United Republic of Tanzania
Ministry of Water, Energy
and Minerals

Kingdom of the Netherlands
Ministry of Foreign Affairs
DGIS

Morogoro Domestic Water Supply Plan

Volume IV

Hydrogeology

Final Report

August 1980

DHV

DHV Consulting Engineers

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CONTENTS PAGE

CONTENTS PAGE

CONTENTS PAGE

LIST OF TABLES:

CONTENTS PAGE

LIST OF FIGURES:

CONTENTS PAGE

CONTENTS PAGE

CONTENTS PAGE

D. HYDROGEOLOGY

1. INTRODUCTION

1.1. General

At the beginning of 1977, following the "Administrative Arrangement" between the Governments of Tanzania and The Netherlands, the International Technical Assistance Department of the Ministry of Foreign Affairs of the Netherlands charged DHV Consulting Engineers with the execution of the Morogoro Domestic Water Supply Plan (MDWSP). The Tanzanian Government appointed the Ministry of Water, Energy and Minerals as executive authority for the implementation of the project.

The aim of the MDWSP is to study the possibilities for improvement of the rural water supply in the northern part of the Morogoro Region. Carrying out a Domestic Water Supply Plan, instead of a Water Master Plan, implied that the study had to be focused on the supply of drinking water for the villagers only. During the discussion with the Tanzanian and Netherlands Governments on the determination of the Terms of Reference, the need was felt to incorporate an implementation component in the study. Based on information derived from earlier studies in the Morogoro Region it was decided to incorporate a drilling programme for exploration and exploitation of deep ground water in the survey.

A first report "Identification of the present conditions and problems of rural water supply in the northern part of Morogoro Region" was issued December 1977.

In September 1978 a Progress Report was presented, dealing with the surveys and studies carried out during the period end May - end August 1978 and including the plan of operations of the team for the following months.

A first review of available and collected data concerning existing water supply systems, water quality aspects, hydrology and hydrogeology was presented in the Interim Report, which was submitted in April 1979.

The domestic water supply plan is presented in this final report. The report consists of six volumes:

volume I	Main Report
volume II	Water Supply Conditions
volume III	Hydrology
volume IV	Hydrogeology
volume V	Water Supply Development
volume VI	Village Data Handbook

1.2. Aim

Within the scope of the Terms of Reference for the project, the aim of the hydrogeological studies is to establish the ground water potential for domestic water supply in the project area.
To this end the activities were aimed at:

- investigation of the general surface and subsurface geology and more particularly the types and occurrences of water-bearing layers (aquifers)
- assessment of the availability and quality of the ground water throughout the project area and near its villages in particular
- determination of feasible means of exploitation of the ground water resources

Together with the results of the hydrological studies (Part C), these data form the basic material on which the Morogoro Domestic Water Supply Plan can be drawn up.

The studies covering both shallow (0-12 m below ground surface) and deep ground water (deeper than 12 m below ground surface) can be divided into:

- collection and examination of existing data
- fieldwork with collection and examination of field data
- drilling
- evaluation of data
- assessment of ground water potential

2. APPROACH

2.1. General

The general approach to the hydrogeological investigations was largely determined by the following considerations:

- the project is not a Water Master Plan but a study in which emphasis is mainly laid on the assessment of the water potential and water supply possibilities for the villages occupying the project area
- results and recommendations of previous hydrogeological studies as well as the First Report of the MDWSP have to be taken into account
- in conformity with the Terms of Reference a deep well drilling programme forms part of the project
- a Morogoro Wells Construction Project, during which approximately 550 shallow (0-12 m) and medium depth (12-50 m) wells will be constructed throughout the Morogoro Region, will follow the MDWSP
- the fieldwork of the MDWSP started at the beginning of the dry season (May) of 1978 and was finished at the end of the succeeding wet season (April 1979)

Collection and evaluation of existing data carried out from mid-May till mid-June and in November and December 1978.

An important part of this hydrogeological study was the collection of field data which should preferably take place during the dry season (May-December) when the water tables are declining, the salinity of the ground water in many aquifers is increasing and the accessibility of the area is optimal. Hence most of the fieldwork was executed in the period from mid-June till mid-November 1978. Geo-electrical investigations were carried out in the Mkata-Wami Basin to study the hydrogeological structure of this basin and to establish the locations of some boreholes to be drilled. The fieldwork was carried out in this basin and to a less degree in a few other parts of the project area in the period end-May till mid-November 1978.
The deep well drilling programme of six months started mid-September 1978, four months after the start of the geo-electrical fieldwork, and ended in Mid-March 1979.
The evaluation of the field data, which started in December 1978, was continued till April 1979.

2.2. Data collection

2.2.1. Geological maps and reports

Geological maps, reports and publications were purchased from the Mineral Resources Division in Dodoma. Together they constitute the basic data for Chapters 4 and 5.
Published literature relating to the subject is given in the list of references.

A complete list of the geological maps is given in sub-par. 4.1.6.; 12 different sheets (scales 1:100,000 and 1:250,000) were available, covering more than 90% of the project area.

A geological map (scale 1:250,000) of the project area has been compiled using existing published and unpublished maps and literature, supplemented by field data and data obtained from aerial photographs and satellite imagery studies.

2.2.2. Consulted studies on ground water

All available reports, publications and memoranda related to the geology and hydrogeology of the project area are mentioned in the list of references.

Reports giving relevant information on ground water in the Morogoro Region are:

- Integrated Development Plan for Morogoro Region, first draft report, Annex II - Water Resources and Development
  Ministry of Foreign Affairs - Directorate of International Technical Assistance, The Hague, 1975

This report covers a wide range of subjects related to the water resources and their development in the Morogoro Region. It was based entirely on existing data available at that time. The report briefly summarizes the geology and hydrogeology of the Region and gives outlines for an approach to the ground water resources study of the Region. Consequently this report formed the basis for the approach of this study.

- Woldai, T (1977).
  The Geological and Hydrogeological Interpretation of Landsat Imagery from the Morogoro Region of Tanzania;
  International Institute for Aerial Survey and Earth Sciences (ITC), Enschede, The Netherlands

The study of Landsat images was carried out within the scope of the MDWSP.
It enabled the delineation of different rock units and their possible hydrogeological characteristics.
The 1:1,000,000 geological map and hydrogeological map presented in this report must be considered as outline maps, giving an overall picture of the hydrogeology of the Morogoro Region. From the Landsat images, some faults could be traced that were not present on the existing geological maps of the project area.

- Morogoro Domestic Water Supply Plan; First Report;
  Identification of the Present Conditions and Problems of Rural Water Supply in the Northern Part of Morogoro Region.
  DHV Consulting Engineers, Amersfoort, 1977.

The report focuses on the location of settlements, the road patterns and the present water supply conditions in the rural areas of the Morogoro and Kilosa Districts. Hence it was an important basis for the approach of the hydrogeological fieldwork.
The 1:250,000 map of the northern part of Morogoro Region presented in this report is used as a basis for most maps in the Interim Report.

Another important result is the identification of problem areas for further investigations into the possibilities to improve domestic water supply systems, based on the criterion of the need of water.

Priority was given to the hydrogeological research in those areas and villages which are identified in this report as areas and villages experiencing problems in their domestic water supply.

2.2.3. Borehole data

Data on boreholes drilled in the Morogoro and Kilosa Districts were extracted from the files of the Water Development and Irrigation Division in Morogoro Town and the Geophysics and Exploration Section in Dodoma.

Since 1931 a total of 125 registered water wells have been drilled in those two Districts, ranging in depth from 12 to 202 m. Part of the technical data, geological well loggings and chemico-physical analyses were available for about 60% of the wells drilled since 1949.
Data on the remaining 40% of the wells drilled since 1949, as well as on those drilled between 1931 and 1949 are very concise, incomplete, or missing entirely.

At present not more than 15 wells are in operation, while about 10 wells, which have been drilled recently by the Water Development and Irrigation Division in Morogoro, are awaiting installation of pumps and construction of pumphouses, pipes and taps.

About 45% of the wells were abandoned because of a high salinity (TDS 1500-13.000 p.p.m.) of the ground water; 35% because of a low yield at the time of completion or a drastic decrease in yield after having been in operation for some time.

A detailed review and evaluation of the existing borehole data are given in sub-par. 3.1.1. of this report.

All available data have been incorporated in a borehole filing system, divided into a technical part (Table DD 2) and a hydrogeological part (Table DD 3).

2.2.4. Geophysical data

Within the scope of the hydrogeological survey, geophysical measurements were carried out to provide more information on the geological structure and the hydrogeological properties of the underground.

In this project use has been made of the geo-electrical and the seismic refraction methods to determine, respectively, the electrical resistivity and the seismic velocity of individual physical layers or a succession of layers.

However, the relation between these physical parameters and the corresponding hydrogeological properties may vary considerably from one area to the next. Very few geophysical data are known in the Morogoro Region. A rough idea of what might be expected was derived from investigations in other regions in Tanzania. Table D 2.2-1 indicates the relation which may exist in this area between formation resistivities and hydrogeological strata and the prospects for ground water of acceptable quality. In a geo-electrical study only the value of the electrical conductivity (EC), which is related to the TDS content can be considered as a quality parameter for water. This table is based on the report of NEDECO on the Shinyanga Region and on the report of Finnwater on the Mtwara and Lindi Regions. Table D 2.2-2 based on the above-mentioned Finnwater report and on handbooks gives the relation between seismic velocities and types of rocks. No information about the salinity of the formation water can be obtained through seismic surveys.

Table D 2.2-1 - Preliminary relation between formation resistivity and hydrogeology .

formation resistivity in ohmm	lithology and ground water quality; electrical conductivity (EC) in mS/m	ground water prospects
< 5	impermeable clayey deposits (EC pore-water > 300) or permeable formations with highly saline water (EC > 600)	very poor
5-10	impermeable clayey deposits or permeable formations with brackish water (EC > 200)	poor
10-20	(semi-) permeable layers, (clayey) sands or weathered bedrock; (EC 100-300)	fair
20-50	(semi-) permeable layers, sands or weathered bedrock (EC < 150)	good
>50	sands with EC < 60 or dry layers or fissured bedrock	variable
>500	fresh bedrock	very poor

Table D 2.2-2 - Relation between seismic velocities and types of rock

seismic velocity in m/sec	type of rock
<1000	unsaturated loose sediments or unsaturated weathered bedrock
1500-2000	saturated unconsolidated sediments
2000-3000	consolidated sediments e.g. sandstone or limestone
1500-2500	weathered bedrock
2500-3500	fractured bedrock
3500-4500	slightly fractured bedrock
>4500	fresh bedrock

2.3. Fieldwork

2.3.1. Hydrogeological survey

The main objective of the hydrogeological field survey was to establish the ground water potential of shallow aquifers throughout the project area and in rural areas in particular. Thus hydrogeological sub-areas could be distinguished where the water supply by means of shallow wells was thought to be possible.

Up to the start of the MDWSP deep well drilling programme the hydrogeological field survey of aquifers at greater depth was limited to the measuring of water levels and salinities in some existing boreholes and the collection of water samples for analyses.

To achieve this objective it was necessary:
- to obtain a general geological field knowledge of the project area
- to find the relation between geology, lithology and ground water
- to complete the existing geological maps with relevant field data
- to establish aquifer parameters by collecting data on seasonal ground water level fluctuations and drawdown of water levels due to withdrawal
- to obtain data on present yields of boreholes, shallow wells and hand dug holes
- to determine the variation of ground water quality throughout the project area
- to determine the variation of ground water quality throughout the year

The hydrogeological field survey of the project area was carried out in the dry period between Mid-May and Mid-November 1978, when ground water levels were declining and salinities generally increasing.
The investigations resulted in:
- the selection of a number of existing shallow wells and water holes which were incorporated into a regular measurement programme (see sub-par. 2.3.5.)
- the selection of areas where special, detailed studies would be carried out
- the selection of areas where hand drillings would be carried out in order to supplement the available hydrogeological field data

Together with the data obtained from the geophysical investigations, deep well drilling, regular measurement programme, hand drilling, special studies and existing borehole data, the hydrogeological field survey data form the basis on which a number of hydrogeological sub-areas could be distinguished (sub-par. 3.1.2. and 5).

2.3.2. Geophysical investigations

The geophysical investigations had the following objectives:
- to study the geological and hydrogeological structure of the Mkata-Wami Basin to gain an insight into the occurrence of fresh ground water and the dimensions of aquifers and to assess the exploitation prospects
- to locate sites for production wells, which were to be drilled in the course of the project

To study the occurrence of fresh ground water at shallow and at greater depth in the Morogoro Region, the geo-electrical and seismic refraction methods were applied. For the deep investigations the geo-electrical method was chosen and for the shallow investigations both the geo-electrical and the seismic refraction methods were chosen. In the latter investigations a major objective should be to test the applicability of these two methods to the surveys for shallow ground water. The obtained results are presented as two special studies in Annex DA 2 and 3.

As indicated already the deep geo-electrical investigations should mainly be restricted to the Mkata-Wami Basin. Depending on the available time, geophysical investigations could also be executed in other areas, if a hydrogeological survey carried out there should indicate that this would be worthwhile.

In a geo-electrical investigation it is essential that borehole and resistivity well-logging data are available. With these reference data the field curves can be interpreted into a relevant hydrogeological model and the obtained resistivity values can be interpreted in hydrogeological terms. To obtain this background information during the investigation and to combine this with the above-mentioned objectives in the most efficient way, the following working scheme was chosen:
- at the start soundings were executed along profiles situated across and parallel to the Mkata-Wami Basin
- after a tentative interpretation of these soundings detail surveys were executed near those villages which were regarded as problem villages and where the soundings indicated good prospects
- in the next phase such a detail study was interpreted preliminarily and a borehole site was chosen
- next the borehole was drilled and well-logging measurements were executed in the uncased borehole
- the borehole drilling and logging data gave the necessary input to establish the relation between the formation resistivity and hydrogeology which holds for the Mkata-Wami Basin
- lastly, the final interpretation could be finished and an evaluation could be made

2.3.3. Deep well drilling

On the basis of the studies carried out during the early 70's, it was decided to incorporate a drilling programme into the survey, because it seemed likely that the exploitation of deep ground water resources would be one of the best possibilities for the domestic water supply in part of the project area. A drilling programme of six months, running approximately from mid-September 1978 to mid-March 1979, has therefore formed part of the survey. The production of the drilling programme was estimated provisionally at 15 boreholes with an average depth of 100 m; the estimated total drilling length was thus 1500 m.

Although the drillings have important exploratory aspects, they were primarily meant to be ground water exploitation wells. To establish the locations of 15 exploitation boreholes, the following criteria were listed:

- boreholes must be located in or near villages faced with problems concerning domestic water supply (supply not maintained throughout the year, considerable walking distances, quality aspects, etc.)
- boreholes must be located in the areas which have been indicated by the geophysical and hydrogeological investigations as the most promising
- boreholes must be located at places where domestic water supply by means of gravity systems is not possible or only possible at exorbitantly high costs
- boreholes must be located at places where domestic water supply by means of shallow wells is not possible or where shallow wells can only serve as a temporary solution (quantity aspects)
- boreholes must be located at places, accessible to the Schramm drilling rig

With regard to the quality aspects, the following classification based on electrical conductivity (a criterion for the salinity) was taken into account (Table D 2.3-1).

Table D 2.3-1 - Classification of ground water in relation to electrical conductivity

electrical conductivity	classification
< 75 mS/m	good
75-125 mS/m	fair
125-200 mS/m	poor
>200 mS/m	beyond acceptable limits

Successful boreholes had to be completed with 6 inch casings and gravel-packed Johnson screens.

Unsuccessful boreholes could be completed as observation wells with piezometers.

2.3.4. Hand drilling

Following the hydrogeological field survey, a number of locations were selected, where hand drillings would be carried out in order to collect detailed hydrogeological data on shallow ground water.
Most of the hand drillings were incorporated in a number of special studies on shallow ground water and salinity problems (DA 4 and 5).

A few isolated holes were drilled to try to correlate subsurface hydrogeological data and well-logging with geo-electrical surface measurements (see par. 3.2.).

In addition to this, hand drillings have been carried out in the project area by the survey department of the Morogoro Wells Construction Project since May, 1978, for the purpose of finding sites for shallow well construction.

The drillings have been carried out with light hand drilling equipment, (see subpar. 2.3.7.).
Maximum drilling depth was about 12 m; pumping equipment for carrying out well tests and taking water samples was available.

Data from hand drillings were used:
- to supplement already collected hydrogeological field data by detailed geological and hydrogeological information
- to correlate hydrogeological data to geophysical measurement data
- to select areas and locations where the construction of shallow wells is thought to be possible

Of all water-bearing layers encountered in the hand drillings the electrical conductivity, a criterion for the salinity of the ground water, was measured and many water samples were taken and analyzed.

During one particular special study piezometers were installed in a number of hand drilled holes to measure water levels and salinities regularly.

The hand drillings were particularly important in order to distinguish hydrogeological subareas and to estimate the shallow ground water potential of those areas.

2.3.5. Regular Measurement Programme

Since it was to be expected that ground water levels and salinities would not be constant, but would change throughout the year and with the seasons most probably, it was decided to develop a regular measurement programme in which a number of selected shallow wells, hand dug holes, boreholes and observation wells would be measured approximately once a month.

Besides the regular ground water level and salinity measurements water samples were taken for chemical as well as bacteriological analyses.

The measurements were carried out in:
- a number of existing shallow wells, hand dug holes and boreholes selected during the hydrogeological field survey
- piezometers, installed within the scope of the MDWSP special studies
- boreholes drilled during the project

The purpose of the measurements was:
- to collect data about seasonal ground water level fluctuations
- to determine the variation of ground water quality throughout the dry season and at the beginning of the wet season
- to obtain information on storage and recharge of different aquifers

For practical reasons the programme has been executed in combination with the regular measurement programme of the hydrological and the water supply section of the MDWSP.

2.3.6. Special studies

Selection of areas and subjects

Within the scope of a hydrogeological field survey of approximately 10 months it is impossible to cover the whole project area in detail. Therefore a limited number of areas had to be selected where detailed surveys would be executed.

Since the detailed study of ground water at greater depths is only possible if an extensive exploration well drilling programme is executed and since such a programme could not be incorporated into the project, it was decided to concentrate the special studies on shallow ground water.

In selecting the areas to be considered for detailed study, the results and recommendations given in the MDWSP Progress Report as well as the hydrogeological field survey had to be taken into account.

Based on the current water needs of the rural population, three major problem areas were identified:
- the northern part of the Kilosa District
- the Ngerengere area

- the area along the western edge of the Wami Valley between Mbigili and Turiani

In these four areas a large number of villages experience major difficulties in obtaining sufficient drinking water of acceptable quality. The water courses in these areas only occasionally contain sufficient water, and ground water sources dry out or give very low yields during the dry period.
Moreover, ground water with salinities far beyond acceptable limits is frequently found in these areas.

Extensive gravity schemes were designed by both the Water Development and Irrigation Division in Morogoro and the hydrological section of the MDWSP in order to supply these problem areas with drinking water. However, since the realization of these schemes is very costly, it was decided to study in detail also the possibilities for the development of shallow ground water sources in the priority areas.

In addition to this, the salinity of the ground water in the priority areas was studied as a special topic.

Methods

In the execution of the special studies the following survey methods were used:
- detailed geological and hydrogeological field observations
- examination of aerial photographs
- regular measurement programme of ground water levels and salinities in existing wells
- drilling of small diameter exploration and observation holes with hand drill equipment
- regular measurement programme of ground water levels and salinities in hand drilled observation wells
- geo-electrical investigations at shallow depth
- seismic investigations at shallow depth
- geophysical well-logging
- examination of drilling samples and execution of well tests to estimate hydraulic properties of shallow aquifers

2.3.7. Equipment

Hydrogeological equipment

A complete camping outfit was available for camping in the field. The following project equipment was used:

2	Edelman augers 0 82 mm
1	bailer

2	riverside augers Ø 82 mm
12	m' casing
20	m' drilling rods
2	handles
3	electrical water level sounding tapes
1	water sample for boreholes
3	EC-meters (temperature compensated)
2	measuring tapes
2	water level gauges (electrical)
1	stopwatch
1	altimeter
2	binoculars
2	thermometers
1	compass
2	geological compasses
2	geological hammers
1	mirror stereoscope
1	pocket stereoscope
1	levelling instrument, complete with tripod and appurtenances
1	spade
1	bucket
	various tools

Besides, a number of devices to be used in the field were purchased or constructed locally.

Amongst these are:

3	probing rods with handle bars
150	m PVC-pipe, 1 inch Ø
1	set of field sieves
1	set of laboratory sieves

Geophysical equipment

a. interpretation of geo-electrical soundings:
  - complete set of three-layer master curves
  - programmable calculator HP 97

b. geo-electrical equipment - greater depth:
  - geo-electrical measuring instrument GEA 76, DGV-TNO; 1000 V, DC, 250 W
  - two car batteries, 12 V, 120 Ah
  - two reels with 800 m cable, for current supply
  - two reels with 300 m cable, for potential measurement
  - current electrodes, pins and spiral hand drills
  - porous potential electrodes with coppersulphate solution
  - hammers

c. geo-electrical equipment - shallow depth:
  - Earth Resistivity Meter, Bison, 2350 A; AC, 10 W¹)
  - 2 reels with 300 m cable for current supply¹)
  - 1 profiling cable, 2 x 13 connections, length 40 m¹)
  - current and potential electrodes, pins
  - hammers

d. seismic refraction equipment - shallow depth:
  - signal enhancement seismograph, Bison, 1507 B
  - geophone with two footplates
  - reel with 80 m cable
  - sledge hammer, 5 kg

e. well-logging equipment - hand operated:
  - probe with 150 m cable on a reel; DGV-TNO SP and resistivity SN = 20 cm and LN = 100 cm
  - Earth Resistivity Meter; Bison 2350 A; AC, 10 W¹)
  - digital voltmeter (SP measurements)
  - Electrical Logging System; Johnson-Keck DR-74, SP and resistivity, SN = 7.6 cm; LN = 76 cm²)
  - Gamma Ray Logging System; Johnson-Keck GR-73²)
  - reel with 180 m cable; Johnson-Keck
  - probe with 25 m cable; self-made, SP and resistivity, SN = 20 cm
  - Earth Resistance Meter; Norma, 1805 GB 2 D/E, AC, 1 W
  - EC probe with 100 m cable on reel, EC of water in cased boreholes and piezometers

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3. DATA COLLECTION AND EVALUATION

3.1. Hydrogeological investigations

3.1.1. Review of existing borehole data

3.1.1.1. General

This paragraph gives a review of all registered boreholes drilled in the Morogoro and Kilosa Districts; MDWSP boreholes which are discussed in par. 3.3., are excluded from this review.
All available, technical and chemico-physical data on existing boreholes and ground water are inserted into the borehole filing systems DD 1, DD 2, DD 3.

Drilling of boreholes in the project area started in 1931. Up to 1949 boreholes were mainly drilled for the water supply of the sisal estates and railway stations in the Ngerengere area.
From the 23 wells drilled between 1931 and 1949, only some technical data and the TDS content of the water are available; geological well descriptions are lacking or very poor.
The field locations of only 5 out of these 23 ancient boreholes could be traced.

Between 1949 and 1978, 102 registered boreholes were drilled, divided mainly over the Ngerengere area, the Mkata-Wami valley and the Gairo area.
About 50% of these wells was drilled on behalf of sisal and sugar estates, Government institutions and prisons, the other 50% for rural and urban water supplies.
Part of the technical data, geological well-logs or drilling-logs and chemico-physical analyses were available for about 60% of these wells.
Field locations of 67 out of the 102 boreholes could be found.
Data on the types of rigs and drilling methods were not given in the borehole files, but from the daily drilling reports, often present in these files, it became clear that the drilling of most wells took several months up to 1½ year; moreover most pump tests were executed by bailing the well.
Hence, the percussion drilling methods are supposed to have been used in most of these boreholes.
Drilling depth ranged from 12 m to 202 m; average depth was 70 m approximately.

Generally speaking, deep well drilling has not been very successful in the project area.

At present not more than 15 out of the 125 drilled deep wells are in operation while 10 wells, which were drilled recently, are awaiting installation of pumps and construction of pumphouses, reservoirs and pipelines.

About 40% of the wells was abandoned immediately after drilling because of a high salinity of the ground water (TDS 1500-13.000 ppm).
In 5% of the boreholes, the salinity of the pumped ground water increased above the maximum acceptable limit of 200 mS/m after some time of operation. Approximately 35% of the boreholes was abandoned because of a low yield at the time of completion or after having been in operation for some time.
The high percentage of unsuccessful boreholes may be explained by the facts listed below:

- Ground water in large parts of the project area, underlain with Precambrian, Jurassic or Karroo rocks is highly mineralized as Tables D 3.1-2/5 demonstrate.
- Yields of the Precambrian metamorphic gneissic rocks generally will be low.
- Siting of locations for boreholes by means of hydrogeological or geophysical investigations was hardly done in the past.
- Geo-electrical soundings, carried out in order to locate some of the borehole sites were not processed and interpreted properly.
- Borehole sample descriptions are very poor or not made at all by the drilling crews.
  For some years borehole samples have been sent to the Water Department and Irrigation Division headquarters in Dodoma, where geologists examine and describe these samples.
  However, the decision as to which aquifer(s) should be developed and at what depth screens should be installed has been left to the judgement of the driller in many cases.
- It has been standard procedure to complete boreholes with gravel-packed, 6 or 8 inch diameter slotted steel casing as a filter.
  The slots are very few in number and cut into the casings with either a saw or an oxy-acetylene cutter; slots are up to 12 mm wide.
  For gravelpack, ¼ to 1 inch size crushed rock chips are used.
  This combination, although poor in design, will not have serious consequences for wells drilled and completed in hardrock formations.
  Problems will arise, if this combination is being used in unconsolidated aquifers.
  The much too coarse gravelpack will allow sand particles to move down into the slots, which either will clog or will admit sand into the filter. If this happens, yields will be reduced seriously and pumps damaged.

Another disadvantage of the use of slotted pipes instead of, for instance, wire-wound screens, is that, because of the small entrance area of the slotted pipes, yields will generally be low and entrance velocities through the slots and drawdowns in the wells will be high.

The existing boreholes penetrated through either metamorphic rocks of Precambrian age (mainly gneiss), Karroo rocks (sandstone, limestone, shale, conglomerate), Jurassic rocks (limestone, sandstone) and Quaternary/Tertiary unconsolidated sands, silts and clays.
The table below summarizes the number of wells, drilled in these different rocks, their depth range and the average depth at which water was struck and the average static water levels.

Table D 3.1-1. - Relation boreholes/geology

	metamorphic rocks	Karroo	Jurassic	Quaternary/ Tertiary
number of wells	49	6	14	57
depth range	16-198 m	43-117 m	39-201 m	12-190 m
average depth	75 m	75 m	115 m	50 m
average depth at which water was struck	33 m	22 m	36 m	different levels
average static water level	21 m	11 m	18 m	10 m

3.1.1.2. Well yields

In general, the yields of the wells in the project area are low.
Average yields of wells in various parts of the area are commonly between less than 1 l/s and 4 l/s.
Only a limited number of wells yield two to four times more. Variations in yields within a certain area are large but there is a tendency for most yields to be small to very moderate.
The probable reasons for this are:

- unfavourable hydrogeological conditions in major parts of the area
- faulty or poor construction of wells

Precambrian metamorphic rocks (see Chapter 4)

About 60% of the 49 boreholes drilled in basement rocks have yields of less than 1 l/s and several of them were dry or dried up after a short period of pumping. Only 15% of the wells have yields of more than 3 l/s.

None of the wells yield more than 10 l/s. The differences in well yields reflect differences in degree of weathering, shearing or fracturing of the rocks.

Karroo rocks (see Chapter 4)

The yields of wells sunk in the Karroo rocks are low, but the differences are small.
Yields are between 1.0 and 3.4 l/s with 2.5 l/s on an average. There were no dry holes in this formation.

Jurassic rocks (see Chapter 4)

The yields of wells drilled in Jurassic limestone and sandstone are almost as low as the yields of boreholes drilled in metamorphic rocks. Half of the wells yield less than 1 l/s while the other half of the wells gave yields between 1.0 and 3.0 l/s.

Quaternary/Tertiary unconsolidated sediments (see Chapter 4)

The average yield of wells drilled in the Quaternary/Tertiary unconsolidated sediments was 4.0 l/s; 17% of the wells yield less than 1 l/s; 34% less than 2 l/s; 66% less than 5 l/s. Only 12% of the wells have yields of more than 10 l/s.

As stated previously, yields of wells sunk in these sediments would probably have been much higher if better types of screens and gravelpack had been used for completion.
This statement has also been confirmed by the results of the boreholes drilled by the MDWSP in the Quaternary/Tertiary deposits of the Mkata-Wami Bassin; tested yields of the production boreholes varied from 7.0 till 11.9 l/s and were 9 l/s on an average.

3.1.1.3. Specific well capacities

The yields of the wells are meaningless if they are not related to the drawdown in the wells, when being pumped. Although the reported yields give some information about the water-bearing properties of aquifers, the great variety of well construction and completion as well as pumping test methods make these well yields subject to differences that cannot be related to aquifer characteristics. Specific well capacities, expressed as the tested yield in l/s per metre of drawdown, will give more useful information.
Although nearly all wells where water was struck were tested for some hours or even one or two days, drawdown data were only available for 50% of the pump tested wells.
The specific capacities of these wells were calculated and listed in DD 1.

Generally they are very low to moderately low.

3.1.1.4. Ground water salinity

The ground water salinity of most of the boreholes drilled in the Morogoro and Kilosa Districts was determined, and expressed either in Total Dissolved Solids (mg/l) or electrical conductivity (mS/m at 25°C). There are four different geological formations of which ground water salinity data are available: the upper Tertiary/Quaternary sediments, the Karroo, the Jurassic and the Precambrian.

a. Upper Tertiary/Quaternary

Salinity data are available from 40 boreholes; water samples were collected in a few drillings from different depths.

Table D 3.1-2. - Classification of boreholes in Tertiary/Quaternary

number of analyses	EC in mS/m	classification
19	<75	good
10	75-125	fair
10	125-200	poor
8	>200	beyond acceptable limits

Variation in EC is between 40 and 300 mS/m. The average EC over 47 determinations is 120 mS/m.

b. Jurassic

Table D 3.1-3. - Classification of boreholes in Jurassic

number of analyses	EC in mS/m	classification
0	<75	good
2	75-125	fair
4	125-200	poor
2	>200	beyond acceptable limits

The variation in EC values is from 120-500 mS/m. The ground water quality of the Jurassic sandstones and limestones is poor, because these sediments were deposited in marine environments and probably still contain fossil water.

c. Karroo

Table D 3.1-4 - Classification of boreholes in Karroo

number of boreholes	EC in mS/m	classification
1	<75	good
3	75-125	fair
1	125-200	poor
2	>200	beyond acceptable limits

The variation in EC values is more or less the same as for the Tertiary/Quaternary sediments: 40-300 mS/m.
The Karroo consists of consolidated sandstones, mudstones and shales, deposited in continental to shallow marine environments. The ground water salinity probably reflects the different sedimentation environments.

d. Basement

The quality of the ground water occurring in these rocks is very poor. More than 80% of the measured EC values are not permissible, only 6% of the wells have ground water with a permissible salinity.

Table D 3.1-5. - Classification of boreholes in Basement

number of boreholes	EC in mS/m	classification
0	<75	good
2	75-125	fair
4	125-200	poor
26	>200	beyond acceptable limits

The variation of EC's in the Ngerengere area is much wider; 95-1700 mS/m. It is possible that highly mineralized water rose to the near surface along faults separating the Uluguru granulites from the gneissic rocks, or that the ground water is virtually stagnant, leading to a gradual mineralization through solution of salts from aquifers and overlying formations.

3.1.1.5. Chemical composition

Rather detailed chemical analyses were made of ground water from 57 boreholes.
A total of 115 chemical analyses were available, because from a number of boreholes water samples were taken at different depths on different data, and analyzed.The results of these analyses are presented in DD 3. As can be seen from this table, there is a large difference in the chemical composition of water from different formations.

25% of the analyses are of ground water drawn from the metamorphic basement rocks. The water contains sodium, calcium, magnesium, chloride and bicarbonate. Fluor contents are between 0.1 and 2.0 ppm.

Ground water analyses data from Karroo rocks were available only from four boreholes drilled near Mikumi. The main constituents are calcium/ magnesium-bicarbonate. Fluoride contents are between 0.2 and 2.0 ppm.

The ground water from wells drilled in Jurassic sediments is rich in sodium and chloride, thus showing marine environment characteristics. Fluoride contents are below 1.4 ppm.

More than 50% of the analyses are of ground water from the Quaternary/ Tertiary Mkata-Wami Basin sediments. In general the water from these sediments contains calcium/magnesium-bicarbonate sodium and chloride being the next important constituents. The majority of the samples had fluoride contents which are below 1.2 ppm.
The fluoride content of ground water between Kilosa and Kimamba tends to be higher; contents from 1.3 ppm up to 6 ppm were found in 5 different samples.
Fluoride contents of boreholes at Dumila and Msowero were 3.5 and 1.9 ppm respectively.
The present temporary Tanzanian standard for fluoride is 8 ppm F.

3.1.2. Hydrogeological fieldwork

The hydrogeological survey of the Gairo area (northern part of the Kilosa District), the Mkata-Wami Valley and the area south and south-east of the Uluguru Mountains was carried out in the period mid-May - end of August 1978.
From the beginning of September up to the start of the rainy season in mid-November, 1978, the survey was continued in the Ngerengere area (west, north and north-east of the Uluguru Mountains), the Mikumi-Kidatu area and the area between Rudewa and Msowero, along the escarpment of the Ukaguru Mountains.
During the same period hydrogeological fieldwork was carried out in more than 150 villages.
Amongst them were all 113 villages which had been identified as villages in the First Report of the MDWSP, contending with problems in their water supply.

Systematically collected hydrogeological data are tabulated in DD 4.

Based on the survey, a tentative division into hydrogeological sub-areas could be outlined (see Fig. D 3.1-1).
Subareas distinguished are:

I	the Berega Basin
II	the area enclosed by the Western Escarpment and the Wami River, between Msowero and Mvomero/Dibamba
III	the Western Escarpment and foothill area between Msufini and Dahinda
IV	the area around Mtibwa Sugar Estate
V	the area around and between Kilosa and Kimamba
VI	the eastern foothills of the Uluguru Mountains
VII	the Mgeta and Ruvu valleys south and east of the Uluguru Mountains
VIII	the area enclosed by the Mkata River and the Uluguru Mountains, between Melela and Doma
IX	the area between Mikumi and the Great Ruaha River
X	the Ngerengere area

This general classification into sub-areas formed the basis on which areas were selected for detailed surveys, regular measurement of water levels and salinities, drilling and geophysical investigations.
Based on results obtained by:

- the hydrogeological survey
- examination of existing borehole data
- MDWSP deep well drilling
- MDWSP hand drilling
- geophysical investigations
- study of ground water salinities and water quality analyses
- study of geological maps and aerial photographs

a further sub-division into hydrogeological areas could be worked out. Detailed descriptions and reports on these sub-areas are given in Chapter 5 of this report.

3.1.3. Hand drilling

Between the end of May 1978 and mid-April 1979, more than 500 hand drillings were carried out in various parts of the project area, by survey teams of both the Morogoro Domestic Water Supply Plan and the Morogoro Wells Construction Project.

The exploration holes, drilled by the MWCP survey teams, were for the purpose of finding sites for the construction of shallow wells.
The areas which were surveyed were:

- The Mkata-Wami Basin along the Western Escarpment, between Dumila in the South-West and Kwamtonga in the North-East.
  Villages surveyed in this area were: Dihombo, Dibamba, Dumila, Hembeti, Kwamtonga, Kigugu, Mabana, Magole, Makuyu, Mbibiri, Mbogo, Mirama, Mhindo, Msufini, Mugudeni, Mvomero.

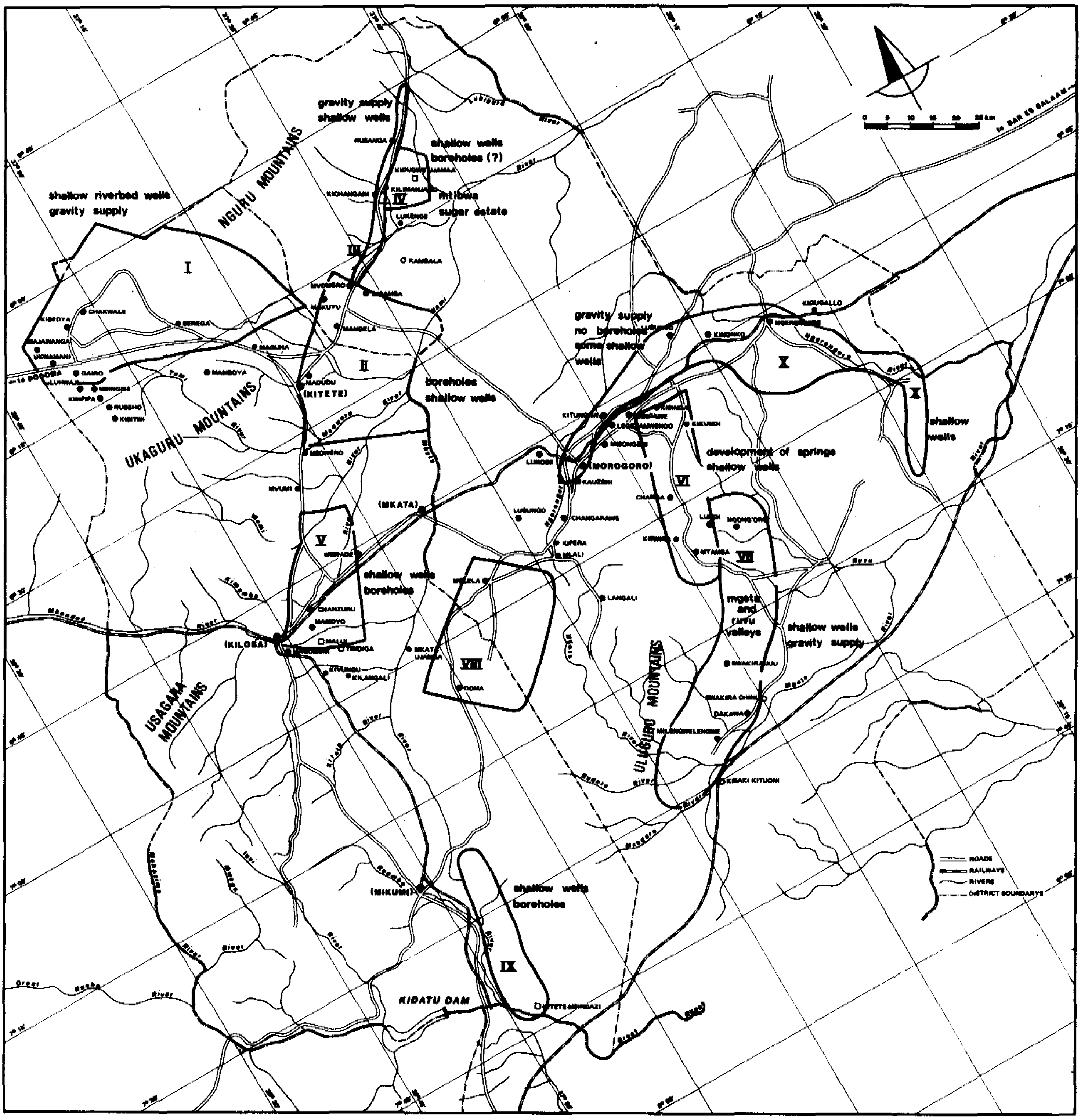


Fig. D 3.1-1 Water potential of hydrogeological sub-areas based on fieldwork

- The Mkata-Wami Basin along the Western Escarpment, between Kondoa in the South and Rudewa Gongoni in the North.
  The villages where hand drillings were carried out are: Chanzuru, Ilonga, Kondoa, Madoto, Rudewa Batini, Rudewa Gongoni, Rudewa Mbuyuni.
- The Western Foothills of the Uluguru Mountains.
  Villages surveyed here are: Konga, Maharaha, Manza, Msongozi, Sanga Sanga.
- The valley of the Kiroka and Kikundi Rivers, north of the Uluguru Mountains.
  Surveyed were the villages: Kibungo, Kikundi, Kiziwa, Kiroka.
- The Ngerengere area, N.E. of the Uluguru Mountains.
  Here, the villages Mikese, Ngerengere Daradjani, and Kinonko were surveyed.
- The Berega area.
  Surveyed were: Italagwe, Iyogwe, Magubike.
- The villages Luhindo and Dakawa, along the road from Morogoro to Mugudeni.

In most villages from 5 up to more than 20 hand drillings were carried out so that much information on the occurrence of shallow ground water in the areas listed above be came available.
The maximum drilling depth was 15 m, but this depth was only reached on one occasion.
Usually the depths of the drillings were not greater than 12 m.
From the drillings, the following data were recorded:

- total drilling depth
- geological sample log
- aquifer thickness and depth
- aquifer type
- water levels during drilling
- EC of the ground water during drilling

In boreholes where aquifers were encountered, a one hour pumping test was executed with a handpump, to find the yield and specific well capacity of the exploration well, as well as the aquifer parameters permeability and transmissivity.
All hand drilled exploration holes that were approved for construction of shallow wells were listed in DD 5.

Most of the hand drillings carried out by the MDWSP survey teams, were incorporated into two special studies on shallow ground water in the Berega area and Ngerengere area (DA 4 and 5).

In the Berega area hand drillings were carried out along profiles, crossing the valleys of the main rivers in this area.
The following villages were surveyed:
Ibindo, Mwandi, Berega, Mabula, Magera, Kinyolisi, Makuyu, Jdibo, Leshata, Madege, Ndogomi, Chakwale, Nguyami, Kiegea.

In this particular study, piezometers were installed and ground water levels as well as salinities were measured regularly.
Through this study, much insight was obtained in the hydrogeology of this area and of its ground water potential.

Near the following villages in the Ngerengere area profiles were drilled at different places across the valleys of the Ngerengere River and its tributaries:
Kihonda, Tungi, Mkambarani, Mkonowarama, Mikese, Lubungo, Ngerengere Daradjani, Kinonko, Muhumgamkola, Visaraha, Masimbu, Mkundi.
A list of boreholes drilled in the Ngerengere area is presented in DD 9.
From most boreholes, a water sample was taken and analysed; the chemical analyses of the shallow ground water in the Ngerengere area are presented in DD 10.

The boreholes drilled by the MDWSP were up to 12 m deep.
The data recorded are:

- total depth
- geological sample log
- aquifer depth and thickness
- aquifer type
- water levels during drilling
- EC of the ground water during drilling

No pumping tests could be executed because no pump was available.

The results of the hand drillings have also made it possible to describe the relation between the geology and shallow ground water in parts of the project area (4.2.), and to distinguish hydrogeological sub-areas, which are described in Chapter 5, and calculate their shallow ground water potential.

3.1.4. Regular Measurements

Regular measurement of ground water levels and EC's of ground water was carried out in about 40 shallow wells and hand-dug holes, located mainly in the Mkata-Wami Basin, the Ngerengere area and the area S.E. of the Uluguru Mountains.
The data are given in DD 4, together with the data from the hydrogeological fieldwork.
Regular measurements were carried out also in the Berega area, where a number of piezometers were installed in shallow alluvial aquifers.
These data are presented in DD 13.
Water levels were measured at regular intervals in the MDWSP boreholes; the data are listed in Table D 4.2-9.

From the regular measurement of water levels, seasonal ground water level fluctuations of both shallow and medium depth - deep ground water could be determined in parts of the project area.

In some cases the volumes of ground water in storage at the beginning and at the end of the dry season could be assessed.
Moreover, aquifers that receive recharge could be distinguished from those that probably are not recharged.

3.2. Geo-electrical investigations for deep ground water

3.2.1. General

In ground water investigations the geo-electrical method is commonly used to gain an insight into the hydrogeological structure of the subsoil. The method is briefly described in Annex DA 1. From resistivity measurements at the surface (soundings), the vertical structure of resistivity layering can be deduced, which is translated afterwards in a hydrogeological structure. It is well known that the relation between the formation resistivities and the hydrogeological layers may vary from one area to another, as mentioned already in 2.2.4.
Consequently in each geo-electrical investigation it is inevitable to determine this relation for the area under study. This relation can be obtained by using the information from boreholes as reference data, in particular resistivity well logs.

The objectives of the geo-electrical survey in this area can be summarized as:

- to obtain a clear understanding of the geological and hydrogeological structure of the Mkata-Wami Basin in order to gain an insight into the occurrence of water-bearing layers and to assess their exploitation prospects
- to locate the exact drilling sites through detail surveys

To attain these objectives a number of distinctive steps had to be followed which are already mentioned in the approach of the study (see sub-par. 2.3.2.). In the following paragraphs the elaboration of the geo-electrical investigations is discussed and their results are presented.

- In the first paragraph the fieldwork is described.
- The paragraph thereafter is used to discuss the limitations of the geo-electrical method and the accuracy of the results.
- The next paragraph gives the applicability of the method in the project area and the relation between the formation resistivity and the hydrogeology.
- Hereafter the elaboration and the results of the detail surveys are illustrated.
- Subsequently the profiles are discussed in detail.
- The last paragraph is used to explain the most efficient approach to locate new drilling sites in this area, based on the experience gained in this project.

The occurrence of water-bearing layers in the Mkata-Wami Basin and the assessment of their exploitation prospects are dealt with in the discussion of the profiles on map D 3 as well as in the description of the prospects for medium depth and deep ground water (sub-par. 4.2.2. and 4.2.12.).

3.2.2. Execution of fieldwork

The geo-electrical soundings were numbered consecutively per 1:50000 topographical mapsheet, published by the Directorate of Overseas Surveys for the United Republic of Tanzania.
During the fieldwork period, which lasted from May 30th to November 14th, 1978, 353 soundings were carried out. Their distribution over the mapsheets is given in the following table.

Table D 3.2-1 - Review of the executed geo-electrical soundings

165/3	: 1	182/4	: 1 - 26
165/4	: 1 - 103	183/1	: 1 - 25
166/1	: 1 - 25	183/2	: 1 -
166/3	: 1 - 41	183/3	: 1 - 19
181/4	: 1 - 2	183/4	: 1 - 9
182/1	: 1 - 41	184/1	: 1 - 5
182/3	: 1 - 54	200/2	: 1

Total: 353 soundings

The situation of the geo-electrical soundings and the profiles are presented on Map D 1. Data concerning the soundings, such as date of execution, location, coordinates, elevation above MSL, the length and the azimuth of the soundings are given in DD 6. The field curves and their interpretation are presented in DD 7.
The soundings were carried out in the Schlumberger configuration. In the field procedure the observations at a sounding station were continued till it became clear that the unweathered bedrock with a very high resistivity had been reached. The maximum value of L/2 which could be applied was 800 m. The average length (L/2 max) of the soundings amounts to 250 m. At some locations the bedrock is situated so deep that the high bedrock resistivity does not show up well in the field curve (182/3-24).
During the execution of a sounding it happened in some cases that the field curve was strongly distorted. In those cases the measurement was no longer continued (166/3-9). In a few cases the spontaneous potential between the potential electrodes changed so strongly and quickly that it could not be compensated for. In that case the measurement was also stopped (182/3-18).
The different branches of a sounding graph are often made to show some overlap. In this way the connection between them, which is necessary for the interpretation, can be executed more accurately (see 3.2.3.2.).

To gain a general insight into the structure of the Mkata-Wami Basin, the fieldwork started, as mentioned already in sub-par. 2.3.2., with the execution of soundings along profiles across and along the basin. For convenience these profiles were chosen along the existing roads.
The spacing between two soundings amounted in general to 1,5 to 2 km. Sometimes it appeared necessary to project extra soundings in between. After a preliminary interpretation additional soundings have been executed near some selected villages in order to investigate the local structure in detail and to locate a borehole site.

The field crew consisted of a geophysical operator and three labourers. The equipment was built-in in a ten-seater Landrover. For the description of the equipment which was used, see sub-par. 2.3.7.

Well-logging measurements

Up to the end of March 1979, well-logging measurements were carried out in fourteen boreholes, drilled within the scope of this project. These well-logging measurements received the numbers of the concerning boreholes. Measurements of the spontaneous potential (SP) and the electrical resistivity were carried out in all those boreholes. Only in the first two holes gamma-ray measurements could be executed. After that the apparatus was out of order. The resistivity measurements comprise a short normal measurement (SN = 7.6 or 20 cm) as well as a long normal one (LN = 76 or 100 cm). With the hand-operated well-logging equipment only point measurements could be carried out. As a standard procedure the spacing between these measurements amounted to one foot (0.3 m). The results are presented in fig. D 3.3-1 upto 17 as a continuous graph. A review of the executed drilling programme is presented in Table D 3.3-1.

3.2.3. The accuracy of the results

3.2.3.1. General

Due to the limitations of the geo-electrical method the accuracy of the results is restricted. The accuracy depends on the following factors, which will be further discussed below:
- measuring errors
- lateral inhomogeneties in the subsoil
- the accuracy of the interpretation of the soundings

To study and to judge the results of this investigation it is for the reader of particular importance to have knowledge of the meaning of these factors, especially the last one. In the discussions of these factors the importance of a hydrogeological concept in selecting one solution out of all possible equivalent interpretations of a sounding will be dealt with.

3.2.3.2. Measuring errors

Normally more than one smooth curve can be drawn through the observation-points of a sounding because each observation is affected by an error. The larger the errors are, the more curves can be drawn and as a consequence many more different interpretations of a sounding are possible (see 3.2.3.4.). The errors are caused among other things by errors in the spacing of the electrodes and by instrumental errors. Too small a spacing between the potential or the current electrodes causes a too small or a too large resistivity value respectively. One special case will be illustrated.

When, during the execution of a sounding, the potential difference between the potential electrodes becomes small, the spacing between these electrodes has to be enlarged while the position of the current electrodes remains unchanged. This often causes a jump between the two curve branches and hampers therefore the drawing of a smooth line through the observation-points of the sounding. In some cases, due to small inhomogeneities near one of the potential electrodes, the jump is such that one whole branch has to be shifted parallel to the ρ_a-axis (see fig. D 3.2-1). To obtain one smooth sounding graph, which can be interpreted, the different branches have to be joined. Because of the measurement errors in each observation-point it is very convenient that the branches show some overlap to obtain a reliable graph. As an example sounding 166/3-25 is presented in fig. D 3.2-2. From the "double points" belonging to the L/2 values of 20, 25 and 30 m it is clear that one of the branches has to be shifted. The values at 100 and 125 m indicate that the second and the third branch coincide.
In this very good sounding just one "double point" should be enough to join the branches. Due to measurement errors, the situation is normally less clear and two or three "double points" are desirable (see e.g. sounding 164/4-47).

3.2.3.3. Lateral imhomogeneities

As mentioned in Annex DA 1 it is assumed in the interpretation of a sounding that the subsoil consists of a sequence of horizontal and homogeneous layers in a relatively large area around the midpoint of the sounding. Strong deviations of this assumption, called lateral inhomogeneities (e.g. strong lateral changes in lithology or thickness of layers) distort the sounding graph especially with those layers situated near the surface. The interpretation of it is of course meaningless. However, in some cases such a "distorted graph" looks very much like a normal, good sounding graph and wrong conclusions can easily be drawn from such a sounding. In fig. D 3.2-3 a sounding executed near and parallel to a fault looks like a sounding over a horizontal, three-layer subsoil.
In practice such cases are sometimes very difficult to recognize, but the interpreting geophysicist has to be aware of these phenomena. They can only be identified by comparing with other, neighbouring, soundings.

