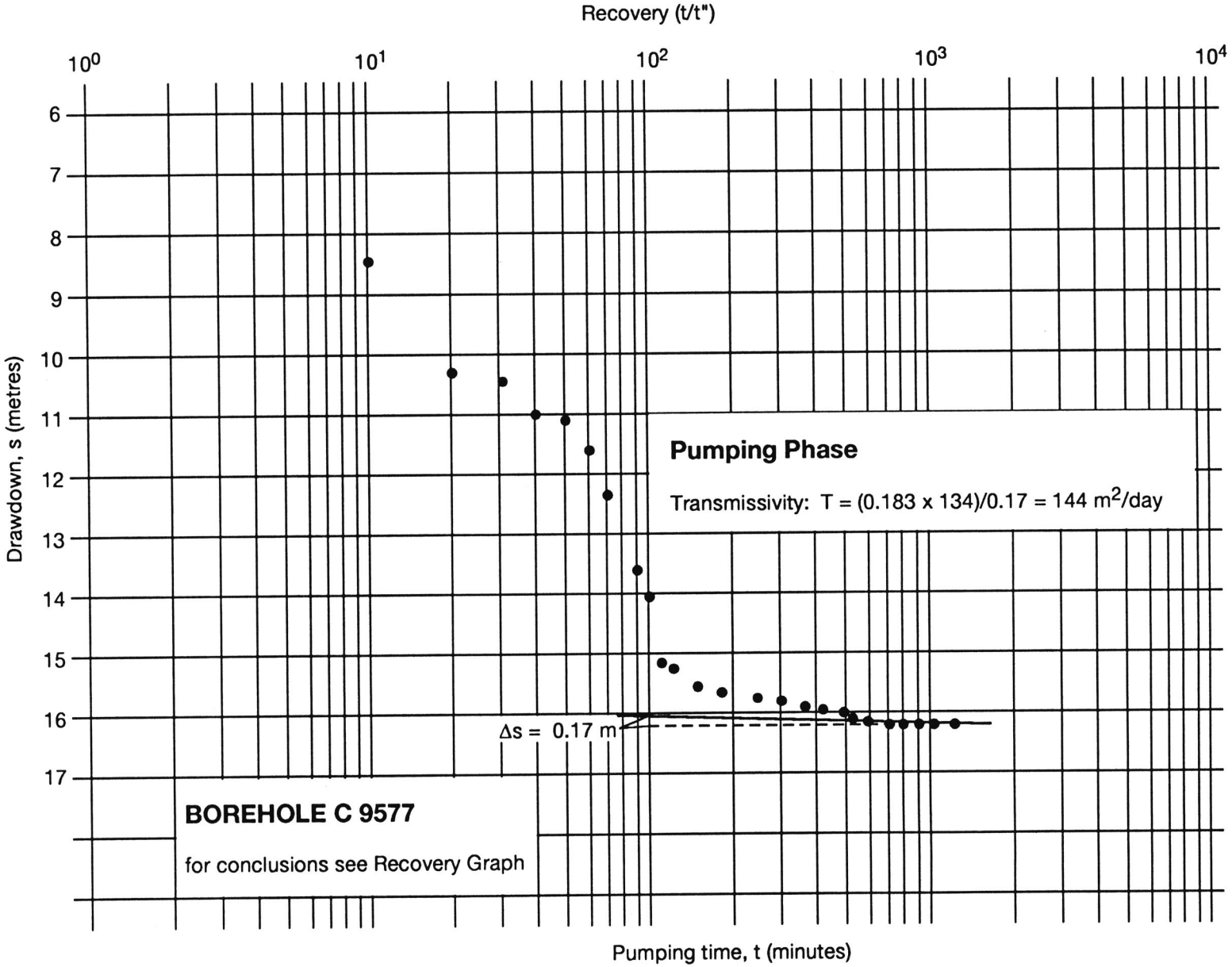

Recovery (t/t")
10^0
10^1
10^2
10^3
10^4
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
Drawdown, s (metres)
Recovery Phase
Transmissivity: T = (0.183 x 323)/0.18 = 328 m2/day
Δs' = 0.18m
Pumping Phase
Transmissivity: T = (0.183 x 323)/0.34 = 174 m2/day
BOREHOLE C 3665
Specific Capacity: Q/s = 183 m2/day
Transmissivity: T = 328 m2/day
Δs = 0.34 m
Pumping time, t (minutes)

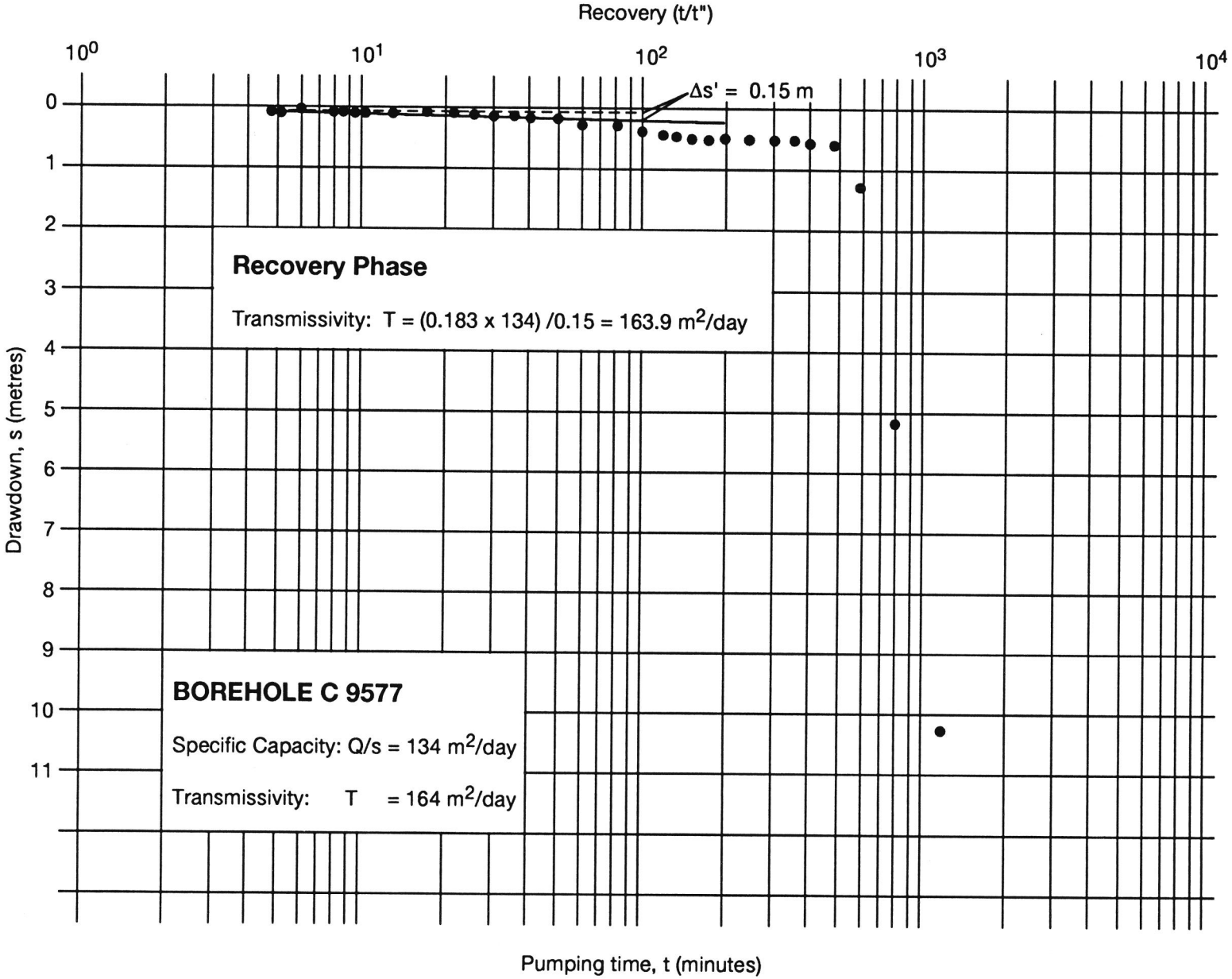

Recovery (t/t')
10^0
10^1
10^2
10^3
10^4
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
Drawdown, s (metres)
Δs' = 0.063 m
Recovery Phase
Transmissivity: T = (0.183 x 288)/0.063 = 836 m²/day
Δs = 0.07 m
Pumping Phase
Transmissivity: T = (0.183 x 288)/0.07 = 753 m²/day
BOREHOLE 9380
Specific Capacity: Q/s = 505 m²/day
Transmissivity: T = 836 m²/day
Pumping time, t (minutes)