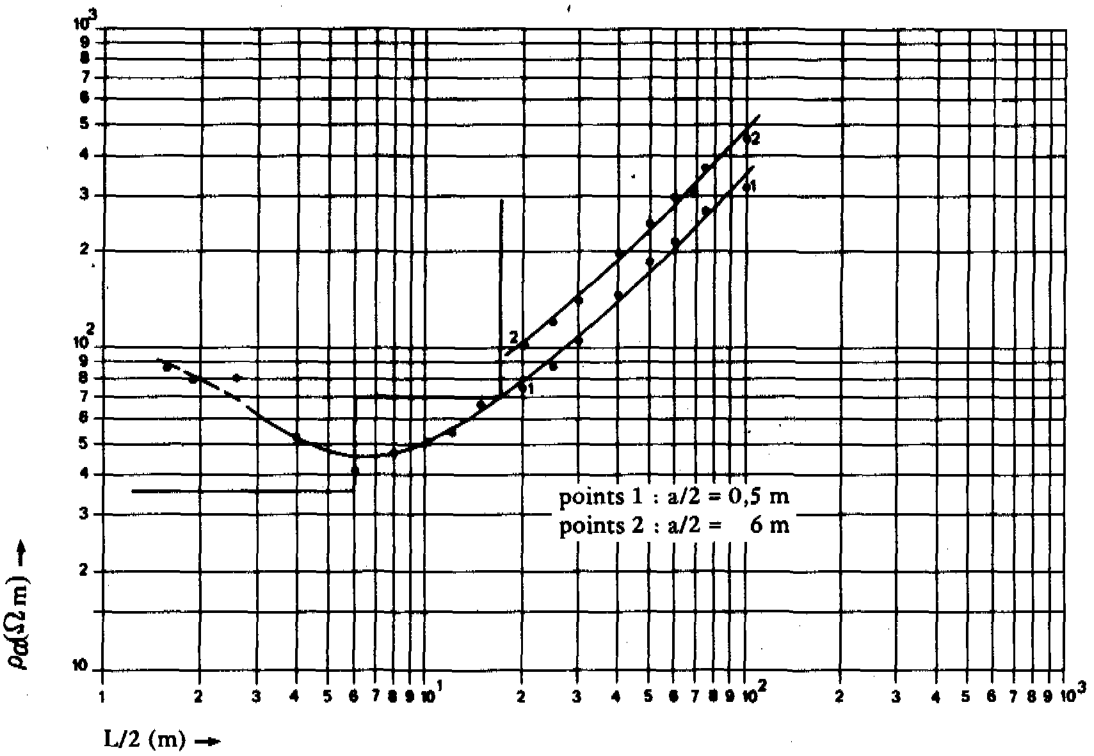


Fig. D 3.2-1 Sounding 183/1-17; one curve - branch has to be shifted parallel to ρ_a-axis

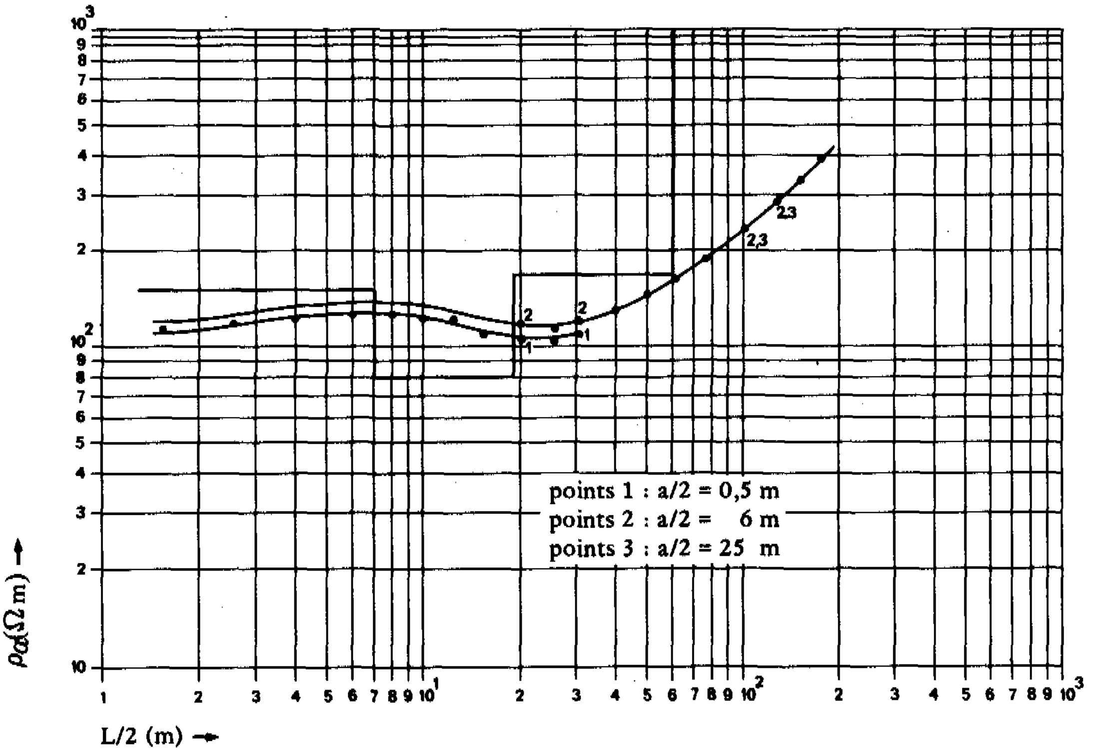


Fig. D 3.2-2 Sounding 166/25; joining two curve-branches

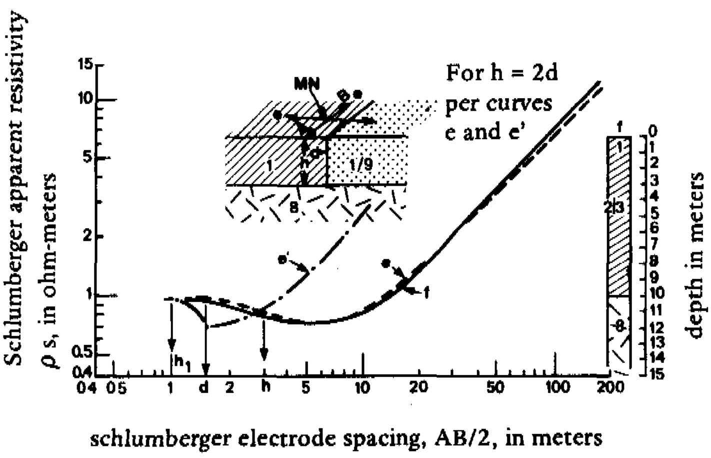


Fig. D 3.2-3 Distortion of a sounding curve due to lateral inhomogeneities (Zohdy etal, 1974)

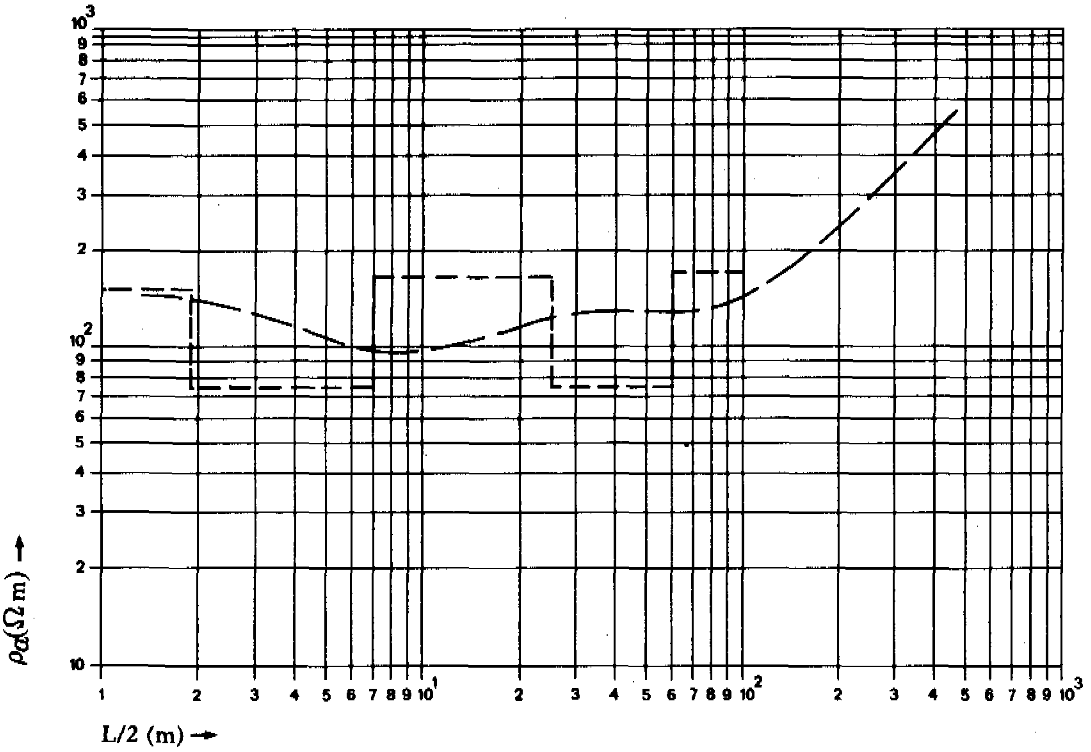


Fig. D 3.2-4 Distorted curve. Sounding 183/3-3 suggests falsely a great depth to the bedrock

As an example sounding 183/3-3 is presented in fig. D 3.2-4. In spite of the scattering of the measurement-points this sounding suggests a large depth to the bedrock of about 100 m. The neighbouring sounding 183/1-17, see fig. D 3.2-1 and profile A-A', shows that the bedrock is met at a depth of 17 m.

3.2.3.4. The accuracy of the interpretation of a sounding

The interpretation of a sounding is nothing but the transformation of the sounding graph into a vertical resistivity structure. This solution however is not unique in practice and there are several different sequences of resistivity layers which produce the same sounding graph within the limits of the measuring errors. The other way round, from a sounding graph several "equivalent interpretations" can be deduced. Which of the equivalent solutions has to be chosen as the final interpretation depends on the information provided by the neighbouring soundings and on the hydrogeological concept of the concerning area. This concept has also to be based on the available data and, therefore, depends on their quantity and quality.
Below, first the phenomenon of equivalent interpretations will be illustrated and afterwards the consequence of some starting-points.

Equivalent interpretations

Three types of equivalent interpretations of a sounding curve can be distinguished. The first two types, in literature called the principle of equivalence and the principle of suppression, are in fact special cases of the third type, which is the most general one.

- Principle of equivalence.
  If in a vertical resistivity structure a layer with a high resistivity value, intercalated between two layers with relatively low resistivity values, is replaced by a thinner layer with a still higher resistivity value, the two sounding graphs concerned are practically identical, see fig. D 3.2-5, model A and B. In the same way a layer with a low resistivity value situated between two layers with relatively high values is "equivalent" to a thicker respectively thinner layer with a higher respectively lower resistivity value, see fig. D 3.2-5, model A and C. In general the consequences of this type of equivalent interpretation in hydrogeological respect are not very important.
- Principle of suppression.
  A layer, of which the resistivity value is intermediate to the values of the layers, situated above and underneath it, often cannot be recognized in a sounding curve, see fig. D 3.2-6, models A, B and C.

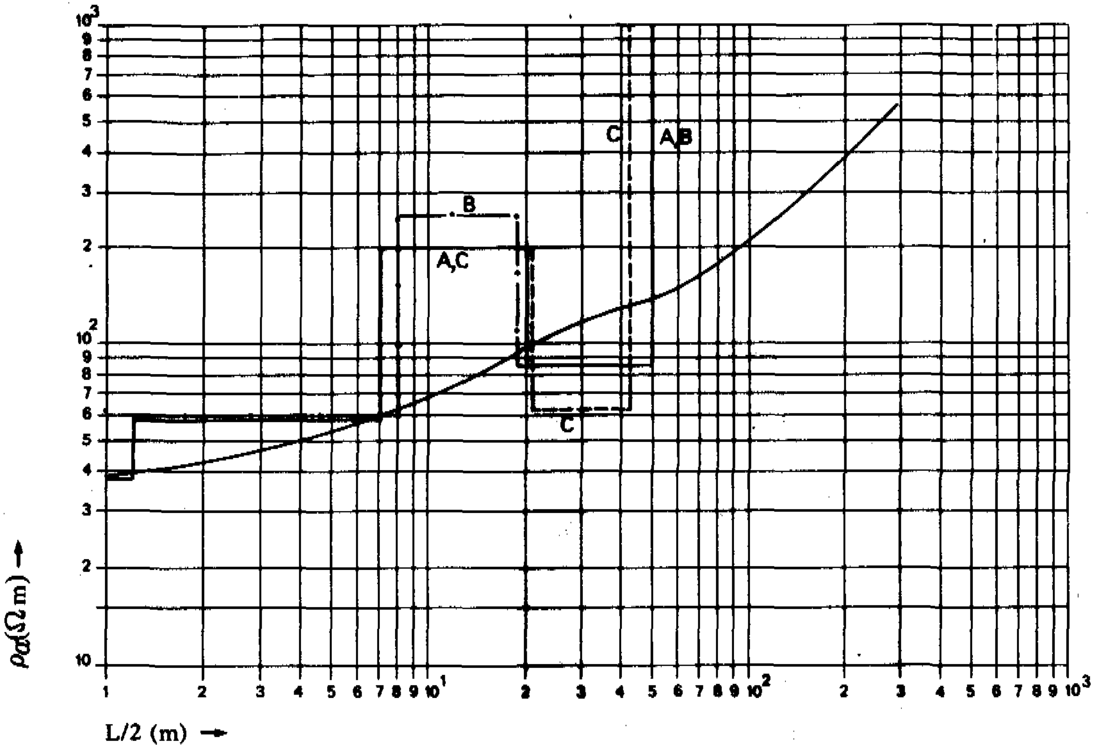


Fig. D 3.2-5 Principle of equivalence. Sounding 166/3-29 and three equivalent models

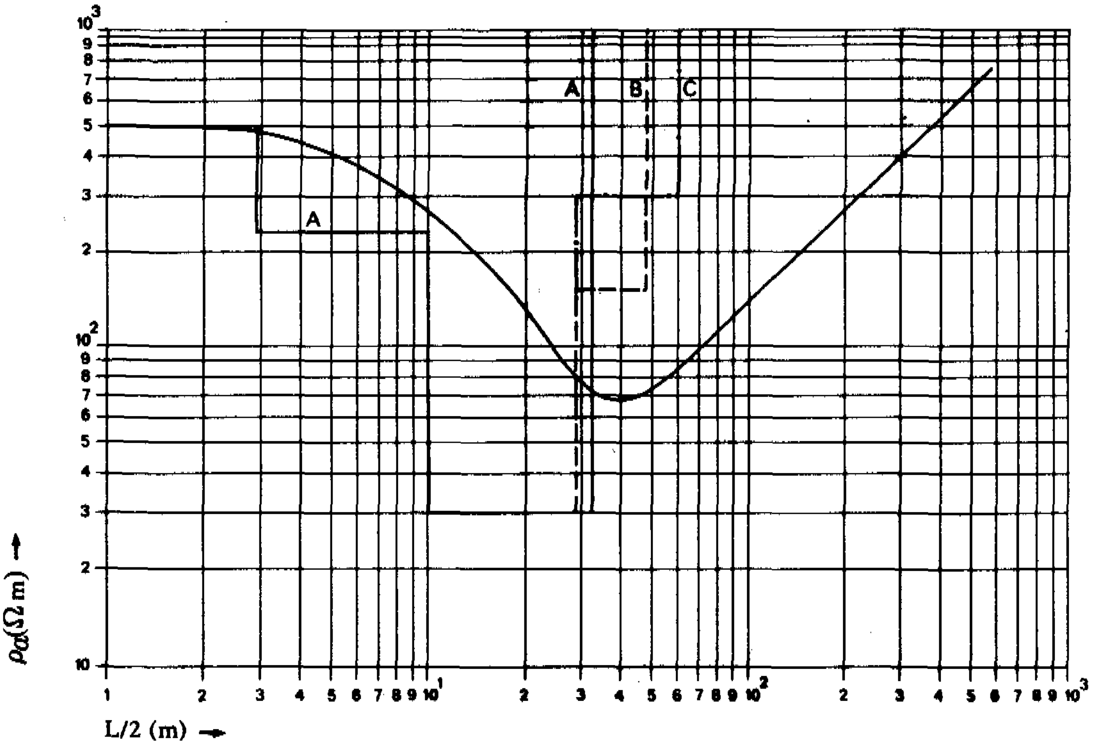


Fig. D 3.2-6 Principle of suppression. Sounding 165/4-16 and three equivalent models

This occurs especially when the layer is not very thick and the contrast between the resistivity values of the layers above and underneath is large. Therefore, the layers situated directly above the bedrock cannot be detected very well. It is clear that the three models of fig. D 3.2-6 implicate quite different hydrogeological structures.

- Different types of vertical resistivity structures.
  In most cases a sounding graph can represent very different vertical resistivity structures, see fig. D 3.2-7, model A and B. No general rules can be given how to find a solution out of the variety of different vertical resistivity structures. Normally a complicated structure can only be interpreted if many sound additional data are available such as a neighbouring borehole in which resistivity loggings were carried out. If such data are not available, only a simple model will usually be deduced. In fig. D 3.2-7 the layer between 4 and 70 m may be understood as a substitution layer of the actual layers and its resistivity value is called the "average resistivity value". In some cases, like this one, a wrong depth to the basement is deduced from the soundings. In fig. D 3.2-8 sounding 165/4-27 is represented, which is situated near borehole 33/78 at Kitete, see profile E-E'. The water-bearing layer which has been met in the borehole from 39 to 56 m can easily be introduced in the interpretation of the sounding and model B is obtained. The other way round, however, the layer with a high resistivity value of 17 ohmm between 42 and 55 m does not follow unequivocally from the sounding. The interpreted, simple model (A) shows only poor prospects for fresh ground water. The same holds for sounding 165/4-34, situated near borehole 17/60 at Magole, which is represented in fig. D 3.2-9. Here a slight difference between the two sounding graphs is encountered. It will be clear that the different hydrogeological conclusions of the different vertical structures can be very important. See for a further illustration also sub-par. 3.2.5., where many other examples of equivalent interpretations are discussed.

Criteria for the interpretation

It will be clear from the discussion above that, due to the phenomena of equivalent interpretation, it is necessary to have some criteria to interpret a sounding. These criteria have to be in agreement with the hydrogeological concept concerning the area under consideration. The criteria are:

- the data of boreholes, especially of those of which resistivity logs are available, have to be used to interpret the neighbouring soundings (cf fig. D 3.2-7, 8 and 9)
- in general it is assumed that the elevation of the surface of the (weathered) bedrock varies only moderately, unless the soundings clearly show the contrary

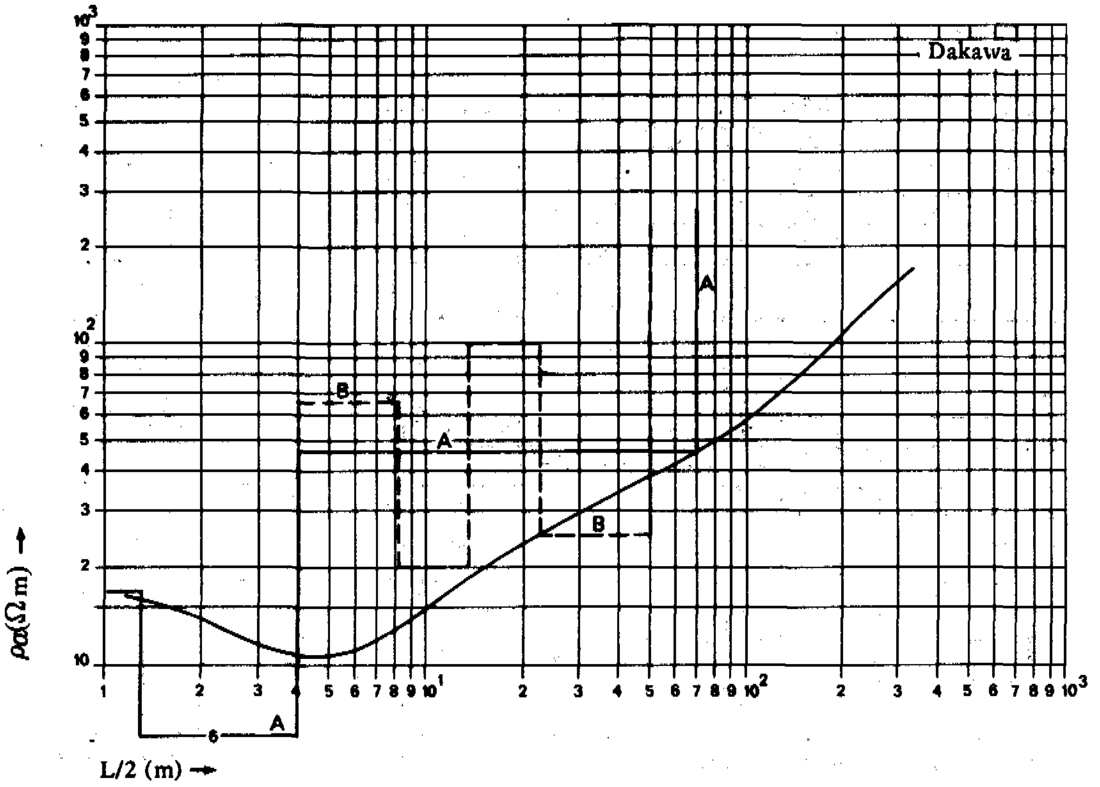


Fig. D 3.2-7 Equivalent resistivity structures. Sounding 166/3-3 and two equivalent models

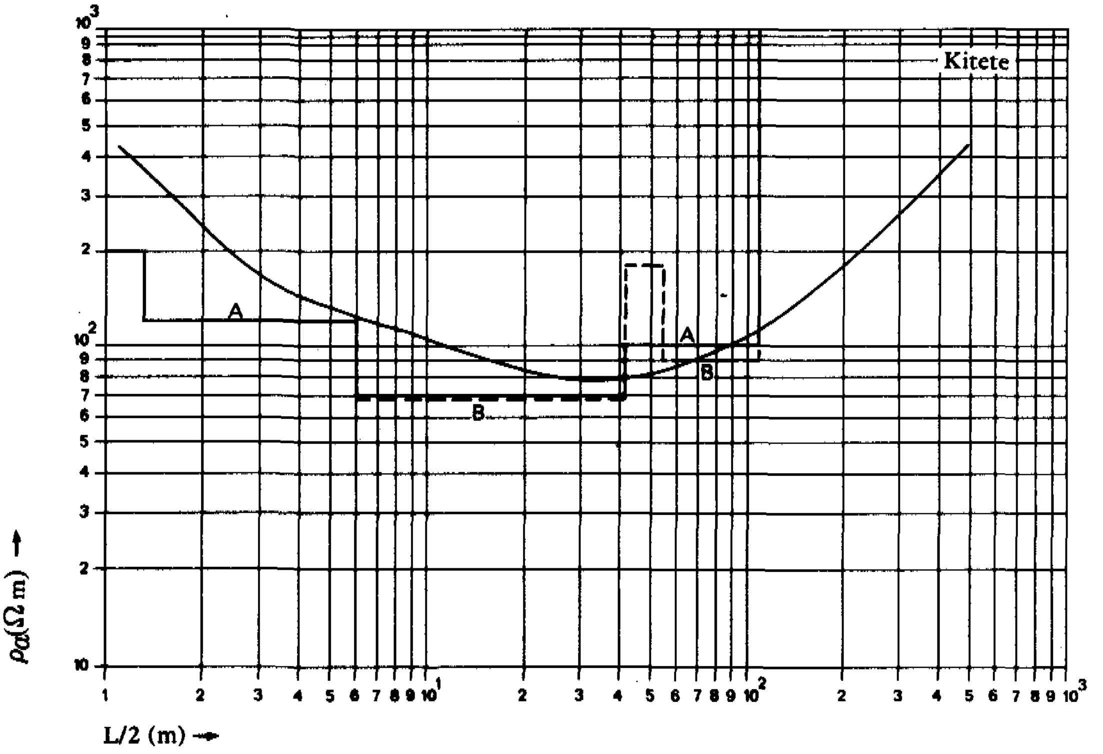


Fig. D 3.2-8 Equivalent resistivity structures. Sounding 165/4-27 and two models

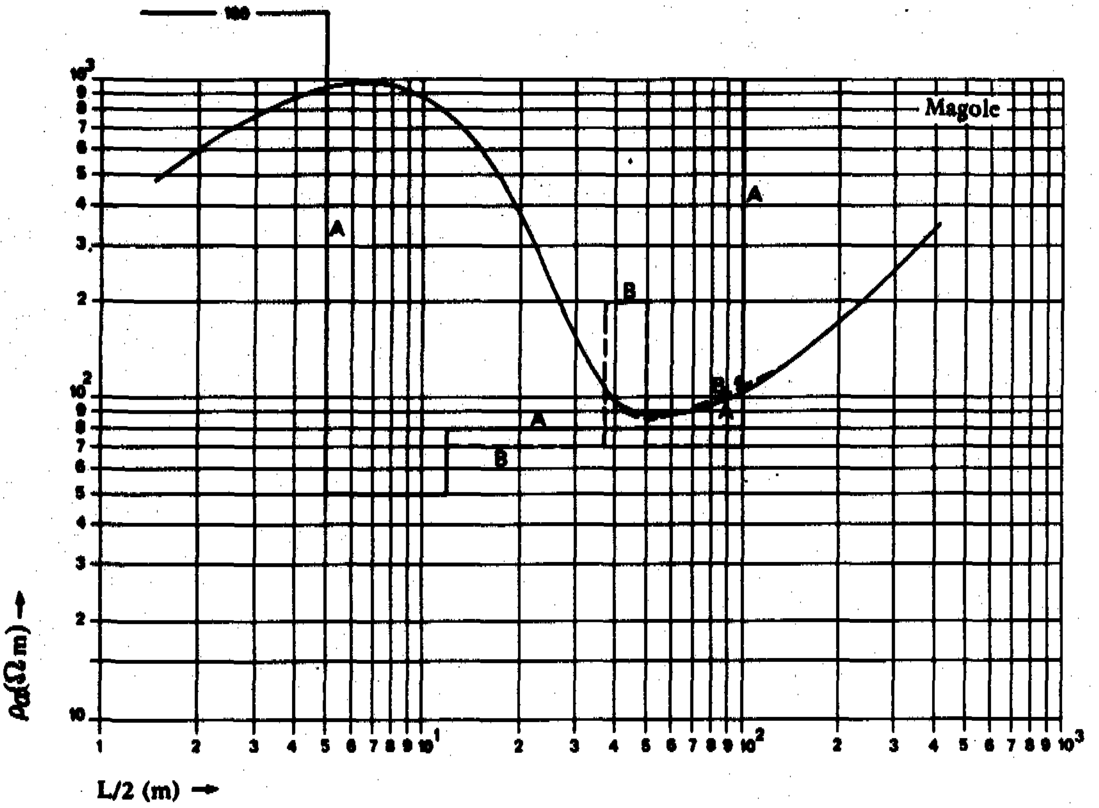


Fig. D 3.2-9 Equivalent resistivity structures. Sounding 165/4-34 and two models

The latter criterion has rather large consequences for the interpretation of many soundings. Without this assumption and by choosing only a simple interpretation of the soundings, large differences in the situation of the bedrock will be encountered as a consequence of the principle of suppression. From the possible equivalent interpretations of sounding 165/4-16 (see fig. D 3.2-6) model B was chosen. In this way the depth to the bedrock is in agreement with the data of the neighbouring boreholes 18/63 and 2/63, see profile A-A'.
As a consequence of keeping the depth to the bedrock more or less fixed, the (average) resistivity value of the sediment layers above the bedrock is then fixed too.

3.2.4. The geo-electrical method in the project area

3.2.4.1. General

To what extent the geo-electrical method can produce the necessary data depends on the measure in which these data can be deduced from the geo-electrical sounding curves.
This is determined by the following factors:

- the types of sounding curves occurring in an area which depend on the hydrogeological situation in that area
- the magnitude of the contrasts between the resistivity values of the different layers of importance

Therefore, the applicability of the geo-electrical method is not equal in each investigation and in each area. Moreover as already mentioned in sub-par. 2.2.4., the relation between the formation resistivities and the hydrogeological situation may vary from one area to another. In the following sub-paragraph the relation is dealt with regarding the Mkata-Wami Basin. In sub-paragraph 3.2.4.3. the applicability of the geo-electrical method in locating borehole sites in the Mkata-Wami Basin and surroundings is discussed.

3.2.4.2. Relation between formation resistivity values and the hydrogeological situation

In sub-par. 2.2.4. the relation between the true formation resistivity and the hydrogeological situation was presented, as it was expected to hold at the beginning of this project. From the results of the detail surveys (see sub-par. 3.2.5.) it appeared necessary to adapt this relation. These detail surveys included the execution and interpretation of geo-electrical soundings and the drilling of boreholes in which electrical well-logging measurements were carried out.

From the resistivity well-logs (SN and LN) the formation resistivity was deduced for the successive layers penetrated. On the basis of all available borehole data the relation between hydrogeological properties of the various strata and the corresponding formation resistivities could be assessed (see the table below).

Table D 3.2-2 - Relation between hydrogeology and formation resistivity as derived from resistivity well logs

lithology	water content and salinity; EC in mS/m	formation resistivity in ohmm	ground water prospects
impermeable clayey deposits	saturated, saline, EC > 200	< 5	very poor
	saturated, fresh, EC < 200	<10	
	moist to dry	10-80	
permeable sandy deposits	saturated, saline EC > 600	< 5	very poor
	saturated, saline, 200 <EC<	3-10	very poor-poor
	saturated, fresh, EC < 200	10-100	fair-very good
	moist to dry	>50	very poor
decomposed bedrock	saturated, EC < 200	10-20	poor
	saturated, EC > 200	5-10	very poor
	moist to dry	15-50	very poor
weathered and fissured bedrock	wet, 800 > EC < 30	30-150	poor-fair
bedrock (fresh)	-	>>100	very poor

From this table it becomes clear that in the area surveyed the relation between the formation resistivity and the hydrogeological situation is not unequivocal.

In some cases certain resistivity values stand for coarse sand layers with fresh water (e.g. 40 ohmm in borehole 151/78, see sub-par. 3.2.5.4.) and in other cases the same values mean dry clayey layers (e.g. 30 and 60 ohmm in borehole 131/78, see sub-par. 3.2.5.2.). The resistivity value of the weathered bedrock varies strongly, depending on the degree of weathering, the occurrence of fissures and the content of fresh or saline water. Therefore, from the resistivity values of the weathered bedrock given in the resistivity well-logs no proper predictions about water content and water salinity can be made.

During the present geo-electrical investigation it appeared that often no individual (waterbearing) layers could be distinguished by means of the geo-electrical soundings, see S46-par. 3.2.3.4. In most cases a simple model consisting of only a few layers could be derived from the soundings, which is not in agreement with the real situation. Each of the interpreted layers represents a succession of actual layers and the resistivity of such an interpreted layer is an "average" of the actual resistivity values. On the basis of these "average" resistivity values, obtained through the geo-electrical investigation, the decision had to be made if and where a borehole should be drilled. Therefore, the relation between "average" formation resistivities, the hydrogeological situation and the prospects for fresh ground water had to be determined. In Table D 3.2-3 the occurrence of fresh ground water and the "average" formation resistivity interpreted from a sounding near the borehole site are indicated for each detail survey.

For the sake of completeness the formation resistivity values of the water-bearing layers (ρ_f) and the water resistivity (ρ_w) are also given together with their mutual ratio. The table illustrates the fact that high resistivity layers may occur within an interpreted layer with a low "average" formation resistivity.

Table D 3.2-3 - Some data from detail surveys and boreholes

location	sub-par.	"average" formation resistivity in ohmm (sounding)	occurrence of fresh ground water	form. res. (ρ_f) of aquifer in ohmm (resist. log)	resist. of water (ρ_w) in ohmm	$F^* = \frac{\rho_f}{\rho_w}$
Luhindo	3.2.5.2.	30	-			
Dakawa	3.2.5.3.	46	+	100	45	2,2
Dibamba	3.2.5.4.	15	+	35/50	25	1,4-2
Mandela	3.2.5.5.	13	+	40	20	2
Makuyu	3.2.5.6.	20	+	70	36	2
Mugudeni	3.2.5.7.	7,5	-			
Mirama	3.2.5.8.	11	(-)			
Mbwade	3.2.5.9.	13	+	40	15	2,6
Madoto	3.2.5.10.	7,5	(+)	14	7,5	1,9
Rudewa B	3.2.5.11.	-	+	120	43	2,8
Kondoa	3.2.5.12.	24	+	50	18	2,7

* F = formation factor

Based on the above-mentioned results the relation between the "average" formation resistivities and the hydrogeological situation could be assessed. It is presented in Table D 3.2-4.

Table D 3.2-4 - The relation between hydrogeology and the "average" formation resistivities derived from soundings

"average" formation resistivity in ohmm	lithology and ground water quality; EC in mS/m	ground water prospects
< 5	clay deposits and/or sand layers with saline water (EC > 600)	very poor
5-10	clay deposits and/or sand layers with brackish water (EC > 200)	poor
	clay deposits with (very) thin sand layers with fresh water (EC < 200)	poor-fair
10-20	clay deposits with rather thick sand layers with fresh water (EC < 200)	fair-good
	dry clay deposits	poor
>20	mainly sand deposits with fresh water (EC < 200)	very good
	dry clay or sand deposits	poor

From the table it appears that a certain "average" formation resistivity may stand for different hydrogeological situations. Therefore no complete certainty about the prospects for a borehole can be given by the soundings alone. However, on the basis of the geo-electrical investigation areas with poor and very poor prospects can be excluded from further investigations, so that expensive drilling programmes can be directed only to the areas with good prospects. Moreover, within a chosen area the most promising location for a borehole can be detected by means of the geo-electrical method (cf. borehole sites in Dakawa, Dibamba, in particular Mandela; sub-par. 3.2.5.). With the information now available from boreholes, well logs and geo-electrical profiles the knowledge on the hydrogeology of the Mkata-Wami Basin has greatly increased. It has now become much easier to locate a new borehole site. For further discussion see sub-par. 3.2.7.

3.2.4.3. The applicability of the geo-electrical method in the project area

In this paragraph the applicability of the geo-electrical method to find the ground water in some parts of the project area will be discussed. This will be done on the basis of the experience obtained during the present investigation, which was mainly confined to the Mkata-Wami Basin. As mentioned in the foregoing sub-parapgraph, there is no unequivocal relation in the investigated part of the project area between the formation resistivities and the hydrogeology (Table D 3.2-2) nor between the interpreted average formation resistivities and the prospects for fresh ground water (Table D 3.2-4). As a result no firm predictions concerning the occurrence of deep fresh ground water can be made on the basis of the geo-electrical soundings alone. Nevertheless, with the geo-electrical method considerable savings can be made on drilling expenses.

Mkata-Wami Basin

In the Mkata-Wami Basin the geo-electrical method has proved to be very useful in the search for deep ground water. The application of the geo-electrical method provided the following results.

- The knowledge of the geological and tectonic structure of the Mkata-Wami Basin has greatly increased. This knowledge forms the basis for further hydrogeological studies.
- An outline could be given of the general features concerning the prospects for potable water in the basin. Areas with no or very thin sandy aquifers or with saline ground water could be classified as poor. Other areas could be qualified as fair or good (see Map D3).
- With the detail geo-electrical surveys, the optimum location for a borehole can be determined. It has become clear that the sedimentary fill of the basin is laterally very inhomogeneous. Without detailed investigations it is practically impossible to locate exactly the place where the most sandy aquiferous beds are present in the underground (see e.g. Dakawa sub-par. 3.2.5.3.).

Of course a great deal of knowledge and experience was gained during the survey especially by the feed-back of the drilling results to the (final) interpretation of the soundings. It means that with the knowledge now available, as summarized in Table D 3.2.4., it has become much easier to give a prognosis if other detail surveys in the Mkata-Wami Basin will be executed.

Other areas

In the areas outside the sedimentary basin, where the weathered bedrock is found at shallow depth, the geo-electrical method is of little use. From the soundings the occurrence of ground water in the weathered zone and its quality cannot be found out in most cases (e.g. Luhindo, sub-par. 3.2.5.2.), because the resistivity of clayey decomposed bedrock varies a great deal, especially due to differences in moisture content (Table D 3.2.-3). Predictions about the water content of the layers above the weathered zone cannot be made. However, the depth to the unweathered bedrock can be detected rather well from the soundings.

Small river valleys

It appeared that the geo-electrical method is not the appropriate method to locate shallow borehole sites (see the special study concerning this subject in Annex DA 2). With the soundings executed in small river valleys, however, the depth to the bedrock can be determined and it can be found out if the ground water is fresh or saline. In general this type of shallow investigation is carried out more efficiently by hand-drillings.

3.2.5. Detail surveys

3.2.5.1. General

Detail geo-electrical surveys were conducted near villages faced with problems concerning domestic water supply and where gravity supplies or shallow wells did not offer an alternative. A selection of villages was made (sub-par. 3.3.1.).

Seventeen detail surveys were conducted in total. In the next paragraphs 11 surveys are reported. Of the remaining six three locations (Kidudwe, Kigugu, Mkundi) were abandoned after the preliminary interpretation, because the possibilities were very poor. The other three (Madudu, Rudewa-Gongoni and Msowero) could not be reached by the drilling rig.

In selecting the areas to be studied in detail the basic information was obtained from the preliminarily interpreted, geo-electrical profiles. On the basis of some additional soundings it was decided, whether in that area a borehole had to be drilled or not. If so, a drilling site was proposed. The ultimate drilling site, however, depended on the accessibility for the drilling rig and the distance to the neighbouring village. Therefore, the drilling site is not always situated at the very location of a sounding.

After completion of the borehole the obtained drilling results and well-logging measurements were used to re-interpret the neighbouring sounding curves in such a way that they were in agreement with the hydrogeological stratification in the borehole. Moreover the correlation between formation resistivities and hydrogeological strata could be improved.

The detail surveys with the newly drilled wells are pre-eminently suited to provide the reference data, which are needed to execute other (regional or local) geo-electrical investigations in the Mkata-Wami Basin.
For a good understanding of the general structure and to obtain a complete set of reference data for the geo-electrical interpretation, it was necessary to execute one drilling at a location (Mugudeni) of which it was clear that the prospects were poor.
The limitations of the geo-electrical method and the applicability of the method for the Morogoro Region, as discussed in sub-par. 3.2.3. and 3.2.4., are mainly based on the results of and the data from the detail surveys.

In this paragraph the detail surveys of locations where a borehole was drilled will be discussed. They are discussed in the same order in which the boreholes were drilled. The locations of the boreholes are represented on map D 1. From each survey the preliminary interpretation of the soundings will be given first. Next the results of the drilling, water quality and well yield are given. Subsequently the final interpretation is given and the correspondence between the soundings and the obtained borehole data will be discussed. Finally conclusions will be drawn concerning further prospects in the neighbourhood of this location for ground water exploitation.
The sounding curves with their interpretations are presented in Data DD 7; the drilling logs, the sample logs and the well logs are dealt with in Fig. D 3.3-1 up to 17.

To clarify the interpretation of the soundings and the elaboration of the detail surveys, the discussion of each detail survey is illustrated with one or two figures. In the cases in which the basement was not reached one figure is given representing a sounding graph, its preliminary interpretation (model A) and the resistivity model deduced from the resistivity well logs (model I). In the cases in which the basement was reached two figures are given. The first one gives a sounding graph and its preliminary (model A) and final interpretation (model B) ; the two models are an equivalent solution of the sounding. The second figure gives two resistivity models and a sounding graph. From the resistivity well logs a resistivity model was derived which was schematized a little (model I). By making an assumption based on a neighbouring sounding for the resistivity values of the top layers and the basement, the theoretical sounding graph is calculated, which corresponds to this second model. Starting from this calculated graph a simplified model (model II) was found which is equivalent to model one.
When comparing the interpreted models of the soundings with the resistivity models deduced from the well logs, the models B have to be compared with the models I and the models A with the models II.

3.2.5.2. Detail survey near "Luhindo"

Location	Luhindo
Mapsheet	166/3
Borehole	131/78, Fig. D 3.3-1
Soundings	166/3-18, 21, 31, 32, 33, 34 and 35
Profile	A-A', Mugudeni-Morogoro, Fig. D 3.2. - 38
Fig D 3.2-11	Sounding 166/3-35 with its preliminary (model A) and its final interpretation (model B)
Fig D 3.2-12	Resistivity models of borehole 131/78 and the calculated sounding graph; model I is a schematic model derived from the well logs and model II is a simplified model

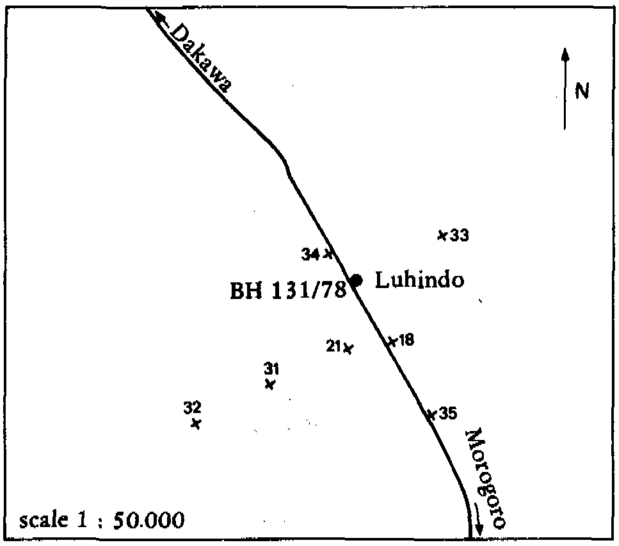


Fig. D 3.2-10 - Location map of detail survey Luhindo

Preliminary interpretation

Apart from some uninterpretable soundings (cf. 166/3-18 and 31) the interpretations of the other soundings can be summarized as:

model	depth (top) in m	resistivity in ohmm
top layer	0	25-100
2nd layer	3	5- 30
3rd layer	5-11	30
basement	25-35	>100

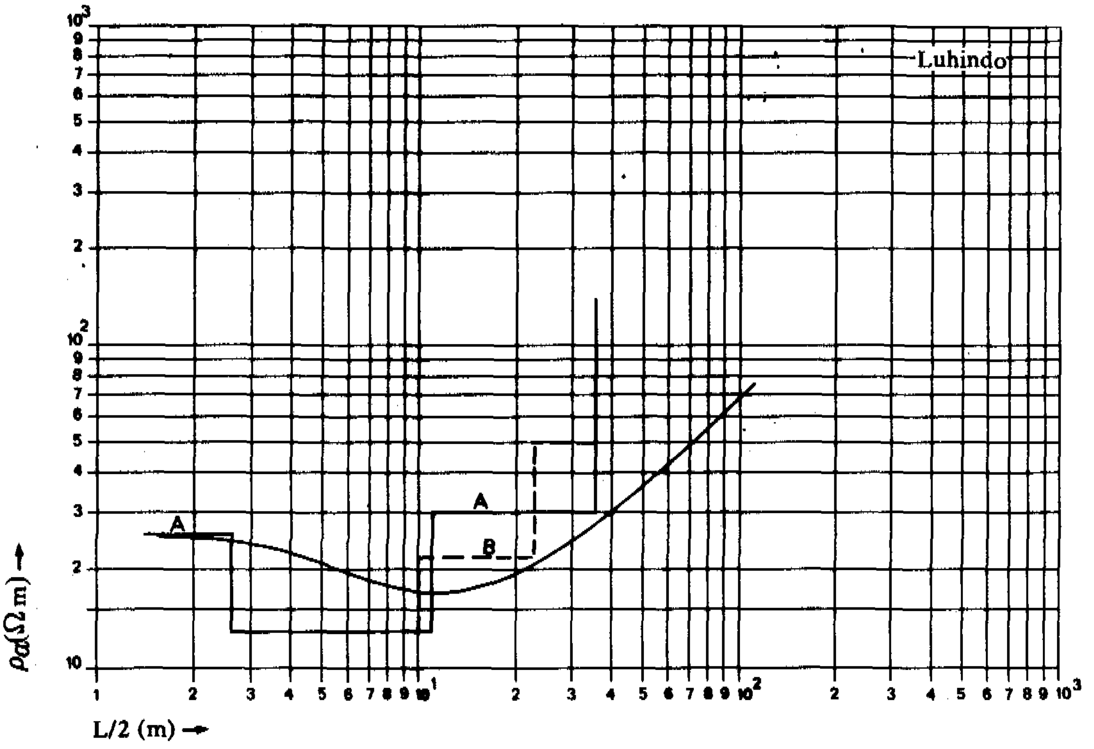


Fig. D 3.2-11 Sounding 166/3-35 with its preliminary (model A) and final interpretation (model B)

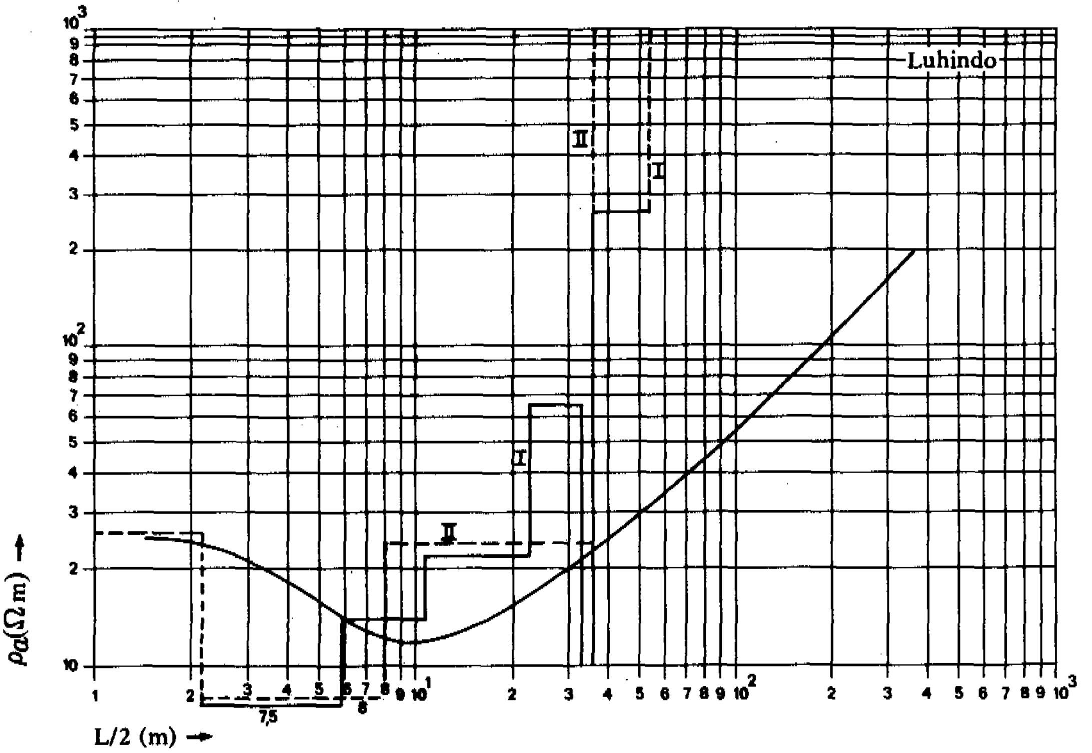


Fig. D 3.2-12 Resistivity models of bore hole 131/78 and the calculated sounding graph

The layer with a resistivity of 30 ohmm seemed to offer good prospects for fresh ground water. A borehole site was proposed near the soundings 166/3-21, 33 and 35.
About 1 km north of sounding 166/3-34 (weathered) bedrock crops out; in the topographical depression south of Luhindo the soundings indicate formation resistivities of about 5 ohmm above the basement (see profile A-A', fig. D 3.2. - 38).

Borehole

The drilling site is situated between the soundings 166/3-21, 33 and 34 within a distance of 600 m. While drilling, up to 33,5 m, only dry gravelly clay was found (air-rotary drilling). Then saline water was struck with an EC of 820 mS/m. The depth to the hard bedrock is 36 m and is in good agreement with the interpreted depth values. Because of this high salinity the borehole was not completed by a screen and has been abandoned.

Final interpretation

Apart from the toplayers, the interpreted resistivity models are well in accordance with the results of the borehole (Fig. D 3.2-11 and D 3.2-12). Only the third layer with resistivity values of 30 ohmm (model A) has to be split up into two layers with a resistivity of 22 and 50 ohmm respectively. The thin water-bearing layer at a depth of 33 m with (saline) water cannot be detected from the sounding, due to the limitations of the geo-electrical method (sub-par. 3.2.3.).
Contrary to expectations the resistivity values of 20 to 50 ohmm do not correspond to water-bearing layers with fresh water, but to dry clay layers with a high gravel content.
Although not visible in the soundings it is now clear that saline water is present in the deepest part of the weathered bedrock, just above the fresh bedrock. This is confirmed to a certain extent by the soundings 166/3-19 and 22 south of Luhindo (see profile A-A'), where the low resistivity is very thick and ground water with a high salinity was found at shallow depth.

Conclusions

The area around Luhindo shows poor prospects for good ground water. From the resistivity logs it is deduced that near Luhindo formation resitivities from 5 to 80 ohmm correspond to clayey and clayey gravel layers, probably decomposed bedrock.
The differences in the resistivity values are probably caused by differences in clay and/or moisture content.

3.2.5.3. Detail survey near Dakawa

Location	Dakawa
Mapsheet	166/3
Boreholes	135A, B, C/78, Fig. D 3.3-2, 3 and 4
Soundings	166/3-2, 3, 5, 36, 37, 38, 39, 40, 41
Profile	A-A', Mugudeni-Morogoro and B-B', Dihombo-Dakawa Fig. D 3.2. - 38 and 39
Fig D 3.2-14	Sounding 166/3-3 with its preliminary (model A) and its final interpretation (model B)
Fig D 3.2-15	Resistivity models of borehole 135A/78 and the calculated sounding graph; model I is a schematic model derived from the well logs and model II is a simplified model

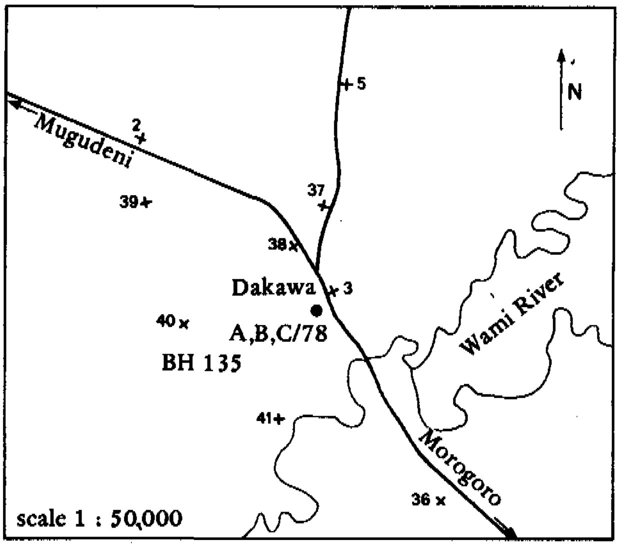


Fig. D 3.2-13 - Location map of detail survey Dakawa

Preliminary interpretation

Based on the shape of the soundings the area surveyed could be divided into three SW-NE directed zones. In the northern zone the soundings 166/3-2, 5 and 39 are situated, in the middle one the soundings 166/3-37, 38 and 40, and in the southern zone near the Wami River, the soundings 166/3-3, 36 and 41. The interpreted models can be summarized as:

model	northern (2, 5, 39)		middle (37, 38, 40)		southern (3, 36, 41)	
	depth (top) in m	restist- ivity in ohmm	depth (top) in m	restist- ivity in ohmm	depth (top) in m	resist- ivity in ohmm
top layer	0	10-40	0	10-300	0	≅30
2nd layer	<2	6- 7	<2	6- 15	1	7- 9
3rd layer	6	15-21	5-10	27- 38	4	45-60
basement	38-44	>100	≅40	>100	50-75	>100

The layer with a formation resistivity of 45 to 60 ohmm in the southern zone was regarded as the most promising one. A borehole site was proposed near sounding 166/3-3.