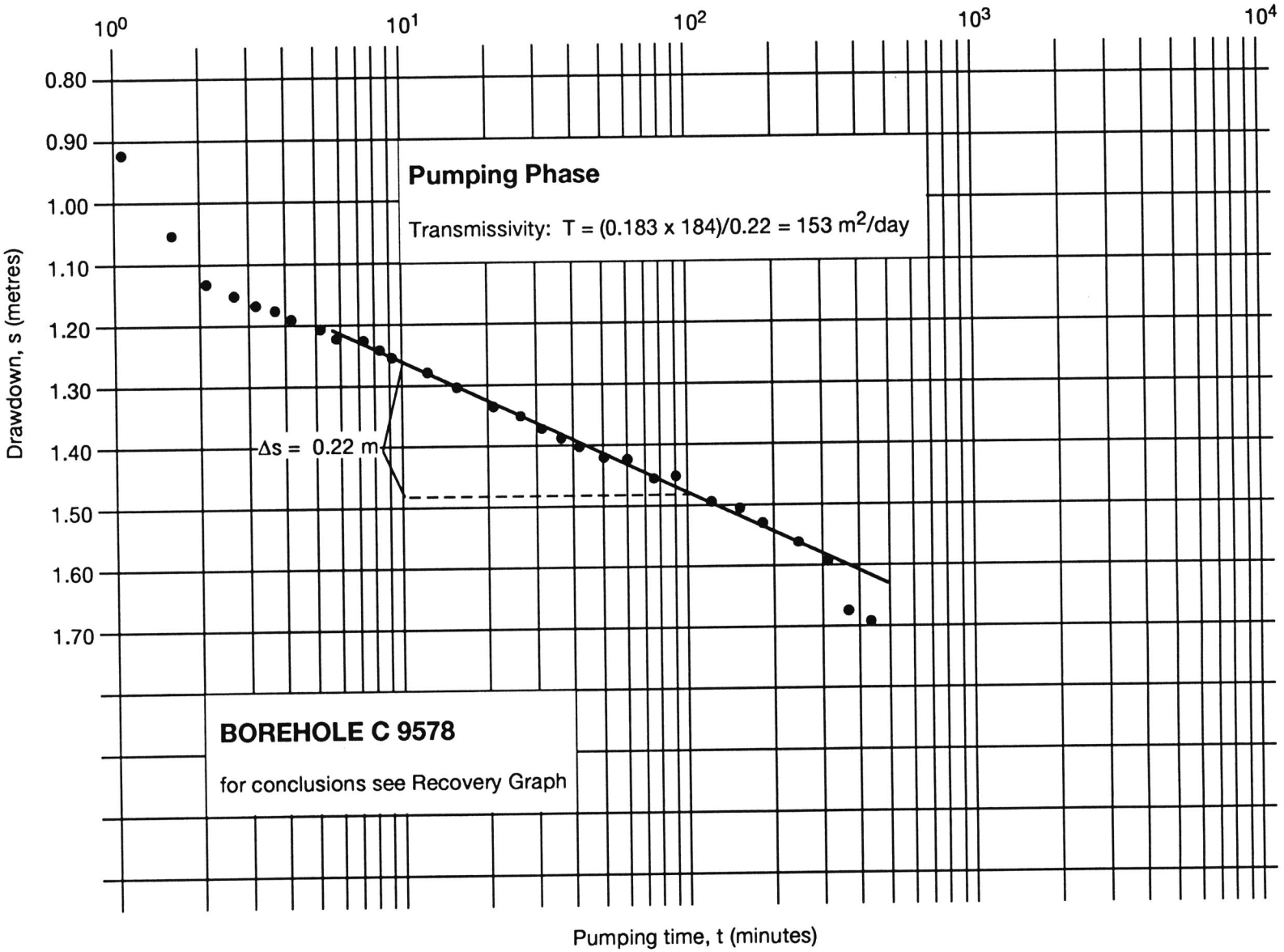

recovery (t/t')
10^0
10^1
10^2
10^3
10^4
Recovery Phase
Transmissivity: T = (0.183 x 305)/0.012 = 4,648 m²/day
Δs' = 0.012m
Δs' = 0.019m
Drawdown, s (metres)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Pumping Phase
Transmissivity: T = (0.183x* 305)/0.019 = 2,935 m²/day
BOREHOLE C 9573
Specific Capacity: Q/s = 7,620 m²/day
Transmissivity: T = 4,648 m²/day
pumping time, t (minutes)

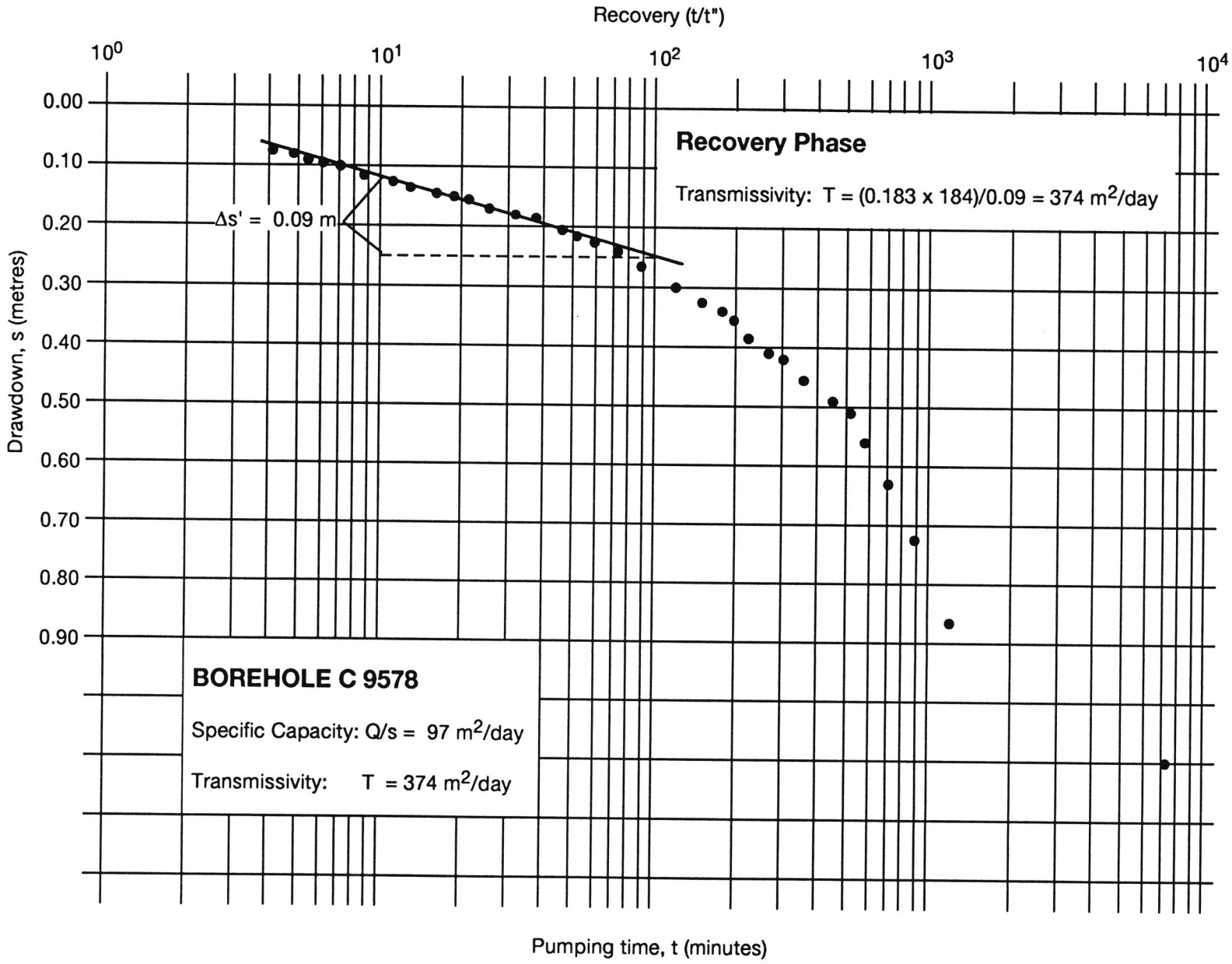

Recovery (t/t')
10^0
10^1
10^2
10^3
10^4
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Drawdown, s (metres)
Recovery Phase
Transmissivity: T = (0.183 x 300)/0.064 = 858 m²/day
Δs' = 0.064 m
BOREHOLE C 9574
Specific Capacity: Q/s = 1250 m²/day
Transmissivity: T = 858 m²/day

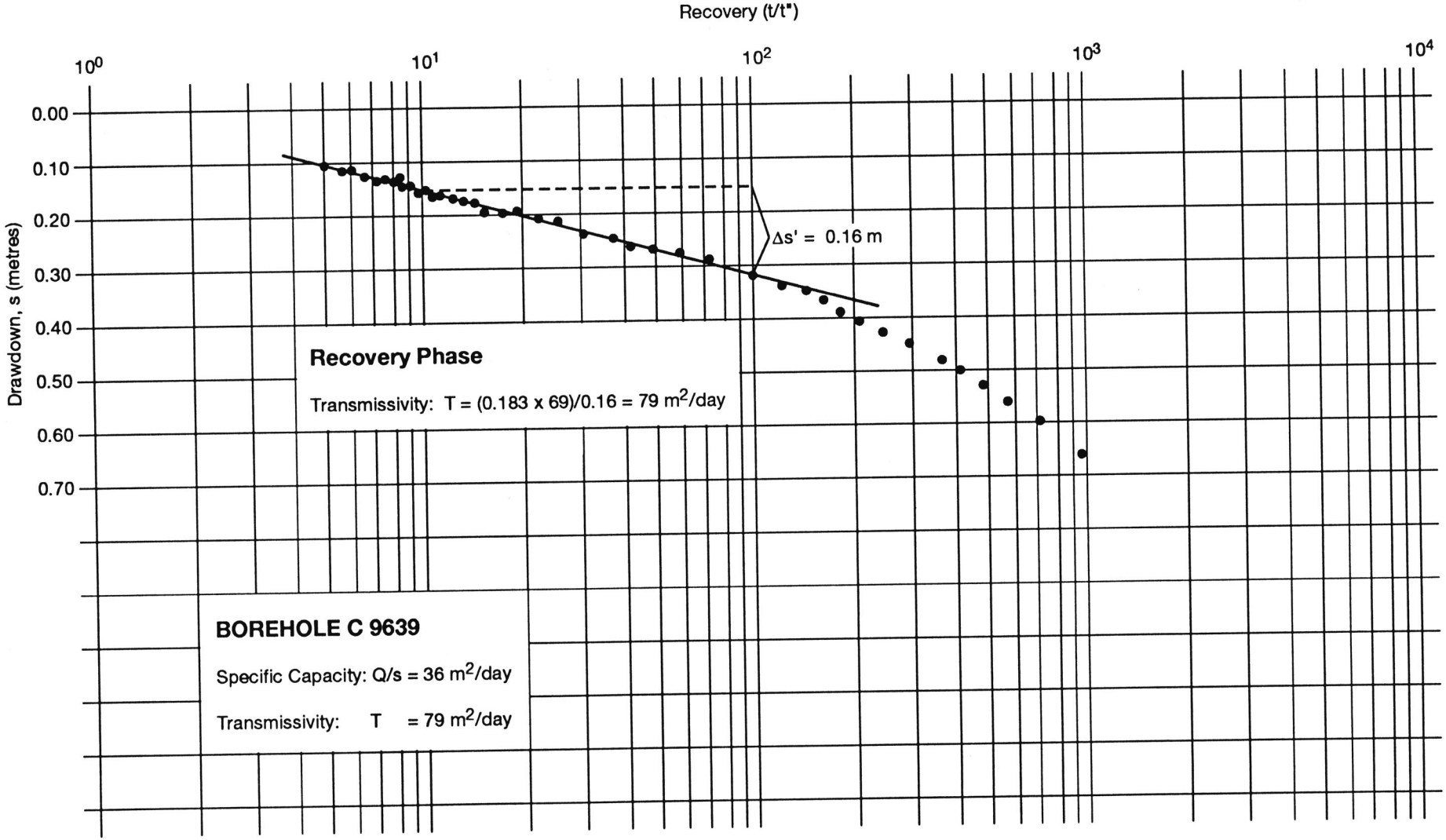

Recovery (t/t')
10^0
10^1
10^2
10^3
10^4
Drawdown, s (metres)
0.00
0.10
0.20
0.30
0.40
Δs' = 0.10 m
Recovery Phase
Transmissivity: T = (0.183 x 299)/0.1 = 546 m²/day
BOREHOLE C 9575
Specific Capacity: Q/s = 878 m²/day
Transmissivity: T = 546 m²/day