Borehole

The location is situated at about 200 m to the west of sounding 166/3-3. For technical reasons (see par. 3.3.3.3.) three boreholes were drilled here very close to each other. In these boreholes two water-bearing layers were found from 3,5 to 8 m and from 14,5 to 27,5 m. In the second layer a screen was placed (borehole 135C/78). The yield is very high and the EC of the water is 18 mS/m.
Under this aquifer clayey layers were found. The (weathered) basement is situated at 42 m below ground level and it contains fresh water with an EC of 32 mS/m (borehole 135B/78, air-rotary drilling).

Final interpretation

The main difference between the final interpretation of sounding 166/3-3 (Fig. D 3.2-14, model B) and the succession of resistivity layers in the borehole (Fig. D 3.2-15 model I) is the difference in resistivity value of the layer between the second aquifer and the basement. The depths to the basement are well in accordance with each other. This schematic resistivity model of the borehole could be simplified into a four layer model (model II). The second layer with a high resistivity value is pronouncedly clear in the (calculated) curve. In the sounding 166/3-3 the corresponding layer is not clearly shown, due to the low resistivity value of the toplayer which affects the shape of the curve. Therefore, the layers between the toplayer and the basement can be replaced by only one substitution layer. As a result a much too great depth to the basement was interpreted at the preliminary interpretation.

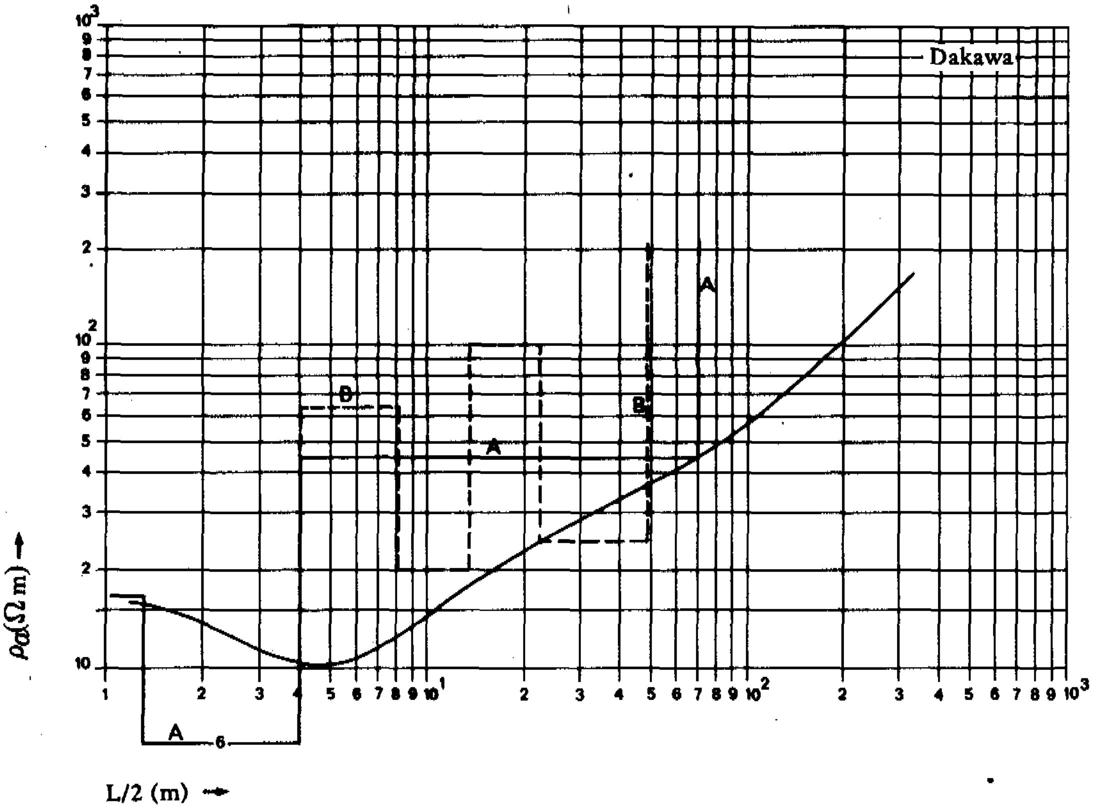


Fig. D 3.2-14 Sounding 166/3-3 with its preliminary (model A) and its final interpretation (model B)

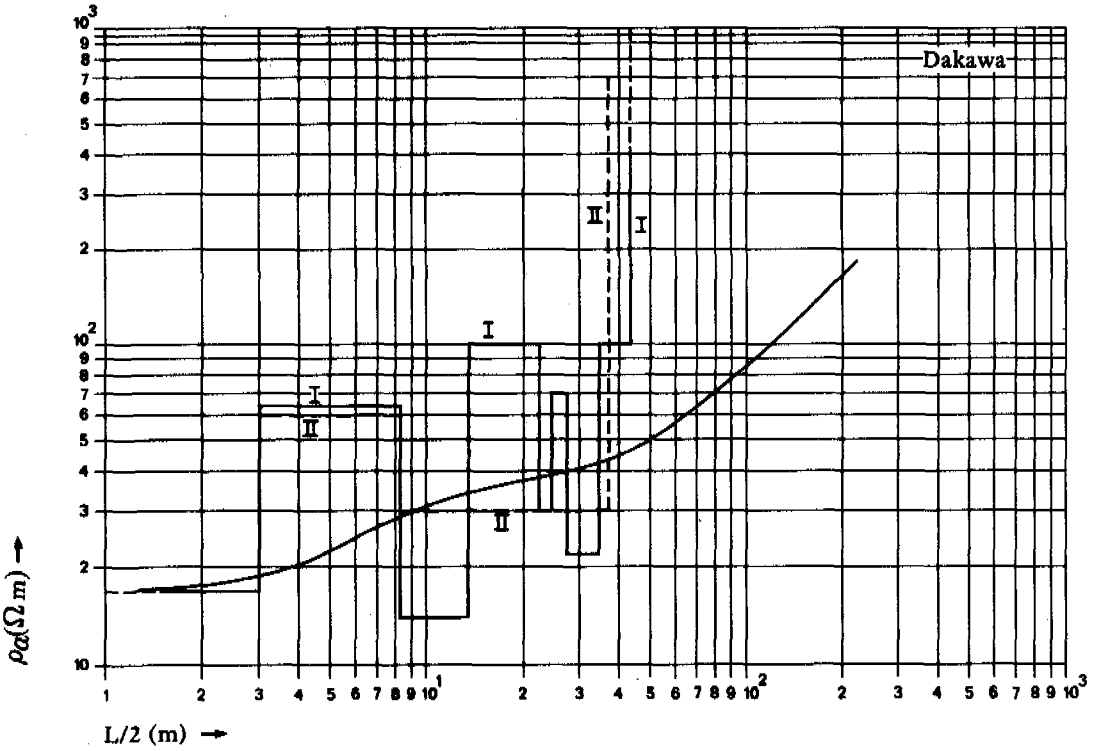


Fig. D 3.2-15 Resistivity models of bore hole 135a/78 and the calculated sounding graph

The interpretation of the nearby soundings 166/3-36, 38 and 41 has been adjusted to the registered resistivity profile in the borehole. At the soundings 36 and 41 it is observed that the second water-bearing layer has the same thickness as found in the borehole. At sounding 38 the aquifer is much thinner. From the gradual lowering of the "average" resistivity along the profiles A-A' and B-B' it is clear that the aquifer is completely wedging out towards the north-west.
From the resistivity well logs (see sub-par. 3.3.3.) it appears that in the upper part of the borehole resistivity values of 60-100 ohmm correspond to water-bearing sand layers, but in the lower part to clayey decomposed bedrock.

Conclusions

A relatively narrow zone bordering the Wami River appears to have good prospects for ground water (soundings, 166/3, 36 and 41). North-west of this zone with good prospects an area with fair prospects is present at soundings 166/3-37, 38, 39 and 40 and to a lesser extent at soudings s 2 and 5.

3.2.5.4. Detail survey near Dibamba

Location : Dibamba
Mapsheet : 165/4
Borehole : 151/78, Fig. D 3.3-5.
Soundings : 165/4-10, 24, 25, 26, 42, 58, 59, 60
Profile : E-E', Kitete-Dihombo Fig. D 3.2. - 42
Fig. D 3.2-17. : Sounding 165/4-59 with its preliminary interpretation (model A) and the resistivity model derived from the well logs 151/78 (model I)

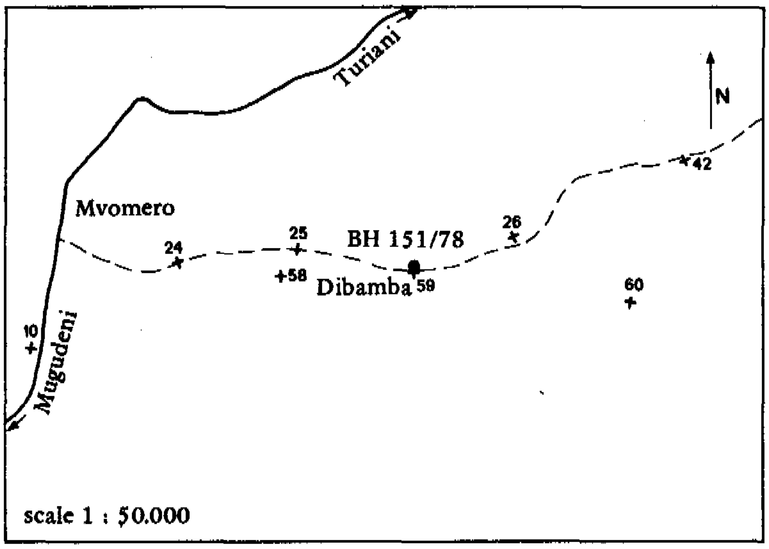


Fig. D 3.2-16 - Location map of detail survey Dibamba

Preliminary interpretation

The soundings 165/4-10, 24 and 58 in the West indicate that the bedrock can be found between 75 and 110 metres. All other soundings show a much greater depth to the basement. The interpreted models can be summarized as:

model	west (10, 24, 58)		east (others)	
	depth in m	resistivity in ohmm	depth in m	resistivity in ohmm
top layer	0	4-300	0	7-700
2nd layer	<4	6- 12	<4	9- 20
basement	75-100	>100	200-300	>100

In many of these soundings the top layer has a very high resistivity which masks the directly underlying layers. The curves are of such a shape that from a depth of 10-20 m down to the basement no separate layers can be distinguished. Therefore, this part is interpreted as one layer. This resistivity layer is in fact a replacement layer - for many actual, separate layers - with an average resistivity value. As a result the interpretation will give too great a depth to the basement (cf Fig. D 3.2-14. model A and B).
It could be expected that the higher the average resistivity is, the higher the chances are to meet sandlayers with fresh water. The drilling site was proposed near soundings 165/4-25 or 59.

Borehole

Borehole 151/78 was drilled within 20 metres of sounding 165/4-59. The majority of the layers are clays and clayey deposits, but also two sand layers were found. In the second one a screen was placed. The yield is rather good and the EC of the water amounts to 28 mS/m. The drilling (mud-rotary) was stopped at a depth of 110 m on a very hard layer, probably cemented sands.

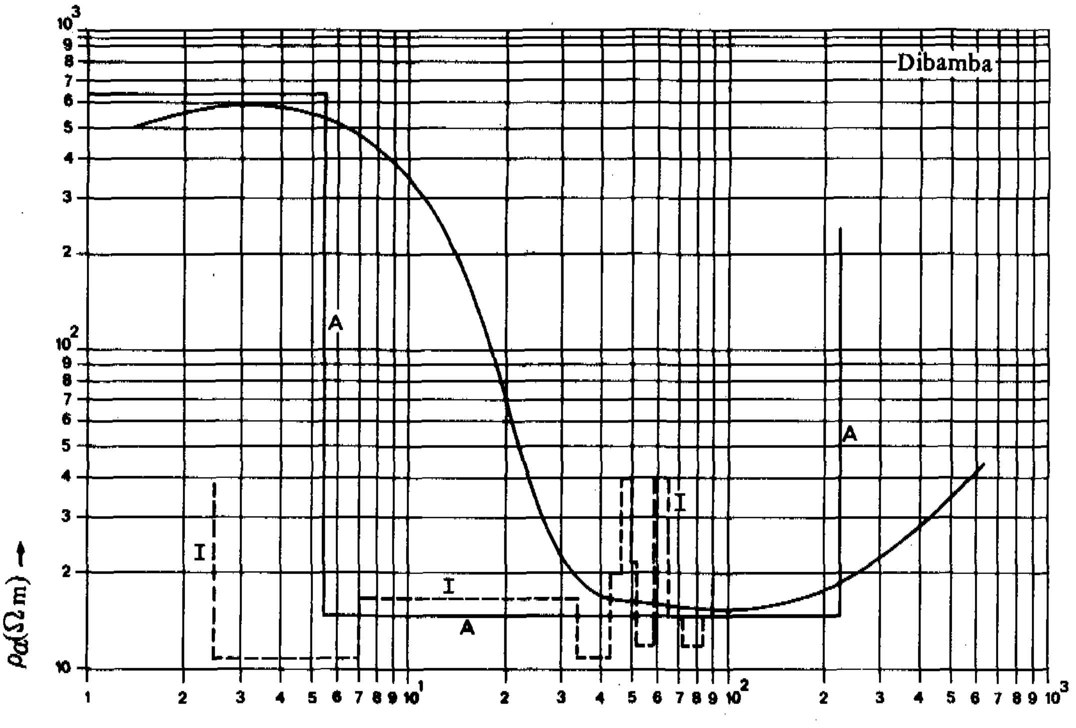


Fig. D 3.2-17 Sounding 165/4-59 with its preliminary interpretation (model A) and the resistivity model of bore hole 151/78 (model I)

Final interpretation

In comparing model I with model A of Fig. D 3.2-17. it appears that, apart from the uppermost five metres, the average value of the resistivities of model I is well in accordance with the interpreted resistivity value of model A. In this case it is not necessary to re-interpret sounding 165/4-59. In the first place the resistivity of the layers above the basement is not known, and secondly the water-bearing layers are so thin in relation to their depth, that they cannot be distinguished separately in the geo-electrical soundings.

Conclusions

Prospects for ground water are good at soundings 165/4-25 and 59, considered fair at 26 and 60 and poor at 10, 24, 42 and 58.

3.2.5.5. Detail survey near Mandela

Location : Mandela
Mapsheet : 165/4
Borehole : 162/78, Fig. D 3.3-6.
Soundings : 165/4-7, 35, 41, 52, 53, 54, 55, 56, 57
Profiles : C-C', Makuyu-Mabana, and E-E', Kitete-Dihombo
Fig. D 3.2-19. : Sounding 165/4-7 with its preliminary interpretation (model A) and the resistivity model derived from the well logs 162/78 (model I)

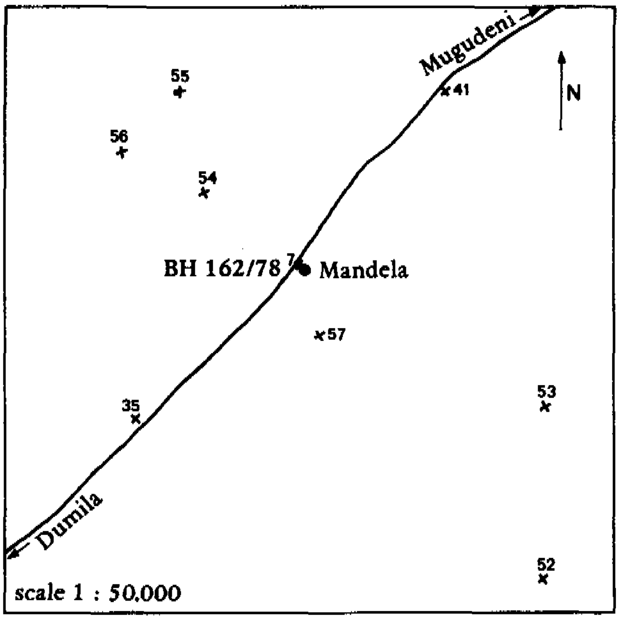


Fig. D 3.2-18 - Location map of detail survey Mandela

Preliminary interpretation

These soundings can be divided clearly into two groups. One group consisting of the soundings 165/4-55 and 56 is situated north of Mandela and indicates a great depth to the basement (see also the detail survey at Makuyu); the other soundings are situated around and south of the village and indicate moderate depths to the basement. The preliminarily interpreted models can be summarized as:

model	north (55, 56)		south (others)	
	depth (top) in m	resistivity in ohmm	depth (top) in m	resistivity in ohmm
top layer	0	60	0	10-700
2nd layer	13	25- 35	10	6
3rd layer	25	18- 22	25	12
basement	160-210	>100	75	>100

The first parts of the soundings 165/4-7, 35, 41 and 54 are uninterpretable, probably on account of shallow lateral inhomogeneities. Sounding 165/4-7 indicates nevertheless, that here the second and third layer have more or less the same resistivity of 13 ohmm. The same can be said with less certainty of nearby soundings 35 and 54.

Although the soundings 165/4-55 and 56 indicated good prospects, these locations were not selected because of the great distance to the village.

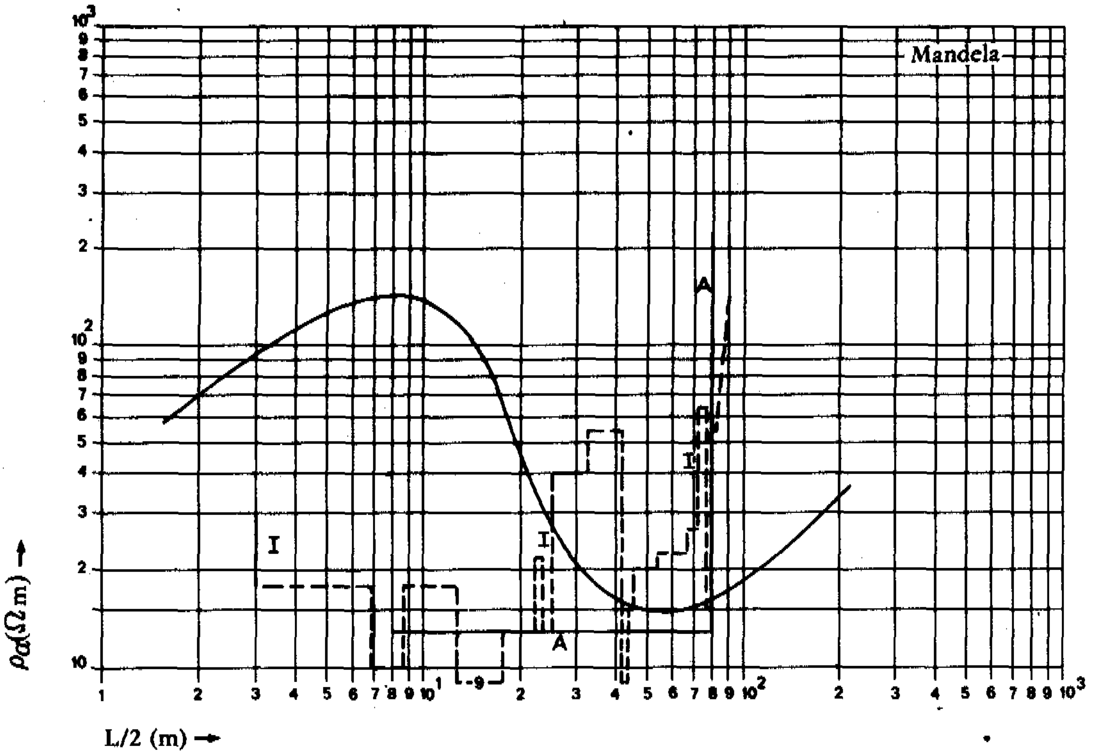


Fig. D 3.2-19 Sounding 165/4-7 with its preliminary interpretation (model A) and the resistivity model of bore hole 162/78 (model I)

Instead the location of sounding 165/4-7 was proposed as a drilling site. In comparison with the neighbouring soundings this one shows the highest resistivity values for the layers at moderate depth.

Borehole

The borehole is situated within 20 m of the sounding 165/4-7.
In this borehole an extensive water-bearing layer was found from 25 down to 38 m, in which a screen was placed. The EC of the water amounts to 38 mS/m and the well yield is very high. Under this sand layer thick clayey layers were found. The drilling stopped at 90 m on a very hard layer, probably cemented sands.

Final interpretation

The models A and I from Fig. D 3.2-19. do not correspond with each other. Apart from the first 10 metres approximately, the average of the resistivity values measured in the borehole (about 20 ohmm) is essentially higher than the average resistivity value interpreted from the sounding (13 ohmm). As mentioned above, the other soundings show even much lower resistivities (6-12 ohmm). From these discrepancies it is concluded that the strata here are changing strongly in a lateral sense. Therefore, it is supposed that the water-bearing layer cannot be very extensive towards the West and East. The condition of uniform and horizontal layering, necessary for a proper interpretation of a sounding (see also sub-par. 3.2.3.) is not fulfilled around 165/4-7. The locations where the soundings show low resistivity values are considered to have poor prospects for fresh ground water.

Conclusions

The borehole near Mandela shows a good and relatively thick water-bearing layer. This exceeds the expectation based on one of the soundings.
North of the fault at soundings 55 and 56 good prospects are present as demonstrated through borehole Makuyu.
The other soundings in the vicinity of Mandela show in general poor prospects for fresh ground water. The lateral extension of the water-bearing layer may be very limited. This is in accordance with the general idea that in a basin like the Mkata-Wami Basin sand deposits and old river beds are intercalated in clayey deposits.

3.2.5.6. Detail survey near Makuyu

Location : Makuyu
Mapsheet : 165/4
Borehole : 173/78, Fig. D3.3-7
Soundings : 165/4-85, 93, 94, 95
Profile : C-C', Makuyu-Mabana

Fig. D 3.2-21 : sounding 165/4-94 with its preliminary interpretation (model A) and the resistivity model derived from the well logs 173/78 (model I).

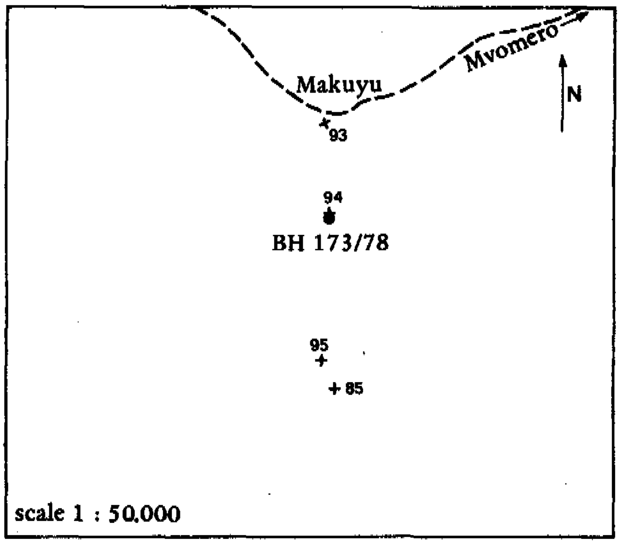


Fig. D 3.2-20 - Location map of detail survey Makuyu

Preliminary interpretation

With the exception of sounding 165/4-93 all soundings show a great depth to the basement and are of the same type as the soundings 165/4-55 and 56, which were executed near Mandela. The interpreted models can be summarized as:

model	depth (top) in m	resistivity in ohmm
1st layer	0	80
2nd layer	20	20
basement	170-190	100

Sounding 165/4-93, situated in the North, shows a relatively small depth to the basement of about 35 m. The obvious conclusion is that between this sounding and sounding 165/4-94 the major fault along the northwestern rim of the Mkata-Wami Basin is situated.
Sounding 164/4-94 was proposed as the drilling site.

Borehole

The drilling location was within 30 m of sounding 165/4-94. Four water-bearing layers were found. A screen was placed in the aquifer which reaches from 42 to 46,5 m. The EC of the water amounts to 27 mS/m and the yield is good. The drilling was stopped at 93 m on a hard layer, probably cemented sands.

Final interpretation

Apart from the layer between 10 and 20 metres, the interpreted model of sounding 165/4-94 (Fig. D 3.2-21.) corresponds rather well with the model deduced from the well logs. Due to the limitations of the geo-electrical method (sub-par. 3.2.3.), it is impossible to deduce the individual (sand) layers from the soundings. Because the basement was not reached and therefore the formation resistivities of the layers above it are unknown, it is of little use to modify the interpretation.

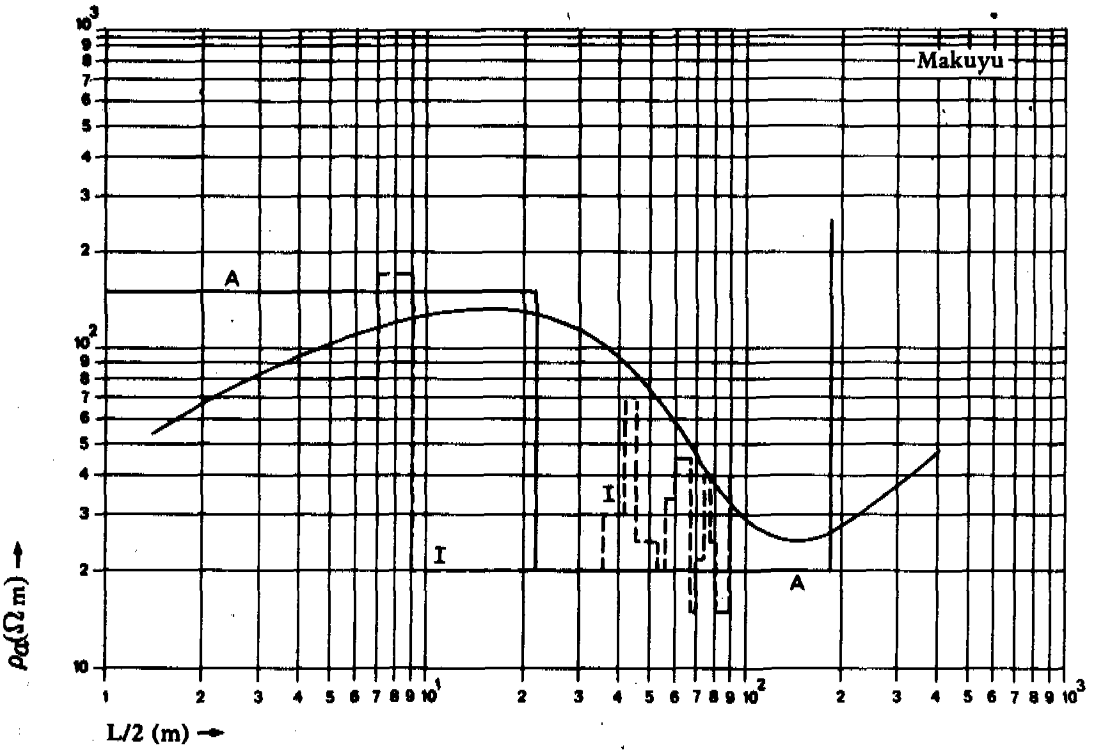


Fig. D 3.2-21 Sounding 165/4-94 with its preliminary interpretation (model A) and the resistivity model of bore hole 173/78 (model I)

Conclusions

The area near Makuyu appears to have good prospects for the exploitation of fresh groundwater.

The results here are in concurrence with the conclusions of the detail survey near Dibamba. The important, relatively thin water-bearing layers cannot be deduced from the soundings separately. To examine the possibilities for ground water in this area the average resistivity value of a substitution layer, interpreted from the soundings, has to be considered. Values of 15 to 20 ohmm appear to indicate good prospects.

3.2.5.7. Detail survey near Mugudeni

Location	:	Mugudeni
Mapsheet	:	165/4
Borehole	:	6/79, Fig. D 3.3-8.
Soundings	:	165/4-9, 13 and 14
Profile	:	A-A', Mugudeni-Morogoro, and E-E', Kitete-Dihombo
Fig. D 3.2-23	:	Sounding 165/4-13 with its preliminary (model A) and its final interpretation (model B)
Fig. D 3.2-24	:	Resistivity models of borehole 6/79 and the calculated sounding graph; model I is a schematic model derived from the well logs and model II is a simplified model

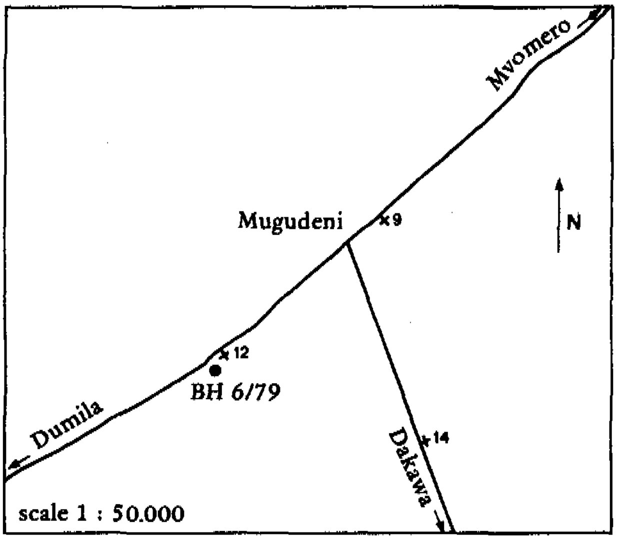


Fig. D 3.2-22 - Location map of detail survey Mugudeni

Preliminary interpretation

The interpreted models of these soundings can be summarized as:

model	depth (top) in m	resistivity in ohmm
1st layer	0	2-16
2nd layer	>13	5- 8
basement	70-100	>100

The layer above the basement has a very low formation resistivity, which indicates poor prospects for fresh ground water.
However, 8 km east of Mugudeni near Magole (see profile E-E') the same low resistivity values are interpreted from the soundings, and there an existing borehole produces fresh water (EC = 72 mS/m).
The purpose of this detail survey was to examine if those areas, where such low resistivity values are deduced from the soundings, really have poor prospects and therefore have to be excluded from further ground water investigations. Sounding 165/4 was selected for an exploratory drilling site.

Borehole

The borehole is situated within 200 m of sounding 165/4-13. During the drilling a lot of clay was found; most of it dissolved in the mud. According to the resistivity well logs no fresh water-bearing layers were present. Because of the low resistivity values it is difficult to distinguish different layers in the well logs. However, it is clear from the well logs that mostly clayey layers occur and that, if sandy layers are present, the pore water is saline (EC > 200 mS/m). Unfortunately the SP-log was of poor quality.

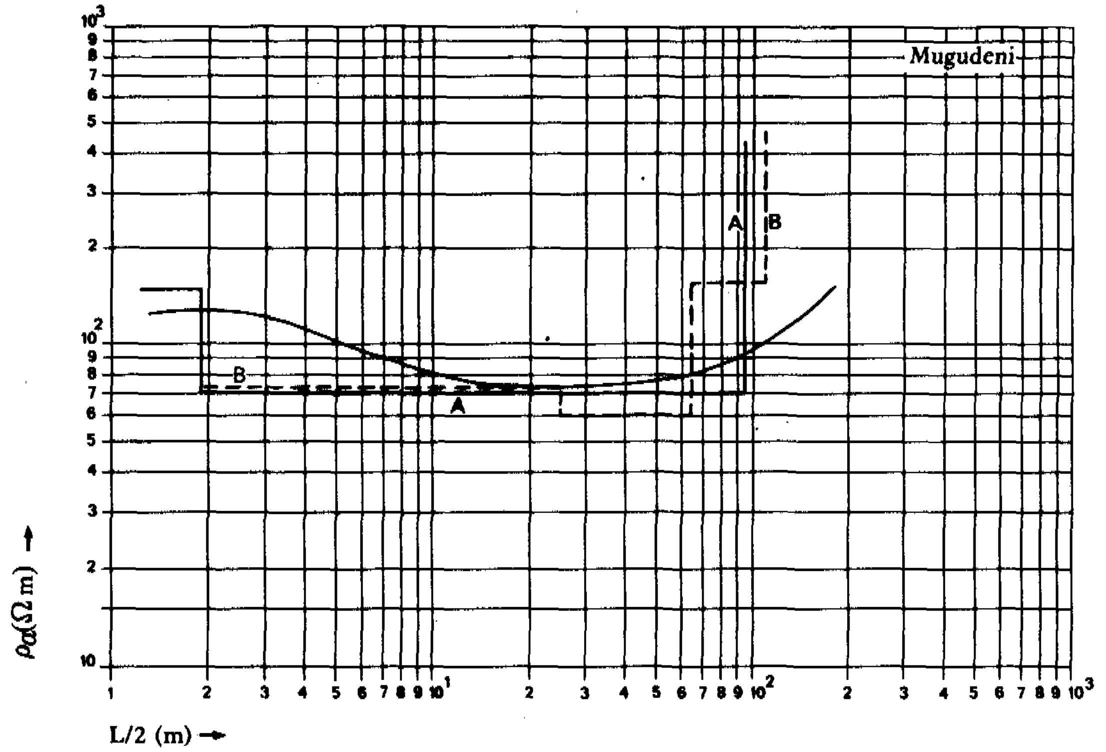


Fig. D 3.2-23 Sounding 165/4-13 with its preliminary (model A) and final interpretation (model B)

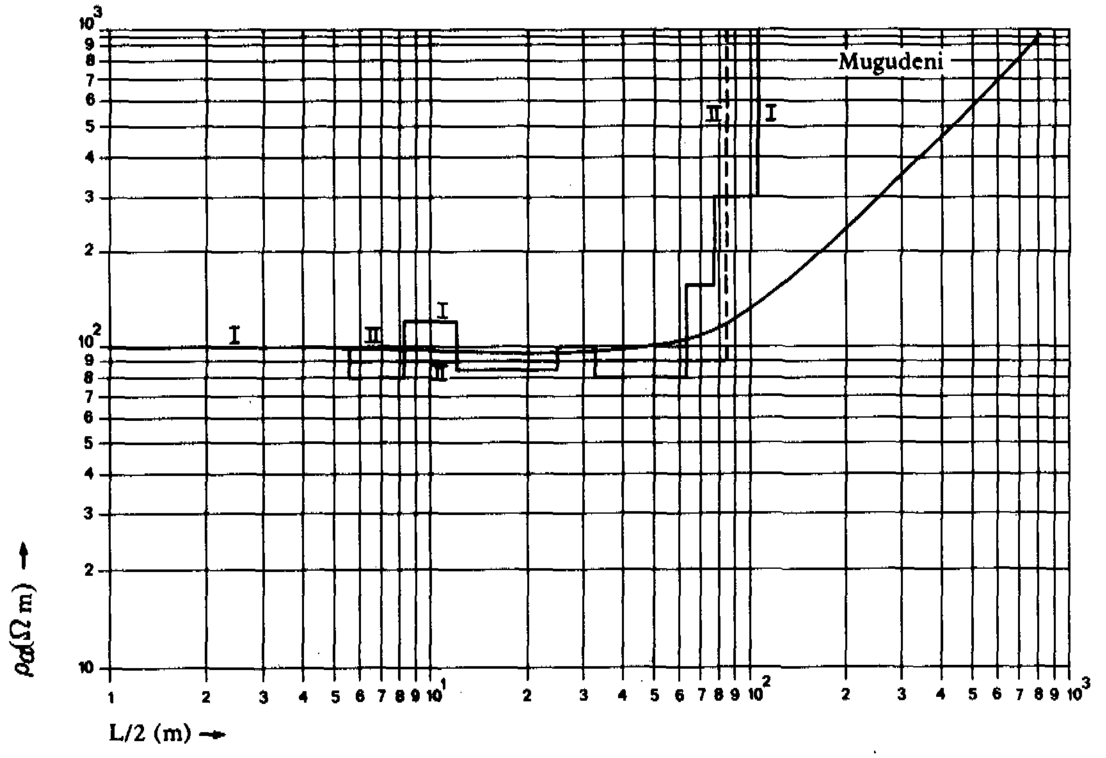


Fig. D 3.2-24 Resistivity models of bore hole 6/79 and the corresponding sounding graph

Dry clay layers occur from about 76 m down to the basement, which was found at a depth of 105 m. In the basement fresh water was struck with an EC of 60 mS/m. From the very low speed with which the water rose into the dry hole, it was concluded that the yield would be too low. The borehole was abandoned.

Final interpretation

The interpreted models of sounding 165/4-13 are well in accordance with the results of the well logs (Fig. D 3.2-23 and 24). The measured values of the layers above the basement (model I) are a little higher than the values of the models A and B, but these differences are not essential.
It corroborates that the low resistivity values deduced from the soundings signify poor prospects for fresh ground water. The occcurrence of fresh water in the weathered basement cannot be recognized from the soundings.
From the resistivity well logs and the sample descriptions it is concluded that in the lower part of the borehole resistivity values of about 30 ohmm correspond to dry clay layers.
It may be concluded that the water-bearing layer at Magole cannot be extensive.

Conclusions

The area around Mugudeni has no possibilities for the exploitation of ground water, except possibly near sounding 165/4-101.
The results obtained from this survey confirm the idea that an interpreted layer with an (average) formation resistivity less than 10 ohmm has poor prospects for good ground water.

3.2.5.8. Detail survey near Mirama

Location : Mirama
Mapsheet : 165/4
Boreholes : 4/79 and 5/79, Fig. D 3.3-9 and 10
Soundings : 165/4-12, 40, 89, 90, 91, 92, 98, 99, 100 and 103
Profile : A-A', Mugudeni-Morogoro, Fig. D 3.2. - 38
Fig. D 3.2-26. : Sounding 165/4-12 with its preliminary (model A) and its final interpretation (model B)
Fig. D 3.2-27. : Resistivity models of borehole 4/79 and the calculated sounding graph; model I is a schematic model, derived from the well logs and model II is a simplified model

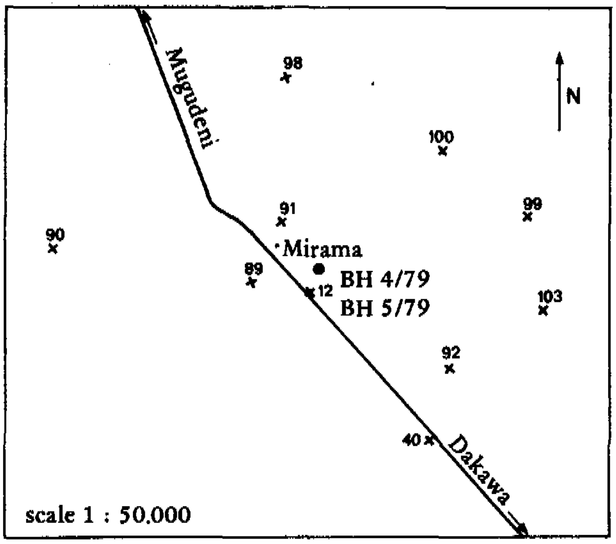


Fig. D 3.2-25 - Location map of detail survey Mirama

Preliminary interpretation

The soundings can be divided into two groups. One group, of which the locations are situated west, south and east of the village, consists of the soundings 165/4-40, 89, 90, 99, 100 and 103. The locations of the soundings belonging to the other group, including the soundings 165/4-12, 91, 92 and 98 are situated in the direct vicinity of Mirama. The interpreted models can be summarized as:

model	around Mirama (40, 89, 90, 99, 100, 103)		inside Mirama (12, 91, 92, 98)	
	depth (top) in m	resistivity in ohmm	depth (top) in m	resistivity in ohmm
toplayer	0	J 50	0	4-J100
2nd layer	F10	6- 9	F13	11- 17
basement	50-70	J100	80	J100

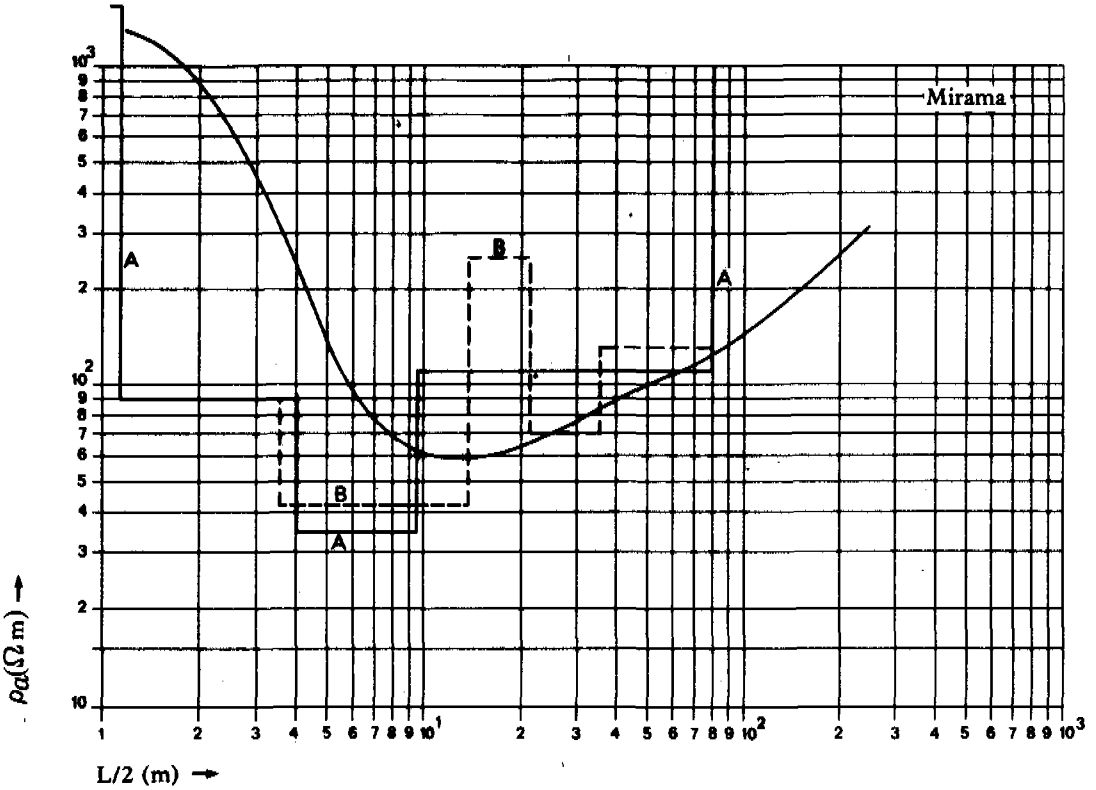


Fig. D 3.2-26 Sounding 165/4-12 with its preliminary (model A) and final interpretation (model B)

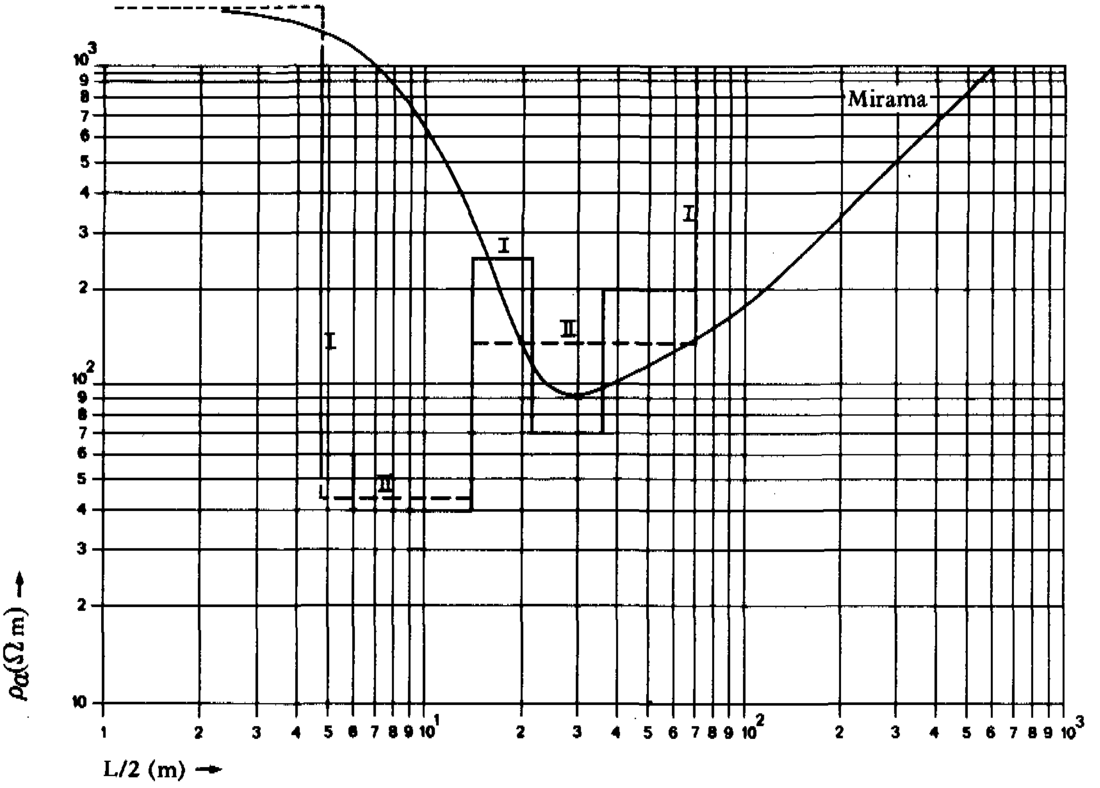


Fig. D 3.2-27 Resistivity models of bore hole 4/79 and the calculated sounding graph

The resistivity values of the first-mentioned group show poor prospects for good water. On the contrary the second layer of the soundings situated inside Mirama shows rather good prospects (cf. detail survey near Dibamba). It was concluded that Mirama was situated on a narrow strip where the formation resistivity of the second layer is of a higher value than around it.

Here too, nothing can be predicted about the water content in the weathered zone and its quality. Sounding 165/4-12 was selected as a borehole site.

Borehole

The borehole is situated at a distance of about 150 m from sounding 165/4-12. A sequence of mainly clay layers was met during drilling. From about 14 to 20 metres downwards the resistivity well logs show relatively high values. A screen was placed at this depth to check if these values stand for a water-bearing layer or not. For technical reasons however, a second shallow borehole had to be drilled (nr. 5/79). In spite of the fact that the screen was installed and developed, the well did not produce any water at all. Nevertheless, when comparing the resistivity log of this borehole with others of more succesful holes it seems quite possible that water can be produced from this layer.

Final interpretation

The resistivity models deduced from the well logs and the interpreted models of sounding 165/4-12 are well in accordance with each other (Fig. D 3.2-26 and D-27.). The layer with an average resistivity value of 11 ohmm of the preliminary interpretation (model A) takes the place of a succession of layers with resistivities which vary from 6 to 30 ohmm. In accordance with the results obtained at Dibamba, Mandela and Makuyu, it is concluded that also near Mirama an average resistivity value of 11-13 ohmm indicates fair prospects for fresh ground water (soundings 165/4-12, 91, 92 and 98).

The soundings belonging to the other group (around Mirama) do not indicate this sandy layer. Their interpretation has only been adjusted to the drilling result with the intercalation of a layer between the second layer and the bedrock.

Conclusions

Near Mirama the prospects for fresh deep ground water are rather poor. If water is found the EC will be in the order of 100 mS/m.

3.2.5.9. Detail survey near Mbwade

Location : Mbwade
Mapsheet : 182/3
Borehole : 7/79, Fig. D 3.3-11
Soundings : 182/3-24, 25, 30 (26, 27 and 31 uninterpretable)
Profile : L-L', Kilosa -Mkata, Fig. D 3.2-47
Fig. D 3.2-29. : Sounding 182/3-30 with its preliminary (model A) and its final interpretation (model B)
Fig. D 3.2-30. : Sounding 182/3-30 with its final interpretation (model B) and the resistivity model derived from the well logs 7/79.

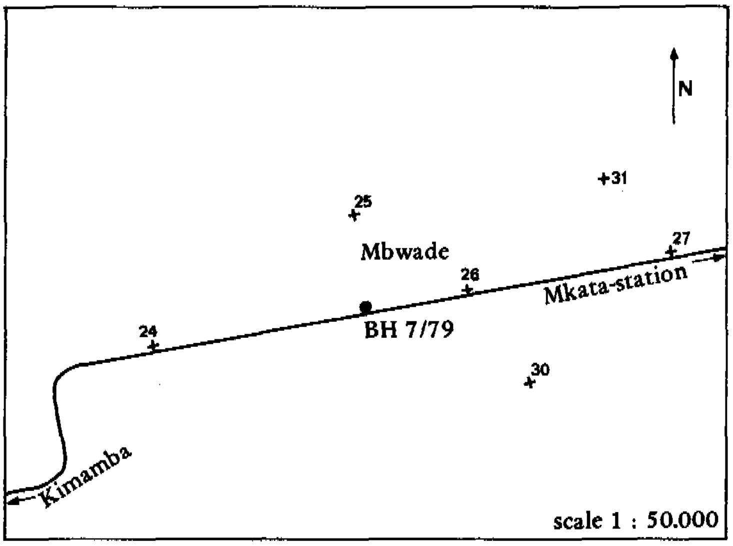


Fig. D 3.2-28 - Location map of detail survey Mbwade

Preliminary interpretation

The soundings all indicate a great depth to the basement. From ground level to about 30 m depth the resistivity amounts to 20 ohmm; from 30 to about 400 m the "average resistivity" is 10 ohmm. The drilling site was originally chosen at the location of sounding 183/3-25. This site was not accessible for the drilling rig, so a location along the road between soundings 24 and 26 was chosen.

Borehole

The drilling encountered clay beds down to 33 m depth, after which sandy layers were found down to 43 m. Again a series of clay was met down to 53 m, after which a coarse sandy layer was drilled to 59 m. Below this level one more good aquifer was found from 65 to 70 m. A screen was set from 53 to 58 m depth. The yield is good and the EC amounts to 65 mS/m.

Final interpretation

The resistivity well log yielded a rather different resistivity structure of the overburden than was assumed in the preliminary interpretation. It appeared to be difficult to reach good agreement between the resistivity borehole log and the neighbouring soundings. The final interpretation of the soundings 182/3-24, 25 and 30 resulted in a model with a clay layer between 20 and 30 metres, below which a resistivity layer of 13 ohmm is present down to a depth of 80 m, which offers fair possibilities for a production well.

At the location of the uninterpretable soundings 26, 27 and 31 shallow hand-drilled holes have been made to try and find out what caused these disturbances. At location 26 for instance two drillings were made not far from each other but on opposite sides of the centre of the sounding. These two differed so much in lithological sequence as to give an explanation for the disturbances in the sounding, viz. lateral inhomogeneity. At the other locations similar observations were made.

Conclusion

Around Mbwade the prospect to drill similar wells as no. 7/79 is considered fair. A series of thin sandy aquifers is present between 30 and 70 m depth in the area studied in detail.