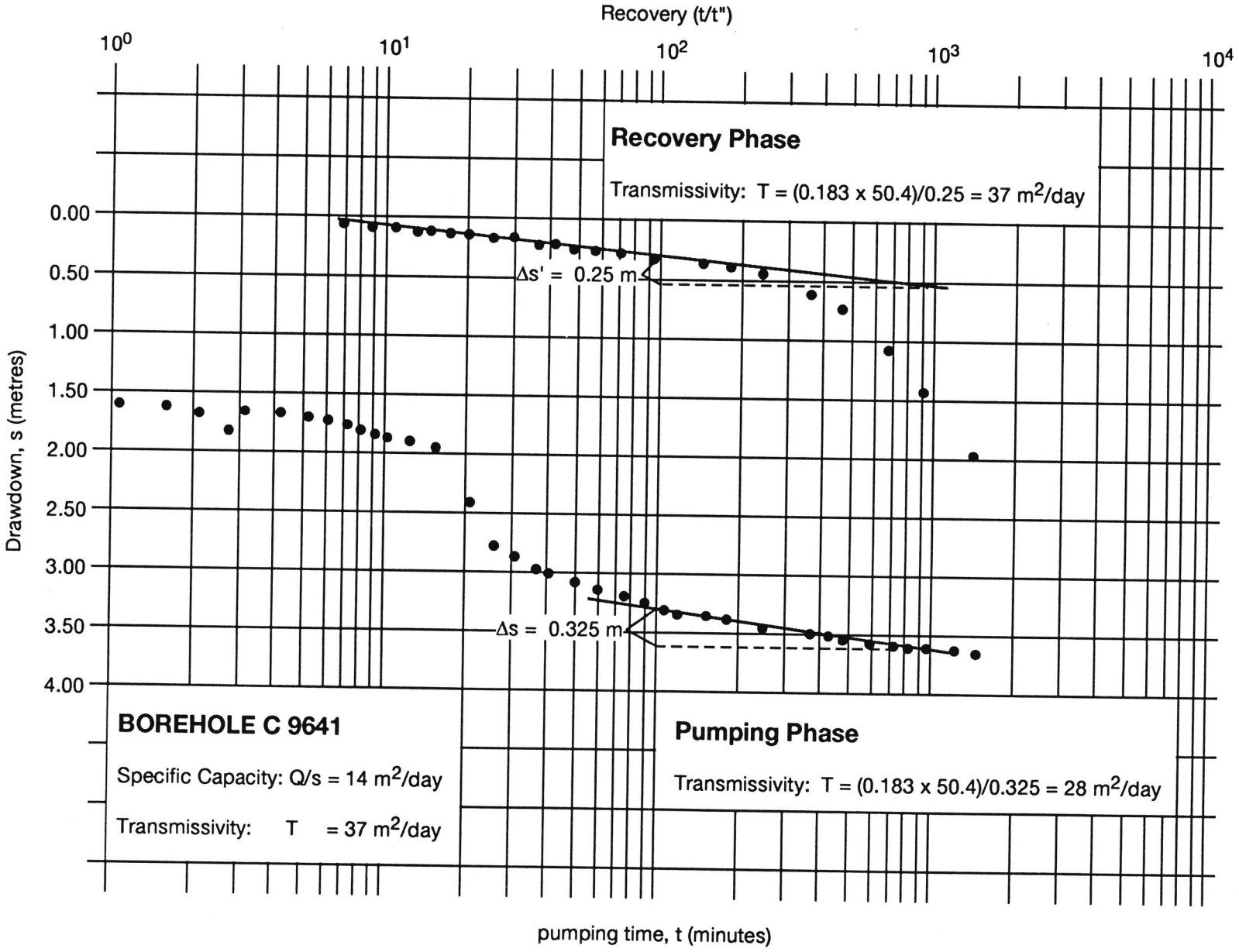

Recovery (t/t')
10^0
10^1
10^2
10^3
10^4
6
7
8
9
10
11
12
13
14
15
16
17
Drawdown, s (metres)
Pumping Phase
Transmissivity: T = (0.183 x 134)/0.17 = 144 m^2/day
Δs = 0.17 m
BOREHOLE C 9577
for conclusions see Recovery Graph
Pumping time, t (minutes)


Recovery (t/t")
10^0
10^1
10^2
10^3
10^4
Δs' = 0.15 m
0
1
2
3
4
5
6
7
8
9
10
11
Drawdown, s (metres)
Recovery Phase
Transmissivity: T = (0.183 x 134) /0.15 = 163.9 m²/day
BOREHOLE C 9577
Specific Capacity: Q/s = 134 m²/day
Transmissivity: T = 164 m²/day
Pumping time, t (minutes)


10^0
10^1
10^2
10^3
10^4
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
1.60
1.70
Drawdown, s (metres)
Pumping Phase
Transmissivity: T = (0.183 x 184)/0.22 = 153 m²/day
Δs = 0.22 m
BOREHOLE C 9578
for conclusions see Recovery Graph
Pumping time, t (minutes)


Recovery (t/t")
10^0
10^1
10^2
10^3
10^4
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Drawdown, s (metres)
Δs' = 0.09 m
Recovery Phase
Transmissivity: T = (0.183 x 184)/0.09 = 374 m²/day
BOREHOLE C 9578
Specific Capacity: Q/s = 97 m²/day
Transmissivity: T = 374 m²/day
Pumping time, t (minutes)


Recovery (t/t')
10^0
10^1
10^2
10^3
10^4
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
Drawdown, s (metres)
Δs' = 0.16 m
Recovery Phase
Transmissivity: T = (0.183 x 69)/0.16 = 79 m²/day
BOREHOLE C 9639
Specific Capacity: Q/s = 36 m²/day
Transmissivity: T = 79 m²/day


Recovery (t/t")
10^0
10^1
10^2
10^3
10^4
Recovery Phase
Transmissivity: T = (0.183 x 50.4)/0.25 = 37 m²/day
Δs' = 0.25 m
Δs = 0.325 m
Drawdown, s (metres)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
BOREHOLE C 9641
Specific Capacity: Q/s = 14 m²/day
Transmissivity: T = 37 m²/day
Pumping Phase
Transmissivity: T = (0.183 x 50.4)/0.325 = 28 m²/day
pumping time, t (minutes)

Appendix 5.3

Chemical Data of Boreholes Wells and Springs

Chemical Data Collected Before WRAP Project

BOREHOLE NUMBER	LOCALITY	PH	EC mS/cm	mg/l												HARD-NESS (CaCO3)	TDS mg/l	AQUIFER SYSTEM
				Na	K	Ca	Mg	Fe	Mn	Cl	HCO3	SO4	NO3	F	SiO2			
C90	Isiolo	6.9	-	-	-	-	-	0.3	-	1.2	453	0	0	0.3	26	100	565	IB
C1612	Longopito	7.4	3.45	276	18	163	203	0	-	530	500	453	199.4	1.5	100	410	2495	IIA
C3636	Mado Gashi	8.7	17.00	3600	13	50	0	0.1	-	3000	3100	1630	57	2	20	66	10600	IA
C3655	Habaswein	7.7	1.00	184	13	30	17	0.4	0	100	480	47	0.5	2.3	35	148	795	IA
C3728	Longopito	7.9	4.90	190	20	404	410	0.3	-	720	303	1420	0	0.8	70	248	4420	IIA
C3805	Sericho	9.1	8.10	2200	8	3	1	0.2	-	1080	2050	827	0	20	2	10	5660	IA
C3814	Sericho	8.6	14.00	3860	18	16	0	0	-	2550	2430	973	4.4	12	20	40	10000	IA
C3822	Sericho	8.5	10.40	2860	26	3	1	0.8	-	2470	2920	800	1.3	37	15	14	7970	IA
C3830	Habaswein	8.4	10.00	2900	32	8	3	0.3	-	2720	1680	1230	4.4	7.6	25	32	8080	IA
C3853	Merti	8.6	26.40	7560	24	14.5	4	0.6	-	8150	2640	3470	-	12.5	30	52	20300	IA
C3864	Merti	7.9	0.87	85	15	41	32	0.3	-	30	483	15	0	0.4	30	234	470	IIB
C3893	Hadado	8.2	2.55	524	16	7	6	0.1	0.0	576	507	183	3.5	1.7	30	44	1500	IA
C3915	Hadado	7.8	6.50	1200	116	56	65	0	-	2850	486	267	0	0.7	70	348	4800	IA
C4424	Kune	9.1	10.90	2400	-	4.4	8.4	1.8	0.13	1947	2252	-	-	8	-	46	-	IA
C4475	Malka Daka	8.0	6.00	1131	-	48	48	2.96	1.04	1156	1053	-	-	0.3	-	1060	-	IA
C6951	Bulesa	8.9	11.52	2900	40	9	21	8.8	0.14	2339	790	0.3	0.07	-	-	120	6912	IIA
C7631	Isiolo	8.6	1.10	137	12	88	53	0.8	0.15	26	744	6	0	0	60	220	800	IB