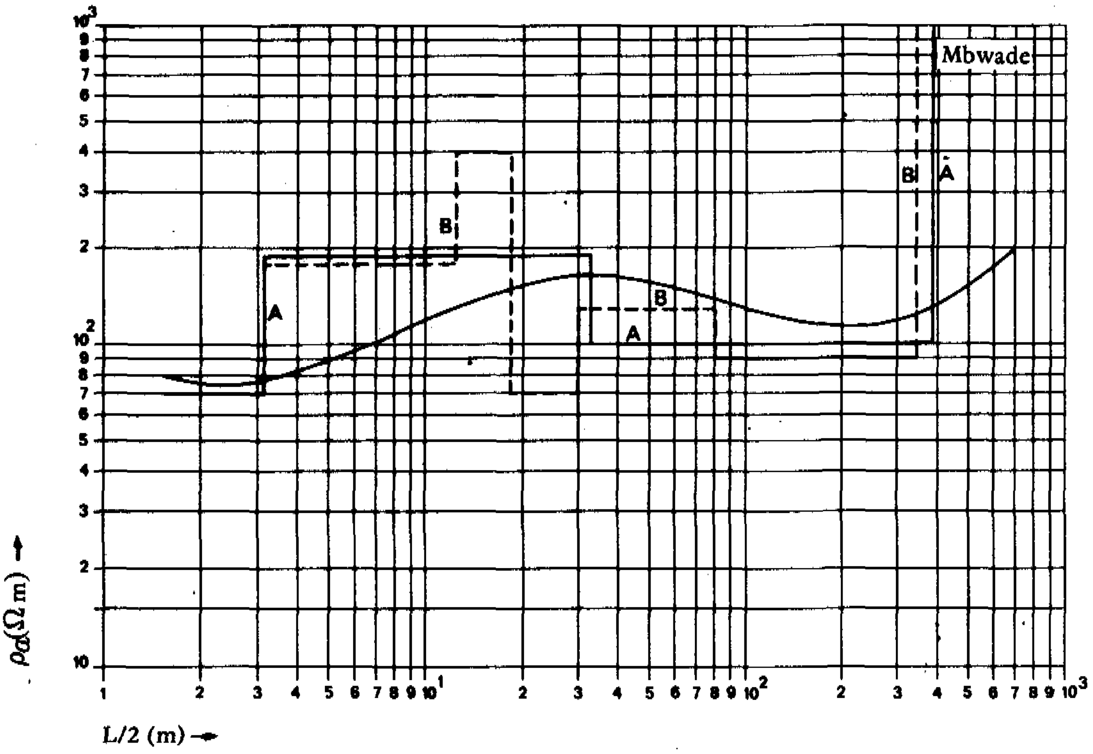


Fig. D 3.2-29 Sounding 182/3-30 with its preliminary (model A) and its final interpretation (model B)

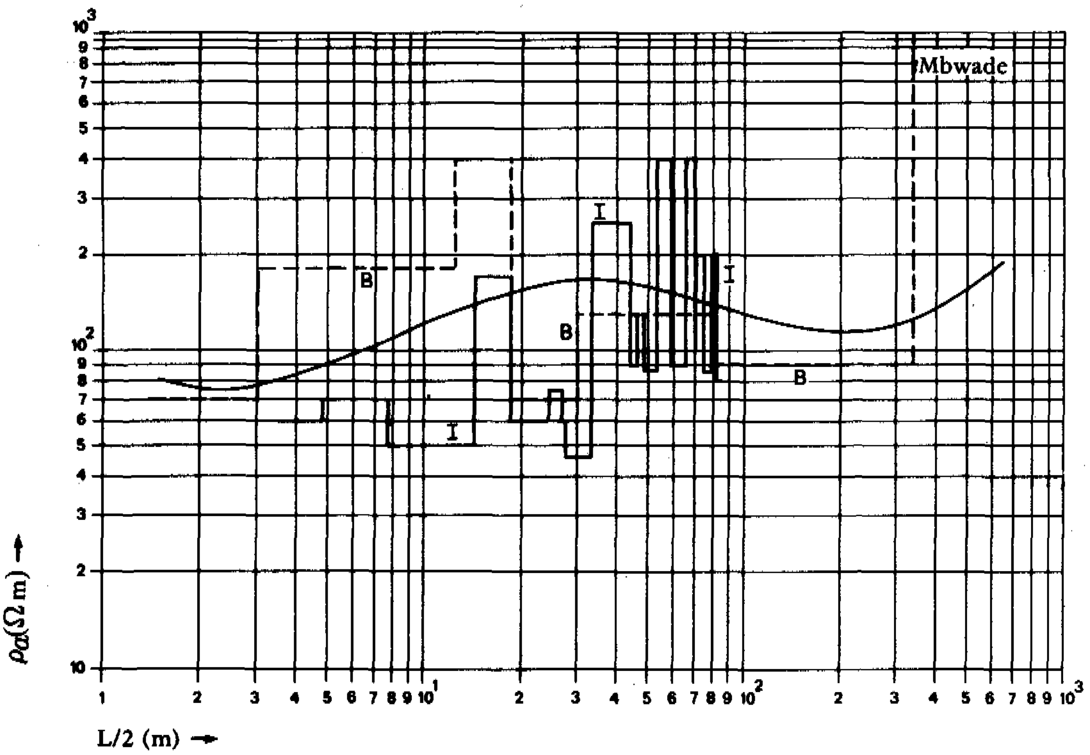


Fig. D 3.2-30 Sounding 182/3-30 with its final interpretation (model B) and the resistivity model derived from the well logs 7/79

3.2.5.10. Detail survey near Madoto

Location	: Madoto
Mapsheet	: 182/1
Boreholes	: 13/79, 24/79 and 27/79, Fig. D 3.3-12, 13 and 14
Soundings	: 182/1-22, 23, 36 and 37; 182/3-13
Profile	: K-K', Rudewa-Batini - Kimamba, Fig. D 3.2-46
Fig. D 3.2-32.	: Sounding 182/1-22 with the preliminary interpretation (model A) and the resistivity model derived from the well logs 24/79 (model I).
Fig. D 3.2-33.	: Sounding 182/1-22 with its final interpretation: two equivalent models (1 and 2).

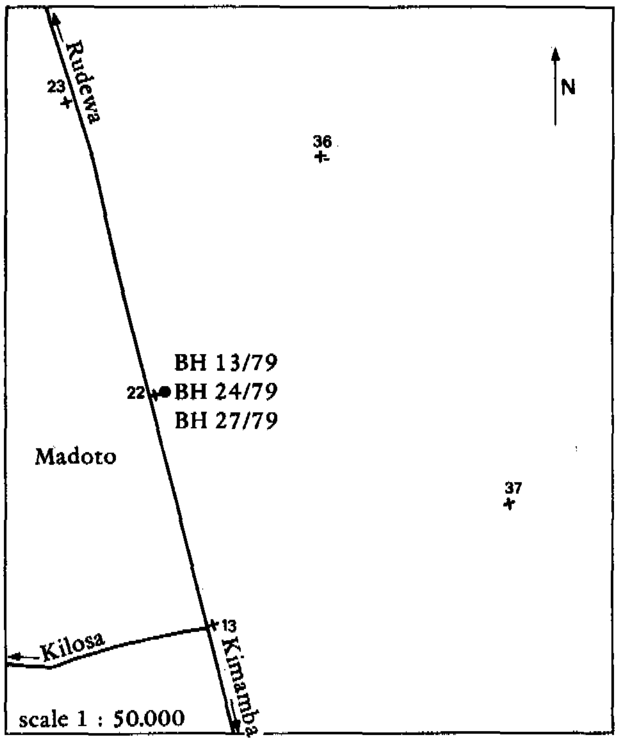


Fig. D 3.2-31 - Location map of detail survey Madoto

Preliminary interpretation

All soundings indicate a depth to the basement of about 400 m. The "average resistivity" varies between 7 and 10 ohmm. Prospects appeared not very good, but nevertheless a borehole location was chosen (at sounding 182/1-22) because near Madoto a private drilling (19/57) at a sisal estate was successful.

Borehole

The borehole was drilled very near sounding 182/1-22. Three holes had to be drilled within 20 m distance from each other due to technical difficulties. Predominantly clay beds were encountered with few sandy intercalations. Only one length of screen was installed at a depth of 23 to 28 m below surface. The EC of the ground water at this depth was 133 mS/m. The yield appeared to be very low, just sufficient for a handpump.

Final interpretation

The resistivity borehole logs are in good agreement with sounding 182/1-22 (see Fig. D 3.2-32). Although only the first 110 m of the vertical resistivity profile are known in detail from the logging, it is much easier to interpret the second part of the sounding by using these fixed data of the first part. The depth to the basement can thus be calculated to be at least 400 m. The maximum possible depth with a different equivalent solution amounts even to 650 m below surface (see Fig. D 3.2-33.).

Conclusions

Prospects in the neighbourhood of this location are rather poor. On closer inspection the existing borehole (19/57) appeared to have a low yield too.

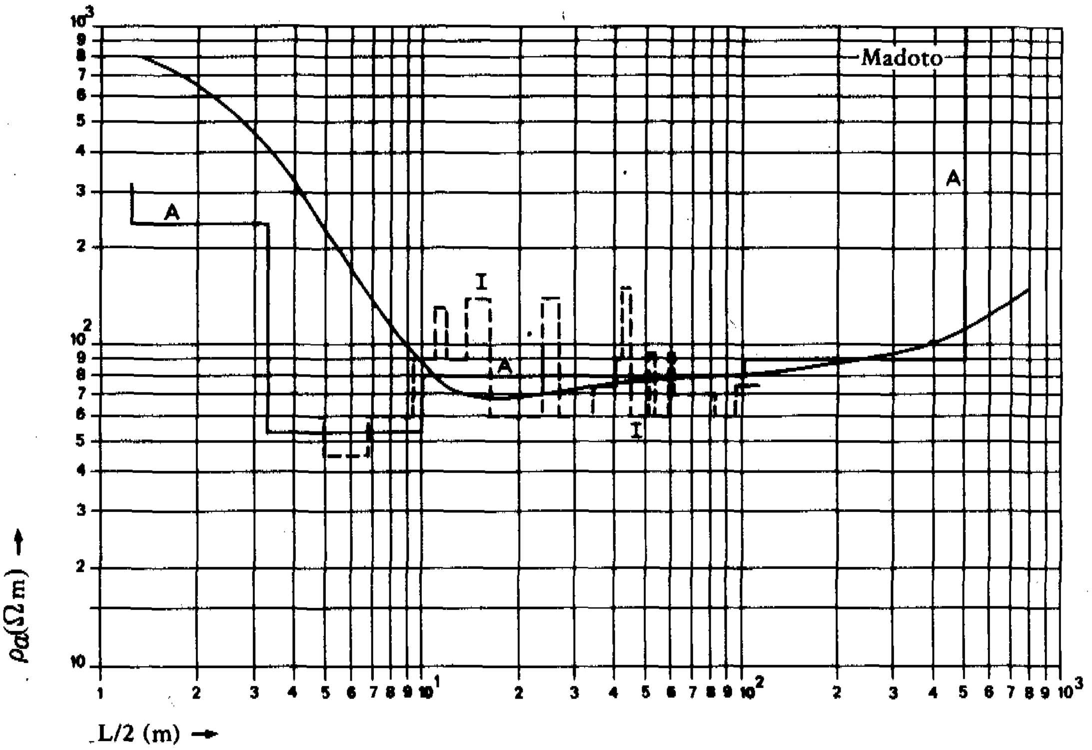


Fig. D 3.2-32 Sounding 182/1-22 with the preliminary interpretation (model A) and the resistivity model derived from the well logs 24/79 (model I)

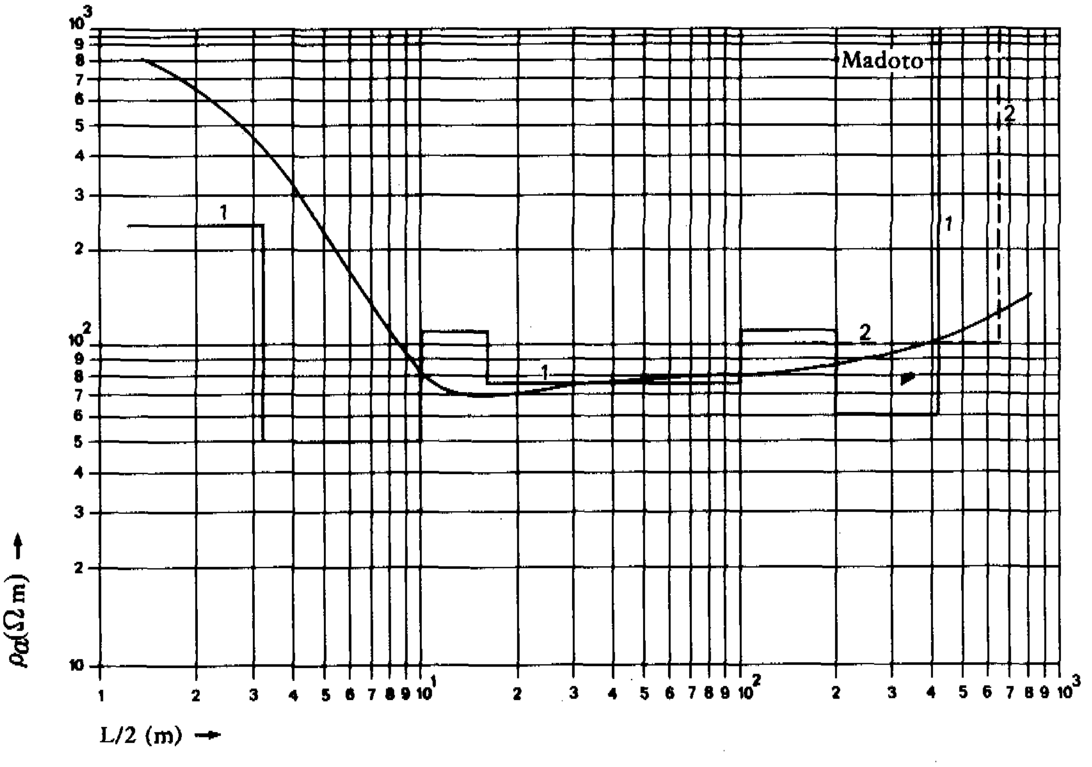


Fig. D 3.3-33 Sounding 182/1-22 with the final interpretation two equivalent models (1 and 3)

3.2.5.11. Detail survey near Rudewa-Batini

Location : Rudewa-Batini
Mapsheet : 182/1
Borehole : 28/79, Fig. D3.3-15
Soundings : 182/1-13, 14, 15 and 21
Profile : F-F', Kilosa - Kitete; K-K', Rudewa-Batini -Kimamba, Fig. D 3.2-43 and 46
Fig. D 3.2-35 : Sounding 182/1-13 and the resistivity model derived from the well logs 28/79

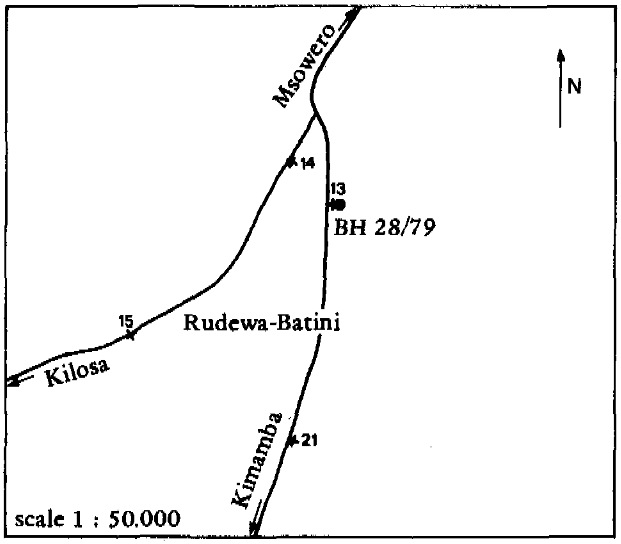


Fig. D 3.2-34 - Location map of detail survey Rudewa-Batini

Preliminary interpretation

All soundings, except no. 15, are very irregular, probably due to lateral inhomogeneities. It can be seen, however, that the resistivities of the upper part of the overburden are high enough to make this a prospective location. Because interpretation was impossible, except of sounding no. 15, which is located rather far from the village, the drilling location was chosen in the middle of the village, near the location of sounding no. 13.

Borehole

The first 15 metres the borehole encountered fine sands and clays, next a coarse sand and gravel series down to 26 m depth, and subsequently clays down to 50 m depth. A screen was installed in the coarse sand. The EC amounts to 23 mS/m; the yield is very high.

Final interpretation

As mentioned before most of the curves were uninterpretable. The final interpretation of sounding 15 did not have to be adapted.

Conclusion

Because the soundings in this area are useless, no prognosis can be made for the neighbourhood of this location. The village, however, is very near the place where the river Wami enters the Mkata-Wami Basin. Considerable flood fans are expected to be present. When new boreholes are planned in this area, it is recommended first to investigate the most suitable location by means of resistivity profiles and a few soundings, because lateral wedging out of the sand channels is very probable.

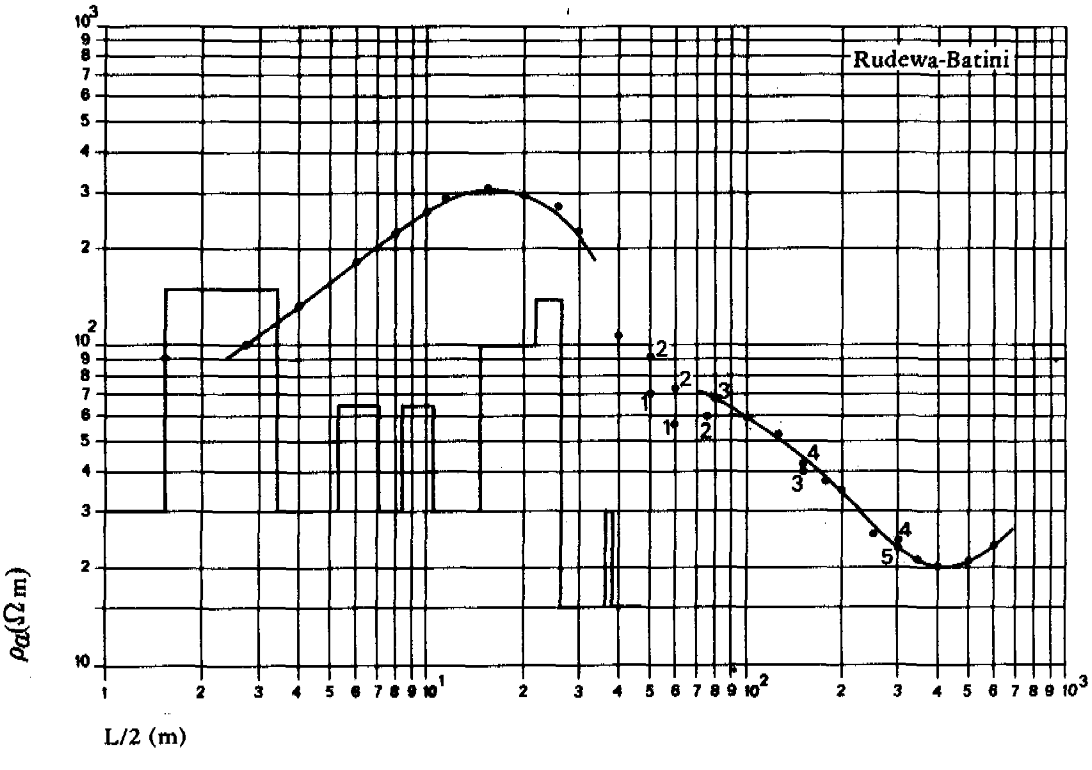


Fig. D 3.2-35 Sounding 182/1-13 and the resistivity model derived from the well logs 28/79

3.2.5.12. Detail survey near Kondoa

Location : Kondoa
Mapsheet : 182/3
Boreholes : 37/79 and 41/79, Fig. D 3.3-16. and 17.
Soundings : 182/3-2, 3, 8, 44, 49 and 54
Profile : L-L', Kilosa - Mkata Station, Fig. D 3.2-47
Fig. D 3.2-37. : Sounding 182/3-49 with its preliminary interpretation (model A) and the resistivity model derived from the well logs 37/79 (model I).

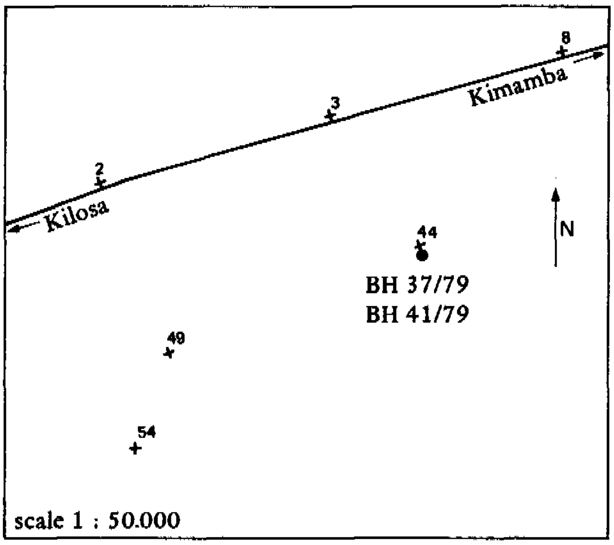


Fig. D 3.2-36 - Location map of detail survey Kondoa

Preliminary interpretation

The preliminary interpretation of the soundings can be summarized as:

model	north (2, 3, 8)		south (44, 49, 54)	
	depth (top) in m	resistivity in ohmm	depth (top) in m	resistivity in ohmm
toplayer	0	5- 10	0	140-500
2nd layer	15-23	15- 20*	3- 7	17- 27
3rd layer	34-37	7,5	-	-
basement	70-75	J100	75-180	J100

* except no. 8

Prospective layers are the 2nd layer at soundings 2 and 3 with 15-20 ohmm, and the 2nd layer of the soundings 44, 49 and 54. The drillhole location was first proposed at 182/3-54 or 49 but appeared impossible to reach with the drilling rig, after which the location of sounding no. 44 was selected.

Borehole

In the borehole clays and clayey sands were encountered down to 18 m depth, from 18 down to 24 m coarse sand was found. Down to 40 m below it a clayey series and from 40 to 45 a second aquifer with coarse sand were met. To final depth loamy clay and dry red sandy clay were drilled through. Due to technical difficulties a second borehole had to be drilled. In this hole a screen was installed from 18-23 m. The EC amounts to 55 mS/m. The yield is satisfactory.

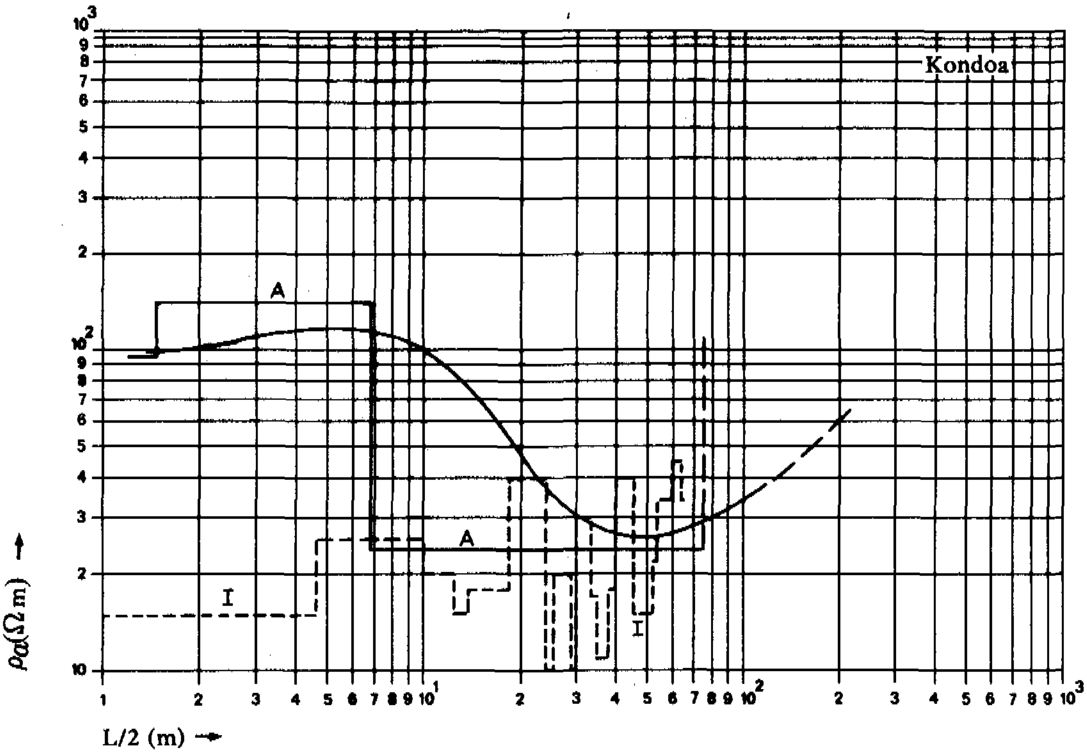


Fig. D 3.2-37 Sounding 182/3-49 with the preliminary interpretation (model A) and the resistivity model derived from the well logs 37/39 (model I)

Final interpretation

Apart from the first ten metres the resistivity log of borehole 37/79 correlates well with the "average resistivity" of 25 ohmm of the soundings. Adaption of the interpretation was not attempted, because the relative thickness of the aquifer is too small.

The last part of soundings 44, 49 and 54 is rather irregular. The interpreted depth to the basement amounts to 140 and 180 m at soundings 44 and 54 and only 75 m at no. 49. The latter depth is comparable with others in the neighbourhood. The irregular nature of the soundings, probably due to lateral inhomogeneities, and the lack of further information makes it impossible yet to give an explanation for this discrepancy.

Conclusion

The area around Kondoa can be qualified as very good for ground water exploitation (soundings 44, 49 and 54). Further north possibilities are less promising. The shallow layer present at soundings 2 and 3 at a depth of 20-35 m might represent a prospective aquifer.

3.2.6. Hydrogeological description of the geo-electrical profiles

3.2.6.1. Introduction

Additional knowledge on the hydrogeological structure of the Mkata-Wami Basin has been obtained through ten geo-electrical profiles across the basin. Care was taken that as many existing and new boreholes as possible were included.

The topography of the profiles is based on the available 1:50000 topographical maps on which 20 metre contours have been indicated. The geo-electrical soundings with their interpretations are represented in Data DD 7. The legend to the profiles is given in fig. D 3.2-48.

The following profiles are given:

- profile A-A': Mugudeni - Morogoro
- profile B-B': Dihombo - Dakawa
- profile C-C': Makuyu - Mabana
- profile D-D': Madudu - Mfulu
- profile E-E': Kitete - Dihomba
- profile F-F': Kilosa - Kitete
- profile G-G': Kisangata - Wami River
- profile H-H': Rudewa Gongoni - Wami Valley
- profile K-K': Rudewa Batini - Kimamba
- profile L-L': Kilosa - Mkata Station

In general the soundings were interpreted according to the simplest model possible; layers of these models usually include several actual layers. Therefore each interpreted layer has an "average formation resistivity".
For a description of the limitations of the geo-electrical method, the criteria for the interpretation of the soundings and for the explanation of conceptions such as "average formation resistivity" and "equivalent models" the reader is referred to sub-par. 3.2.3. The relation between the formation resistivity and the hydrogeology was discussed in sub-par. 3.2.4.2.

In the profiles the resistivity values of more than 100 ohmm of the basis layer were correlated to bedrock. A transition zone might exist where the bedrock is fissured and slightly weathered. The resistivity of this zone is intermediate between that of the overburden and the very high resistivity of the fresh bedrock, and will not be noticed in the soundings due to "suppression".
In some parts of the Mkata-Wami Basin above the bedrock dry clayey layers with much coarse gravel were encountered while drilling.
In fact these layers are zones of completely decomposed bedrock. According to the well logs its resistivity varies between 20 and 100 ohmm.
In most cases these layers do not contain water, but even if they do, they are not of much interest because the yield is very low or nil.

The best possibilities for ground water extraction are found where resistivity layers with "average" values of 10-30 ohmm are met at intermediate depths of 15-50 m below surface. The uppermost part of the profiles is in general clayey or dry sand. Below the aquiferous zone the zone of decomposed bedrock mentioned earlier is found.

3.2.6.2. Profile A-A': Mugudeni-Morogoro, fig. D 3.2-38

This profile starts in the Nguru Mountains in the North, crosses the Wami valley, the Mindu Mountains, the Ngerengere valley and ends against the Uluguru Mountains in the South.

In the extreme northern part of the Mkata-Wami Basin a deep trough is found where the depth to the bedrock exceeds 200 metres. This trough continues westward and is recognized very clearly in profile C-C' (3.2.6.4.). The average formation resistivity in the trough of 16 ohmm indicates good prospects for water-bearing layers with fresh ground water in the upper part of the overburden. Also at sounding 165/4-101 the overburden down to 50 m depth offers good prospects.

In the area from Mugudeni to Dakawa the bedrock is situated at about 320 m above MSL. Here the prospects of finding fresh water are poor. From the two boreholes 6/79 and 4/79, drilled during the project, it is clear that in this part of the profile the resistivity values of about 15 ohmm, which are encountered above the (fissured) bedrock, mean dry clayey layers, in fact strongly weathered bedrock (see 3.2.6.1.). Only at Mirama a sand layer with fresh water can probably be encountered from about 13 to 20 m (see sub-par. 3.2.5.8.). It is learnt from the boreholes 18/63 and 2/63 that some waterbearing layers may be encountered but their water is saline (EC = 275 mS/m).

In the lowest part of the Wami Valley, near Dakawa, high resistivity values were interpreted from the soundings, which correspond well with the resistivity well-logs from borehole 135A/78 (see 3.2.5.3.). In the upper part of the subsoil these high resistivity layers represent water-bearing layers with fresh water (EC = 22 mS/m). These coarse water-bearing layers are river sediments deposited by the Wami River.
In the lower part, however, dry clayey layers are again present, which have the same resistivity values. The water in the fissured bedrock, of which a sample was taken in borehole 135B/78, appeared to be fresh (EC = 32 mS/m).

The Mkata-Wami Basin southwards of sounding 166/3-36 is bounded by a fault. On the south bank of the Wami River a few kilometres of Luhindo the bedrock crops out. The soundings near Luhindo show rather high (20-60 ohmm) formation resistivities. According to the results of borehole 131/78 they have to be correlated here with dry clayey layers (sub-par. 3.2.5.2.). Just above the bedrock saline water with an EC of 800 mS/m was found. In a shallow topographical depression south of Luhindo very low resistivities are met. Hand drillings here struck water with an EC of 2000 mS/m.

Climbing up to the Mindu Mountains, formation resistivities of 30 to 50 ohmm are met under a shallow toplayer. These resistivities are interpreted as strongly weathered bedrock. Little can be said about the water content and water quality, but the possibility to strike water by means of a borehole is considered very small.

In the Ngerengere Valley too very low resistivities are found. In this valley a special study was carried out (see DA 4); the EC of the ground water varies from 190 to 1000 mS/m. In Morogoro the bedrock lies at shallow depth with a water conductivity of about 800 mS/m. South of Morogoro a shallow basin occurs which also contains saline water according to the low resistivity values.

3.2.6.3. Profile B-B': Dihombo-Dakawa, fig. D 3.2-39

This profile crosses the Wami valley between Dihombo and Dakawa. No villages are present in between.

The basin is bounded in the north by the Wami Rift Fault. In this part the greatest depth to the basement is found. Elsewhere the surface of the bedrock is slightly undulating. Its elevation is in good agreement with the results of profile A-A', and also with the data of the boreholes 56/69 and 58/69, situated about 2 km east of the profile.

'In the greater part of the profile low resistivities are encountered. So the prospects for potable ground water are thus poor. The conductivity of the water from boreholes 56/69 and 58/69 is rather high (EC = 210 and 205 mS/m. The resistivity of the layer above the bedrock in the northern part of the profile ranges from 12 to 17 ohmm, probably representing dry clayey layers. Only where this resistivity is met in the upper part of the overburden the prospect is better, as in the case of sounding 29. The situation at the soundings 7, 8 and 10, of which the last part of the sounding graph is irregular and uninterpretable, is worth investigating further in case water is needed in this area. The situation near Dakawa is described in detail in subpar. 3.2.5.3.

3.2.6.4. Profile C-C': Makuyu-Mabana, fig. D 3.2-40

This profile runs from the escarpment on the north-western borders of the valley southwards to the Mkundi River. Near Makuyu a deep trough is present with a depth of 200 m to the basement. The possibilities of exploiting ground water are great here, as confirmed by borehole 173/78. Coarse sandy aquifers are present representing buried river channels. Recharge of the aquifers seems to be good as shown by the fluctuation of the water levels during the last wet season (see Table D 4.2-9). Between 100 and 200 m depth no information from boreholes is available. The possibility to find suitable ground water at this level is considered much lower. Probably clayey deposits and weathered bedrock will be found here.

South of the second fault bordering the southern rim of the graben, the borehole near Mandela was sunk. Here too a good aquifer is present. The extent is limited, however (see sub-par. 3.2.5.5.). Towards the South the resistivities indicate few possibilities of exploiting acceptable ground water. One exception is seen at sounding 165/4-87 where the formation resistivity amounts to 18 ohmm. It remains rather hazardous, however, to drill a borehole at this location without additional investigations, because this higher formation resistivity was only observed at one sounding.

3.2.6.5. Profile D-D': Madudu-Mfulu, fig. D 3.2-41

A short profile was measured along Madudu and Mfulu. Sounding 165/4-71 is situated near the north-western rift fault of the Mkata-Wami Basin. The basement is found at a fairly constant level of 340-350 m above MSL, or 130 to 80 m below ground level. Except for the surface layers, the resistivities are ranging from 6 to 8 ohmm, which indicates poor prospects for ground water.

Clayey deposits and saline water will be found here. Only sounding 67 is anomalous. It was interpreted with a resistivity of 15 ohmm for the deepest part of the overburden. Information from boreholes elsewhere in the basin indicates dry clayey layers. At soundings 68, 69 and 74 a shallow resistivity layer of 12-16 ohmm is present with a thickness of 10-15 m. This location could be worth investigating for the shallow to medium depth wells programme.

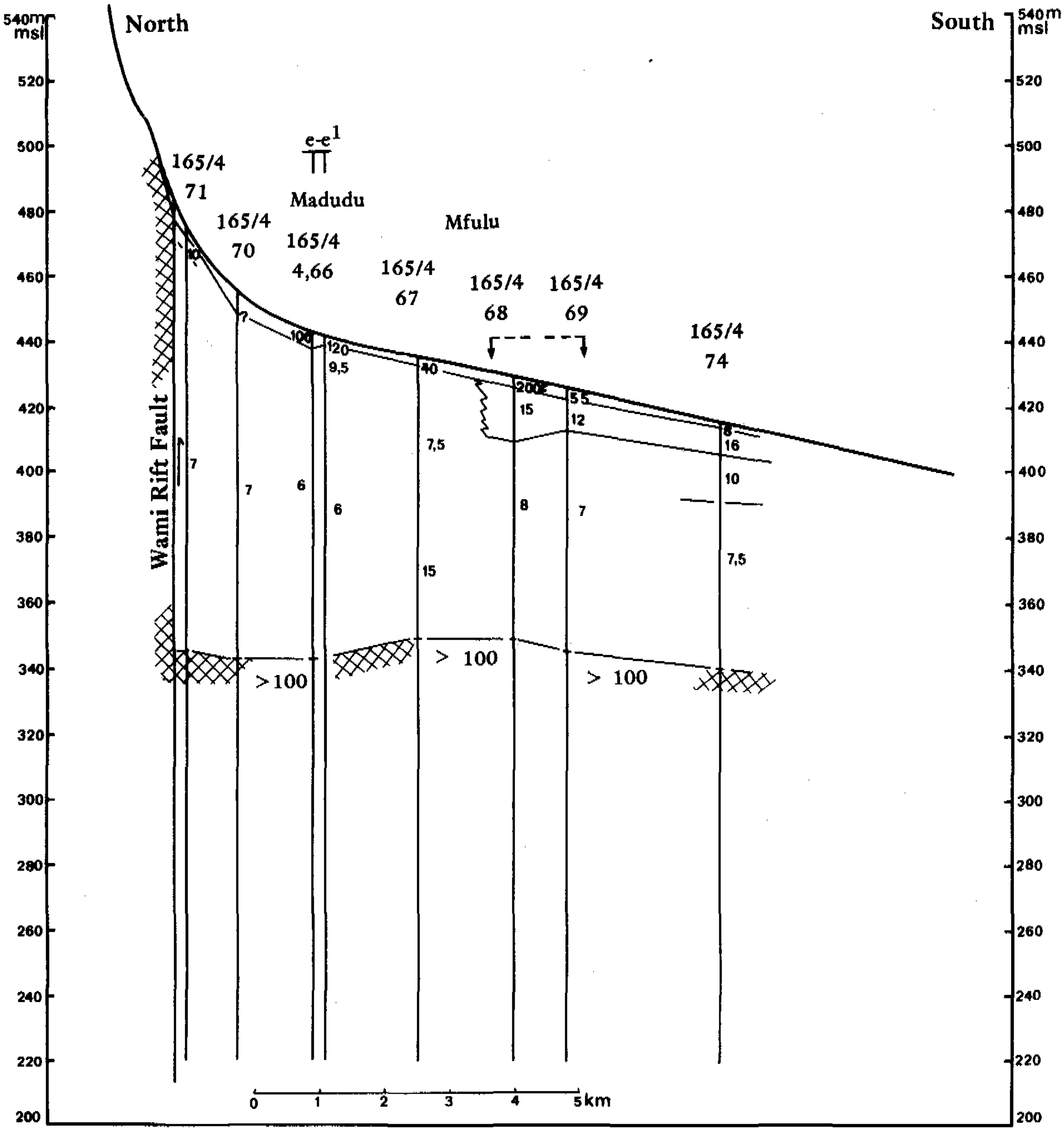


Fig. D 3.2-41 Profile D-D^1 : Madudu-Mfulu

3.2.6.6. Profile E-E': Kitete-Dihombo, fig. D 3.2-42

This profile runs SW-NE in the length direction of the Mkata-Wami Basin, near the Wami Rift Fault.

For the greater part the basement is found at a fairly constant level of 320-340 m above MSL. Only between Dibamba and Dihombo much greater depths are determined. The tectonic structure is probably much more complicated than is represented here in profiles and maps. Detailed investigations will be needed to clarify the structure of this area.

In the south-western part the resistivities of the overburden are not very promising. Around 10 ohmm for the lowest part and even lower, 5-8 ohmm for the upper part. Nevertheless in a number of boreholes recently drilled by Maji-Morogoro fresh water was found. It has to be stated here again that the geo-electrical method is restricted (see sub-par. 3.2.3.). It is increasingly difficult to detect thin layers with increasing depth and even more difficult if the resistivity of these layers does not strongly contrast with those of the neighbouring layers. The latter is the case with the boreholes at Kitete (see fig. D 3.2-8) and Dumila, where fresh water with a rather high EC was found in relatively thin water -bearing layers. So the conclusion for this part of the profile is, that the prospects are poor, but that it is possible to tap thin aquifers and extract small quantities of ground water.
If so, the drillings should be executed near soundings 165/4-28, 29 or 30.

The situation near Magole was discussed in par. 3.2.3.4. as an example of the "principle of equivalence". Not much information was obtained from this borehole. The interpretation of sounding 165/4-34 (fig. D 3.2-9) makes clear, however, that by taking into account the EC-value of 72 mS/m, the thickness cannot be very great and so the yield must be fairly low.

The interpretation of the soundings near Mandela was discussed in par. 3.2.5.5. Possibilities are good in this rather restricted part of the profile.

Further north-eastwards from Mugudeni to Mvomero the prospects are very poor (see sub-par. 3.2.5.4. and 7). North of the assumed fault between the soundings 24 and 25 a small area offers better opportunities. It concerns the area near the soundings 25, 59 and 26, where the resistivity down to a great depth is relatively high. At sounding 42 the resistivity drops again below 10 and the prospects become poorer. Over a distance of about 5 km no soundings could be made. The last stretch of the profile, however, is interesting because a gradual rise of the basement can be followed and the resistivities of the overburden indicate fair prospects for ground water exploitation.

3.2.6.7. Profile F-F': Kilosa-Kitete, fig. D 3.2-43

This profile runs along the road from Kilosa to Kitete, near the escarpment to the north-east and crosses the rift fault several times.

Thus the level of the basement is strongly determined by the position of the profile, east or west of the fault. Going from Msowero to the southwest the offset of the main fault, the Wami Rift Fault, is very large. The basement is found at a depth of 300 to 400 m below surface, or below 200 m above MSL. The Wami Rift Fault runs from Rudewa approximately southwards and no longer parallel to the profile (see map D 3). A branch of smaller importance, the Ilonga Fault, runs still parallel with the profile towards Kilosa. On the eastern side of this fault the basement is found in general at about 100 m below surface, or at about 350 m above MSL.
Near Msowero the offset of the Wami Rift Fault is gradually diminishing. The depth to the basement going north-east from Msowero varies between 140 and 80 m; the level being at about 340 m above MSL. Along all trajects where the profile runs on the upthrown side of the faults the basement is found at shallow depth.

In all deep troughs up to Msowero the resistivities indicate that prospects for fresh ground water are good as demonstrated by borehole Rudewa-Batini 28/79 (see sub-par. 3.2.5.11.). This holds not only for the troughs in the profile but also for a zone several kilometres wide and parallel with the profile, where the basement is found at great depth (see map D 3, and profiles G-G' and H-H'). In the shallower troughs along the Ilonga Fault the prospects in the southern part near Kilosa are good. Near Msimba the prospect is fair.

Near Msowero at soundings 182/1-5 and 6 the possibilities are small; on the north-eastern side at soundings 182/1-3 a fair prospect for drinking water exists. Further along the profile towards Kitete prospects are poor, except maybe the layer at a depth of 10 to 30 m at soundings 165/4-46, 47 and 48, which offers a fair prospects, see also profile E-E'.

3.2.6.8. Profile G-G': Kisangata-Wami River, fig. D 3.2-44

This profile runs from Kisangata southwards to the Wami River. It illustrates the situation in the immediate vicinity of the Wami Rift Fault. The basement is situated at great depth (below 200 m above MSL).

In the upper part of the overburden at soundings 182/1-26 and 35 a layer is present at a depth of 10-50 m with resistivities of 20-25 ohmm, where prospects for ground water are considered good.

3.2.6.9. Profile H-H': Rudewa/Gongoni-Wami valley, fig. D 3.2-45

This profile runs east from Rudewa-Gongoni and passes the Wami Rift Fault, which splits up here in two separate branches. The basement goes down stepwise from 20 m, via 100 m, to 300-400 m below surface.

Prospects for ground water exploitation are considered fair at sounding 182/1-39 and 34. Prospects are good at soundings 182/1-26 and 40 in the upper 50 m of the overburden.

3.2.6.10. Profile K-K': Rudewa Batini-Kimamba, fig. D 3.2-46

This profile runs from Rudewa-Batini southwards along Kimamba.
Along the whole length the basement is situated at great depth, on the average at 400 m below surface, which means almost at sea-level (MSL) (see subpar. 3.2.5.10.).

The sedimentary fill of the graben consists mainly of clays, clayey sands and a few sandy layers. Only near the Wami Rift Fault thicker coarse sandy layers are present (see 3.2.5.11.).

The resistivities indicate good prospects near Rudewa, much poorer prospects near Madoto, and rather good prospects again around Kimamba to exploit ground water of acceptable quality.

3.2.6.11. Profile L-L': Kilosa-Mkata Station, fig. D 3.2-47

This profile runs west-east across the southern part of the Mkata-Wami Basin from Kilosa to Mkata Station.

In the central part near Kimamba the basement is found at great depth, 300 to 400 m below surface (see also sub-par. 3.2.5.10.). On the western side two faults are present. The Ilonga Fault near Kilosa, where the basement from near surface descends to about 100 metres below surface. The second, the Wami Rift Faults has a much greater offset. Near Chanzuru the basement is found at more than 300 m below surface. Eastwards, from Mbwade onwards, the basement gradually rises: at sounding 182/3-29 300 m below surface, at No. 33 it is 250 m, at No. 182/4-3 to 6 it amounts to 200 m. Near Mkata it rises, probably along one or two faults, quickly to the surface.

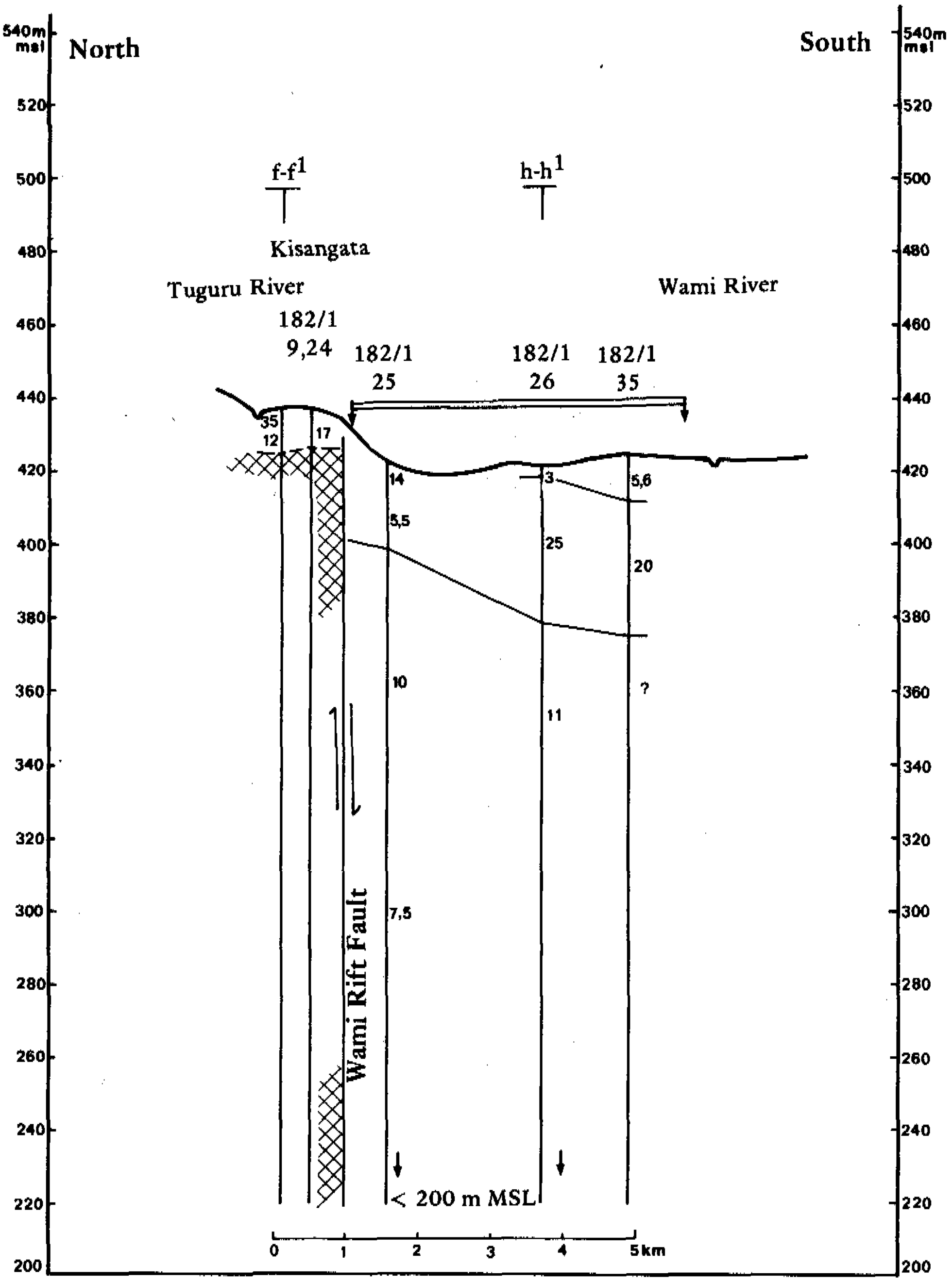


Fig. D 3.2-44 Profile G-G^1 : Kisangata-Wami River

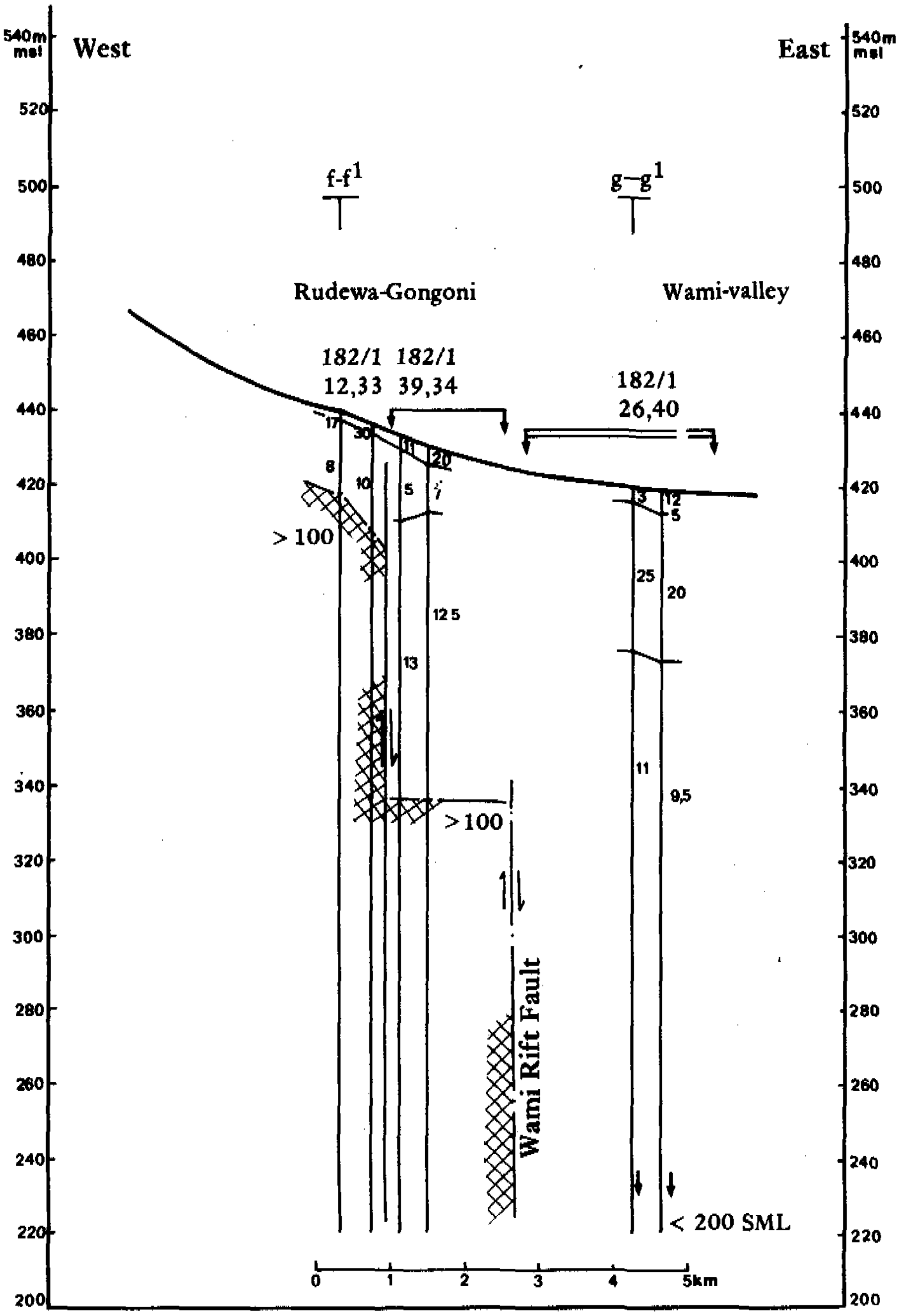
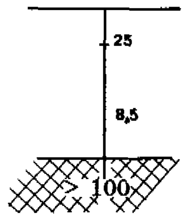
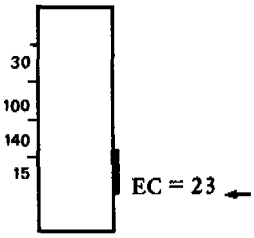
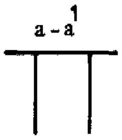
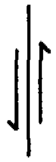
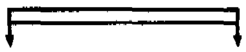


Fig. D 3.2-45 Profile H-H^{1} : Rudewa Gongoni-Wami Valley

Fig. D 3.2-48 Legend to the geo-electrical profiles

Lithologic legend: see fig. D 3.3-18

$\frac{182/3}{7}$	location of geo-electrical sounding nr. 7 on mapsheet 182/3
	resistivity of toplayer in 25 Ω m, of the second layer 8,5 Ω m and of the bedrock > 100 Ω m bedrock
BH 28/79	location of borehole 28/79
	30, 100, 140, 15 = resistivity values derived from well logs position of screen
EC = 23	Electrical Conductivity of groundwater as 23 m s/m (1 m s/m = 10 μs/m = 10 μ mhos/cm)
'BH 58/69'	location of borehole (or sounding) is shifted
	crossing with profile A-A'
A-9	handdrilling
MSL	mean sea level
	fault
	good prospects for groundwater
	fair prospects for groundwater

The resistivities of the alluvial deposits in the basin indicate a zone with good prospects near Kondoa with several coarse sandy intercalations (see also sub-par. 3.2.5.12.). A borehole near Chanzuru shows that the number and thickness of the sandy aquifers are less. Here in the deeper part of the basin a water-bearing layer is met at a larger depth. This is in agreement with sounding 182/3-9, which gives an average formation resistivity of 12 ohmm for the deeper part. At soundings 182/3-10 and 11 prospects are much poorer according to the low resistivities.
At Kimamba prospects for ground water are considered fair as demonstrated by several boreholes. Near Mbwade a layer with an average formation resistivity of 13 ohmm between 30 and 80 m below surface, consisting of a sequence of sandy layers, offers fair prospects (see 3.2.5.9.). This layer can be traced eastwards, but becomes thinner near soundings 182/4-1 and 2. At soundings 182/4-3, 6 and 7, and at greater depth at soundings 4 and 5, the resistivities of the third layer in the range of 12 to 14 ohmm probably offer fair prospects in the upper part. The lower part of this layer is considered to consist of decomposed and weathered bedrock.

3.2.7. Approach to locate new borehole sites

Based on the experience gained during this project a scheme will be presented to locate a borehole near a village in the Mkata-Wami Basin in the most efficient way. The knowledge obtained concerns the hydrogeological structure of the basin presented in the profiles and on map D 3 and the relation between the hydrogeology and the formation resistivities, dealt with in sub-par. 3.2.4.
The proposed procedure is as follows:

- First map D 3 and the profiles have to be consulted to study the hydrogeological structure and the prospects for deep ground water near the village where a borehole has to be drilled.
- Then the neighbouring soundings (Data DD 7) have to be looked at to become familiar with the shapes of the curves and with the average resistivity values which occur in that area. These values are directly related to the prospects (see Table D 3.2-4).
- During the next step about ten soundings have to be executed around the village in a regular network, as done in the detail surveys.
- After that the soundings have to be interpreted, taking into account that the soundings have to be mutually correlated. From the interpreted structure and average resistivity values conclusions have to be drawn.

At this phase there may be various possibilities.

a. The situation is clear; either the best location for a drilling can be selected or there are no possibilities to drill a good borehole.
b. The situation is not quite clear yet and only some additional soundings have to be executed to elucidate the situation.

c. The situation is very complicated: with the exception of just one or two soundings all the soundings show poor prospects and/or the sounding graphs are distorted and therefore uninterpretable but they indicate some prospects in a qualitative sense. This situation may occur when the aquifer has a restricted extent such as buried old riverbeds which are very prospective for ground water exploitation. This distortion of the curves is caused in these cases by strongly lateral changes in the lithology, see sub-par. 3.2.3.
To determine the location of such channels the method of horizontal profiling is very useful. This method is mentioned in many handbooks (p.e. Zohdy et al, 1974) and is explained in short below. In the detail surveys near Mandela and Ruweda-Batini (sub-par. 3.2.5.5. and 3.2.5.11.) such a situation was found as well. Unfortunately due to lack of time no horizontal profiling programme could be carried out during this project.

Horizontal profiling programme

In a horizontal profiling programme a fixed electrode spacing is chosen, based on the neighbouring soundings, and the whole electrode array is moved along a profile after each measurement. In this way several profiles are made parallel to each other. The value of the apparent resistivity is plotted at the geometric centre of the electrode array. Maximum apparent resistivity anomalies are obtained by orientating the profiles at right angles to the (expected) alignment of the channel.
The results are presented as apparent resistivity profiles or apparent resistivity maps, or both. In executing resistivity profiles it is recommended that at least two different electrode spacings are used, as a means to distinguish the effects of shallow lateral inhomogeneities from the effects of deeper ones, which are looked for.
The spacing between the current electrodes has to be chosen in such a way that the differences between the different types of stratification are most clearly expressed. In a horizontal profiling near Mandela the spacing should amount to L/2 = 10 and 50 m; in a horizontal profiling near Rudewa-Batini it is less clear, but here too these values are recommended. The spacing between each measurement along a profile and between the profiles depends on the extent of the aquifer. To start with, it is suggested to take a spacing of 100 metres between the midpoints of the array along the first profile. After finishing this run it has to be decided if and how many measurements have to be executed in between. For the following profiles the same spacing should be used. For the spacing between the successive profiles a distance of 200 to 300 m is suggested.

3.3. Deep well drilling

3.3.1. Selection of location

Drilling started in and remained mainly restricted to the western part of the Mkata-Wami Basin. Available geological information and recently carried out MDWSP geo-electrical soundings, have indicated that in this area the basement complex is down-faulted and is covered with unconsolidated sediments of an average thickness between 40 and 120 m, but locally exceeding 200 m. Ground water occurs in fluviatile, lacustrine and swamp deposits, which have accumulated in the basin since the late Tertiary.

The drilling of boreholes in areas other than the western part of Mkata-Wami Basin has not been taken into consideration since hydrogeological as well geo-electrical investigations indicated that no promising fresh water-bearing formations at greater depths, are present.

On the basis of the hydrogeological and hydrological surveys as well as of the results of the hand-drilling programme, the western part of the Mkata-Wami Basin has been divided into a number of distinct (inbabited) sub-areas with different hydrogeological and hydrological characteristics.

In the areas thought suitable for deep well drilling, the possibilities for water supply by means of gravity as well as by shallow wells have been considered. To this end the villages in these areas have been listed and their existing water supply and possibilities for improvement have been studied.

The information gained was related to the criteria mentioned in sub-par. 2.3.3., resulting in a list of villages where the location of boreholes for the improvement of the water supply was thought desirable and possible. These villages are:

Lihindo
Dakawa
Dibamba
Mandela
Makuyu
Mirama
Mbwade
Madoto
Rudewa Gongoni
Rudasa Batini
Msowero
Madudu
Nigugu
Mhundi
Kidudwe Ujamaa
Kondoa

For exploratory reasons, explained in sub-par. 3.2.5.7. it was thought necessary to drill a borehole in Mugudeni.

A detailed geo-electrical survey was carried out in and around the above-mentioned villages to determine the exact locations for the boreholes.

3.3.2. Aspects of well drilling and design

3.3.2.1. Drilling

For the drilling of deep exploitation and exploration wells, a truck-mounted Schramm rotary rig, type 68H, was made available by the Water Development and Irrigation department of the Ministry of Water, Energy and Minerals in Dodoma.
Although this rig is principally a mining rig, designed for drilling medium depth (up to 100 feet) exploration and blast holes in hard rock formations, holes up to a maximum of about 200 m depth can be drilled in unconsolidated and semi-consolidated sediments.
The heavy weight of the rig, 25 tons, limits its use to locations along or close to an all-weather road or track.

The drilling crew started drilling in single shifts of 9 to more than 12 hours a day.
After a few months however, a daily two-shift system was introduced.

Between September 16th, 1978 and March 29th 1979 a total of 1170 m has been realized.
This is about 22% less than was expected.
The following factors prevented an optimal execution of the well drilling programme:

- a major breakdown of the rig's compressor causing a delay of 3 weeks
- small repairs frequently had to be carried out on the rig as well as on the supporting lorry
- problems with fuel and water supply
- the necessity to re-drill and re-ream the boreholes because of swelling clays
- the fact that most of the drilling was done in the rainy season when roads are in poor state
- communication problems

For one borehole with an average depth of 100 m, the activities, from moving to the location up to and including test pumping, took about 14 days.
To expedite the execution, removal of the drilling material was done during test pumping, and camp-moving was kept to a minimum; a transportable steel mud reservoir was constructed to avoid the laborious digging of mudpits.

Drilling was mainly done by the normal mud-flush rotary method. Air rotary was used in a few cases to drill through cemented formations and in bedrock; a string of casings was first inserted to check the unstable sediments.

Wing bits of various diameters up to 13 inches were used.
The standard procedure established during this project was to drill a 6 or 9 inch pilot hole using a wing bit, down to the maximum possible depth for sampling and logging.
The well was then enlarged in accordance with requirements.
Rock roller bits were sometimes used to cope with cemented layers or to prove bedrock.

Penetration rates exceeding 18 m/hr have been achieved when drilling slim holes in sands and soft clays.
Average penetration rates for tough clays were 3 to 7 m/hr while cemented layers and bedrock were drilled with penetration rates of 1.5 m/hr and less.

Bentonite based mud, produced locally by the Meerschaum Factory in Arusha, was used and phosphate mud conditioner (PO 49 N), was used to disperse and break down the mudcake from the surroundings of the screen.

3.3.2.2. Sampling, well logging and interpretation

During the drilling a representative borehole sample was collected at every two feet, so that a sample description could be made afterwards. After the execution of the fifth borehole it became a normal procedure to note the drilling time which was necessary to penetrate one foot (30.5 cm) as well as the weight which was put on the drilling rods. These measurements were carried out over every two feet. In each borehole physical well-log measurement was performed, which needed an uncased and mudfilled borehole. As standard procedure only the SN and LN resistivity and the SP measurements could be carried out. After the second borehole the gamma-ray apparatus was out of order.
Two types of resistivity well-log equipment were at our disposal (see sub-par. 2.3.7.). The SN and LN spacing amounts to 7.6 and 76 cm respectively 20 and 100 cm. All equipment with which point measurement could be executed was hand-operated. In this project the standard spacing between the measurements was chosen to be 1 foot. The execution of the SP, SN and LN measurements over 20 metres took about 1 hour.
When the hole appeared to be plugged after pulling out the drilling rods, the hole had to be cleaned again. This procedure only had to be given up with borehole 135B/78. When it was decided to drill deeper after performing the well-log measurements, these measurements were later carried out a second time over the remaining part of the borehole. Directly after finishing the execution of the well-logging measurements, it was decided, mainly on the basis of these measurements, whether a screen had to be placed or not and if so, at what depth. The final lithologic log was produced at the office.
Although the breakdown of the gamma ray apparatus caused some problems in interpretation, the combined resistivity and spontaneous potential logs proved to be adequate for the needs of the project. They indicated far more detail than logs obtained from the borehole samples.

3.3.2.3. Hydraulic properties of well samples

The hydraulic conductivity of a number of samples was estimated by using a nomogram published by the RID in the Netherlands.
The values closely corresponded with those determined by pumping tests for two wells, but for the greater part they were too high.
This may be because the samples were disturbed and not truly representative of the formation.

3.3.2.4. Well design

Casings

It has been the general practice to use nominal API-standard 6-inch diameter casing and screen for production wells in the Morogoro Region.
This was continued during the project.
This size ideally receives a pump with nominal 4-inch bowls. It will receive nominal 6-inch bowls, but this is marginal, particularly if the well is out of line and not plumb.

In selecting materials for the construction of the project wells a choice had to be made between PVC or steel casings.
The use of PVC casing reduces corrosion to a minimum, but the material is not as strong as steel and therefore most suitable for relatively shallow boreholes.
For this reason and for reasons of supply, 20 feet long steel casings were used.

Screens

There was no choice in the materials for screens.
Only double galvanized steel screens were available in standard lengths of 16 feet. The use of this material is generally recommended only for temporary wells or for use in areas with non-corrosive ground water.
Since no data on the corrosiveness of ground water in the Mkata-Wami Basin are available, predictions concerning the life of the screens cannot be given.
The screens are Johnson wire-wound screens which have a high proportion of open area while maintaining a high degree of strength. Number 40 slot size (1 mm approximately) was used since this size generally suits most conditions.

Screen entrance velocity should be less than 0.1 foot per sec. to reduce friction losses, corrosion and incrustation to a minimum.
The open area for a 6-inch Johnson wire-wound screen with no. 40 slot size is 65 sq.inch/foot of screen and so the maximum transmitting capacity is 20 gallons per minute per linear foot of screen.

Consequently sixteen feet of this screen would transmit 320 gpm (24 l/s) with an entrance velocity of 0.1 ft/s.
Since the yield per project borehole while pumping need not be more than 10 l/s it has been the practice to install only one gravelpacked 16 feet length of screen in a well with a moderate to high hydraulic conductivity of the aquifer.

Gravelpack

Due attention has been paid to the finding and screening of proper gravelpack material since the combination of screen and gravelpack largely determines the quality of the well.
In a gravelpacked well, an artificial, graded gravel has to be chosen which will retain practically all of the formation material. Conditions favouring the use of artificial gravelpacks are:

- fine uniform sands
- extensively layered or laminated formations
- thick artesian aquifers
- losely cemented sand or sandstone

Gravelpack material should preferably be of clean well-rounded grains which are smooth and uniform. It should consist mostly of siliceous material and should have a porosity of 20%-35%. Crushed rock chips should never be used.

The grading of a gravelpack has to be selected on the basis (of the sieve analysis) of the finest sand; so a well screen opening has to be selected of a size that will retain 90% or more of the gravelpack material. For installation in the MDWSP boreholes, only screens with 1 mm (no. 40) slot size were available. Hence the minimum grain size of the finest type of artificial gravelpack material should be about 1.5-2.0 mm.

A set of sieves was constructed by using local mosquito netting, small mesh wire-netting and aluminium plate, in which innumerable round holes were drilled; mesh openings are:
1.6 mm
2.5 mm (round)
4.0 mm (round)
5.6. mm

With these sieves different gravelpacks can be graded with average grain sizes of about 2.0 mm, 3.2 mm and 4.8 mm respectively.

Sufficient quantities of gravelpack material were found in river beds near Kilosa, Mkundi, Mvomero and Wami prison. The Kilosa gravel consists for more than 98% of quartz but is angular to subangular.
The Mkundi, Mvomero and Wami prison gravels consist for about 90% of quartz, 7% of feldspar and 3% of iron beans; this gravel is subangular to subrounded and was therefore preferred to the Kilosa gravel.

Before the installation of casing, screens and gravelpack, the boreholes were always reamed with a 12½-inch bit.
The annular space between the borehole wall and a 16 feet screen is theoretically 0.25 m^3, which is roughly the volume of gravel to be inserted.
It has been the general practice to use about 25% more gravel to allow for setting.

3.3.2.5. Well head

The Mkata-Wami Plain regularly receives heavy rains. Drainage is not good in many places and during the rainy season the ground water table is high; therefore the wells are finished with the casing well (0.3-0.-8 m) above ground level and completed with a concrete slab.

3.3.2.6. Well development

During the installation of the screen and gravelpack, polyphosphate was introduced into the screen area to disperse and break down the mudcake. After demudding, development methods included jetting with fresh water, surging, agitation with compressed air and pumping.

3.3.2.7. Test pumping

Compressed air, delivered by the rig's own compressor, was used to airlift water from the wells during the performance of well tests.
Airlift operation and performance vary with total lift and with submergence of the airline below pumping level.
The submergence ratio of the airline assembly during pumping was maintained at about 50-60% since with this ratio air development produces best results.
The diameters of the ejector pipe and the airline used, 4 inch and 1 inch respectively, permit a maximum pumping of about 11.0 l/sec.

Discharges were measured volumetrically by timing the filling of a 210 litre barrel.
Water levels were measured with electrical water level sounders.

In most instances a preliminary short test was followed by a test at a constant discharge rate up to 24 hours.
Aquifer parameters k and kD are calculated from the time - drawdown and recovery - drawdown relations, using the Jacob modification of the Thies non-equilibrium formula.
The time-drawdown or recovery-drawdown graphs are plotted on semi-logarithmic paper.
Time t (in minutes) is plotted horizontally on the logarithmic scale; drawdown or recovery S is plotted vertically on the linear scale.

The equation is:

transmissivity $$T = kD = \frac{2.3 \times Q}{4\Pi \times \Delta S}$$

in which:

Q = average pumping rate in m^3/day

ΔS = slope on the time-drawdown or time-recovery graph, expressed as the draw-down or recovery difference in m per log cycle of time

D = thickness of the aquifer in m

k = permeability in m/day

This equation may be applied to test data from pumped wells, provided the aquifer is confined and the flow to the well is in unsteady state.

3.3.2.8. Chemical analyses

The specific electrical conductivity of the ground water was measured in the field during the test pumping.

Chemical analysis of the borehole water samples was performed by the water supply section of the MDWSP using a small portable laboratory (Hach model DR-EL/2).
The analyses are listed in Table D 3.3.-2.

3.3.3. MDWSP borehole data

3.3.3.1. Executed drilling programme

Drilling with the Schramm Rig 42 started on September 26th, 1978 and ended March 29th 1979; 17 boreholes were drilled at eleven different locations as shown in Table D 3.3-1.

Table D 3.3-1 - Drilling Programme Rig 42 MDWSP executed between September 16th, 1978 - March 29th, 1979

location	date	depth ft.	depth m.	Σ ft.	Σ m.	filter ft.	filter m.	expl.w.	target	result	borehole nr.
Luhindo	16.9 -24.9	185	56	185	56	-	-		production well	negative	131/78
Dakawa	28.9 -14.10	145	44			-	-				135A/78
		150	46			-	-				135B/78
		108	33	588	179	59 - 75	18-23	I	production well	positive	135C/78
Dibamba	19.10-30.10	360	110	948	289	200 -216	61-66	II	production well	positive	151/78
Mandela	31.10-11.11	295	90	1243	379	82.5-114.5	25-35	III	production well	positive	162/78
Makuyu	13.11-24.11	306	93	1549	472	138 -154	42-47	IV	production well	positive	173/78
Mugudeni	13.12-30.12	368	112	1917	584	-	-		exploration hole	positive from invest. point or view	6/79
Mirama	1.1 -10.1	218	66	2135	650	-	-		production well	negative	4/79
		72	22	2207	672	-	-		observation well	negative	5/79
Mbwade	11.1 -25.1	280	85	2487	757	174 -190	53-58	V	production well	positive	7/79
Madoto	26.1 -15.2	400	122	2887	879	-	-			hole collapsed	13/79
		400	122	3287	1001	-	-			hole collapsed	24/79
		100	30	3387	1032	76 - 92	23-28	VI	production well	positive, low yield, sufficient for hand pump	27/79
Rudewa	20.2 -28.2	145	44	3532	1077	54 - 86	16-26	VII	production well	positive	28/79
Kondoa	3.3 -29.3	220	67	3752	1144	-	-				37/79
		85	26	3837	1170	58 - 74	18-23	VII	production well	positive	41/79

Each drilling site had been carefully selected on the basis of detail geo-electrical surveys, described in sub-par. 3.2.5.
Total drilling depth up to the end of the programme is 1170 m.
Eight of the boreholes could be successfully completed as exploitation wells; one well was completed as an observation well. The borehole at Mugudeni, meant to be an exploration borehole, was successful from this point of view. Problems encountered during the execution of the drilling programme are explained in sub-par. 3.3.2. The executed well-logs, the sample descriptions and the interpreted lithologic logs are presented in Figs. D. 3.3-1 to 17.
The time-drawdown and time-recovery graphs of pumping tests, are presented in DD8. The legend to the borehole logs is given in Fig. D 3.3-18.
Chemical data on ground water from the production wells as well as on basement water from two other wells are tabulated in Table D 3.3-2.
The different boreholes will be dealt with separately in the next paragraphs.

Table D 3.3-2 - Chemical data on groundwater from MDWSP boreholes

location borehole nr.		Luhindo 131/78 (basement water)	Dakawa 135/78	Dibamba 151/78	Mandela 162/78	Makuyu 173/78	Mugudeni 6/79 (basement water)	Mbwade 7/79	Madoto 27/79	Rudewa 28/79	Kondoa 41/79
date of sampling		26-09-1978	19-10-1978	28-10-1978	10-11-1978	23-11-1978	10-1-1979	24-1-1979	19-2-1979	29-2-1979	29-3-1979
date of analysis		23-10-1978	20-10-1978	31-10-1978	17-11-1978	25-11-1978	10-1-1979	26-2-1979	20-2-1979	1-3-1979	2-4-1979
sample method		bailer	air lift	air lift	air lift	air lift	bailer	air lift	air lift	air lift	air lift
Water Analysis	Unit										
electrical conductivity	mS/m (25°C)	820	22	40	50	29	60	65	132	22	45
pH		7.8		7.5	7.5	7.7	8.3	8.5	7.5	6.9	7.1
calcium	mg/lCa^{2+}	180		24.0	44	18	30	64	96	18	52
magnesium	mg/lMg^{2+}	389		24.3	19.5	11	18.2	29	73	8.5	18
total hardness	mg/l$CaCO_3$	2050		110	190	90	150	280	540	80	195
iron	mg/l Fe	0.1	0.14	0.4	0.06	0.33	0.25	0.04	0.2	0.8	0.07
manganese	mg/l Mn	0.25	0.1	0.8			0.01	0.5	0.5	0.7	1.4
fluoride	mg/l F^-	1.3	0.2	0.4	0.3	0.5	1.3	0.4	0.5	0.3	0.5
chloride	mg/l Cl^-	2070		15	55	27	30	17.5	80	7.5	15
bicarbonate	mg/l HCO_3^-	635		201	201	128	317	299	561	92	185
nitrite	mg/l NO_2^-					0.006	0.007	0.001	0.01	0.002	0.002
nitrate	mg/l NO_3^-	71	1.8	2.7	3.5	6.2	3.5	3	0.6	2.22	3.0
sulphate	mg/l SO_4^{2-}	900		5	19	4.0	nil	90	170	0.5	37
phosphate (ortho)	mg/l PO_4^{3-}				0.8	2.2	0.1	1.6	0.6	3.3	1.1

3.3.3.2. Borehole 131/78 at Luhindo (Fig. D 3.3-1)

The detail geo-electrical survey carried out at Luhindo (sub-par. 3.2.5.2) indicated the presence of a layer with good prospects for ground water (resistivity 30 ohmm), just north of the village, at depths between 25 and 35 m below ground level. Borehole 131/78 was drilled 100 m north of the village, along the road to Dakawa-Wami. Its co-ordinates are 339.4-9285.7 on map sheet 166/3. The approximate elevation is 365 m above MSL. From 0 m down to 33.5 m, where water was struck, the hole was air-rotary drilled; later the hole was reamed down to 36 m by mud-rotary.
The samples were mainly angular gravels in a matrix of grey-greenish clay. The gravel was a mixture of pinkish quartz, chips of gneissic rock and an abundance of mica; the grain size varied from 2-12 mm.
This clayey gravel is considered to be either highly (in situ) weathered basement material, or colluvial material.
No water was present in this layer.

From 33.5 m to 36.0 m depth a water-bearing layer was struck.
The samples from this depth do not differ from those above. The drilling process was much slower however, and at 36 m basement rock was found. Hence the layer between 33.5 m and 36 m is probably the highly fissured and weathered upper part of the basement rock.

From 36 m down to 56 m the hole was drilled by the pneumatic hammer/air method, after the installation of a string of casings to a depth of 29 m. No water was found during this part of the drilling.
The samples contained light-grey to pink coloured quartz, feldspar and mica. This mineralogical composition indicates the presence of an acid granitic or gneissic basement here. It is worth mentioning that one km north of this drilling, biotite gneiss crops out.

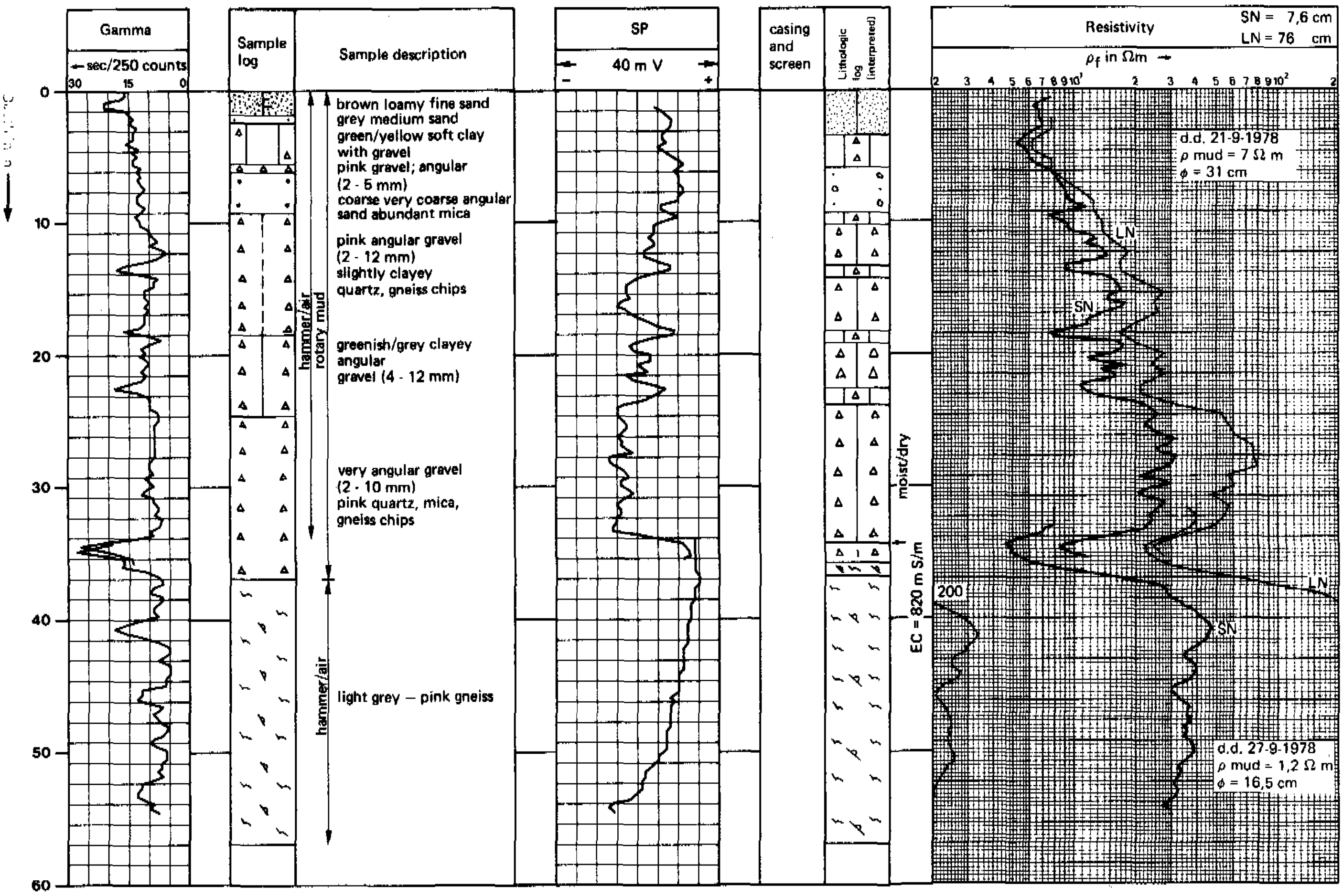
The well-logs of the SP, SN, LN and gamma-ray correspond very well with each other. The resistivity values gathered from the SN and LN logs in the upper part of the borehole are between 5 and 80 ohmm and correspond to dry clay deposits. In the gamma-ray log three levels of radiation can be distinguished; they are >25, 20-15 and about 10 sec/250 counts.

These levels are correlated to sandy, clayey and feldspar bearing deposits respectively.

The ground water from the water bearing zone between 33.5 and 36 m is saline; an EC of 820 mS/m was measured.
Therefore the borehole was abandoned and no casing or screen was left in the hole.

Fig. D 3.3-1

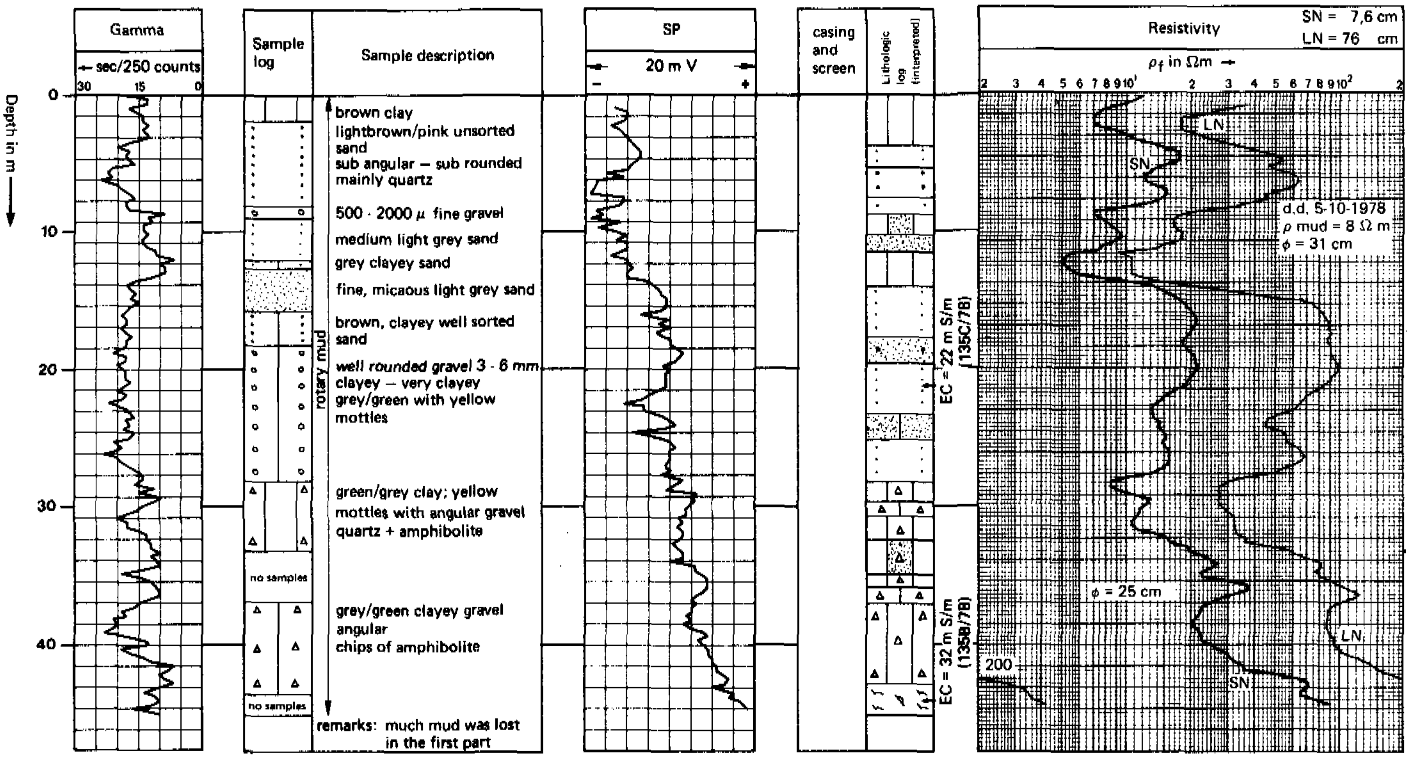
Borehole: 131/78
Mapsheet: 166/3
Location: Luhindo
Co-ordinates: 339,4-9285,7
Elevation: 365 m. above MSL



Number: 135^A/78
Mapsheet: 166/3
Location: Dakawa

Co-ordinates: 337,6-9288,1
Elevation: 355 m. above MSL

FIG. D 3.3-2



Legend: see figure D3.3-18

A chemical analysis of this water is presented in Table D 3.3-2. the main constituents are chloride, sulphate, bicarbonate, sodium (not analysed but calculated), calcium and magnesium.
The nitrate content was also high (71 ppm NO_3^-).

Summary of data on borehole 131/78 at Luhindo

date of commencement	16-9-1978
date of completion	27-9-1978
total depth	56 m
well-logging	resistivity; long normal and short normal; gamma-ray SP
water struck	33.5 - 36 m
static water level	approximately 6 m below ground level
pumping test	not applicable
EC ground water	820 mS/m
remarks	abandoned no casing or screen left

3.3.3.3. Boreholes 135A, B, C, C/78 at Dakawa (Fig. D 3.3-2, 3 and 4)

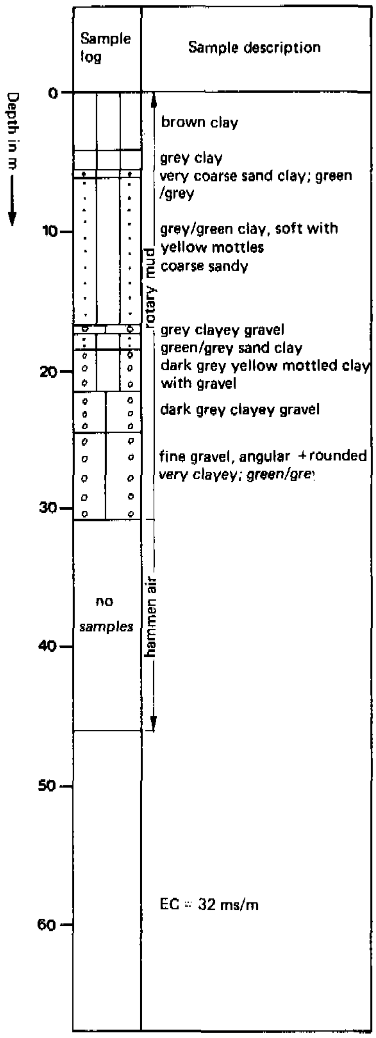
As a result of the detailed geo-electrical survey of the area around Dakawa (sub-par. 3.2.5.3.), the zone between this village and the Wami River was pointed out as the most promising area with regard to the occurrence of ground water.
The location of the boreholes is 500 m north of the Wami River, along the road to Dakawa.
Distance to the edge of this village is 200 m.

Borehole 135A/78 was drilled by mud-rotary down to a depth of 44 m. Between 14 m and 21 m depth, mud was lost in the formation resulting in much caving in.
The correlation between sample log and the geophysical well-logs was reasonable.
The lithological sequence from top to bottom was as follows:

- From 0-3.6 m a stiff, brown clay.
- Between 3.6 m and 8.2 m the first aquifer consists of medium coarse to coarse sub-rounded sand, the resistivity of which (65 ohmm) shows a good chemical quality of the ground water.
- Between 8.2 and 13.4 m the sediments are predominantly clayey.
- From 13.4 to 27.0 m a second aquifer made up of coarse to very coarse sand and well rounded gravel (3-6 mm). Again the LN resistivity indicates an excellent chemical quality of the ground water (resistivity of 100 ohmm).
- From 27.0 m down to basement, which was reached at a depth of 41.7 m, gravelly clays and very clayey gravels occur.
  The clay is a greenish clay with yellow mottles; the gravel is very angular and contains pieces of quartz and amphibolite.

Number: $135^{B}/78$
Mapsheet: 166/3
Location: Dakawa
Co-ordinates: 337,6-9288,1
Elevation: 355 m. above MSL

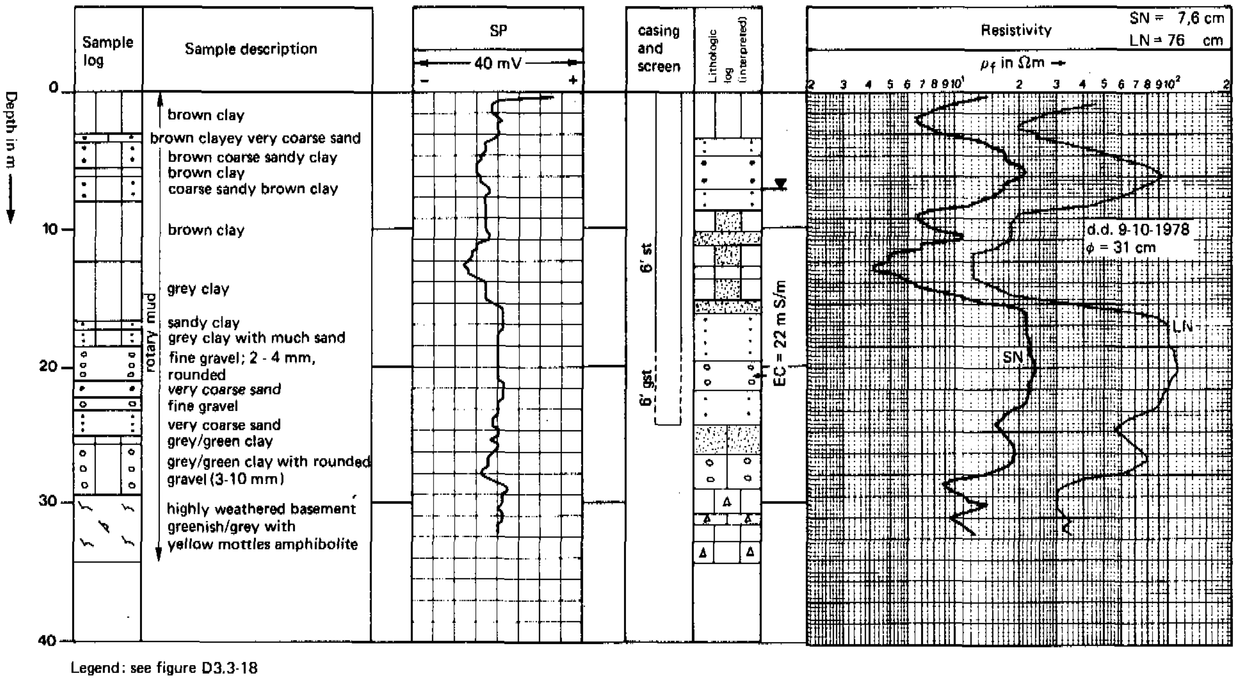
Fig. D 3.3-3



Number: $135^{C}/78$
Mapsheet: 166/3
Location: Dakawa

Co-ordinates: 337,6-9288,1
Elevation: 355 m. above MSL

Fig. D 3.3-4



Legend: see figure D3.3-18

> From 0-27 m, the sediments are typically fluvial: the well-rounded sands and gravels indicate the presence of channel deposits. Between 27 m and 41.7 m the gravel is very angular and clayey and contains much basement material; these sediments may have been deposited in mud flows.

In order to determine the location of the basement and to establish the hydrogeological characteristics of the upper part of the basement it was tried to drill a few metres through the hard rock by the hammer/air method.
After installing of a string of casing in the hole however the lower part of the hole collapsed.
Therefore s second hole, 135B/78, was drilled 10 m west of 135A/78.
A one inch diameter PVC observation filter was installed in 135A/78 at a depth of 36 m.
Borehole 135B/78 was drilled by mud rotary down to 30 m, and from 30 m - 46 m with hammer/air.
The sample log did not show clean sands or gravels; the whole sample sequence was very clayey.
Geophysical well-logging of this hole could not be done, because it became plugged by swelling clays.

Therefore a third borehole, 135C/78, had to be drilled; its location is 5 m south of 135A/78. Total drilling depth was 31.4 m.
Although the sample log shows some differences with the one of borehole 135A/78, the two resistivity logs are very much alike.

In 135C/78, a gravelpacked screen was installed in the second aquifer, between 17.4 m and 22.3 m.
After completing and developing the hole two pumping tests were carried out.
A first test of 8 hours had a yield of 3.6 l/s and a second one of 20½ hours with a yield of 7.0 l/s. The time drawdown and time-recovery graphs of both tests are presented in DD 10.
The average permeability (k) and transmissivity (kD) of the aquifer as calculated from the different tests are:
k = 80 m/day and kD = 650 m^2/day

The specific capacity of the well (Q/m') is the yield in l/s divided by the maximum drawdown.
For this well it is:

$$\frac{7 \quad l/s}{4.87 \ m} = 1.4 \ l/s/m' \text{ of drawdown}$$

Optimum well operating characteristics generally occur at a drawdown which is about 67% of the maximum possible drawdown.
The maximum drawdown in this well is 22.3 m (bottom screen) - 7.3 m (static water level) = 15 m.

Hence the drawdown at which operation of the well would be optimum is 10 m.
With a specific well capacity of 1.4 l/s, the optimum yield of this well would be 14 l/s.
A summary of data on boreholes 135A, B, C/78 is given below.

Borehole 135A/78	Dakawa Wami
date of commencement	28-09-1978
date of completion	5-10-1978
total depth	44 m
well-logging	resistivity; long normal, short normal; gamma-ray; SP
remarks	observation filter installed at 36 m depth

Borehole 135B	Dakawa Wami
date of commencement	6-10-1978
date of completion	6-10-1978
total depth	46 m
well-logging	not applicable
remarks	abandoned

Borehole 135C/78	Dakawa Wami
date of commencement	7-10-1978
date of completion	11-10-1978
total depth	31.4 m
well-logging	resistivity (SN, LN), gamma-ray
aquifer	13.4-27.0 m very coarse sand and rounded fine gravel
gravelpacked screen	17.4-22.3 m
static water level	7.33 m - collar level
pumping test	20 hours
drawdown steady state	4.87 m -collar level
tested yield	7.0 l/s
calculated permeability	80 m/day
calculated transmissivity	650 m^2/day
specific well capacity	1.4 l/s/m of drawdown
optimum well yield	14 l/s
EC ground water	22 mS/m
remarks	the yield of this borehole is more than sufficient to supply both Dakawa and Luhindo with water

3.3.3.4. Borehole 151/78 at Dibamba (Fig. D 3.3-5)

A detail geo-electrical survey carried out between Mvomero and Dibamba, and in and around Dibamba (sub-par. 3.2.5.4.) showed good prospects for the occurrence of ground water in the area around Dibamba and especially in the eastern part of the village.

Therefore borehole 151/78 was drilled in Dibamba itself, along the main road from Mvomero through the village.

Its co-ordinates are 330.1-9302.8 on mapsheet 165/4. Its elevation is approximately 400 m above mean sea level.

The total length of this 110 m deep borehole, was drilled by mud-rotary.

Drilling had to be stopped at this depth because very hard layers were encountered.

The sample log is very unreliable; only the upper 18 m show correlation with the geophysical well-logs.

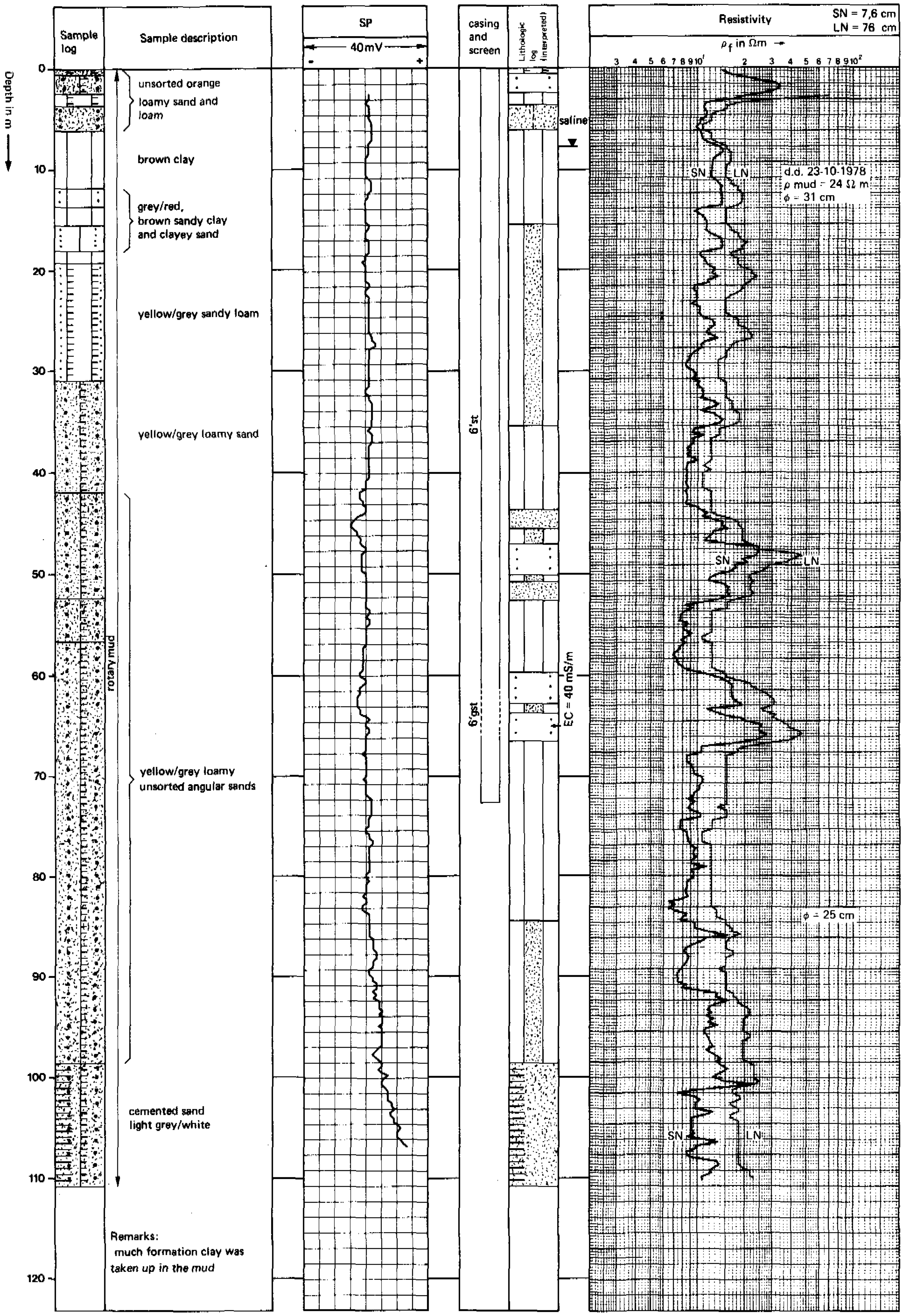
Due to the lack of the gamma-ray log, the small differences in the resistivity logs and the fact that large differences in resistivity values of clayey deposits are possible, it is difficult to distinguish the sand and clay layers from above 42 m and below 66 m.

Combination of the sample log with the geophysical logs gives the following interpreted sequence of layers:

- The upper 2.4 m sandy and probably dry.
- From 3.3 m - 6.0 m there is another sand layer with probably saline ground water (EC > 200 mS/m).
- From 6.0 m to 43 m depth the sediments are predominantly clayey, the upper part of which is brown and the lower part yellow/grey coloured.
- Between 43 m and 52 m there is a first aquifer;
  its upper and lower parts are finely textured, while its middle part is medium coarse sand.
- Between 52 m and 59 m there is a clay layer;
  no sample of this clay was found amoung the drilling samples.
- From 59 m to 65 m there is a second aquifer, consisting most probably of medium coarse sand.
  The samples recovered from this depth are sub-angular, light grey/white, unsorted, loamy sands.
  From the resistivity logs resistivity values of 35-50 ohmm are deduced, which are promising for the occurrence of ground water with a low salinity.
- Below this aquifer, the sediments are clayey down to a depth of 97 m.
  The colour of this clay is probably purple because from this depth the colour of the drilling mud changed from grey to purple.
- From 97 m down to the bottom of the hole cemented sand was found. The degree of cementation gradually increases with the depth. The samples recovered from this level show light grey/white unsorted fine to coarse, angular sands.

Fig. D 3.3-5

Number: 151/78
Mapsheet: 165/4
Location: Dibamba
Co-ordinates: 330,1-9302,8
Elevation: 400 m above MSL



Legend: see figure D3.3-18

A screen was installed in the second aquifer, at depths between 60.9 m and 65.8 m below ground level. After completing and developing the well a 24 hours pumping test was executed with an average discharge of 9.5 l/s (DD 10).
After 22 hours of pumping the water level in the well was stabilized at a drawdown of 26.94 m.
The aquifer parameters calculated from this test are:
permeability : k = 8 m/day
transmissivity : kD = 50 m^2/day

These values are characteristics of very unsorted sands or very fine sands.

Samples point to the first possibility.

The specific well capacity $Q/m = \frac{10}{26.94} = 0.37$ l/s per m of drawdown

Optimum operation characteristics for this well would be obtained at a drawdown of 36.7 m (67% of the maximum possible drawdown).
Hence optimum well yield would be:
36.7 x 0.37 (specific capacity) = 13.7 l/s.

The EC of the ground water, 40 mS/m, did not change during the pumping tests. The chemical composition of the ground water is presented in Table D 3.3-2.

Summary of data

Borehole 151/78	Dibamba
date of commencement	17-10-1978
date of completion	27-10-1978
total depth	110 m
well-logging	resistivity (LN, SN), SP
aquifer	59.4-65.8 m
gravelpacked screen	60.9-65.8 m
static water level	9.06 m below collar level
pumping test	24 hours
tested yield	10.0 l/s
drawdown steady state	26.94 m below collar level
calculated permeability	8 m/day
calculated transmissivity	50 m^2/day
specific well capacity	0.37 l/s per m of drawdown
optimum well yield	13.7 l/s
EC ground water	40 mS/m
remarks	a yield of about 5 l/s will be sufficient to supply Dibamba as well as Mvomero with water. A maximum drawdown of about 13 m may be expected then.

3.3.3.5. Borehole 162/78 at Mandela (Fig. D 3.3-6)

The location of this borehole resulted from a detailed geo-electrical survey in and around Mandela (sub-par. 3.2.5.5.). The borehole was drilled in the S.W. part of the village, along the road to Kilosa.
Its co-ordinates are 321.9-9371 on mapsheet 165/4; its approximate elevation is 430 m above MSL.
The total depth of the mud-rotary drilled borehole is 90 m; drilling was stopped at this depth because very hard, cemented layers were encountered here. The recovery of the samples was good this time because they correlate with the geophysical well-logs:

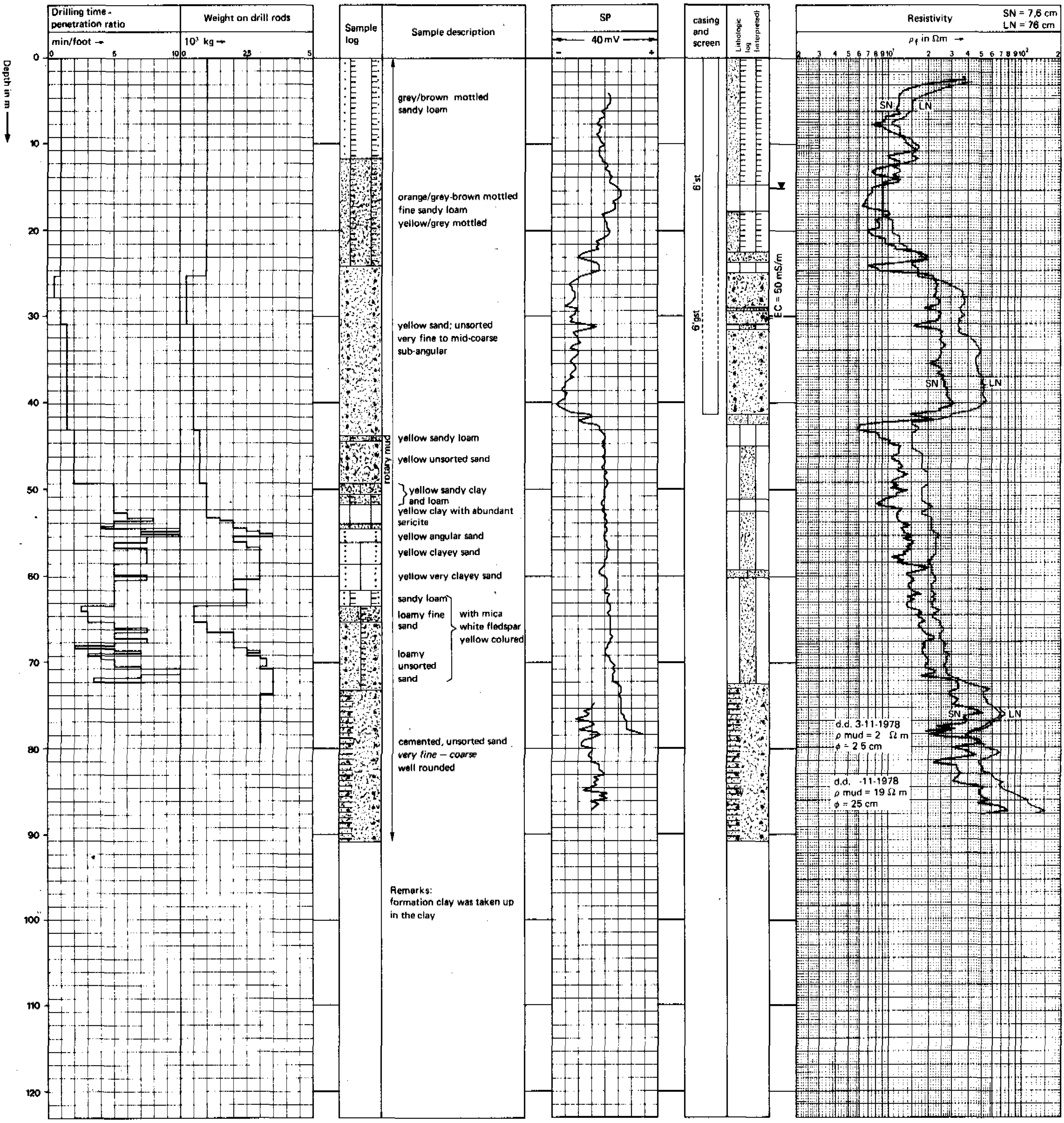
- From ground level down to 22.3 m depth, there is finely textured, sandy loam, the upper part of which is orange/brown-grey mottled and the lower part yellow-grey mottled.
- Between 22.3 m and 23.5 m there is a thin sandy aquifer.
  Shallow wells near the borehole, tapping this aquifer, dry up during the dry season.
  The EC of the ground water in this layer is 64 mS/m.
- From 23.5 m to 24.7 m a clay layer occurs.
- Between 24.7 and 41.8 m there is a relatively thick aquifer.
  Samples acquired from this part of the drilling are yellow coloured, unsorted, sub-angular, fine to medium-coarse sands; an alluvial fan deposit most probably.
  The resistivity logs show resistivity values of 40 and 55 ohmm, which are very promising.
- Between 41.8 m and 71.3 m depth the sediments are predominantly clayey.
  Samples from these depths are yellow coloured clayey and loamy fine sands to sandy clays and loams.
  The samples contained much mica (sericite) and whitish feldspar.
- From 71.3 m depth down to the bottom of the hole, there are cemented sands.
  Samples from this level are unsorted, well-rounded sands.