- Not determined

Chemical Data from Boreholes, Wells and Springs

BH NO., WELL, SPRING	LOCALITY	DATE OF SAMPLING	pH	EC mS/cm	mg/l												Hard-ness (CaC03)	TDS mg/l	AQUIFER SYSTEM
					Na	K	Ca	Mg	Fe	Mn	Cl	HC03	S04	N03	F	Si02			
C2324	Kula Mawe	29/02/88	7.9	2.116	158.0	39.0	59.0	112.0	<0.1	<0.1	71.0	244.0	38.0	-	0.2	-	608.0	1297.0	IB
C3864	Merti	28/09/88	8.4	0.961	746.0	6.1	1.6	3.4	0.1	<0.1	52.0	172.0	25.0	-	0.1	-	18.0	577.0	IIB
C3915	Hadado	29/06/89	7.6	8.01	1300.0	38.0	43.0	59.0	0.2	<0.1	2225.0	406.0	492.0	-	0.7	-	348.0	4803.0	IA
C4543	Merti	28/09/88	8.5	0.937	231.0	5.7	2.4	1.0	0.1	<0.1	44.0	164.0	32.0	-	1.1	-	10.0	562.0	IIB
C4699	Yamicha	25/03/91	7.8	0.62	137.0	17.0	8.0	7.8	<0.1	<0.1	27.0	264.0	4.8	-	0.6	-	52.0	372.0	IA
C5795	Habaswein	23/09/88	7.9	1.922	735.0	7.8	16.0	25.0	0.1	<0.1	43.0	340.0	24.0	-	0.8	-	146.0	1153.0	IA
C7325	Sericho	'87	8.7	1.100	402.0	2.4	0.8	0.5	1.1	0	25.0	688.0	50.0	0.0	1.2	55.0	4.0	900.0	IIB
C7327	Sericho	'87	8.7	-	393.0	1.6	0.8	0.0	3.2	0	20.0	746.0	16.0	0.0	2.0	50.0	2.0	900.0	IIB
C7329	Sericho	22/03/88	8.2	1.474	254.0	5.3	0.8	5.8	0.2	<0.1	36.0	616.0	32.0	-	1.8	-	26.0	884.0	IIB
C7329	Sericho	'87	8.4	0.900	286.0	2.0	1.6	2.0	1.6	0	24.0	588.0	16.0	0.0	2.0	50.0	12.0	650.0	IIB
C	Karimet	30/09/88	7.5	1.320	73.0	4.8	25.0	119.0	0.1	<0.1	70.0	186.0	13.0	-	0.8	-	554.0	792.0	IB
C7344	Ngare Mara	30/09/88	7.8	1.560	91.0	12.0	9.6	122.0	<0.1	<0.1	44.0	186.0	7.0	-	0.6	-	524.0	936.0	IB
C7632	Shaba	30/09/88	7.5	0.912	116.0	23.0	20.0	39.0	<0.1	<0.1	19.0	120.0	3.8	-	1.0	-	210.0	547.0	IB
C7713	Garfasa	26/09/88	8.7	1.245	1759.0	1.6	2.4	2.4	<0.1	<0.1	41.0	420.0	31.0	-	1.1	-	14.0	2018.0	IIB
C8976	Ngare Mara	19/01/90	7.1	1.70	126.0	15.0	205.0	33.0	<0.1	<0.1	38.0	834.0	15.0	-	0.8	-	650.0	1017.0	IB
C9384	Diri	20/02/91	8.0	4.60	1120.0	22.0	0.4	4.0	0.2	0.7	480.0	1240.0	600.0	0	3	-	26.0	3300.0	IA
C9573	Garba Tula	19/04/91	7.6	1.55	221.0	105.0	37.0	121.0	<0.1	<0.1	117.0	788.0	43.0	-	0.5	-	590.0	931.0	IB
C9574	Garba Tula	17/04/91	7.5	1.70	397.0	164.0	34.0	109.0	<0.1	<0.1	145.0	818.0	68.0	-	0.6	-	532.0	1020.0	IB
C9575	Garba Tula	21/04/91	7.5	1.65	221.0	126.0	42.0	123.0	<0.1	<0.1	134.0	792.0	60.0	-	0.5	-	616.0	990.0	IB
C9577	Bibi	28/04/91	7.8	1.38	154.0	59.0	55.0	152.0	<0.1	<0.1	58.0	798.0	28.0	-	0.3	-	760.0	828.0	IB
C9639	Boji	25/04/91	7.8	0.78	88.0	59.0	47.0	47.0	<0.1	<0.1	20.0	64.0	8.0	-	0.3	-	312.0	468.0	IB
W1	Boji	29/09/88	7.9	1.535	126.0	31.0	51.0	107.0	<0.1	<0.1	72.0	212.0	17.0	-	1.0	-	570.0	1153.0	IB
W2	Garba Tula	24/09/88	8.0	1.849	914.0	75.0	20.0	109.0	0.1	<0.1	160.0	356.0	44.0	-	0.4	-	498.0	-	IB
W3	Garba Tula	24/09/88	7.6	1.918	903.0	73.0	4.8	119.0	<0.1	<0.1	150.0	804.0	41.0	-	0.4	-	500.0	2090.0	IB
W4	Garba Tula	24/09/88	7.8	1.910	840.0	75.0	33.0	95.0	0.1	<0.1	146.0	798.0	37.0	-	0.4	-	474.0	2306.0	IB
W5	Mado Gashi	23/09/88	7.4	0.560	242.0	6.3	43.0	-	0.1	<0.1	20.0	302.0	40.0	-	0.4	-	16.0	360.0	IIB
W6	Moliti	27/09/88	8.4	0.881	55.0	16.0	43.0	34.0	0.3	<0.1	23.0	204.0	2.6	-	1.1	-	204.0	504.0	IB
SP5	Buffalo	30/09/88	7.3	1.399	116.0	9.3	44.0	27.0	<0.1	<0.1	49.0	578.0	7.8	-	0.3	-	224.0	1153.0	IB
SP5	Buffalo	04/10/88	8.2	1.800	105.0	19.0	80.0	102.0	<0.1	<0.1	0.0	834.0	16.6	-	0.3	-	620.0	1080.0	IB
SP6	Archers	30/09/88	8.2	1.248	137.0	21.0	39.3	50.0	0.1	<0.1	31.0	170.0	5.4	-	1.0	-	304.0	865.0	IB
SP9	Natorbe I	30/09/88	8.1	1.523	10.5	31.0	28.0	71.0	0.1	<0.1	102.0	162.0	16.0	-	0.7	-	367.0	1081.0	IB
SP10	Sarova	30/09/88	8.2	1.365	116.0	29.0	61.0	96.0	<0.1	<0.1	46.0	404.0	10.4	-	0.6	-	530.0	864.0	IB
SP11	Natorbe II	30/09/88	8.5	1.497	200.0	33.0	32.0	50.0	<0.1	<0.1	82.0	194.0	16.0	-	0.2	-	290.0	1008.0	IB
SP23	Kinna	27/09/88	7.5	0.814	231.0	9.8	49.0	32.0	<0.1	<0.1	14.0	192.0	4.0	-	0.0	-	256.0	504.0	IB