It was intended to place a screen between 30.7 and 40.5 m depth, in the lower part of the aquifer.
However, the screen was installed at the wrong depth and was placed in the upper part of the aquifer, between 25.0 m and 34.7 m.

After completing and developing this borehole, two pumping tests were executed (DD 10). The first test was run for 18 hours; recovery could not be measured because of a breakdown of the pump.
Therefore a second test was run for 5½ hours, followed by a recovery test of 100 minutes.
Average aquifer parameters, calculated from these tests are:
permeability : k = 125 m/day
transmissivity : kD = 2000 m^2/day

Number: 162/78
Mapsheet: 165/4
Location: Mandela
Co-ordinates: 321,9-9397,1
Elevation: 430 m. above MSL

Fig. D 3.3-6



Legend: see figure D3.3-18

These values are higher than can be expected from unsorted fine to medium coarse sands.
Probably the aquifer is built up of alternating fine and medium coarse, well-sorted sand layers.
The specific capacity of the well, calculated from the 18 hour pumping test, is 6.6 l/s/m' of drawdown. Optimum well operating characteristics would be obtained at a drawdown of 12.66 m and a yield of 83 l/s.

However, the maximum permissible yield of this borehole with 2 screen lengths installed is 48 l/s, as was shown in subpar. 3.3.2.4.
The EC of the ground water is 50 mS/m; a chemical analysis is presented in Table D 3.3-2.

Summary of data

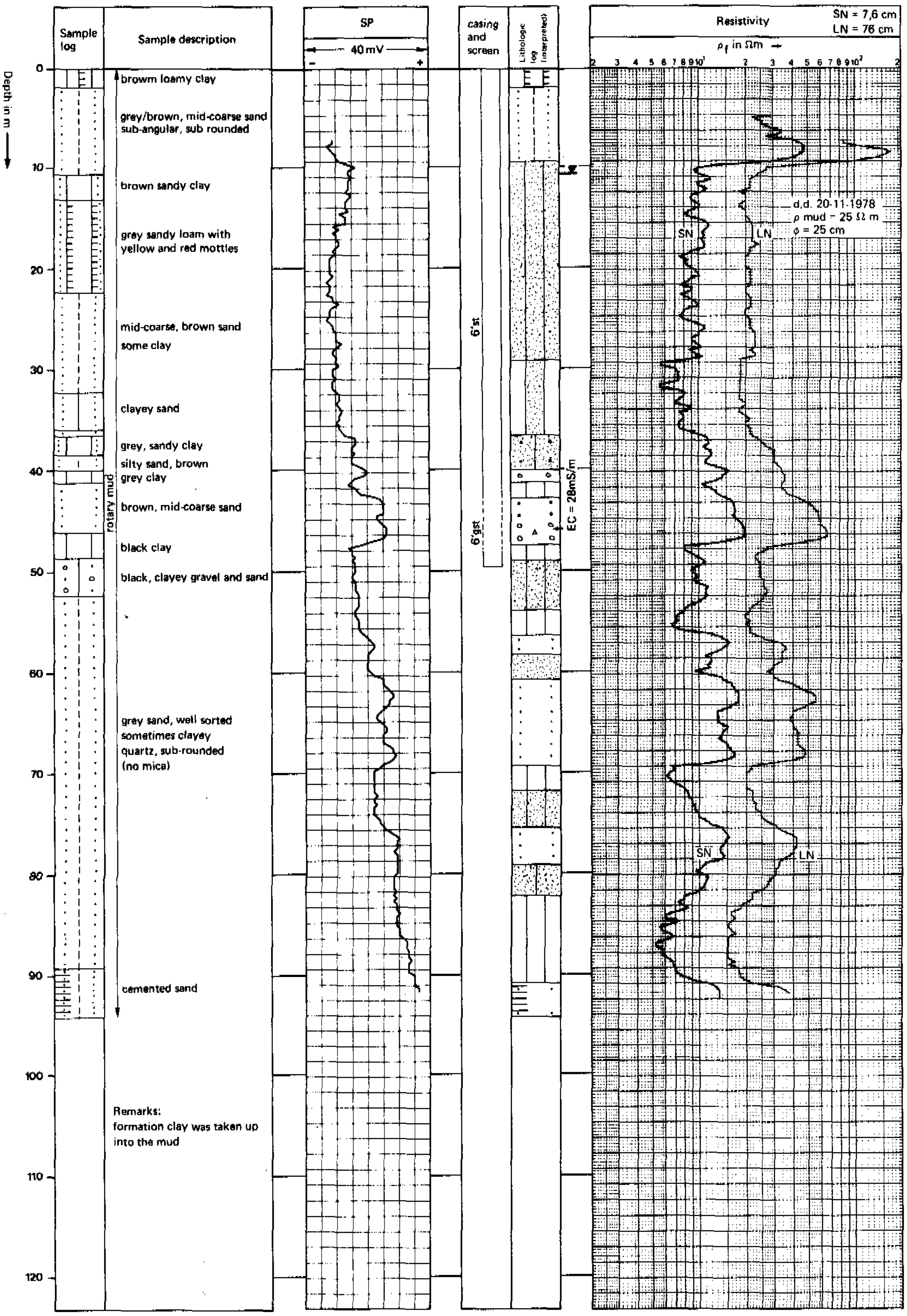
Borehole 162/78	Mandela
date of commencement	31-10-1978
date of completion	10-11-1978
total depth	90 m
well-logging	resistivity LN, SN; SP
aquifer	24.7 m - 41.8 m
gravelpacked screen	25.0 m -34.7 m
static water level	14.95 m - ground level
pumping test	18 hours
tested yield	10 l/s
drawdown steady state	1.52 m
calculated permeability	125 m/day
calculated transmissivity	2000 m^2/day
specific well capacity	6.6 l/s/m' of drawdown
maximum permissible well yield	48 l/s
EC ground water	50 mS/m
remarks	the screen was installed too high in the aquifer. The yield of this borehole is more than sufficient to supply both Mandela and Mugudeni with water.

3.3.3.6. Borehole 173/78 at Makuyu (Fig. D 3.3-7)

A detail geo-electrical survey carried out at Makuyu (subpar. 3.2.5.6.) showed good prospects for the occurrence of ground water near this village.
The borehole was drilled 200 m S.E. of Makuyu, along the short-cut to Mandela.
Its co-ordinates are 320.7-9300.9 on mapsheet 165/4; its approximate elevation is 440 m above MSL.
Total drilling depth was 93 m.
As in Dibamba and Mandela, drilling had to be stopped in hard, cemented sand layers.

Fig. D 3.3-7

Number: 173/78
Mapsheet: 165/4
Location: Makuyu
Co-ordinates: 320,7-9300,9
Elevation: 440 m above MSL



Legend: see figure D3.3-18

The upper 52 m of the sample log correlate reasonably well with the geophysical well-logs; below this level, however, there is no correlation any more.

- Between 1.6 m and 9,0 m there is a first shallow aquifer consisting of brown, medium coarse, sub-angular to sub-rounded sand.
- From 9.0 m to 36.0 m the sample log shows an alternation of brownish loamy and clayey medium coarse sands and clay layers.
  The geophysical logs, however, do not show much variation between these depths.
- From 36.0 m to 40.0 m the sands contain less clay and are somewhat coarser.
- Between 42.0 m and 47.0 m there is a second aquifer. The resistivity values are about 70 ohmm, indicating good prospects for the occurrence of ground water with a low salinity.
- From 47.0 m down to 55 m, the geophysical well logs indicate clay. The samples from these depths are black clay and black, clayey, very coarse sand to fine gravel.

  The high content of organic material in the clay indicates deposition in a swamp environment.

  Below 55.0 m the borehole samples are all identical. They are grey coloured, slightly silty, well-sorted, medium-coarse sands, which are sub-rounded.
  However, probably taken up in the drilling mud because geophysical logs show considerable variations from 55.0 m down to the bottom of the hole.

- Between 55.0 m and 68.3 m there is a third aquifer, most probably made up of medium-coarse sand.
  The resistivity values indicated by the logs are between 40 and 50 ohmm, which is lower than those of the second aquifer.
- There is a clay layer from 68.3 m to 74.6 m, below which a fourth aquifer occurs. Its resistivity values are about 40 ohmm.
- From 80.7 to 89.9 m depth the resistivity gradually decreases, which probably indicates an increase of the clay content.
- From 89.9 m to 93.0 m, hard cemented sand was found.

A screen was installed in the second aquifer at depths between 42.0 and 46.9 m below ground level. Because of problems with the compressor of the rig, only a very short pumping test could be executed. After development of the well, a 4½ hour pumping test was made with a yield of 7.6 l/s.
Time-drawdown and time-recovery graphs of the test are presented in DD 10.

At the end of the 4½ hours of pumping, steady state conditions were not yet reached.

Therefore it is not possible to calculate the specific yield and the optimum of the well.
Aquifer parameters calculated from the test are:
permeability : $k = 30$ m/day
transmissivity : $kD = 150$ m^2/day

The EC of the ground water is 28 mS/m; a chemical analysis is presented in Table D 3.3-2.

Summary of data
Borehole 173/78

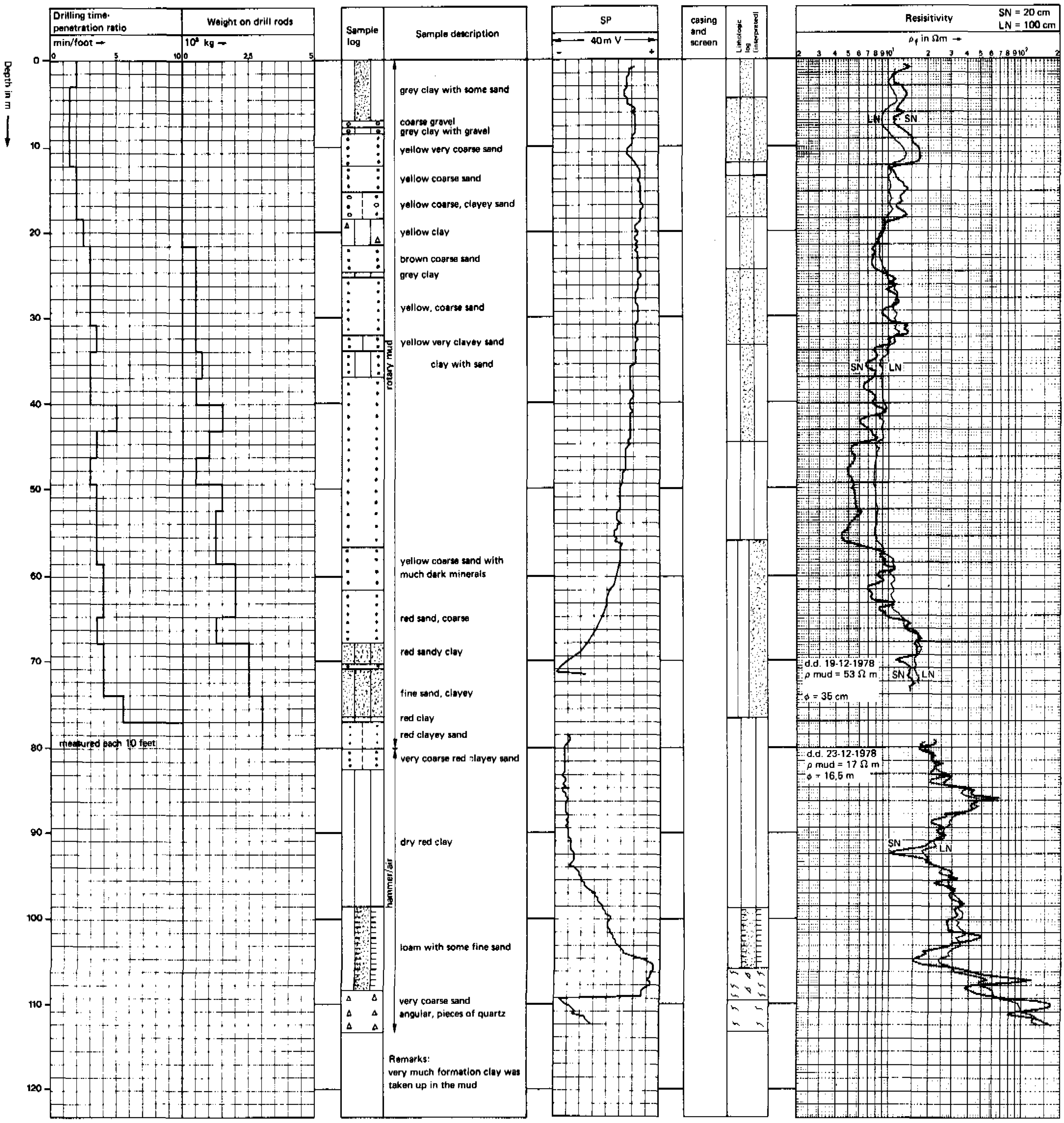
date of commencement	13-11-1978
date of completion	24-11-1978
total depth	93 m
well-logging	LN, SN, SP
aquifer	42.0-47.0 m
gravelpacked screen	42.0-46.9 m
static water level	11.33 m below ground level
pumping test	4½ hours
tested yield	7.6 l/s
drawdown after 4½ hours of pumping	14.89 m
calculated permeability	30 m/day
calculated transmissivity	150 m^2/day
EC ground water	28 mS/m

3.3.3.7. Borehole 6/79 at Mugudeni (Fig. D 3.3-8)

The geo-electrical soundings carried out in the area around Mugudeni show very low resistivity values (sub-par. 3.2.5.7.), which means poor prospects for fresh ground water. To examine the delicate question whether in all the areas where such low resistivity values are found further investigations for deep ground water have to be given up, an exploration borehole was drilled here. Borehole 6/79 is located along the road from Mugudeni to Magole about 1 km west of the road division to Turiani and Morogoro.
Its co-ordinates are 324.9 - 9266.6 on mapsheet 165/4.
Its elevation is approximately 420 m above MSL.
Up to 79 m the borehole was drilled by mud-rotary. After than hammer-air drilling was applied to reach the basement. The final depth amounts to 113 m.

Fig. D 3.3-8

Number: 6/79
Mapsheet: 165/4
Location: Mugudeni
Co-ordinates: 324,9-9266,6
Elevation: 420 m.above MSL



Legend: see figure D3.3-18

The sample log is very unreliable. In this hole there was much clay mixed with the mud so that the mud had to be continuously diluted. The resistivity logs show very low resistivity values (<10-15 ohmm) over the first 64 m.

Therefore it is difficult to distinguish the individual clay layers and sand layers with saline water (EC >200 mS/m). From the logs it becomes clear that here no sand layers with fresh water occur, which is in accordance with the prediction. From a hand-drilled borehole, specially drilled at a distance of less than 20 metres from 6/79, it appeared that a sand layer at a depth of 8 m contains saline water with an EC of more than 200 mS/m. From the hammer-air drilling below 79 m it became clear that the very hard layer, which hampered the rotary-mud drilling, consists of dry, red clay deposits. These layers were found up to 105 m.

Below this depth weathered bedrock and after that unweathered bedrock were found in succession. In the weathered zone fresh water with an EC of 60 mS/m was struck. The speed with which the water rose in the hole was too low to justify exploitation. This borehole was abandoned. No screens and casings were left.

Summary of data

Borehole 6/78	Mugudeni
date of commencement	13-12-1978
date of completion	29-12-1978
total depth	113 m
well-logging	resistivity (LN, SN), SP
EC basement water	60 mS/m

3.3.3.8. Borehole 4/79 and 5/79 at Mirama (Fig. D 3.3-9 and -10)

On the basis of the geo-electrical survey executed near Mirama (sub-par. 3.2.5.8.) a drilling was suggested. The borehole is situated at the southern end of the village, at a distance of about 100 m from the road. Its co-ordinates are 327.9 - 9296.2 on mapsheet 165/4 and its approximate elevation amounts to 400 m above MSL.

The total depth of the mud-rotary drilled hole is 66 m; drilling was stopped because progress was very slow at this depth.

Fig. D 3.3-9

Number: 4/79
Mapsheet: 165/4
Location: Mirama
Co-ordinates: 327,9-9296,2
Elevation: 400 m.above MSL

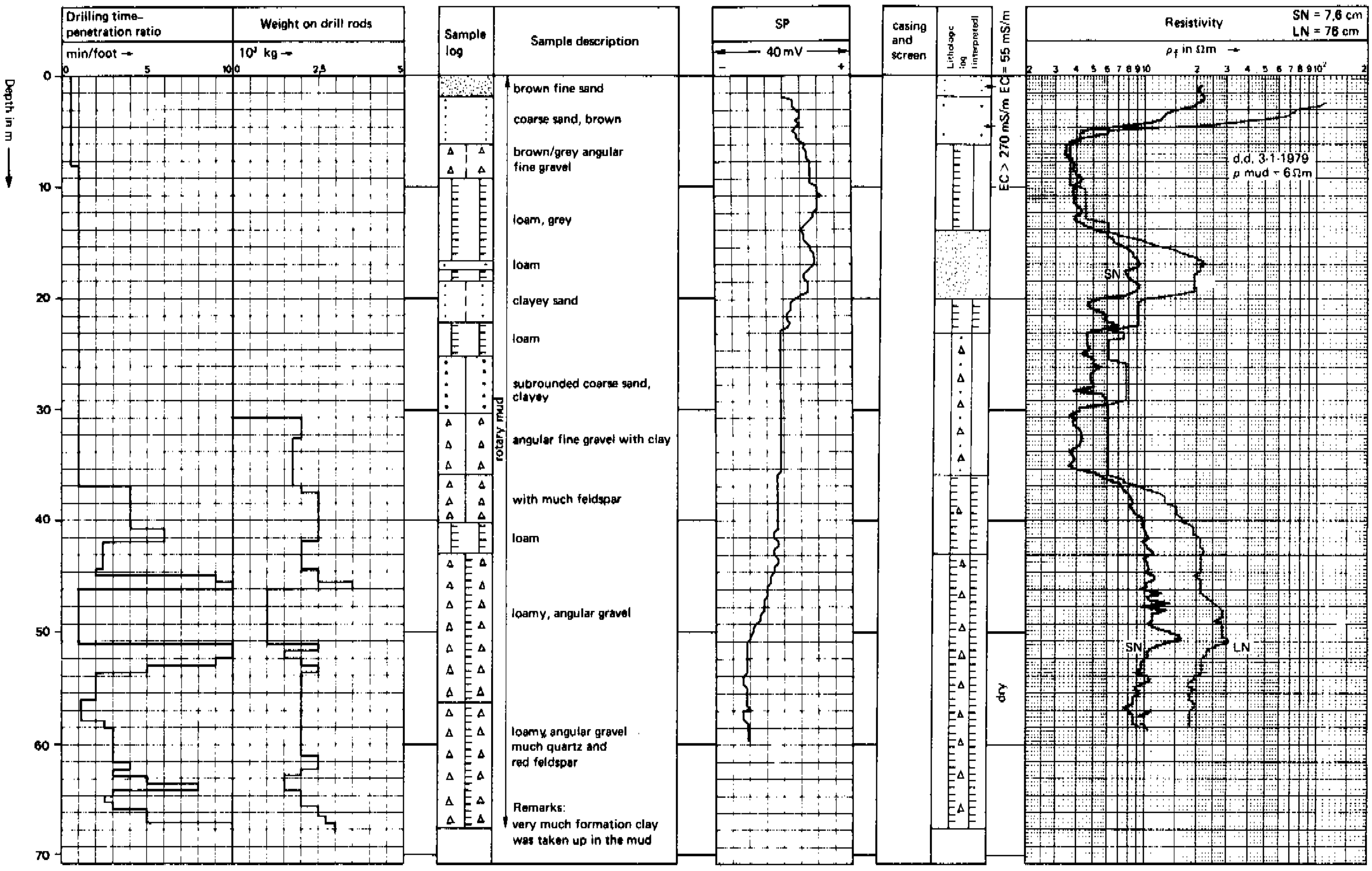
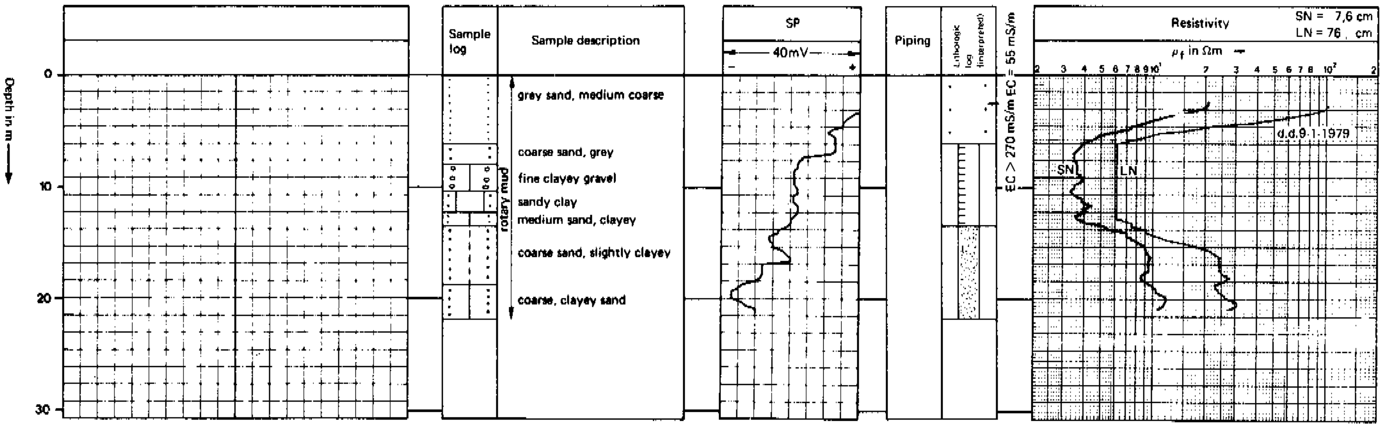


Fig. D 3.3-10

Number: 5/79
Mapsheet: 165/4
Location: Mirama

Co-ordinates: 327,9-9296,2
Elevation: 400 m above MSL



Legend: see figure D 3-3-18

The recovery of the samples was rather good, although a great deal of clay was mixed in the mud. Apart from the first 6 m no high resistivity values are found in the well-logs of borehole 4/79. The whole lithogic log is very clayey. From a sample stuck to the drilling bit, it is concluded that the high resistivity values of 20 to 30 ohmm below 35 m correspond to dry clay deposits with angular gravel components. Between 14 and 20 m a layer with a resistivity value of about 20 ohmm is found in the resistivity logs. To check the possibility whether this layer corresponds to a water-bearing layer, it was proposed to install a screen at this depth. Because this was not done properly, the location was abandoned, and another hole (nr. 5/79) was drilled down to 22 m at a distance of about 4 m from the first hole. The resistivity logs of this hole are very similar to those of the first hole. In spite of the fact that here the screen was placed and developed properly, no water was produced by this layer. Therefore, it is concluded that at this depth no sand layer is present, but clayey deposits also. From special hand-drilled holes at distances less than 40 m it was found that at a depth of 2 m the EC amounts to up to 55 mS/and at a depth of 6 m to more than 270 mS/m.
These boreholes were abandoned and no screens and casings were left.

Summary of data

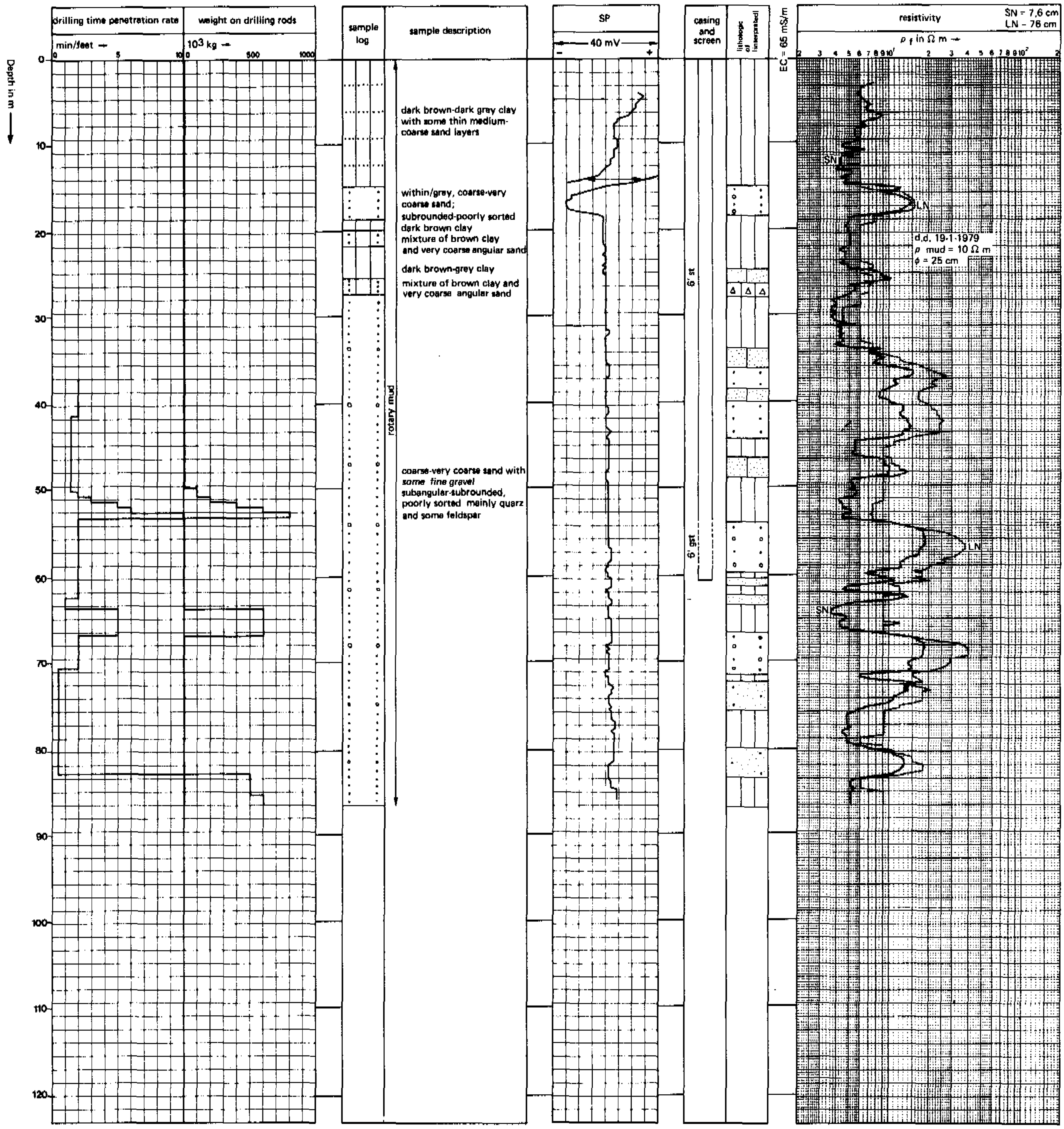
Borehole 4/79	Mirama
date of commencement	1-1-1979
date of completion	5-1-1979
well-logging	resistivity (LN, SN); SP
Borehole 5/79	
date of commencement	9-1-1989
date of completion	9-1-1979
well-logging	resistivity (LN, SN); SP

3.3.3.9. Borehole 7/79 at Mbwade (Fig. D 3.3-11)

The geo-electrical detail survey carried out in the area around Mbwade (3.2.5.9.), showed intermediate resistivity values (13 ohmm) between depths of 30 and 80 m.
The prospects to drill successful wells in this area have therefore been classified as fair. Because the drilling site originally chosen at the location of sounding 25 was not accessible for the rig, a location along the main road from Mkata to Kimamba, between soundings 24 and 26 was chosen as the new drilling site for borehole 7/79.
The borehole is situated at the western side of the village; its co-ordinates are 297.7-9252.3 on mapsheet 182/3. Its approximate elevation is 430 m above MSL.
The total drilling depth of this borehole was 85 m, because as explained above, water-bearing sands were expected at depths up to 80 m.
The recovery of the samples from the upper 27 m was good.

Fig. D 3.3-11

Number: 7/79
Mapsheet: 182/3
Location: Mbwade
Co-ordinates: 297,7-9252.3
Elevation: 430 m. above MSL



dark brown-dark grey clay with some thin medium-coarse sand layers

within/grey, coarse-very coarse sand; subrounded-poorly sorted

dark brown clay

mixture of brown clay and very coarse angular sand

dark brown-grey clay

mixture of brown clay and very coarse angular sand

coarse-very coarse sand with *some fine gravel* subangular-subrounded, poorly sorted mainly quarz and some feldspar

Legend: see figure D 3-3-18

The upper 15 m show predominantly dark brown to dark grey clay, alternated with some thin sand layers; the sand is medium coarse coarse.
Most probably there are fair prospects for shallow ground water here.
Between 15 and 18 m there is an aquifer consisting of coarse-very coarse sand. The resistivity of this formation is 15 ohmm. This aquifer offers good possibilities for medium-depth wells.
From 18 down to 27 m, the sequence is predominantly clayey, sometimes mixed with very coarse, angular sand.
In the resistivity logs, a thin sand layer seems to be present between 24 and 25 m depth.
Below 27 m, the recovery of the samples is very poor.
The samples from 27 m, down to the bottom of the hole are all identical. They are coarse very coarse, sub-angular subrounded sands, mixed with some fine gravel.
The resistivity logs however, show an alternation of relatively thick sand layers and clays.
According to these logs, there is a second aquifer between 33 and 43 m. The resistivity value of this sand layer, which is probably clayey in its middle parts, is 25 ohmm.
From 43 to 53 m, the resistivity is low, indicating the occurrence of clays at these depths.
A third aquifer is present between 53 and 58 m depth; its resistivity is 38 ohmm, indicating the presence of probably clean sand with ground water of a low salinity.
From 58 m to 66 m there is a clay layer again and a fourth aquifer is present from 66 to 73 m.
Below 73 m, thin layers of clay and sand alternate.

A screen was installed in the third aquifer, at depths between 53 and 58 m below ground level.
This aquifer was chosen because of its high resistivity value.
After completing and developing this well, a 23 hours pumping test was executed with a constant discharge of 11.2 l/s (DD 10).
After 1½ hours of pumping the water level almost stabilised at a drawdown of 5.13 m.
After 8½ hours of pumping however, there was a drop in water level and the maximum drawdawn after 23 hours of pumping was 5.53 m.
After shut down of the pump, a recovery test was executed.
The aquifer parameters calculated from the first part of the pumping test are:
- permeability : k = 180 m/day
- transmissivity : kD = 880 m^2/day,

However, since after 8½ hours of pumping the drawdown increased again, these values are probably only applicable to the part of the aquifer directly around the well.
The aquifer parameters, calculated from the recovery test, i.e.:
permeability : k = 60 m/day
transmissivity : kD = 270 m^2/day

are probably better approximations of these hydraulic parameters of the aquifer as a whole.

The approximate specific yield for this well is:

$$\frac{Q}{3} \cong \frac{11.2}{5.53} \cong 2.0 \text{ l/s/m}$$

Optimum operational characteristics for this well would be obtained at a drawdown of 38.8 m, hence optimum well yield would be:
38.8 x 2.0 = 77.6 l/s.

As pointed out in 3.3.2.4., the maximum allowable pumping discharge for one length of screen (16 ft) is 24 l/s, which therefore is also the maximum yield of this well.

The EC of the ground water, 65 mS/m did not change during the pumping test.
The chemical composition of the ground water is presented in Table D 3.3-2.

Summary of data

Borehole 7/79	Mbwade
date of commencement	11-1-1979
date of completion	25-1-1979
total depth	85 m
well-logging	resistivity (LN, SN), SP
aquifer	53 m - 58 m
gravel packed screen	53.0 m - 57.9 m
static water level	12.95 below collar level
pumping test	23 hours
tested yield	11.2 l/s
drawdown (max.)	5.53 m below collar level
calculated permeability	approx. 60-100 m/day
calculated transmissivity	approx. 250-500 m^2/day
specific well capacity	2.0 l/s/m
optimum well yield	24 l/s
EC ground water	65 mS/m

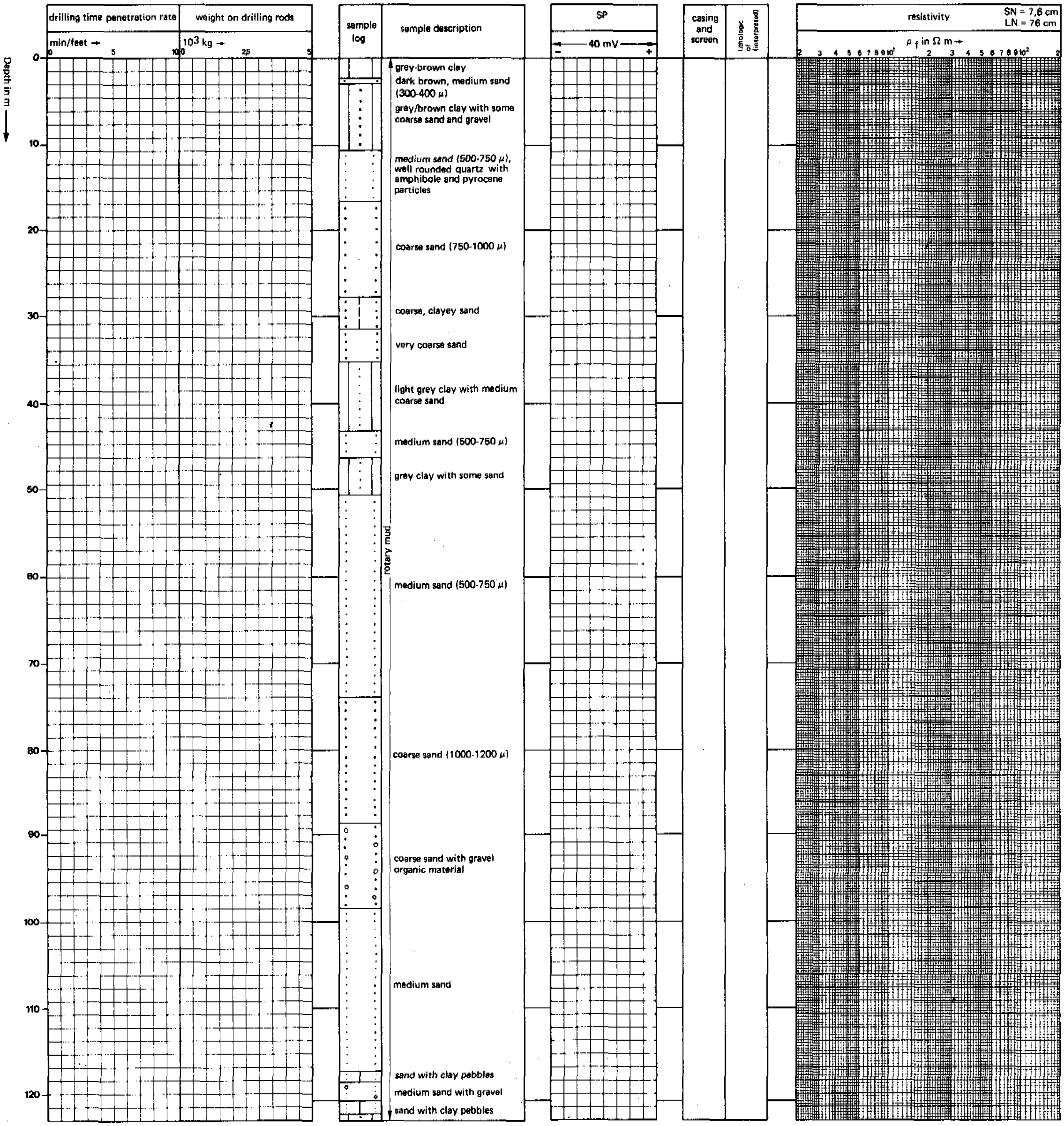
3.3.3.10. Boreholes 13/79, 24/79 and 27/79 at Madoto

(Fig. D 3.3-12, 13 and 14)

The geo-electrical detail survey, carried out near Madoto, did not indicate good or even fair prospects for ground water.
The average resistivity of the soundings in this area, varied from 7 to 10 ohmm.
Nevertheless a borehole location was chosen at sounding no. 22, because of the fact that Madoto seriously needs a water supply and shallow wells most probably are not or hardly possible here.
Borehole 13/79 was drilled down to a depth of 122 m.

Fig. D 3.3-12

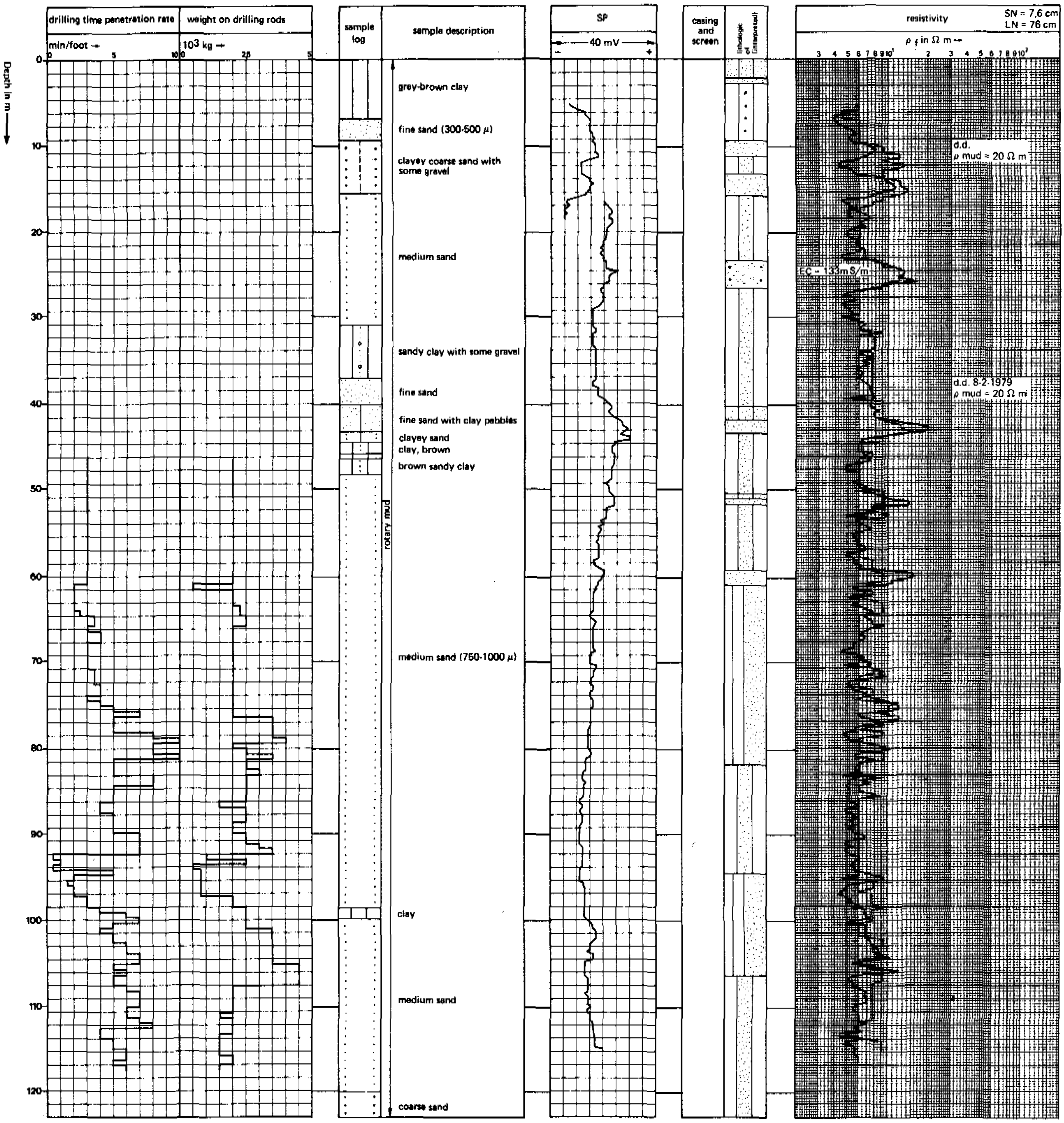
Number: 13/79
Mapsheet: 182/1
Location: Madoto
Co-ordinates: 292,9-9254,3
Elevation: 435 m above MSL



Legend: see figure D 3-3-18

Fig. D 3.3-13

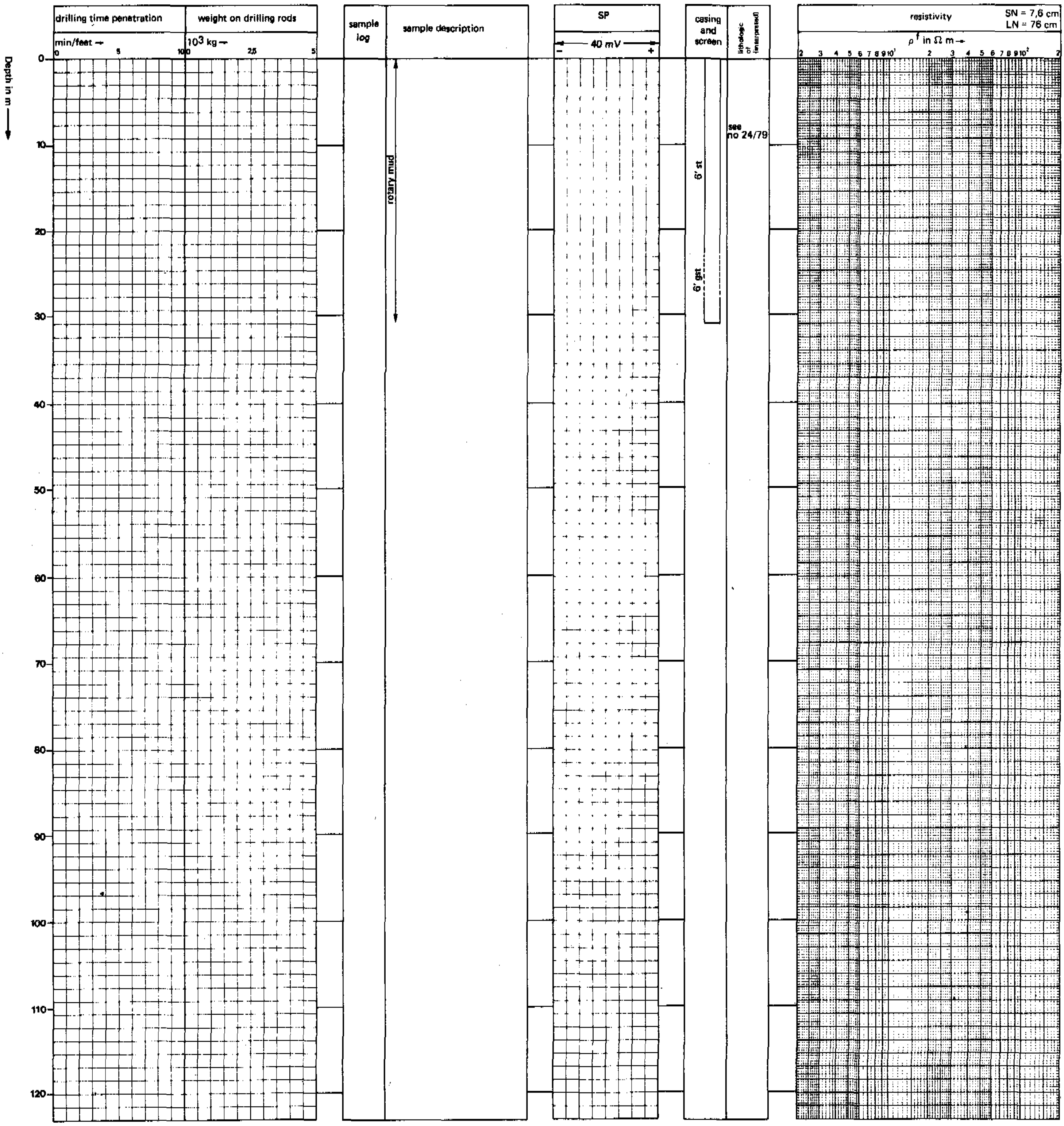
Number: 24/79
Mapsheet: 182/1
Location: Madoto
Co-ordinates: 292,9-9254,3
Elevation: 435 m above MSL



Legend: see figure D 3.3-18

Fig. D 3.3-14

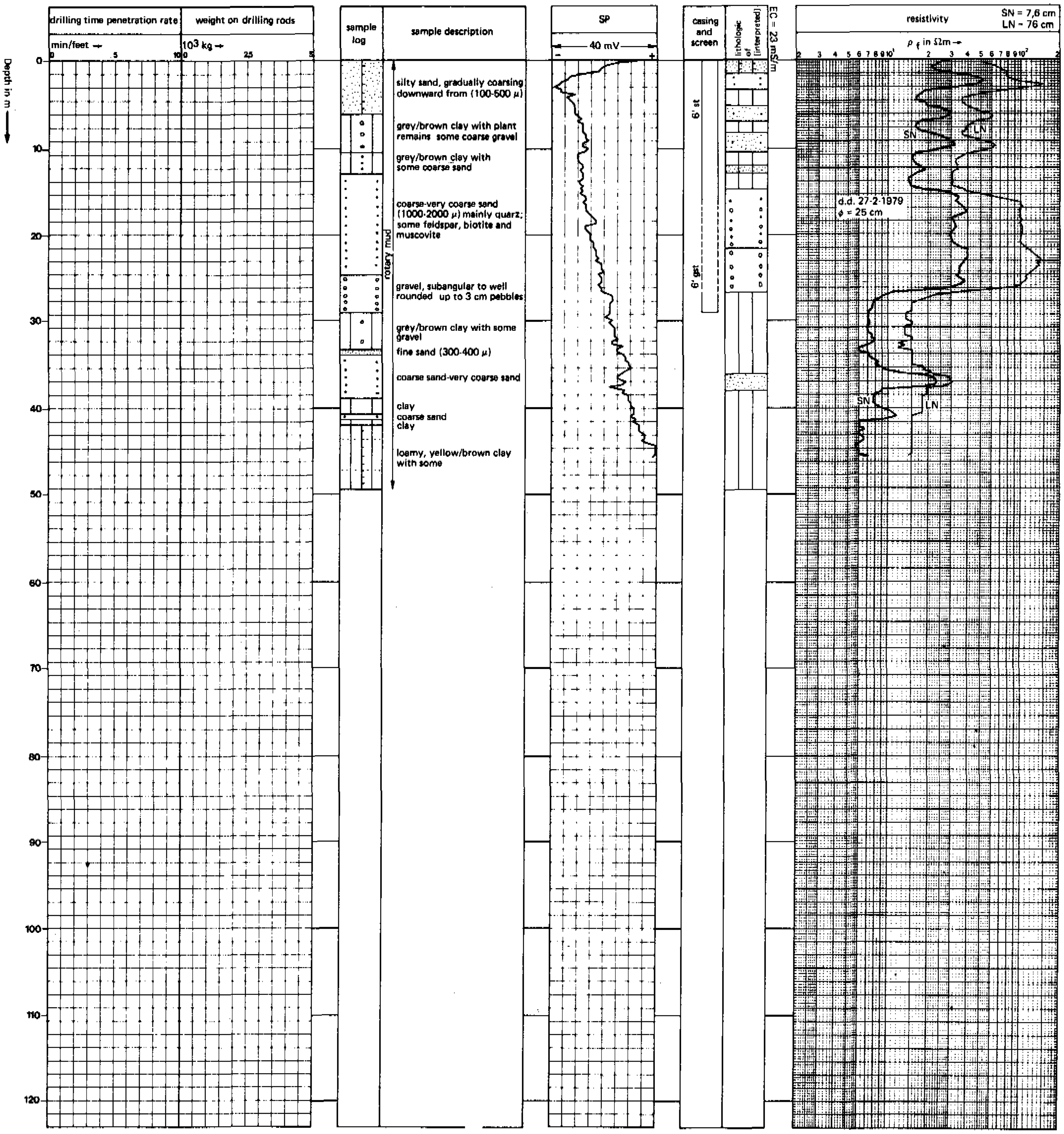
Number: 27/79
Mapsheet: 182/1
Location: Madoto
Co-ordinates: 292,9-9254,3
Elevation: 435 m above MSL



Legend: see figure D 3.3-18

Fig. D 3.3-15

Number: 28/79
Mapsheet: 183/1
Location: Rudewa-Batini
Co-ordinates: 292,7-9260,9
Elevation: 435 m above MSL



Legend: see figure D 3.3-18

Before this borehole could be well-logged, the rig sunk more than 1 m into the muddy, soft ground.
This location had to be abandoned therefore, and a second borehole, 24/79, was drilled about 10 m from 13/79.
Borehole 24/79 was also drilled, down to 122 m.
Shortly after the well-logging of this hole, the rig again sunk into the mud.
A third borehole, 27/79, was drilled therefore, to be completed as a production well. Its location is about 10 m from both 13/79 and 24/79.
In order to prevent the collapse of this borehole for the third time, it was completed immediately after drilling; no well-logging was done.
The co-ordinates of the three boreholes are: 292.9 - 9254.3, on mapsheet 182/1. The elevation is approximately 435 m above MSL.

Sample descriptions have been prepared for boreholes 13/79 and 24/79.
The recovery of the samples from both boreholes, was not good from its upper parts, and very poor from the lower parts.
A complete set of well-loggings exists only for borehole 24/79.
This borehole will be described below, as is it thought to be representative for boreholes 13/79 and 27/79 as well.

The correlation between the sample log and the well-loggings is poor for the upper 50 m, and non-existent below this depth.
From the surface, down to 90 m, there is a grey/brown clay.
Between 9 m and 13 m there are some sand layers with resistivities of not more than 15 ohmm; these layers are only 2 m thick but may offer some possibilities for shallow wells.
From 13 m, to 23 m the sequence is predominantly clayey.
An aquifer is present between 23 and 26.5 m; the resistivity is 12 ohmm, indicating the presence of ground water with a salinity between 100 and 200 mS/m most probably.
Below this level, the resistivities vary between 6 and 9 ohmm, indicating very clayey or loamy sediments, with only a few peaks representing thin (up to 1.5 m) sand layers.