- not determined

Interpretation of Chemical Data Analyses

Aquifer System	BH NO. WELL, SPRING	meq/l							Difference % between sums of the Cation and Anions
		Na+K	Ca	Mg	Cl	HCO3	SO4	Sum of react-values	
IA	C3636	156.86	2.50	0.00	84.51	50.82	33.96	328.65	3.02
IA	C3655	8.33	1.50	1.42	2.82	7.87	0.98	22.92	1.83
IA	C3805	95.86	0.15	0.08	30.42	33.61	17.23	177.35	8.36
IA	C3814	168.29	0.80	0.00	71.83	39.84	20.27	301.03	12.34
IA	C3822	125.01	0.15	0.08	69.58	47.87	16.67	259.36	3.42
IA	C3830	126.91	0.40	0.23	76.62	27.54	25.63	257.33	0.87
IA	C3853	329.31	0.73	0.33	229.58	43.28	72.29	675.52	2.19
IA	C3864	32.59	0.08	0.28	1.47	2.82	0.52	37.76	74.52
IA	C3915	57.49	2.15	4.92	62.68	6.66	10.25	144.15	10.43
IA	C4424	104.35	0.22	0.70	54.85	36.92	12.00	208.69	0.55
IA	C4475	49.17	2.40	4.00	32.56	17.26	4.20	109.59	1.41
IA	C4699	6.39	0.40	0.65	0.76	4.33	0.1	12.63	17.82
IA	C5795	32.15	0.80	2.08	1.21	5.57	0.50	42.31	65.58
IA	C6951	127.11	0.45	1.75	65.59	12.95	0.01	208.16	24.24
IA	C9384	49.26	0.02	0.33	13.52	20.33	12.50	95.96	3.40
IB	C2324	7.87	2.95	9.33	2.00	4.00	0.79	26.94	49.59
IB	C	3.30	1.25	9.92	1.97	3.05	0.27	19.76	46.45
IB	C7344	4.26	0.48	10.17	1.24	3.05	0.15	19.35	54.10
IB	C7631	6.26	4.40	4.42	0.73	12.20	0.13	28.14	7.18
IB	C7632	5.63	1.00	3.25	0.54	1.97	0.08	12.47	58.46
IB	C8976	5.86	10.25	2.75	1.07	13.67	0.31	33.91	11.26
IB	C9573	12.30	1.85	10.08	3.30	12.92	0.90	41.35	17.19
IB	C9574	21.46	1.70	9.08	4.08	13.41	1.42	51.15	26.06
IB	C9575	12.84	2.10	10.25	3.77	12.98	1.25	43.19	16.65
IB	C9577	8.21	2.75	12.67	1.63	13.08	0.58	38.92	21.94
IB	C9639	5.34	2.35	3.92	0.56	1.05	0.17	26.61	12.74
IB	W1	6.27	2.55	8.92	2.03	3.48	0.35	23.60	50.34
IB	W2	41.66	1.00	9.08	4.51	5.84	0.92	63.01	64.23
IB	W3	41.13	0.24	9.92	4.23	13.18	0.85	69.55	47.49
IB	W4	38.44	1.65	7.92	4.11	13.08	0.77	65.97	45.55
IB	W6	2.80	2.15	2.83	0.65	3.34	0.05	11.82	31.64
IB	SP6	5.28	2.20	2.25	1.38	9.48	0.16	20.75	6.22
IB	SP8	6.49	1.96	4.17	0.87	2.79	0.11	16.39	53.99
IB	SP10	1.25	1.40	5.92	2.87	2.66	0.33	14.43	18.78
IB	SP11	5.79	3.05	8.00	1.29	6.62	0.22	24.97	34.88
IB	SP13	9.54	1.60	4.17	2.31	3.18	0.33	21.13	44.91
IB	SP24	10.29	2.45	2.67	0.39	3.15	0.08	19.03	61.95
IIA	C1612	12.46	8.15	16.92	14.93	8.20	9.44	70.10	7.08
IIA	C3728	8.77	20.20	34.17	20.28	4.97	29.58	117.97	7.04
IIB	C3864	4.08	2.05	2.67	0.85	7.92	0.31	17.88	1.57
IIB	C4543	10.19	0.12	0.83	1.24	2.67	0.67	15.72	4.73
IIB	C7325	17.54	0.04	0.04	0.70	11.28	1.04	30.64	15.01
IIB	C7327	17.13	0.04	0.00	0.56	12.23	0.33	30.29	13.37
IIB	C7329	12.53	0.08	0.17	0.68	9.64	0.33	23.43	9.09
IIB	C7713	76.48	0.12	0.20	1.16	6.89	0.65	85.50	79.65