A gravel packed screen was installed in the only reasonable aquifer, encountered in this borehole, between 23.0 and 27.9 m.
Part of the screen (1.4 m) is installed opposite clay layers.
After completion and development of this borehole, a pumping test was done for 16½ hours (DD 10).
The yield that could be obtained from the borehole was very low: 0.9 l/sec on an average.
Steady state was reached after some 1½ hours of pumping.
The maximum drawdown was 17.92 m.
The specific capacity of this well is $\frac{0.9}{17.92} = 0.05$ l/s/m.

The aquifer parameters, calculated from both the pumping test as well as the recovery test, are identical:

- permeability : k = 5 m/day
- transmissivity : kD = 18 m^2/day

The recovery test showed better hydraulic parameters for the aquifer in the direct surroundings of the well.
During the pumping test, the EC of the ground water changed from 200 mS/m, to 175 mS/m and a water sample taken at the end of the test and analysed in the laboratory, had an EC of 135 mS/m.
Because of the very low specific well capacity of borehole 27/79, it is not suitable for installation of a motor pump.
This well can only be completed with a hand pump.

Summary of data

Borehole 13/79	Madoto
date of commencement	26-1-1979
date of completion	31-1-1979
total depth	122 m
well-logging	not done
remarks	hole collapsed

Borehole 24/79	Madoto
date of commencement	2-2-1979
date of completion	14-2-1979
total depth	122 m
well-logging	resistivity (SN, LN), SP
remarks	hole collapsed

Borehole 27/79	Madoto
date of commencement	15-2-1979
date of completion	17-2-1979
total depth	30 m
well-logging	not done
aquifer	23.0 - 26.5 m
gravelpacked screen	23.0 - 27.9 m
static waterlevel	5.78 m below collar level
pumping test	16½ hours
tested yield	0.9 l/s
drawdown steady state	17.92 m
calculated permeability	5 m/day
calculated transmissivity	18 m^2/day
specific well capacity	0.05 l/s/m
EC ground water	135 mS/m
remarks	yield only sufficient for completion with handpump

3.3.3.11. Borehole 28/79 at Rudewa (Fig. D 3.3-15)

The geo-electrical detail survey, carried out in and around Rudewa-Batini, showed good prospects for the occurence of fresh ground water, in the upper parts of the sediments, thus at medium depth (3.2.5.11.).
Borehole 28/79 was drilled in the middle of the village of Rudewa, near the location of sounding no. 13. Its co-ordinates are 292.7 - 9260.9, on mapsheet 183/1.
The elevation of this location is approximately 435 m above MSL.
The borehole was drilled down to a detph of 44 m.
Both the well-loggings and the sample log, showed the presence of an excellent aquifer, at shallow depth. The correlation between the logs is quite good.
Between the surface, and 15 m depth, there is an alternation of clay and sand layers, 1.5 - 2 m thick; the sand layers offer good prospects for shallow ground water. The first, thick aquifer is present between 15.0 m and 26.0 m. From 15.0 to 21.0 m, the aquifer consists of coarse very coarse sand, mixed with some fine gravel; between 21.0 m and 26.0 m, there is a gravel layer made up of predominantly well rounded pebbles. The resistivity of this layer is very high. Below 26.0 m, the sequence down to the bottom of the hole is mostly clayey, with only one thin sand layer around 36 m depth.

A screen was placed between 16.5 and 26.2 m below ground level.
After completion and development of this well, a pumping test was run for 19½ hours, with a constant discharge of 10.4 l/s.
After about 45 minutes of pumping, a more of less steady state was reached (DD 10).
The maximum drawdown was very low; only 1.83 m.

The specific yield of this well is $\frac{Q}{s} = \frac{10.4}{1.83} = 5.7$ l/s/.

The optimum well yield of the borehole, which would be reached at a drawdown of 17.0 m (67% from the maximum possible drawdown in the well), thus would be 17.0 x 5.7 = 97 l/s.

The two lengths of wire wound screen that could be installed in the aquifer, however will not admit more than 48 l/s, as was explained in 3.3.2.4. and 48 l/s is therefore the maximum yield of borehole 28/79.

The aquifer parameters, calculated from the pumping test and the recovery test are:

- permeability	:	k	=	23 m/day
		k	=	36 m/day
- transmissivity	:	kD	=	260 m^2/day
		kD	=	408 m^2/day

The average permeability of the aquifer therefore is about 30 m/day and the transmissivity 330 m^2/day.

Summary of data

Borehole 28/79	Rudewa
date of commencement	22-2-1979
date of completion	28-2-1979
total depth	44 m
well-logging	resistivity (SN, LN), SP
aquifer	15.0 - 26.0 m
gravelpacked screen	16.5 - 26.2 m
static water level	5.64 m below collar level
pumping test	19½ hours
tested yield	10.4 l/s
drawdown (steady state)	1.83 m
calculated permeability	30 m/day
calculated transmissivity	330 m^2/day
specific well capacity	5.7 l/s/m
optimum well yield	48 l/s
EC of ground water	23 mS/m

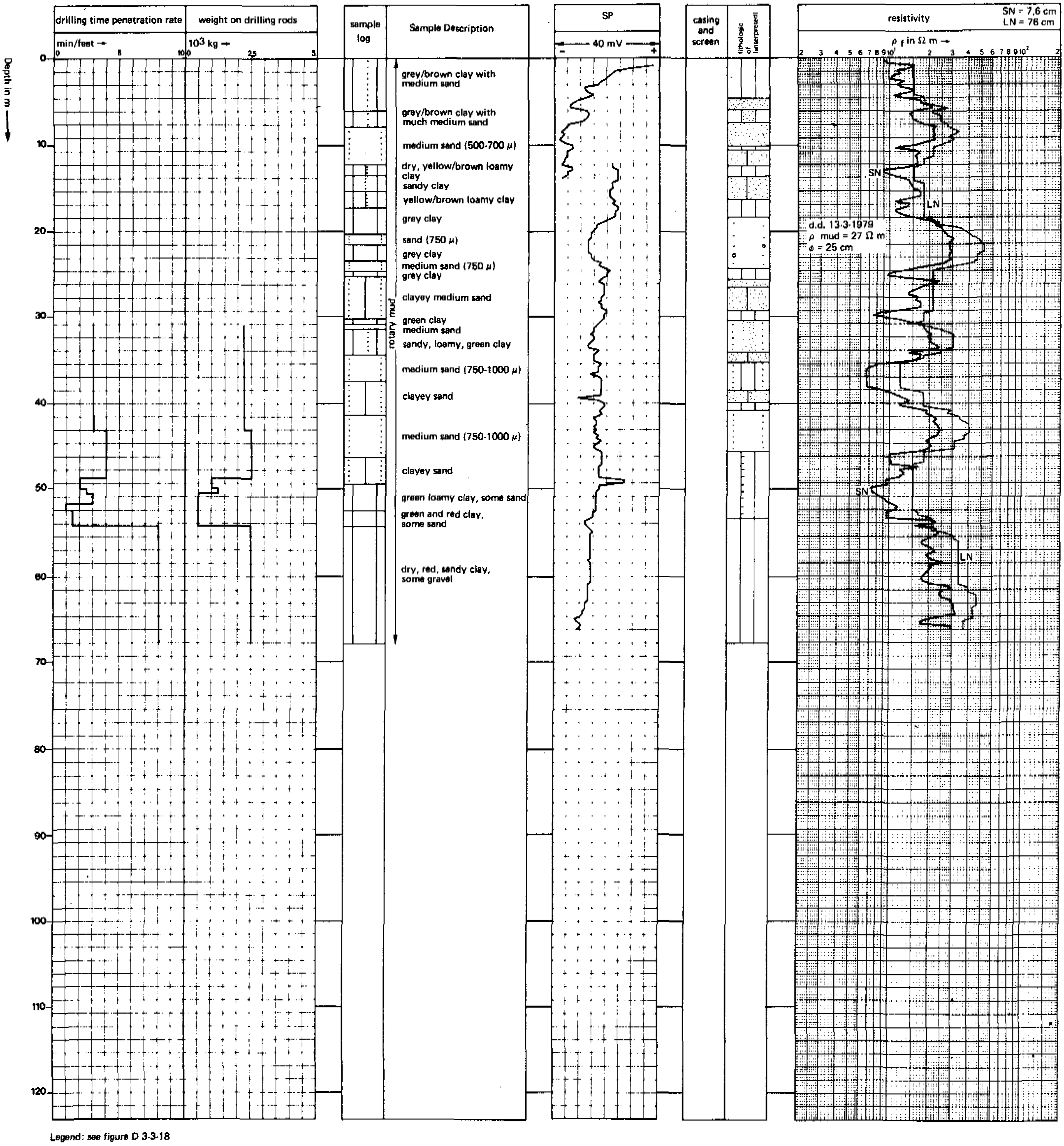
3.3.3.12. Boreholes 37/79 and 41/79 at Kondoa (Fig. D 3.3-16 and -17)

A geo-electrical detail survey, executed at Kondoa, indicated good prospects for medium-depth and deep ground water.
Borehole 37/49 was drilled at the location of sounding 44.
The co-ordinates are 284.4 - 9246.2, on mapsheet 182/3.
The elevation of the area is approximately 465 m above MSL. The borehole was drilled down to a depth of 67 m, and well-logged thereafter.
Only the correlation between the well loggings and the sample log of the upper 18 m is reasonable. Below this depth the correlation is poor, because there is a shifting of layers on the sample log, compared with the well logs.

The upper 4.5 m consist of clay and between 4.5 m and 15.8 m, the sequence is mainly composed of fine sand and clayey sand alternated with thin clay layers.
The shallow sand layers certainly offer good possibilities for wells of shallow depth.
Below 18 m, there are 3 aquifers, each about 4.3 m thick, alternated with clay layers of the same thickness.
The resistivities of the sand layers, 40-50 ohmm, indicated good prospects for the occurrence of ground water with a low salinity.

Fig. D 3.3-16

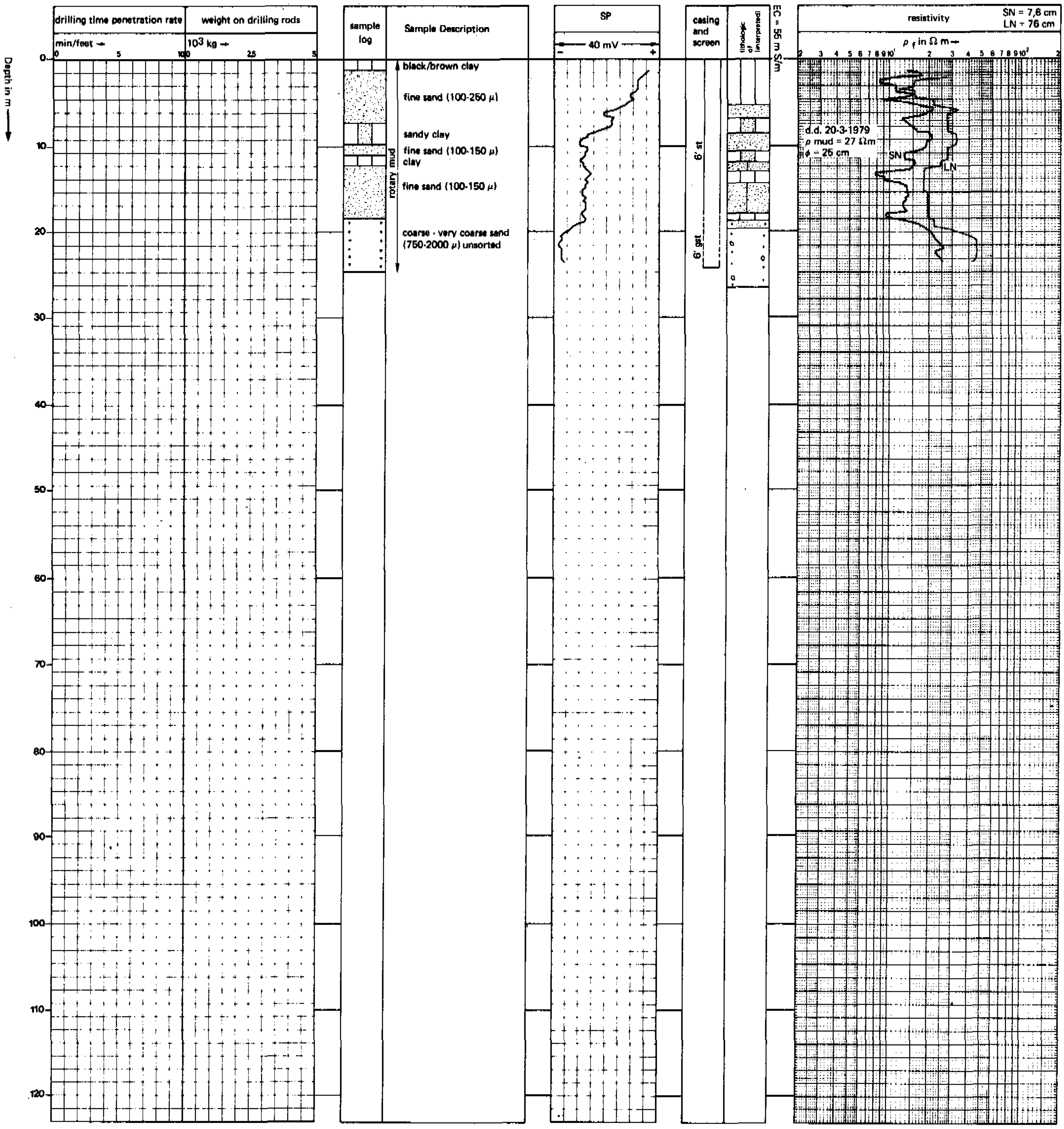
Number: 37/79
Mapsheet: 182/3
Location: Kondoa
Co-ordinates: 284,4-9246,2
Elevation: 465 m above MSL



Legend: see figure D 3-3-18

Fig. D 3.3-17

Number: 41/79
Mapsheet: 182/3
Location: Kondoa
Co-ordinates: 284,4-9246,2
Elevation: 465 m above MSL



Legend: see figure D 3-3-18

A screen was installed in borehole 37/79, between the depths of 39.9 and 44.8 m below ground level. However, even after trying to develop this well for several hours, no water would pass through the screen. Possibly the screen openings were sealed by sticky clay, while pushing the string of screen and casings down.
As was explained in 3.3.2., many clay layers encountered in the MDWSP boreholes, had the characteristics of swelling clays.
The screen and casings could not be pulled out of the borehole.
Therefore, the hole was backfilled, sealed and abandoned.

A second borehole, 41/79, was drilled about 8 m from 37/79.
Its total depth was 26 m.
A screen was installed this time, in the uppermost aquifer, at depths between 17.7 and 22.6 m.
After completion and development of the well, a pumping test was run for 12 hours, with an average discharge of 6.4 l/s.
After 12 hours of pumping, a steady state was not yet reached and it is therefore not possible to calculate the specific well capacity and the optimum yield of this well.
The aquifer parameters, calculated from the pumping test as well as the recovery test, were are respectively:

- permeability : k = 117 m/day
  k = 150 m/day
- transmissivity : kD = 465 m^2/day
  kD = 753 m^2/day

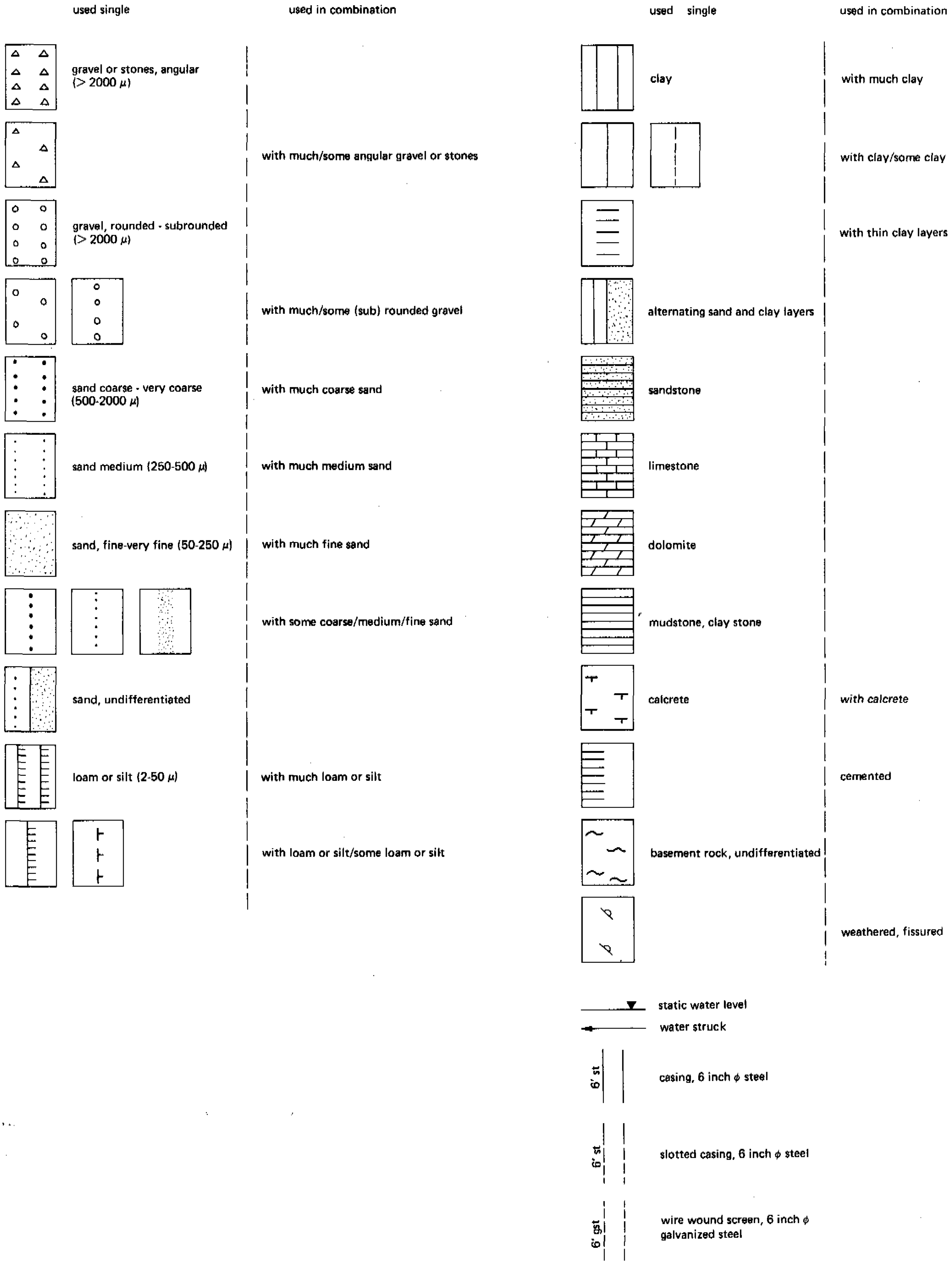
The average permeability and transmissivity for the aquifer are:
k = 130 m/day
kD = 600 m^2/day

Summary of data

Borehole 37/79	Kondoa
date of commencement	3-3-1979
date of completion	17-3-1979
total depth	67 m
well-logging	resistivity (SN, LN), SP
aquifer	40.5 - 45.1 m
gravelpacked screen	40.5 - 45.4 m
remarks	no yield, probably due to faulty construction of the well

Borehole 41/79	Kondoa
date of commencement	20-3-1979
date of completion	28-3-1979
total depth	26 m
well-logging	resistivity (SN, LN); SP
aquifer	18.9 - 25.9 below ground level

Borehole legend



4. HYDROGEOLOGICAL DESCRIPTION OF THE PROJECT AREA

4.1. Physiography and geology

4.1.1. Main geological units

The rocks in the project area can be grouped according to their age into four major divisions:

- Precambrian rocks (appr. 70% of the project area)
- Karroo rocks (appr. 6% of the project area)
- Jurassic rocks (appr. 4% of the project area)
- Tertiary/Quaternary rocks (appr. 20% of the project area)

Precambrian rocks crop out in the mountain ranges and bordering foothills in the western and northern part of the project area as well as in the Uluguru Mountains and its foothills in the central part of the project area. They crop out also locally in the area enclosed by the Uluguru Mountains and foothills and the Mkata and Wami rivers.
The rocks are mainly meta-sedimentary rocks and can be divided into three major lithological groups: acid gneisses, granulites and crystalline limestones.

The Karroo rocks occupy the area south and south-east of the Ulugurus as well as the southern most part of the Mkata Basin.
The rocks consist mainly of sandstones, siltstones and shales deposited in shallow fresh to brackish water.
Their age may vary from Permian to Triassic.

Jurassic rocks occur only in the eastern-most part of the project area. They consist of coarse sandstones, mudstones and oolitic limestones deposited in marine environments.

Sediments of upper Tertiary and Quaternary age occur in the downfaulted Mkata/Wami Basin. They are 30 m up to more than 400 m thick and were deposited in fluvial, alluvial fan and swamp environments. Probably only sediments of Holocene age are at the surface.
Limited occurrences of Quaternary fluvial deposits are found in the valleys of present rivers and streams.

4.1.2. Topography and landforms

Two mountain ranges, the Ukaguru and Usagara Mountains occupy the western part of the project area. They represent a dissected plateau landscape. The highest summits of these mountains which are over 2100 m above MSL, are thought to be remnants of the late-Jurassic peneplain.
Erosion levels between 1500 and 1900 m probably represent Cretaceous to early Tertiary surfaces.

The foothills which border these mountain ranges to the east, represent a fairly deeply dissected country, at levels between 500 and 800 m. Deep weathering has taken place over much of the area.

An undulating area studded with many inselbergs of different shapes and heights separates the Ukaguru Mountains and the Nguru Mountains in the north of the project area. This lower area is drained mainly by the Berega River.

In the northern part of the project area the Nguru Mountains rise sharply from their surroundings to elevations of more than 2000 m.
They are composed of granulites while the Ukaguru and Usagara mountains as well as the Berega area are underlain mainly by acid gneisses.
South and east of the Nguru Mountains there is a narrow zone of dissected foothills at elevations between 400 and 600 m.

The Uluguru Mountains occupy the central part of the project area.
They rise at their highest parts to more than 2600 m above sealevel.
Two high-level surfaces have been recognized in the Ulugurus.
They are separated by steep slopes of more than 1000 m, before any other erosion surfaces are reached. Remnants of the Jurassic peneplain occur in the Ulugurus at elevations of approximately 2500 m. A lower erosion surface is developed at about 1600 m. Below these plateaux, the mountains are very dissected.
The core of the Uluguru Mountains is a meta-anorthosite body, surrounded by granulites.
To the west, south and east of the high mountains there is a fairly steep drop to a highly dissected foothill zone. This zone is generally situated between 450 and 800 m with a few hills rising above this level.
The western and southern foothills are underlain mainly by acid gneisses and quartzo-fedspatic gneisses and granulites.
The foothills to the east of the Uluguru Mountains are underlain mainly by crystalline limestones.

To the north and north-east, the Uluguru Mountains descend sharply to a plain between 360 and 500 m above sealevel. This well developed erosion level, known as the Miocene peneplain, has the form of a dissected peneplain, which extends west and north of the Ulugurus, finally merging into the floodplain of the Mkata and Wami rivers.
The Ngerengere and Lukondo rivers have developed wide valleys, in this peneplain.
The surface is covered with red soil, varying in thickness from a few up to more than 20 m and has residual mountains rising sharply out of it: Mindu (1260 m), Lugallo (900 m) and Nguru ya Ndege (1360 m).
These residual hills have extensive pediments of coarse sandy soils and some superficial limestone.

To the south and east of the Uluguru Foothills extensive plains of the Ruvu and Mgeta rivers, occur.

These plains form part of the Pliocene erosion surface which cuts into rocks ranging in age from Precambrian to Jurassic. They are for the main plain covered with alluvium.
The planing of the surface by erosion was far advanced before the alluvium was deposited, leaving a smooth surface with very few hills rising from it. The surface was formed by erosion by streams grading towards the sea level at that time. Since its formation the surface has partly been raised and deformed. The level of this plain is everywhere below 300 m and the greater part is below 200 m.
This plain forms a base level for the rivers of the foothill zone and this has resulted in gorges with strong vertical relief in the foothills.

Between the foothills of the Usagara, Ukgaguru and Nguru Mountains in the west and the Miocene peneplain in the east the fault bounded SW-NE orientated Mkata/ Wami Basin is situated. The surface of this plain which slopes gently towards the NE is between 450 and 350 m above sea level.

4.1.3. Geological history and stratigraphy (see table D 4.1-1)

The Precambrian rocks of the project area belong to the Usagaran System. They are typically high-grade metamorphic rocks, mostly of sedimentary parentage. The exact age of the original sediments is still in doubt since no conclusive age determinations are yet available.
Based on a few isotopic age determinations, a tentative late-Archean age (2000-1600 m.y) has been asigned to the Usagaran sediments. The rocks have been highly metamorphosed as a result of extensive migmatisation and local granitization that occurred during periods of orogenesis in Proterozoic to probably Cambrian times.

This Mosambiquian orogeny resulted moreover in intensive regional folding, faulting and thrusting of the Usagaran rocks.
Syn-orogenic to post-orogenic intrusions of late-Archaean to Cambrian age are represented by partly metamorphosed basic and ultra-basic rocks, amphibolites, granodiorites and ortho-gneisses.
In addition to these intrusions, rocks of the Usagaran systems have been invaded by innumerable pegmatites, dykes and small bodies of rocks ranging from acid to basic in character.

Rocks of lower and middle Palaeozoic age have not been found in the whole of East Africa. This period was mainly one of erosion and peneplanation.
During the late Palaeozoic and early Mesozoic, Tanzania formed part of the super-continent Gondwanaland consisting of large parts of Africa, India, Australia and Antarctica when rocks of the Karroo system were laid down in an extensive marine or fluviatile environment.

TABLE D 4.1-1 : STRATIGRAPHICAL TABLE OF PROJECT AREA

ERA	PERIOD	EPOCH		MAIN STRATIGRAPHICAL UNITS		SEDIMENTS	MAXIMUM THICKNESS	INTRUSIVE ROCKS	CONTEMPORARY EVENTS AND CONDITIONS OF DEPOSITION
CAINOZOIC	QUATERNARY	HOLOCENE PLEISTOCENE		Alluvium Mkate/Wami beds		Alluvial clays, loams, sands, gravels	250 m	No activity	Development of present river systems and deposition of alluvium *in Mkata-Wami Basin and main river valleys* Rift and blockfaulting along pre-existing structure
	TERTIARY	PLIOCENE	UPPER	Hiatus					Erosion
			MIDDLE	Mkindu beds		Pebbly gravels	60 m		Deposition of Mkindu beds in terrestrial environment
				Hiatus					Erosion: development of Pliocene Peneplain
			LOWER					Igneous Dykes and plugs Carbonetites Basic silicate Dykes	Rejuvenation of faults and Warping
		MIOCENE OLIGOCENE EOCENE							Erosion: development Miocene Peneplain
		PALAEOCENE							Regional uplift
MESOZOIC	CRETACEUS								Erosion: development of Late Cretacaeous Peneplain Deposition of sediments in continental to marine environments, just outside the project area
	JURASSIC	UPPER JURASSIC							Erosion: development of Late-Jurassic Peneplain
				Station beds		Siltstones, calcareous sandstones reef limestones	1800 m		Marine transgression; deposition of sediments in shallow marine environments *Rejuvenation of faults that developed during the Permian and* Triassic Periods
				Oolite horizon		Oolitic limestone, calcareous sandstones	100 m		
		MIDDLE JURASSIC		Ngerangere beds		Arkosic sandstones	300 m		
		LOWER JURASSIC		Hiatus					Regional Uplift
	TRIASITIC			KARROO SYSTEM	Ruhembe beds	*Conglomeratic sandstones* mudstones	1200 m		Major faulting along margin of throughs, development of basins with partly faulted margins Deposition of sediments in continental to near-shore environments
					Gombati beds	Calcareous sandstones, carbonaceous shales	300 m	No activity	
PALAEOZOIC	PERMIAN				Ndeka beds	Feldspatic sandstones, red shales	900 m		
					Tulo beds	Varved shales, conglomeratic sandstones	1000 m		
	CARBONIFEROUS			Hiatus					Deposition, erosion and peneplanation
	DEVONIAN								
	SILURIAN								
	ORDOVICIAN								
	CAMBRIAN	UPPER CAMBRIAN							
		LOWER CAMBRIAN		USAGARAN SYSTEM		Migmatitic acid gneisses, granulites crystalline limestone and dolomite meta-igneous rocks	Not known	Granite, Granodiorites, Pyroxenites, Periodites, Gabbros, Anorthosites, Pegmatites	Mosambiquian orogeny: metamorphosis, regional folding, faulting and thrusting of rocks of Usagaran System
PRE-CAMBRIAN	PROTEROZOIC	*UPPER PROTEROZOIC*							
		LOWER PROTEROZOIC							
	ARCAEAN	UPPER ARCHAEAN						No activity	Deposition of sandstones, greywackes and limestones in geosynclinal environment

The principal tectonic events of this period were major faulting along margins of troughs and formation of basins with partly faulted margins. Faulting often ocurred along pre-existing Precambrian structures.
The Karroo rocks in the project area overlie Precambrian metamorphic rocks unconformably and are frequently preserved by down-faulting into them. The rocks are generally undisturbed except by faulting and tilting. In the SW part of the project area as much as 3000 m of sediments is inferred.
The Karroo consists of a succession of sandstones, conglomerates, mudstones, marls, limestones and thin coal seams.
In the Mvuha area, Karroo rocks consist mainly of varve-like sediments of fluvio-glacial origin.
An area affected by carbonatitic activity during post-middle Karroo times, is present in the SW foothills of the Uluguru Mountains.

Fragmentation of Gondwanaland started during mid-Jurassic times and the separation of Africa from the other continents was followed by a widespread marine transgression.
The Jurassic rocks in the project area are middle to upper Jurassic inage; they are marine sediments consisting of a succession of feldspathic sandstones, grits and limestones with local estuarine and lagunal beds.
Some rejuvenation of the faults that developed during the Karroo period occurred.
After a period of erosion and peneplenation at the end of the Jurassic, marine Cretaceous sediments were deposited in the western part of Tanzania; Cretaceous sediments are not present, however, in the project area. During the upper Cretaceous there was again a period of erosion and peneplenation, followed by a period of regional uplift at the beginning of the Tertiary.

An erosion surface was formed during the lower and middle Tertiary. This surface, which at present lies between 400 and 550 m above sea level, is a dissected peneplain. It extends west and north of Morogoro for many kms, finally merging into the flood plain of the Mkata and Wami Rivers. This peneplain, which has been referred to as the Miocene or mid-Tertiary surface is covered with a thick orange/red soil and has isolated residual mountains rising sharply out of it.

After the development of the Miocene peneplain there was a period of rejuvenation of faulting and warping.

During the early Pliocene a flat erosion surface was formed on rocks of different age. This surface which now lies between 150 and 300 m above sea level, comprises that part of the project area situated east and south of the Uluguru Mountains. Coarse gravels, known as the Mkindu beds, were deposited on the early Pliocene erosion surface during the middle part of the Pliocene.

Most of these gravels have been removed by erosion leaving only small outliers in the SW part of the project area.

Rift and block faulting along pre-existing structures started in the upper Pliocene and continued even during Holocene times. Earthquakes in the area suggest that the faulting has not yet ceased.
The Uluguru, Ukaguru and Usagara Mountains have attained much of their present elevation in late Tertiary to Recent times.
The Mkata-Wami Basin, which is a down-faulted or possibly block-faulted basin, was filled with alluvial sediments from Pliocene to Recent.

4.1.4. Description of formations (Map D 2)

4.1.4.1. Precambrian

Precambrian rocks occupy more than 60% of the project area.
They crop out in the Ukaguru and Usagara Mountains in the western part of the project area, as well as in and north of the Uluguru Mountains in the central and eastern parts of the project area. These rocks all have been assigned to the Usagaran system which is mainly of late-Archaean age.
Isotopic age determinations indicate ages in the range from 2000 m.y. to 1600 m.y. for the late-Archaean in Tanzania.
The rocks of the Usagaran System are typically high-grade metamorphic rocks, mostly of sedimentary parentage.
The sedimentary rocks and their associates are of two contrasting groups, the one a typically metamorphosed greywacke association (characteristic of eugeosynclines) and the other a limestone-quarzite association (characteristic of miogeosynclines). These two lithological associations in the Usagaran rocks are usually fairly distinct.
The rocks of the Usagaran System are extensively migmatized and one of the most common rock-types is a more or less migmatitic biotite gneiss. This migmatization is synorogenic but it is nowhere associated with large belts of synorogenic granitic rocks.
Granitic rocks are uncommon and quite subordinate to the migmatic rocks.

The Usagaran System is extensively cut by dykes, stocks, plutons and masses of a variety of intrusives ranging from anorthosites and dolerites to granites and charnokites. Ultrabasic rocks are especially common and are of several ages. All ultrabasic and basic igneous rocks display some signs of metamorphism.
The granitic and other acid and intermediate intrusives are apparently post-metamorphic and are generally regarded as late-orogenic intrusives. Most of them are probably Proterozoic in age.
Pegmatites too are very common in many parts of the Usagaran.
The most important intrusive in the Usagaran System is the meta-anorthositic complex of the Uluguru Mountains.

Table D 4.1-2 - Lithological Division of the Usagaran System in the project area

intrusive rocks meta-igneous rocks meta-sedimentary rocks	
Acid gneisses (migmatitic)	- biotite gneiss - biotite-garnet-kyanite/syllimanite gneiss - muscovite-biotite migmatite - hornblende-diopside gneiss - feldspathic quartzite
granulites	- banded pyroxene granulite - hornblende-pyroxene granulite - biotite granulite - biotite-hornblende granulite - hornblende-biotite gneiss and granulite - garnet-kyanite granulite - graphite granulite and schist
Crystalline limestones	- bedded crystalline limestone - crystalline limestone bedded with amphibolites, sharns, and horblende, gneiss and granulite - massive crystalline limestone
Ultrabasic intrusiva	meta-pyroxenite and peridotite
Basic intrusiva	meta-gabbroic rocks meta-anorthositic rocks
Intermediate-aced intrusiva	amphibolitic rocks charnockitic rocks
	granitic rocks syenitic rocks peridotitic rocks
	pegmatite and quartz veins

Acid gneisses

Biotite gneiss

The dominant type of rock in the western part of the project area is migmatitic biotite gneiss and migmatitic quartzo-feldpathic biotite gneiss, which consists essentially of quartz, oligoclase, microcline, biotite and some muscovite and garnet.
With an increase of muscovite the rock may grade locally into biotite-muscovite gneiss.
Non-migmatitic biotite gneiss occurs as remnants in the migmatitic biotite gneiss and thin bands and lenses of garnet amphibolite or hornblende gneiss are common.
The texture of the biotite gneiss group as a whole is coarse and somewhat granular.

Biotite garnet-kyanite/syllimanite gneiss

This type of gneiss is very similar to the dominant migmatitic biotite gneiss, apart from the presence of garnet and kyanite or syllimanite.

This gneiss is the characteristic rock type in the whole of the Usagara Mountains which occur in the SW part of the project area; it also crops out extensively in the area west of Rudewa and Ilonga. The typical mineral assemblage is quartz, andesine/oligaclase, biotite, garnet and kyanite or syllimanite. The rock is coarse to medium-grained and migmatitic in part.

To the north-east of the Uluguru Mountains, a belt of migmatitic biotite-garnet gneiss extends from a few km north of Kisanga, stand along the Ruvu River and continues north of the project area.
The main constituents are quartz, oligoclase, biotite, garnet, kyanite and some hornblende. The rock is well foliated with dark bands being rich in biotite.
This large area is very monotonous in rock type and strike. The general strike is NE to N with dips of about 30° to the east.

Muscovite-biotite migmatite

The inselbergs Mindu, Lugalla and Nguru ya Ndege that stand out above the peneplain to the west and north-west of Morogoro are composed largely of acid migmatites.
These rocks are banded migmatized gneisses, rich in both biotite and muscovite ranging from leucocratic quartzo-feldspathic separated from the granulites of the Uluguru Massif by the superficial deposits in the Ngerengere Valley which conceal a fault.

The mineralogy of the rocks is relatively simple, they are made up of quartz, oligoclase and flakes of biotite and muscovite. Migmatites with the same lithological assemblages as described above crop out in a north-south orientated, fault bounded zone, south of Ngerengere.

Hornblende-diopside gneiss

These meta-calcareous rocks are very variable in character and their representation on the map indicates an association rather than a rock type. They mainly occur in the western part of the project area. The common rocks in this group are hornblende-diopside gneiss, hornblende-diopside quartzite and some crystalline limestone.
The gneiss, which is migmatitic in part, may contain dolomite, calcite, scapolite, hornblende, diopside, vermicullite and talc.

Feldspathic quartzite

Feldspathic quartzite, associated with the meta-calacreous hornblende-diopside gneiss, crops out in the western part of the project area. They are harder than the surrounding rocks and usually form ridges. The rocks are light-coloured, coarse-textured and banded and may be massive or schistose.
They consist essentially of quartz, oligoclase, microcline and may contain biotite, hornblende, diopside and kyanite in addition.
They are metamorphosed sandstones and calcareous sandstones.

Granulites

The main mass of the Uluguru Mountains in the central part of the project area and the Nguru Mountains in the north, are made up of granulites.

In the Ulugurus, the lowest formation consists almost entirely of banded pyroxene granulite. Above the banded granulite lies a suite of hornblende granulites which ressemble them in many ways; within them, however, occur minor bands of graphite and biotite-rich rocks.
In the SW part of the Ulugurus the pyroxene and hornblende granulites are separated from each other by a relatively wide zone of biotite-rich granulite.

The granulites in the Nguru Mountains are also banded.
They have been subdivided into pyroxene granulites and non-pyroxene granulites containing hornblende and biotite.

Banded pyroxene granulites

A considerable area in the central part of the Uluguru Mountains, surrounding the meta-anorthositic complex has been delimited as pyroxene granulites. Pyroxene granulites also crop out extensively in the Nguru Mountains.

These rocks are typically banded into light and dark bands, due to metamorphic differentiation. Quartzo-feldspathic granulites form the light bands; the feldspar is oligoclase and other minerals are garnet, hypersthene, hornblende, biotite and diopside.
The dark granulites have a relatively high proportion of mafic minerals, garnet, diopside, hypersthene, hornblende and biotite.
The whole formation is very homogeneous and has a granular texture. These granulites represent metamorphosed greywackes.

Hornblende-pyroxene granulite

The area lying to the east of the banded pyroxene granulites in the Uluguru Mountains, is made up of hornblende-pyroxene granulites. Stratigraphically these rocks appear to be on top of the pyroxene granulites. In this lithological group of rocks, hornblende becomes more dominant at the expense of pyroxene. Biotite is more common and the banding is less pronounced. Quartz and both oligoclase as well as plagioclase are the major constituents.
The occurrence of graphitic rocks as well as marked horizons of graphitic and biotitic granulites and schists is characteristic.

Biotite granulite

Intercalated with both the pyroxene and hornblende granulites are rocks in which biotite is a dominant mineral and in the eastern part of the Uluguru Mountains, between the banded pyroxene granulites and the hornblende-pyroxene granulites there is a band of biotite granulite which possibly represents a line of thrusting or a band of weakness along which migmatization could occur. These rocks contain a greater proportion of felsic minerals than the other granulites. The amounts of pyroxene and hornblende are subordinate to biotite. Garnet, muscovite and oligoclase as well as plagioclase are common.

Biotite-hornblende granulite

This type of granulite crops out in the Nguru Mountains.
The granulite is practically devoid of pyroxene. Hornblende and/or biotite are the essential mafic minerals.
They are banded as the pyroxene granulites.

Hornblende-biotite gneiss and granulite

On the western side of the Uluguru Mountains, south of Mlela-Sanga Sanga, rocks that vary considerably occur in mineral composition but which have been grouped together. The same type of rocks is found also within and near the granulites of the Nguru Mountains.
Generally they contain pyroxene in more limited amounts than elsewhere in the granulites and hornblende and biotite are more common. Both the textures and mineral assemblages of these rocks are those of gneisses and granulites.

The rock types include migmatitic quartzo-feldspathic granulite, garnet-biotite gneiss, garnet-pyroxene-hornblende granulite, garnet-biotite gneiss and hornblende gneiss. The rock are banded and well foliated.

Graphitic granulite and schist

Graphitic gneisses, granulites and schists are conspicuous lithological types in the eastern part of the Ulugurus.
Generally the graphitic beds are between 5 and 25 m thick and they may occur at intervals throughout rock sequences with a thickness of a few hundred meters.

Garnet-kyanite granulite

A most unusual rock consisting of coarse garnet and kyanite with quartz, occurs in the eastern Ulugurus.
The body has an area of roughly 8 km^2. On weathering the garnets are left in the soils, forming garnet gravels locally.

Crystalline limestone

The crystalline limestone group consists of considerably thick layers of dolomitic and calcareous marbles, coarsely crystalline, which are in part interbedded with micaceous and hornblende schists and granulites. Rocks of this group occur in the eastern foothills of the Uluguru Mountains.
The main area is situated in the catchment areas of the Mvuha and Ruvu rivers between Mkyuyuni in the north and Bonye/Mbwade in the south. There is a second, smaller area north of Kiroka and Kiziwa. The contact between the limestone formation as a whole and the granulites, has been interpreted as a thrust-plane or slide.
The structural form of the main area is synclinal, it may, however, be an overturned anticline. Two considerably different parts have been distinguished; a thinly bedded part and a massive part.

Bedded crystalline limestone

The beds of crystalline limestone are thin and are intercalated with several other types of meta-calcareous rocks.
The proportion of calcite to dolomite varies greatly. Generally they contain more calcite than the more massive marbles. Dominant mineral assemblages are: calcite or dolomite, phlogopite-tremolite-quartz-graphite or dolomite-forsterite-calcite.

Crystalline limestones, interbedded with amphibolite, sharns, gneiss and granulite

This group of rocks has been distinguished from the former, because of the higher proportion of meta-calcareous rocks other than crystalline limestone. The meta-calcareous rocks and amphibolites associated with bedded marbles are a highly assorted group of rocks.

Meta-calcareous biotite gneisses are very varied in composition and degree of migmatization. The granulite bands include quartz granulite, garnet granulite and pyroxene granulite. The amphibolites are rich in hornblende and contain oligoclase and some biotite and garnet.

Massive crystalline limestones

This part of the crystalline limestones consists largely of pure dolomitic marble.

Other minerals may occur in subordinate amounts and the commonest assemblage is dolomite, quartz, graphite and diopside.

The rocks interbedded with the massive marbles are very subordinate in amount.

In general they are calc-silicate granulites and gneisses with hornblende, biotite, muscovite, garnet and kyanite.

Meta-igneous rocks

Meta-ultrabasic rocks

Small, bodies of meta-ultrabasic rocks occur throughout the area.

They usually are composed of hornblende, dipside and hypersthene with occasional garnet. They include meta-pyroxenite, meta-peridotites and anthrophylite-tremolite-actinolite-chlorite schists.

Meta-gabbroic rocks

These rocks include metamorphosed, basic intrusive bodies, which are clearly derived from gabbroic rocks.

Some of them have been metamorphosed to amphibolites of various types, others partly to basic granulites and gneisses.

Other basic intrusions occur as dykes or sills in the acid gneiss formations; they are meta-dolerites and garnet-pyroxene amphibolites.

Meta-anorthositic rocks

The Uluguru meta-anorthosite is the most conspiuous of the meta-igneous occurrences in the project area.

This rock is composed entirely of meta-anorthosite and meta-gabbroic anorthosite. Smaller meta-anorthositic bodies occur south of Melela, west of the Uluguru.
The feldspar which forms the bulk of this rock is labradorite. Other minerals include garnet, diopside, scapolite, spinel, hypersthene, iron or and sphene.

Amphibolitic rocks

Meta-igneous amphibolites of intermediate to acid composition crop out extensively in the Ukaguru Mountains in the central-western part of the project area.
Locally they appear to be associated with granitic intrusiva. They are garnet-pyroxene amphibolites and have been subject to migmatization.

Charnockitic rocks

Rocks of charnockitic affinities are found in two areas of outcrop in the Nguru Mountains; they are mostly acid to intermediate in nature. Charnockitic rocks crop out also in the Uluguru Mountains where they are intermediate to basic.
The mineralogy of these rocks is very similar to that of the surrounding granulites. They are hornfelsic rocks, sometimes lightly banded, with medium, even grained minerals.

Intrusive rocks

Granitic and syenitic rocks

This group of rocks includes gneissoid granite and granodiorite as well as gneissic hornblende syenite and graphite syenite. They crop out extensively in the Ukaguru Mountains, south of the Berega Syncline. The granitic rocks generally are coarse-textured and pegmatitic in character. These plutonic rocks were intruded after the regional migmatization and are of late-Usagaran age.

Peridotitic rocks

West of Msowero outcrops can be found of intrusive, coarse-grained peridotite composed of olivine and pyroxene with biotite, hornblende and iron ore.
Part of these rocks are metamorphosed, fine grained kentallenites with a mineralogical composition consisting of pyroxene, biotite, olivine and albite. These intrusions are younger than the syenite complex near Msowero, unlike the peridotitic rocks.

Pegmatite and quartz veins

Pegmatites, pegmatitic quartz and quartz veins are widely spread over the area. They often intruded along joint planes.
These intrusions are connected with shearing and fault movements.
They are believed to be of late Usagaran age.

4.1.4.2 Karroo

Rocks ranging in age from Permian and perhaps uppermost Carboniferous, to Trias and in some places to the lower part of the Jurassic, crop out in the southwestern and southeastern part of the project area. These rocks belong to the Karroo system.
The Karroo rocks in the project area consist mainly of sandstones, frequently coarse-grained, with minor amounts of argillaceous deposits. These sediments which are at least 3000 m thick, belong to the coastal facies of the Karroo and were deposited for the most part in shallow fresh or brackish water.

Karroo rocks in the SW part of the project area

The Karroo rocks in the south-western part of the project area were deposited in a narrow, north-south orientated, fault bounded rift depression or in a fault angle in an area of westerly tilted block-faulting, between the Precambrian Usagara and Uluguru massifs.
This outcrops of Karroo rocks extends from the main road through Mikumi National Park in the north, to the Great Ruaha River in the south.
Much of the Karroo rock is covered with thin alluvium. At the northern end of the outcrop, the rocks are covered by Quaternary deposits of the Mkata River System. It is not know how far north the Karroo rocks extend under the younger unconsolidated sediments of the Mkata/Wami Basin.
In the soouthern part of this area of outcrop, the beds have a uniform dip of 18 to 20 degrees to the west and are cut by relatively few SW-NE striking faults.
In the northern part of this area of outcrop, the beds dip more steeply, 20 up to 40 degrees, to the west and north-west and are more affected by faulting. The beds are in a normal position, hence the sequence from older to younger beds is from the east to the west. Three lithological units have been recognized in the south-western outcrop area.

The Ndeke Beds, the oldest beds which are a 600-900 m thick sequence of poorly sorted, often conglomeratic arkoses with some interbedded thin shales; usually reddish or brownish in colour.
The Gombati Beds which lay conformably on the Ndeke Beds and consist of about 300 m of fine-grained sandstones and siltstones.
The Ruhembe Beds, the youngest formation consisting of a 1000 to 1200 m thick series of unsorted gritt and massive sandstone, often conglomeratic, with some thin intercalated shales.

They rest inconformably on the Gombati Beds.

The Ndeke Beds

The lowest Karroo sediments rest on a surface of decomposed Precambrian rocks and consist of detritus derived from the weathered and eroded gneiss, transported only a short distance before deposition.
The lower Ndeke Beds consist of relatively soft, coarse sandstones, usually conglomeratic, interbedded with red-brown to purplish mudstone. The sediments are poorly sorted and poorly bedded. The middle part of the Ndeke Beds consists of massive, pale brown, coarse grained, highly feldspathic sandstone. The upper part consists of the same coarse, highly feldspathic sandstones as the middle part, but is grey-green coloured and alternating with thin black shale layers.

The Gombati Beds

The Gombati Beds are usually dark coloured, often nodular and sometimes calcareous or carbonaceous. At several horizons, sediment structures indicating deposition in shallow water are apparent and plant remains are common; fresh water molluscs have been recorded also. The lower part of these beds consists mainly of black silty shale with only a few beds of coarse silty sandstones. There are layers of hard, black calcareous shale.
The middle part of the Gombati Beds mainly consist of silty sandstone with only some shale layers.
The upper part again consists mainly of black silty shales alternating with some thin beds of black dolomitic limestone and calcareous sandstone.

The Ruhembe Beds

These beds are unconformably on the underlying Gombati Beds. The unconformity is not marked by any change in dip, but its presence is shown by fragments of the upper Gombati Beds in conglomeratic beds at the base of the Ruhembe Beds.

Mollusc remains have been found in two horizons of the Ruhembe Beds.
The lower part of the Ruhembe Beds consists of fine to coarse-grained feldspathic, calcareous sandstone, interbedded with dark grey shales, black calcareous mudstones and soft olive-green coloured mudstones.
The top of the lower part of the Ruhembe Beds is marine.
The middle part of the Ruhembe Beds consists mainly of coarse and medium grained, grey-geen feldspathic sandstone the base of which is conglomeratic.

The upper part consists mainly of fine-grained sandstones and siltstones with some coarse sandstone and argillaceous sediments; at the base the strata are red coloured; above they are grey-green to olive-green.

Karroo rocks in the upper Ruvu catchment area

This outcrop extends for 50 km in a NNW to SSE direction and has a width of about 15 km.

The Karroo beds are faulted against basement rocks in the west, north and east and in the south they are covered by alluvium of the Mgeta plain. Most of this outcrop area is a very flat, drift-covered plain in which the rocks are poorly exposed.

The Karroo of this area consists largely of very coarse sandstones and green shales; fine sandstones and siltstones occur also.

This sequence, named the Tulo Beds, was laid down in a basin bounded in the west by the eastern foothills of the Uluguru Mountains and in the east by low hills of acid gneiss.

The Tulo Beds are gently folded and faulted but in general the dip is 5-15 degrees to the west and north-west, toward the hinge line of the basin, marked by the eastern Uluguru boundary fault.

The Tulo Beds

The Tulo Beds have a normal position hence the oldest beds are in the east and the youngest in the west.

The total thickness of the Tulo Beds is more than 1000 m.

The oldest beds are about 200 m thick and consist of dark green varved shales and siltstones interbedded with some medium and coarse-grained sandstones. On top of these beds 250 m thick, hard, massive sandstones occur; they are very coarse-textured, feldspathic and contain small pebbles of quartz, feldspar and dolomite.

The next sequence of beds which is about 300 m thick, consists again of grey-green varved shales and siltstones, interbedded with fine and medium-grained sandstone.

The youngest Tulo Beds are very coarse conglomeratic sandstones and fine gravels, alternating with some green, varved shales.

The most abundant constituent of the sandstones and gravels is dolomite, in large angular fragments. These debrital graines of dolomite have been derived from the massive beds of white, coarse-grained dolomite limestones of the basement system, which outcrop extensively on the eastern side of the Uluguru Mountains.

The nature of the sediments of the Tulo Beds suggest that they are glacial deposits. This is indicated by the varves of the fine sediments, the poor sorting of the coarse sediments and the absence of organic remains.

The Tulo Beds are thought to be older than any of the other Karroo sediments in the project area. Their age is probably upper Carboniferous or lower Permian.

Karroo rocks south-east and north-east of the Mgeta plain

Karroo rocks crop out in the area south-east and north-east of the Mgeta plain. This area of Karroo outcrop is separated from the Karroo rocks in the Upper Ruvu catchment area by an upfaulted block of basement rock. The Karroo beds in this area have an easterly dip of about 10 degrees; their position is normal. To the west they are faulted against rocks of the Precambrian basement; to the east they dip under beds of middle Jurassic age and to the north a dip fault, with the down thrown side to the north, brings down Jurassic beds against them. The Karroo beds consist of a thick sequence of uniform medium-grained, feldspathic sandstones. The colour is pinkish-brown to greenish-grey. Most of the sandstone is massive. A few beds have a calcite matric and near the top some conglomeratic beds occur.

The total thickness of these beds is more than 1500 m. This group of massive, medium-grained sandstones can probably be correlated with the upper part of the Ruhembe beds which occurs in the SW part of the project area. The age of these beds may therefore be upper Permian to Trias.

Karroo rocks in the south-eastern corner of the project area

Karroo rocks crop out in the area north of the Great Ruaha River, west and north of the Rufiji River and south of the Mgeta Plain.

Towards the west these Karroo beds, which are mainly sandstones, are faulted against the basement rocks. The structure of the Karroo rocks in this area is different from that of the other areas described before. The beds are folded into a series of anticlines and synclines with their axes extending in a direction slightly east of north.

These folded rocks are cut by numerous faults of small throw, with a uniform direction of 140 degrees. The main fold is the wide, shallow Natumbula syncline, the axis of which follows the west bank of the Rufiji River. The total sequence of the Karroo beds in this area is at least 700 m thick.

From top to bottom the following types of rock have been distinguished:

- Massive, brownish, fine-grained sandstone and thinly bedded, reddish micaceous sandstone. About 300 m thick.
- Laminated grey-brown and olive coloured, fine-grained, micaceous sandstone; light coloured compact sandstone. About 100 m thick.
- Massive light-grey, coarse-grained, arkosic sandstone alternating with green shales; compact, laminated calcareous sandstone. About 150 m thick.
- Green sandy shales. Dense, grey-green sandstone and grey to white fine-grained sandstone. About 50 m thick.
- Coarse-grained, light coloured, dense sandstone and dark grey, fine-grained micaceous sandstone. About 100 m thick.

Although there are differences in lithology between the two areas, the Karroo succession in this area can probably be correlated with the Karroo succession in the SW part of the project area.

The outstanding difference between the outcrops in both areas is the absence in the area just described, of thick beds of black, silty shale.

4.1.4.3. Jurassic

Rocks of Jurassic age crop out only in the eastern part of the project area, from the Ruvu River in the south, to beyond the Ngerengere River in the north. The contact of the Jurassic sediments with the metamorphic basement is partly a fault, partly an unconformity. At the south-western limit of their outcrop they rest unconformably against and on rocks of the Karroo formation. The Jurassic beds are almost entirely marine; the sediments close to the contact with basement and Karroo rocks are of shallow-water origin, often of shore-line facies.
The dip of the beds is towards the east. The dip is steepest, about 10 degrees, near Kidugalo and decreases to the north and south. Average dip of the Jurassic is 5 degrees.
East of Ngerengere the Jurassic rocks are folded into an anticline with a north-east to south-west axis. The western outcrops of the rocks are crossed by several faults, most of which have a north-west to southeast strike.

At the base is a series of almost non-fossiliferous coarse sandstones which have been called the Ngerengere Beds; they are more than 300 m thick in the south and about 500 m thick in the area of Ngerengere. Overlying the Ngerengere Beds are hard, oolitic limestones which stand out along their outcrop to form a ridge which extends from 10 km north of Kidugalo, to the Ruvu River. The ridge is offset at many places by north-west to south-east striking faults. The main oolitic limestone is about 30 m thick. Above the oolitic limestone a group of beds occurs called the Station Beds consisting of siltstones, sandstones and marls.

The Ngerengere Beds

The Ngerengere Beds embrace all the sediments lying below the Oölite Horizon.
In the Ngerengere area they include grey, brownish and reddish, current-bedded, arkosic, coarse and medium-grained sandstones and grits with conglomeratic bands, fine-grained whitish sandstones and reddish-brown to greenish sandy siltstones.
The pebbles and cobbles in the conglomeratic sandstones are made up of gneiss and quartz. In its upper part, occasionally thin limestone and oolitic bands occur. In the Ruvu area the Ngerengere Beds consist mainly of very coarse, in places calcareous, conglomeratic sandstones.
They are poorly sorted, consisting of a mixture of all grades of sand with pebbles and boulders. Many pebbles are composed of single feldspar crystals, most probably derived from the Uluguru Mountains.
Pebbles of medium-grained sandstone are derived from the underlying Karroo sandstones.

The exact age of the Ngerengere Beds is uncertain but probably ranges from Lias to lower Bajocian. They generally give rise to fairly sandy soils.

The Oölite Horizon

There is a gradual transition from the upper Ngerengere Beds which are mainly sandstones, to the limestones of the Oölite Horizon, with an intermediate zone of calcareous sandstone. The Oölite horizon consists of a sequence within which white, grey and bluish, oölitic and pisolitic limestones are prominent among other hard beds of calcareous sandstone and grit.

In the south of the area individual bands of oölite, thinner than those in the north, occur over a greater total thickness of strata. The Oölite Horizon is of Bajocian age.
Generally reddish, fine sandy soils occur on top of it.

The Station Beds

In most of the area the Station Beds overlie the Oölite Horizon with conformity. Locally, however, they rest unconformably on the Ngerengere Beds or overlap on the metamorphic basement.
The Station Beds in the area of Kidugallo are largely siltstones and fine sandstones. Further south, quite massive, medium and coarse-grained, brown sandstones occur, alternating with some argillaceous limestones.
Litoral deposits of the cycle of sedimentation producing the Station Beds occur locally. They consist of reef limestones sometimes autobrecciated, with calcareous sandstones and thin siltstone intercalations underlain in places by conglomerates.
The Station Beds are Bajocian in their lower part, but probably pass up into the Bathonian. They give rise to rather heavy, poorly drained, brown, clay soils which are intensively cultivated.

4.1.4.4. Tertiary

Coarse pebbly gravels occur in the SE part of the project area. These gravels, which are known as the Mkindu Beds, were deposited on the Pliocene peneplain, most probably during the late Pliocene.
The thickness of the gravels varies from less than 15 m to about 45 m. Parts of this deposit have been removed by erosion, leaving only a thin layer of gravels on the watersheds of the Pliocene peneplain.
The Mkindu Beds consist of an unsorted and unstratified mass of coarse gravel, containing abundant well-rounded pebbles and small boulders.
The gravel is poorly cemented and because of this the material is highly porous and permeable.
The gravels have been deposited by torrential braided streams decending from the surrounding mountains and spreading over the flat erosion surface.

The nature of the sediment suggest that the climate at the time of deposition was arid.

4.1.4.5. Tertiary-Quaternary

Sediments of Tertiary to Quaternary age, occur in the Mkata-Wami Basin, which is a tectonical valley, bounded by major faults.
The sediment fill is thickest in the SW part of the basin, where more than 400 m of sediment occur.
Towards the east and north-east, the sediments thin out gradually; west of Mkata and east of Mvumi the sediments covering the basement are about 200 m thick. In the northern part of the basin the sediments gradually thin out to less than 50 m but more than 200 m of sediments occur in narrow troughs north of Mandela and Dibamba.
The surface of the basin slopes gently towards the N and NE in the southern part of the basin, and towards the east in its central and northern parts. Hence the sediment fill is more or less wedge-shaped, being thickest in the SE and thinnest in the NW.

The stratography of the sediments has never been studied and therefore the exact age of the sediments is not known.
It is assumed that the oldest sediments in the basin are of Pliocene age because the major tectonic movements along the rift faults started at that time. However, since the faults were already active in Palaeozoic times, it is not unthinkable that sediments older than the Pliocene occur in the deeper parts of the basin.

The sediments that filled the basin were derived mainly from the western mountain ranges: the Nguru, Ukaguru and Usagara Mountains. The coarsest sediments, sands and gravels, were deposited along the western boundary of the basin.
The major rivers draining the western mountains build up extensive alluvial fans which contain relatively much coarse-grained sediments. These alluvial fans thin out rapidly towards the east and in the central and eastern parts of the basin, predominantly fine-grained material was deposited with sands occurring only locally in burried channels.
Coarse sands and gravels occur also in the zones, directly west of the eastern rift fault.
At Dakawa boreholes 135A, B, C/78 struck relatively thick sands and gravels, deposited by the Wami River which at present flows along the eastern rift fault.

4.1.4.6. Superficial deposits

Red-Orange/brown soils

The most extensive of the superficial deposits are the red-orange/brown coloured soils that occupy the plains north and north-west of the Uluguru Mountains. Formation of these soils started after the development of the Miocene peneplain.

The thickness of the soil varies considerably from place to place. At Masimbu railway station, borehole 1/40 has been reported to pass through more than 30 m of red soil before reaching hard rock; this is in sharp contrast to the 3-6 m of red soil covering the basement rock in the area of Morogoro, Tungi and Pangawe.

The area shown on the geological map as red-orange brown soil is made up of various soil types, but red-orange/brown soils are the predominant feature.

The soils usually are sandy loams with a fairly high content of clay. Because of the very high degree of chemical weathering, it has not been possible up to now, to determine exactly the geological character of the original material.

It is assumed that the soils represent deeply weathered residual, eluvial and colluvial material.

The soils rest on metamorphic rocks in various states of weathering.

At places, calcrete horizons are found within, or underlying the soil. The occurrence of these superficial limestones points to periods of high evaporation.

Slopewash deposits

Small areas of light-yellow or grey, very sandy deposits occur mainly as pediments of the inselbergs in the area west of Morogoro as well as north of the Nguru Mountains.

These deposits are confined to the lower slopes of these inselbergs, which consist of migmatitic gneiss, and are the results of deposition by the torrential run-off from these hills during heavy rains.

The slopewash sediments are up to 8 m thick and include sands, loamy sands and loams; angular gravelly material locally occurs in its lower parts.

The deposits rest on gneiss, in various stages of weathering.

Alluvial deposits

Alluvial sands, loams, clays and gravels occur in and along many rivers and streams.

All major rivers have thick and extensive alluvial deposits where their courses cross the plains and the larger rivers even have fairly extensive deposits in their mountains tracts.

The Mgeta River, south and southeast of the Uluguru Mountains has deposited alluvial sediments in a large area.
The usually sandy to gravelly channel fills of recent river beds in the mountainous areas, are up to 10 m thick.
Flood plain deposits and fluvial terraces bordering many of the rivers are clayey to sandy and up to 20 m thick.

4.1.5. Structures

4.1.5.1. Main Structures

The dominant structure of the area is one of rift and block faulting which occurred mainly during upper-Tertiary and Quaternary times along pre-existing Precambrian structures.
From west to east the area can be roughly divided into four main structural blocks, bounded by NNE to SSW striking major faults: an uplifted mountain block, the downfaulted Mkata Wami Basin, the uplifted Uluguru block and the downfaulted area east of the eastern Uluguru boundary fault.

In the western part of the project area the uplifted Precambrian Usagara, Ukaguru and Nguru Massifs are bounded to the east by a major fault.
This boundary fault is a normal fault with an easterly dip.
South of Mikumi the dip of this fault is as low as 30°; north of this area the dip is steeper. This major fault can be traced locally by a zone of silicification and shearing.
The western and eastern edges of the Uluguru Mountain block are bounded by very prominent normal faults which are probably of early-Karroo age but have been active up to recent times.
These faults continue north of the Mountain block in NE direction.

The generally downfaulted area east of the Uluguru block is divided by two NS striking major faults in a westerly downfaulted basin filled with Karroo sediments, a central uplifted Precambrian block and an easterly downfaulted area underlain by Karroo, Jurassic and younger sediments.

4.1.5.2. General structures of the Usagara and Ukaguru Mountains and foothills

In general the foliation dips in the gneisses are relatively shallow and easterly or westerly, but local swings occur.
These characteristic low dips indicate only slight folding.
However, there is evidence of overfolds and imbrication in the southern part of the Ukaguru Mountains and the Usagaran rocks as a whole may contain large scale overtwined folds and thrusts.
In the northern part of the Ukaguru Mountains a broad complex anticlinal structure is present striking SE-NW.

The sharply downfaulted ring complex in the SW part of the Ukaguru is thought to be a metamorphozed carbonatite ring complex of Precambrian age.
The faults in this area are probably of Precambrian origin as is indicated by the presence of sheared and epidotized pegmatites and vermiculite schists which are typical of Precambrian faults and shears.

4.1.5.3. General structures of the Nguru Mountains and foothills

Major faults surround the Nguru mountain block.
These faults are related to the period of main rifting formation and block faulting. They are characterized by silicification and potassium enrichment.
The regional foliation in the Nguru Mountains has a general trend of SSE-NNW and its dip is either to the east or to the west.
The regional foliation is interrupted locally due to intense migmatization. The folding is of the plunging isoclinal type.

4.1.5.4. General structures of the Berega area

In between the Usagara Mountains in the SW and the Nguru Mountains in the NE, the Precambrian gneisses are folded into a broad synclinal complex. The folding is gentle with strikes between east-west and southeast-north-west.
There is no evidence of major faults in the area but minor faults and shear zones occur locally.

4.1.5.5. General structures of the Uluguru Mountains and foothills

Major faults surround the uplifted Uluguru block. The mountains show complex and intense folding and faulting.
Rocks forming the main mountain mass of the Ulugurus trend generally north-south to NNE-SSW; the whole mass being tilted gently towards the east.
The eastern side of the mountains is composed of a series of thrust masses which have been thrust over the tilted block.
The bands of migmatized biotite granulite and graphite schists are representing planes of thrust. The eastern part of the mountains has many strongly developed east-west tear faults of younger age than the thrusting.
The crystalline marbles west of the eastern Uluguru boundary fault are folded into a prominent syncline which may also be an overfolded anticline; minor anticlinal and synclinal folds occur in the southern part of this syncline and the whole is cut by faults and overthrusts.
The crystalline marbles north of Kiroka are folded into a broad, east-west striking syncline. The SW part of the mountain mass is dominated by a series of shearzones trending NE to north.

The foliation in the western foothills of the Ulugurus generally dips to the east. This foliation has been imposed during large scale overfolding in Precambrian times.
There are prominent sets of fractures, striking about NW-SE.

4.1.5.1. General structures of the area north of the Uluguru Mountains

This gently sloping area is largely covered with thick red soils which conceal most of the structures.
The migmatites that crop out in the inselbergs north and west of Morogoro, dip gently to the east or SE.

4.1.5.7. General structures of the Karroo in the southern part of the

The Karroo rocks in this area were deposited in a narrow, north-south orientated graben. The sediments are in a normal position and dip towards the west to NW. In the south of this area the dips are between 18 and 20°, in the northern part, the dip is up to 40°.
The Karroo is only slightly affected by faulting.

4.1.5.8. General structures of the Karroo in the basin east of the Uluguru Mountains

The Karroo rocks occur in a NNE-SSW orientated basin, bounded by major faults.
The rocks are gently folded and faulted but in general the dip is 5-15 degrees to the west and NW, toward the hinge line of the basin, marked by the eastern Uluguru boundary fault.

4.1.5.9. General structures of the Karroo in the south-eastern part of the project area

The Karroo rocks of this area are faulted towards the west against Precambrian rocks. The rocks are folded into a series of anticlines and synclines with their axes in a NNE-SSW direction. These folds are cut by numerous faults with a NW-SE strike direction.

4.1.5.10. General structures of the Jurassic

The contact with the basement and Karroo rocks in the west is partly faulted. The dip of the beds is towards the east; the average dip is 5 degrees. The western part of the rocks are crossed by several faults, most of which have a WNW-ESE direction.

4.1.5.11. General structures of the Mkata-Wami Basin

The Mkata-Wami Basin is an elongated tectonical valley, bounded by approximately parallell running normal faults.
The strike of the main faults, delimiting this basin is NNE-SSW.
The most pronounced fault is the western boundary fault for which the name "Wami Rift Fault" has been introduced in this report. The total vertical throw along this fault is at least 1000 m. Movements along this fault were not only in a vertical direction. The drawdown block rotated slightly along an imaginary WNW-ESE axis, bringing the NNW part of the downthrown block upward and the SSW part downward (see below).

The result of this tilting is demonstrated by the contours representing the surface of the down thrown basement block above MSL (see general map of the region).
In the area around Kimamba in the SW part of the valley, the buried surface of the basement is less than 100 m above MSL; in the NE part of the valley, the surface of the buried basement is 300-350 m above MSL.
Antithetical as well as synthetical step faults and adventive faults accompany the Wami Rift Fault.

The eastern boundary of the Mkata-Wami Basin is much less pronounced than the western boundary because there is no escarpment. The throw along the eastern rift fault is probably much less than along the Wami Rift Fault. The structures delimiting the basin towards the south are not known; south of Mikumi village, rocks of the Karroo system crop out in the southern extension of the rift valley.

4.1.6. Thermal Springs

Thermal springs occur at two places along the fault system that extends from south of the Ulugurus to the Great Ruaha River.
The fault system is characterized by carbonation and silicification.
Agate-like pebbles in the Mkindu Beds derived from siliceous thermal springs deposits indicate that the springs were active already before the Pliocene. The biggest thermal spring is Maji ya Weta, 6 km south of Kiaki Kituoni.
Small mounds of calcareous sinter have been built up around the mouths of the spring.

The discharge is 25 l/S; it also discharges gas and the temperature is quite high, 72°C.
The analysis of the water and gas is given below.

Table D 4.1-3 Analysis of water and gas of the Maji ya Weta Thermal Spring

	Water		MDWSP (1978)		
(Spence, 1975)					
NaCL	290	ppm	CL^-	205	ppm
NA_2CO_3	1100	ppm	HCO_3^-	1617	ppm
Na_2SO_4	690	ppm	NO_3	27	ppm
NaF	15	ppm	SO_4	420	ppm
$NaHCO_3$	1850	ppm	F^-	8	ppm
$CaCO_3$	160	ppm	Ca^{2+}	46	ppm
$Ca(HCO_3)_2$	200	ppm	Mg^{2+}	23	ppm
$MgCO_3$	110	ppm	T.H.	210	ppm
$Mg(HCO_3)_2$	175	ppm	PH	7.3	ppm
SiO_2	65	ppm	EC	350	mS/m
PH	7.1				
Gases					
CO_2	90	ppm			
O_2	1	ppm			
He	0.06	ppm			
N_2	1	ppm			

The existence of a hot spring 5-10 km north of Lubungo in the Ngerengere area (most probably along one of the faults in this area) has been reported but no data are available.

4.1.7. Riview of information, used for compiling the geological map of the project area (Map D 2)

The taxonomic units shown on Map D 2 are genetic-lithological complexes and types in their spatial arrangement.
The data and methods that have been used in assessing the map units are:

- existing geological maps;
- reconnaissance mapping;
- aerial photography;
- geophysical investigations.

The map units have been characterized by:

- evaluation of existing data;
- boring and sampling;
- geophysical investigations.

The geological maps listed below, published by the Geological Survey Department in Dodoma, have been used.

Sheet no.	Name of Map	Scale
53 NE (164)	Mlali	1:125.000
53 SE (181)	Kilosa	1:125.000
182	Kimamba	1:125.000
183	Morogoro	1:125.000
184	Kidugallo	1:125.000
199	Mikumi	1:125.000
200	Doma	1:125.000
64 NE (201)	Uluguru	1:125.000
64 SW (218)	Kidodi	1:125.000
64 SE (219)	Mkalinzo	1:125.000
185, 201	Geology of Part of the Eastern Province of Tanganyika	1:500.000

The following unpublished geological maps were available:

Sheet no.	Name	Scale
146	Kwehivu	1:100.000
147	Mziha	1:100.000
165	Mvomero	1:100.000
166	Turiani	1:100.000
217	Kidatu	1:100.000

Additional information on the geological structure of the project area was obtained by study of Landsat Imagery (ref. 47) and geophysical investigations.
Aerial photographs of restricted parts of the project area, namely those areas where special studies have been carried out, were studied; special attention was paid to the occurrence of alluvium.

Published literature relating to the geology of the project area is given in the list of references (2.4).

4.2. Ground water in relation to geology

4.2.1. Hydrogeological classification of rocks (see table D 4.2-1)

The rocks occurring in the project area vary in age from Precambrian to Recent.

Each different litho-stratigraphical unit has its specific lithological, mineralogical, textural and structural characteristics and the hydrophysical properties as porsity, permeability, transmissivity, storage capacity and ground water quality have been found to vary accordingly.

Therefore a hydrogeological classification of the rocks in the project areas has been adopted, based principally on their litho-stratigraphy and litho-facies.

In this classification, most Precambrian rocks with different mineralogical compositions but with essentially identical hydrophysical characteristics, have been grouped together. Different stratigraphical units within the Karroo system have been grouped together also on the basis of strong similarities in their lithological and hydrophysical properties.

The genetic-hydrogeological classification is presented in table D 4.2-1.

The age, genetic groups, lithological descriptions and geological-geomorphological characteristics of the different groups of rocks, are based largely on data obtained from geological maps, lithological descriptions and studies of topographical maps and aerial photographs.

The descriptions of the vertical lithology and the general hydrogeological conditions of the different groups of rocks are based on hydrogeological field data obtained by hydrogeological field measurements in existing boreholes anf wells, geo-electrical and seismical investigations, drilling of deep boreholes and exploration holes of shallow depth, as well as evaluation of data from boreholes not drilled by the MDWSP.

Patterns that more or less reflect the lithological character of the different hydrogeological units have been designed, to form the lithological basis from map D 3 and map D 4, which respectively show the prospects for medium-depth and deep ground water and shallow ground water.

Table D 4.2-1 - Genetic-hydrogeological classification

age	genetic group	pattern	lithology vertical lithology	geological-geomorphological characteristics	general hydrogeological conditions
Quaternary	fluvial deposits		SANDS, predominantly medium-very coarse with clayey intercalations; lower parts sometimes gravelly 5-10 m thick	channel fill of recent riverbeds, older terraces	water bearing; unconfined water level 0-4 m below GL, coefficient of permeability 100-1000 m/day EC generally below 200 mS/m
			CLAYS, with intercalated fine-coarse sand 5-20 m thick	floodplain alluvium, during the rainy season frequently flooded	sands are water bearing; semi confined-confined, water levels 0-2 m below GL, coefficient of permeability 10-100 m/day, EC variable but frequently higher than 150 mS/m
	alluvial, fluvial, swamp deposits		ALTERNATING SANDS, CLAYS, LOAMS and GRAVELS, 30 to more than 400 m thick	sediments derived mainly from the western mountain ranges, deposited in tectonical basin, the surface is gently sloping towards the east, large areas flooded during the rainy season	ground water occurs in aquifers of varying thickness and at various depths; confined aquifer thickness 5-10 m; water levels 5-15 m below GL, coefficient of permeability 10-200 m/day, EC 20-220 mS/m but generally below 100 mS/m
	slope wash deposits		SANDS, LOAMY SANDS, and LOAMS stony loams and gravels in lower parts 2-8 m thick, on partly weathered metamorphic rocks	pediments, derived from and surrounding inselbergs composed of metamorphic rocks	sand and gravel layers water bearing; unconfined-confined, water levels below GL low-medium permeabilities EC 30-80 mS/m
Post-Miocene	residual soils, eluvium, colluvium		LOAMS, sandy to clayey; red-orange/brown coloured, 3 to more than 10 m thick, sometimes underlain by 1-2 m thick calcrete on partly weathered or decomposed metamorphic rocks	strongly weathered residual, eluvial and colluvial material, covering the Miocene peneplain, the surface is very gently undulating and dissected by streams	loams not water bearing, ground water occurs locally in calcrete horizons and upper parts of weathered basement, permeabilities low, due to the high contents of loam and clay, EC generally higher than 150 mS/m
Pliocene	braided river deposits		GRAVELS, well rounded, poorly sorted, poorly cemented, 10-45 m thick on rocks of different age and lithology	gravels derived from the Uluguru Mountains, deposited by braided rivers on the Pliocene peneplain	not water bearing, the infiltrating water drains immediately because of the very high permeability
Jurassic	near shore - shallow marine deposits		SANDSTONES, medium-coarse, poorly sorted, firmly cemented, well bedded conglomaratic in part, occasional fine grained sandstones and siltstones	crop out in the Pliocene peneplain gently rolling surface dip of the beds 5°-10° East weathering to sandy soils	water bearing; confined, average water level 6 m below GL, secondary permeability: zones of fracturing, well yields 1-3 l/s, EC 200-300 mS/m
			LIMESTONES, Oolitic-pisolitic sandy limestones and calcareous sandstones in upper and lower parts	these beds forms a topographical ridge which rises to a maximum of 200 m above the surrounding peneplain, dip of beds 5°-10° E	water bearing; confined water levels 0-40 m below GL, secondary permeability: zones of fracturing and solution, EC 100-200 mS/m
			SANDSTONES and SILTSTONES fine grained, firmly cemented, well bedded, lower parts calcareous	crop out in the Pliocene peneplain gently rolling surface, dip of beds 5°-10° E, weathering loamy and clayey soils	only locally water bearing, water levels 10-30 m below GL secondary permeability: zones of fracturing EC more than 400 mS/m

Table D 4.2-1 - Continued

age	genetic group	pattern	lithology vertical lithology	geological-geomorphological characteristics	general hydrogeological conditions
Post-Triassic	intrusive rocks		QUARTZITES and CARBONATITES	forms narrow dykes along fault planes	highly mineralized thermal springs occur locally along these dykes
Triassic upper-Carboniferous	shallow, fresh-brackish water deposits		SANDSTONES, coarse-very coarse, conglomeratic firmly cemented, well bedded-massive intercalated with mudstones and shales	sediments deposited in tectonical basins, the surface is flat to undulating and partly covered with alluvium, dip of bed 10°-30° W	water bearing: confined water levels about 10 m below GL secondary permeability: zones of fracturing, well yields 3-5 l/s, EC 150-225 mS/m but generally below 200 mS/m
			SANDSTONES, fine-medium, firmly cemented, well bedded	crop out in the Pliocene peneplain, gently rolling surface, beds locally folded and faulted dip of beds generally E, partly covered with alluvium	no data available most probably water bearing
Pre-Cambrian	meta-sedimentary rocks		GNEISSES, migmatitic in part; foliated	crop out in elevated, dissected plateau type mountains, undulating surface with inselbergs	ground water occurs only locally in fractured zones and in weathered upper parts of the gneiss, well yields generally less than 1 l/s, EC 180-350 mS/m but generally higher than 200 mS/m
			GRANULITES, massive	crops out in tectonically uplifted mountain blocks	virtually impervious; not water bearing
			DOLOMITE and LIMESTONE, crystalline; bedded to massive	forms part of the uplifted mountain block of the Uluguru, deeply incised surface, synclinal structures	Karst area occurrence of many springs: discharge 1-10 l/s, secondary permeability: zones of solution, EC 50 mS/m
	meta-igneous rocks		META-GABBRO'S and ANORTHOSITES massive	metamorphosed basic intrusive bodies, occurring mainly in the uplifted granulite mountain blocks	impervious; not water bearing
			CHARNOKITES, massive	metamorphosed intermediate-acid intrusive bodies, occurring mainly in the uplifted granulite mountain blocks	impervious; not water bearing
			GRANITES and SYENITES, massive	partly metamorphosed acid intrusive bodies, constituting the higher parts of the Ukaguru Mountains	impervious; not water bearing
			METAMORPHIC ROCKS, undifferentiated	no data available	not data available

contact between different lithological complexes

major fault, with direction of downthrown side: observed or inferred

fault, with direction of downthrown side: observed or inferred

concealed major fault, with direction of downthrown side: inferred partly from geo-physical investigations

concealed fault, with direction of downthrown side: inferred partly from geo-physical investigations

4.2.2. Explanation of Map D 3: Prospects for medium-depth and deep ground water

As has been explained in 4.2.1, the lithology of rocks, which determines many characteristics of ground water occurrence, movement and chemical composition, has been taken as a basis for the delineation of aquifers and aquifer complexes and of aquitards.

Medium-depth aquifers are defined here as aquifers between 12 and 50 m ground level and deep aquifers as aquifers occurring at depths below 50 m groundlevel.

Map D 3 which shows the prospects for medium-depth and deep ground water, is a combination of three different types of hydrogeological information:

- the lithology of the rocks, represented by different patterns;
- the water-bearing characteristics of the rocks;
- the EC of the ground water.

Different colours and combinations of colours have been used on the map, to indicate the presence or absence of ground water, and its EC:

- Blue colours stand for the presence of water-bearing zones with ground water of acceptable salinity (EC < 200 mS/m).
- Brownish colours stand for rocks which are only very locally ground water-bearing or which are virtually impervious.
- Orange and red colours stand for the presence of saline ground water (EC > 200 mS/m).

Hydrogeological information on medium-depth and deep ground water was available mainly from:

- existing borehole data	(DD 1, 2, 3)
- MDWSP borehole data	(D 3.3)
- geophysical investigations	(Map D 1; D 3.2.6)

The distribution of the borehole locations and the position of the geo-electrical profiles show, that relatively small parts of the project area have been studied and that there are vast areas virtually without data.

For the areas underlain by virtually impervious rocks (the brown areas), it is not interesting to give the reliability of the information, but for the areas where water-bearing zones are present or thought to be present, the reliability of the information has been indicated by different tones of blue:

- dark coloured tones stand for areas where hydrogeological information is available from boreholes and/or from geophysical investigations;
- light coloured tones stand for areas of which the prospects for ground water have been assumed on the basis of extrapolation.

4.2.3. Explanation of Map D 4: Prospects for shallow ground water

As has been explained in 4.2.1., the lithology of rocks, which largely determines the characteristics of ground water occurrence, movement and chemical composition has been taken as a basis for the delineation of aquifers and aquifer complexes, and aquitards.
Shallow aquifers are defined here as aquifers, situated not deeper than 12 m below ground level.
If the top of an aquifer is situated within 12 m below ground level, but its bottom is beyond this depth it is considered as a shallow aquifer.
Map D 4, which shows the prospects for shallow ground water, is a combination of four different types of hydrogeological information:

- the lithology of the rocks, represented by different patterns;
- the water-bearing characteristics of the rocks;
- the most important hydrogeological features of the aquifers;
- the EC of the ground water.

Different colours and combinations of colours have been used on the map, to indicate the presence or absence of ground water and its EC:

- Blue colours stand for the presence of shallow aquifers with ground water of acceptable salinity (EC < 200 mS/m).
- Brown colours stand for rocks which are only locally ground water-bearing or which are virtually impervious.
- Orange, red and violet colours stand for the occurrence of saline to extremely saline ground water (EC > 200 mS/m).

Hydrogeological information on shallow ground water was available mainly from:

- Existing shallow wells and handdug holes	(DD 4);
- MDWSP hand drilled exploration holes	(DD 9-13);
- Geophysical investigations	(Map D 1)

The information gathered on shallow ground water included data on:

- the occurrence of ground water;
- the depth and thickness of aquifers;
- the type of aquifers (confined/unconfined, lithology);
- water levels;
- seasonal water level fluctuations;
- transmissivity and permeability of aquifers;
- EC of ground water;
- chemical composition of ground water.

On map D 4, all villages of the project area have been indicated by either a blue or a red circle; a blue circle indicating that exploitation of shallow ground water within a distance of 1 mile from the village is possible, a red circle indicating that exploitation of shallow ground water within a distance of 1 mile from the village is not possible or thought not possible.

The figures, plotted around these circles representing the villages, give data on average well depth, aquifer thickness, water level and EC of the ground water.

The reliability of the map is more or less indicated by the presence or absence of figures. If no figures have been plotted, no data were available and the prospects for shallow ground water in such an area have been extrapolated from similar, nearby areas.

4.2.4. Ground water in Precambrian rocks

4.2.4.1. General

The rocks of the Precambrian basement are for the greater part crystalline and impervious.

Locally they are deeply weathered, the process involving the decomposition of feldspars and ferromagnesian minerals into clay minerals. Although the weathered rocks may become more porous, the hydraulic conductivity will generally be too low to consider them as good aquifer material.

4.2.4.2. Granulites and meta-igneous rocks

The granulites and meta-igneous rocks offer no prospects at all for ground water.

These rocks are quite massive and crop out only in the highest mountain ranges of the project area.

Clayey soils up to 1 m thick, locally cover the practically unweathered rocks. No boreholes or shallow wells have been constructed in these types of rock.

4.2.4.3. Gneisses

Medium-depth and deep ground water

The gneisses are less massive, foliated and locally the upper parts of these rocks are fractured or weathered, giving rise to water-bearing zones with low porosities and permeabilities.

Table D 4.2-2 however shows that the prospects for medium-depth and deep ground water in gneissic rocks are extremely poor. Boreholes drilled in gneiss generally show very low yields and/or high salinities of the ground water. Thirty-two out of the fourty-three boreholes drilled in gneissic rocks had yields of less than 1 l/s and the ground water was saline in twenty out of the fourty-three boreholes.

It is notable that boreholes 23/54, 14/66, 8/34 and 23/59 with yields between 3 and 10 l/s, were drilled in fault zones. Practically all boreholes drilled in the gneiss were abandoned immediately after their construction.

Boreholes 2/53, 23/59, 18/65 and 41/67 had to be abandoned after some time of operation because either their yields decreased drastically, or the salinity of the ground water increased gradually.

It is apparent therefore that the amounts of fresh ground water, stored in the fractured and weathered parts of the gneiss are very limited, and that ground water in the deeper parts of these rocks is often highly mineralised.

At present there is only one borehole (14/16) which is still in operation. This borehole was drilled almost on the junction of two faults, one of which is the Wami Rift Fault.

Shallow ground water

The prospects for shallow ground water in the areas underlain by gneissic rocks, have been classified as poor to extremely poor. Most of the area underlain by gneiss is hilly to mountainous and not, or hardly so, covered with weathered material. The occurrence of shallow ground water is limited to valleys and depressions were usually a thicker weathered zone covers the unweathered gneiss.

The zone of partly decomposed rock, below the zone of abudant clay size material is the most promising because permeabilities generally are highest here.

In fact, very few shallow wells have been constructed in weathered, water-bearing zones in gneissic rocks.

In areas underlain by gneiss, the important aquifers usually are alluvial deposits. Generally the salinity of ground water in the upper parts of the weathered or fractured gneiss, is lower than in the deeper parts of these rocks because the circulation of ground water is better in the upper, frequently more permeable zone.

In the gneiss area north of the Uluguru Mountains, the ground water salinity in shallow wells penetrating the weathered basement, varies from 185 to 350 mS/m.

In Melela, west of the Ulugurus, a shallow well definitely penetrating fractured gneiss, delivers ground water with a EC of 85 mS/m.

Table D 4.2-2 - Boreholes drilled in Precambrian gneiss

Borehole no.	Depth m bGl	Water struck at m bGl	Static water level m mGl	Tested yield l/s	Drawdown m	EC mS/m
1 /31	73.14	10.67	8.84	0.4		130
2 /33		dry				
8 /34	118.26	74.68	24.69	9.3		1020
14 /34	68.57	48.16	24.69	3.8		510

Table D 4.2-2 (continued)

Borehole no.	Depth m bGl	Water struck at m bGl	Static water level m mGl	Tested yield l/s	Drawdown m	EC mS/m
1 /35	45.77	16.76	11.28	0.4		110
3 /35	150.67	73.15	60.96	0.01		
7 /38	86.26	45.42	39.62	0.4		185
14 /38	39.62	17.68	3.05	0.8		122
5 /39	80.15	45.00				550
1 /40	54.56	30.48	16.46	0.8		180
8 /47	142.65	35.05	27.13	0.2		513
17 /47	76.20	6.71	6.40	0.3		saline
9 /49	121.92	7.62	3.05	0.1		1580
21 /49	33.53	7.62	1.22			1850
37 /52	40.84	dry				
2 /53	73.76	32.31	54.25	0.5		198
41 /54	42.06	23.77	19.20	0.9		356
21 /56	74.07	57.91	57.30	0.08		18
18A/59	85.04		15.24	0.3		saline
18B/59	49.07		17.07	0.6		saline
23 /59	56.08	15.85	13.41	8.8		100
15 /59	75.29	dry				
16 /60	62.79	34.75	29.26	0.2		saline
34 /60	68.88	64.92	52.37	0.5		saline
37 /60	67.97	56.39	52.22	0.1		94
5 /63	37.19	10.67	7.32	2.2	19.51	
31 /64	76.20	3.05	1.67	2.3	28.82	saline
18 /65	76.20	13.72	0.61	1.3		489
33 /65	99.22	51.82	47.55	0.7	12.19	220
14 /66	36.60	35.05	1.82	3.2	15.69	88
41 /67	60.69	6.10	7.62		30.48	800
49 /67	22.55	10.67	3.66			saline
17 /68	67.36	65.84	16.80	1.3	67.36	
38 /72	135.33	13.72	8.53	1.3	55.0	650
79 /72	16.80	12.60	12.00	0.1		
90 /75	30.48	3.05	0.61	8.53		saline
41 /76	91.44		19.81	0.01		
282 /76	62.48		22.86	1.1	25.91	175
77 /77	36.58		4.88	1.3	2.21	
149 /77	25.60	7.62	7.62	0.4	9.31	
175 /77	51.21		3.66	0.6		155
104 /78	40.0	dry				
117 /78	18.0	15.0	2.4	6.0	7.5	

4.2.4.4. Crystalline Dolomites and limestones

The crystalline dolomites and limestones east of the Uluguru Mountains, are ground water-bearing. The area is a karst area and ground water moves through these rocks mainly along solution openings and zones of fracturing and faulting.

The occurrence of karst springs which discharge 1-10 l/s, and the fact that many streams take their rise in this area, point to the existence of active ground water flow systems.

The salinity of the ground water in this karst area is very constant; EC values vary from 45-55 mS/m.

Although at present there are no boreholes and shallow wells drilled or dug into these rocks, there certainly are possibilities to make succesfull wells here.

Valleys will offer the best locations for such wells because often they are developed along zones of fracturing or faulting.

4.2.5. Ground water in Karroo Rocks

4.2.5.1. Medium-depth and deep ground water

Data on the hydrogeological characteristics of Karroo rocks are available only from 8 boreholes drilled in the Karroo rocks that occur in the SW part of the project area.

The table below summarizes these boreholes.

Table D 4.2-3 - Boreholes in Karroo rocks

Borehole no.	Depth m bGl	Water struck at m bGl	Static water level m mGl	Tested yield l/s	Drawdown m	EC mS/m
15 /59	92.05	6.10	3.96	3.1		153
19 /95	71.63	6.10	3.35	3.1		150
4 /64	75.18	22.86	0.96	3.1	6.40	151
13 /64	43.28	33.53	15.00	2.5	6.10	225
75 /71	76.20	24.28	18.59	5.1	15.52	
112 /71	46.93	21.34	5.79	2.7	4.34	92
136 /71	62.48	20.30	8.70	3.4	2.00	

From these data it is apparent that the Karroo Rocks in this part of the project area are water-bearing and most probably offer fair prospects for boreholes with low to moderate yield and specific capacities between 0.1 and 1.7 l/s/m.

The Karroo Rocks in this area are predominantly sandstones, alternating with mudstones and shales.
The rocks are firmly cemented and thus have a very low primary porosity and permeability. They are well bedded however and ground water will move principally along bedding planes and zones of fracturing.
The EC of the ground water in these rocks is high but generally below the maximum standard of 200 mS/m.
No data on the occurrence and salinity of medium-depth and deep ground water in the Karroo cropping out in the eastern and south-eastern parts of the project area are available. Because of similarities in lithology and structure the Karroo Rocks in these parts have tentatively been classified in the same catagory as the Karroo Rocks in the SW.

4.2.5.2. Shallow ground water

Few data exist on the occurrence of shallow ground water in rocks of the Karroo system. This is mainly because there are only a few villages situated in areas where Karroo rocks crop out.
In the Karroo rocks in the SW part of the project area, south of Mikumi, handdug holes at Kidogobasi supply small amounts of ground water from weathered Karroo rocks.
The water levels vary from 1.0 - 3.0 m below ground level and the EC of the ground water is 150 mS/m.
Boreholes 15/59 and 19/59 at Mikumi Town, struck water at a depth of 6.10 m below ground level; static water levels were 3.96 and 3.35 m bGL respectively and the yields were 3.1 l/s. The EC of the ground water is 150 mS/m. From these data it is tentatively concluded, that locally there are possibilities for exploitation of shallow ground water with low to moderate yields and an EC of about 150 mS/m.

No data are available on shallow ground water from the Karroo areas in the SE part of the project area.

4.2.6. Ground water in Jurassic sandstones (Ngerengere Beds)

4.2.6.1. Medium-depth and deep ground water

In the surroundings of Ngerengere, 5 boreholes were drilled into the Ngerengere Beds and one borehole penetrated these beds at Mkulazi.
The Ngerengere Beds are predominantly medium-coarse, poorly sorted, firmly cemented, feldspathic sandstones; they are well bedded and partly conglomeratic.
Occasionally they are intercalated with fine-grained sandstones and siltstones.

Table D 4.2-4 - Boreholes in Ngerengere Beds

Borehole no.	Depth m bGl	Water struck at m bGl	Static water level m mGl	Tested yield l/s	Drawdown m	EC mS/m
4/ 34	145.70	45.72				
6/ 34	119.48	18.29	8.25	2.5		27
7/ 34	50.90	24.38	16.67	5.0		200
6/ 35	63.09	11.58	4.27			256
3/ 53	117.39	10.69	7.92			330
8/ 62	10.90	62.48	52.73	0.4		227

It may be concluded from the fact that ground water was present in all six boreholes that the Ngerengere Beds contain water-bearing zones.
The beds in the area of Ngerengere are strongly faulted and it is therefore possible that ground water moves mainly along faults and fractured zones.
Boreholes 4/34 and 7/34 are located along the major fault, which separates the Precambrian gneiss in the west from the Ngerengere Beds in the east and this faults might well be the reason for the relatively high yield of borehole 7/34 and the low salinities of the ground water in boreholes 4/34 and 6/34.
The salinities of the ground water in boreholes 6/35, 3/53 and 8/62 which were not drilled in or near this fault, were much higher: 230-260 mS/m.
The faultzone, delimiting the Ngerengere Beds towards the west, offers fair possibilities for successfull boreholes with moderate to low yields and ground water of acceptable salinity.
Smaller faults running through the Ngerengere Beds may also be good locations for boreholes.

4.2.6.2. Shallow ground water

At two locations, Mkulazi and Chanyumbu, shallow ground water from the soils overlying the Ngerengere Beds, is being used.
The soils are very sandy and only a few m. thick. The water levels vary from 0.5 m below ground level during the rainly season, to 3.0 m below ground level during the dry season. The ground water is unconfined.
The very low EC's (7-13 mS/m) point to relatively "young" ground water and a regular recharge. At Chanyumbu, the yields of the hand-dug holes are moderate, but at Mkulazi they are very low and some holes dry out.
Exploitation of shallow ground water is probably locally possible, especially in topographically lower areas.
Since the soils covering the Ngerengere Beds are thin, it might be necessary to drill a few m. into the unweathered sandstones.

4.2.7. Ground water in Jurassic limestones

4.2.7.1. Medium-depth and deep ground water

The Jurassic limestones are ground water-bearing and offer fair possibilities for boreholes. Along their outcrop, the beds form a topographical ridge; the beds dip 5-10° towards the east and therefore the 500-1000 m wide zone, east of the outcrop of the limestone offers the best possibilities for boreholes up to 200 m deep.

In the surroundings of Kidugallo data from 4 boreholes drilled into the limestones are available.

Table D 4.2-5 - Boreholes in Jurassic limestones

Borehole no.	Depth m bGl	Water struck at m bGl	Static water level m mGl	Tested yield l/s	Drawdown m	EC mS/m
2 /34	146.31	92.66	0.00	2.4		130
23 /53	121.92	30.48	16.76	1.3		190
2 /56	122.23	65.74	53.74	2.2	25.30	106
46 /71	201.78	63.70	36.27	1.2	59.44	150

The yields of these boreholes are not high but yields between 1 and 3 l/s seem to be guaranteed from this formation.
The EC of the ground water in the limestone is quite constant: 120-190 mS/m.

4.2.7.2. Shallow ground water

Ground water at shallow depth is not present in the Jurassic limestones, because they form a topographical ridge in the landscape that everywhere rises more than 12 m above its surroundings.
In boreholes, drilled into the limestone, ground water was struck at depths between 30 and 93 m below groundlevel.

4.2.8. Ground water in Jurassic sandstones (Station Beds)

4.2.8.1. Medium-depth and deep ground water

These sandstones are fine-grained, firmly cemented, well bedded and intercalated with siltstones. Data are available from 4 boreholes penetrating these rocks.

Table D 4.2-6 - Boreholes in Station Beds

Borehole no.	Depth m bGl	Water struck at m bGl	Static water level m mGl	Tested yield l/s	Drawdown m	EC mS/m
2 / 36	145.70	10.76	+ 0.30	0.4		420
6 / 56	111.56	19.81	13.41	2.2		435
7 / 62	121.92	9.14	7.01			
9 / 62	111.56	37.19	30.48	0.4		504

From the data listed above it is apparent that the Station Beds most probably offer no possibilities for exploitation of medium-depth or deep ground water, because the ground water in these beds is highly saline. Owing to the fine texture of the sandstones and siltstones the primary permeability is very low.

The Station Beds have not been faulted and fractured as for instance the Ngerengere Beds and therefore the secondary permeability will be low too as is demonstrated by the very low yields of the four boreholes.

Hence there probably are no active ground water flow systems through the deeper parts of the Station Beds and the high salinity of the ground water may therefore be caused by the presence of connate saline water, trapped in the pores of these marine sediments at or shortly after their time of deposition.

4.2.8.2. Shallow ground water

Data on shallow ground water are not available.

Because of similarities in lithology between this area and the area underlain by Ngerengere Beds, it is expected that locally possibilities exist for exploitation of shallow ground water. The soils of the Station Beds are fine-textured and thicker than those covering the Ngerengere Beds. Therefore low yields must be expected.

4.2.9. Ground water in Pliocene gravels (Mkindu Beds)

These gravels occur mainly in the SE corner of the project area where they cover sandstones of the Karroo system and limestones and sandstones of Jurassic age.

The beds themselves offer no possibilities for ground water. The gravels are very coarse, well rounded and only slightly cemented and therefore very porous and permeable.

Ground water infiltrating into these 10 m up to 45 m thick gravels, drains away very fast.

On aerial photographs, the area underlain by the Pliocene gravels looks very much like a desert with hardly any vegetation because of the lack of ground water.
Boreholes may be drilled through the Mkindu Beds, into the water-bearing zones of the Karroo sandstones or Jurassic limestones.

4.2.10. Ground water in post-Miocene soils

Deeply weathered, red-orange/brown coloured residual soils, eluvium and colluvium cover large areas underlain by gneissic rocks. The soils mainly are clayey-sandy loams. Although this material has a fairly high porosity, its permeability is very low and the loams can therefore not be considered as an aquifer.
Locally the 3 m up to 30 m thick soils are underlain by calcrete which was found to be water-bearing in a few hand-drilled exploration holes near Tungi and Kihonda.
Within the scope of the special studies of the Berega area and the Ngerengere area, a number of hand-drillings has been carried out in these residual soils, to collect data on its water-bearing characteristics and the quality of the ground water.
The average depth of these holes was 5 m.

Table D 4.2-7 - Hand-drilled holes in the post-Miocene soils

Hand-drilling No.	EC (mS/m)	Hand-drilling No.	EC (mS/m)
A- 3	(dry)	C-6	120
A- 4	(dry)	F-6	(dry)
A-11	(dry)	F-7	(dry)
A-12	(dry)	G-1	(dry)
B- 4	(dry)	G-2	(dry)
B- 5	800	G-8	(dry)
B- 6	800	I-1	(dry)
B- 7	(dry)	I-2	(dry)
B- 8	(dry)	165/1- 8-2	
B- 9	200	165/1- 7-3	120
B-17	525	165/1- 3-6	350
B-18	(dry)	165/1- 3-9	800
		165/1-321	400

In the Ngerengere area, the EC of ground water in these soils varied from 120 to 800 mS/m but generally was higher than 200 mS/m.
At Lubungo, the ground water from the lower parts of the soils has an EC of 70 mS/m.
In the Berega area the EC of the ground water in the red loamy silts also varied from 120 to, 800 mS/m.

From the data above it is concluded that the prospects for ground water in these soils are poor. Ground water occurs only locally, in zones with low to very low permeabilities.
The salinity of the ground water varies considerably from place to place but generally is quite high.
In the areas were these soils cover the basement, the best prospects for low yield wells (< 1 l/s) of medium or shallow depth, are found in the zone just below the superficial soils, in the weathered upper part of the gneissic rocks (see 4.2.2.3.) or where present in the calcrete horizons that occur below and sometimes in the soils.

4.2.11. Ground water in Quaternary pediments

Pediments, surrounding isolated mountains occur west of Morogoro and north of the Nguru Mountains.
Hydrogeological data on these deposits are available from hand-dug holes and shallow wells at Lukobe and Mkundi and from hand-drilled exploration wells at Mkundi.
The shallow well at Lukobe is 3.5 m deep and taps water from a sand layer of unknown thickness. Bedrock was reported to be present at a depth of 5 m below ground level.
Water levels in this shallow well vary from 3.4 m below ground level during the dry season, to 0.5 m above ground level during the rainy season. The EC of the ground water is 140 mS/m.

Water levels in hand-dug holes at Mkundi vary from 0.5-5.0 m below ground level and the EC of the ground water is 22 mS/m.

In hand-drilled holes L-4, L-5 and L-6 at Mkundi (Table DD 5), a medium to coarse sandy aquifer with an average thickness of 2 m, was found between depths of 1.0 and 5.5 m below ground level.
The EC of the ground water was about 40 mS/m.

From the data above and the borehole descriptions the following conclusions may be drawn.
The pediments are up to 8 m thick and consist of alternating sands, sandy loams and loams, with coarse slope debris in their lower parts.
The sands are medium to coarse and locally water-bearing,
The seasonal water leveel fluctuations in these partly confined, partly unconfined aquifers are quite high.
Water levels vary from 0.5 m above ground level during the rainy season to more than 5 m below ground level during the dry season and some aquifers dry up completely.
The EC of the ground water in these pediments is low, about 60 mS/m on an average. The prospects for shallow ground water have been classified fair therefore.

4.2.12. Ground water in Tertiary/Quaternary sediments (Mkata-Wami Basin)

4.2.12.1. General

As is indicated on Maps D 3 and D 4, the sediments of the Mkata-Wami Basin offer the best prospects for medium-depth and deep as well as shallow ground water in the project area.
Data on the hydrogeological structure of the basin are available from:

- geo-electrical investigations;
- existing boreholes;
- MDWSP boreholes.

A total of 358 geo-electrical soundings have been carried out distributed mainly over the central and northern parts of the basin. The results of most of these soundings have been indicated in ten profiles, the descriptions of which are given in 3.2.6.

Since 1938, approximately 53 boreholes were drilled in the basin sediments, a review of the existing borehole data is given in 3.1.1. and the boreholes are listed in DD 2.

Additional information on the hydrogeological composition of the basin, was obtained by the drilling of MDWSP boreholes, at 10 different locations.
The data of the MDWSP boreholes are presented in 3.3.3.

As can be seen on maps D 1 and D 3 the geo-electrical soundings, as well as the boreholes are located mainly in those parts of the basin, that are accessible by roads: the central part of the basin (the area between Kilosa-Msowero-Mkata) and that part of the basin, north of the line Kitete-Dakawa.
The insight gained into the hydrogeological structure of these two areas however, is sufficient to be able to draw a general hydrogeological picture for the basin as a whole.

4.2.12.2. Medium-depth and deep ground water

The sediments that filled the basin were derived mainly from the western mountain ranges; they were transported to and deposited in the basin by major rivers that built up alluvial fans along the western margin of the basin.
The coarsest material, gravels and very coarse sands, were deposited in relatively thick layers, close to the western boundary of the basin.
Towards the west the sands rapidly thin out and become less coarse textured.
Huge alluvial fans were thus built up by both the Mkondoa and Mkundi rivers which probably existed already in early Quaternary or even Tertiary times.

In the central and western parts of the basin, mainly fine textured sediments, floodplain clays, loams and clayey and loamy sands, were deposited.
In these parts, clean sands occur only locally and usually such sand layers are not thicker than a few metres.
The sands are thought to be channel deposits of rivers and streams, flowing towards the NE.
Well rounded coarse sands and gravels were found also in boreholes along the eastern margin of the basin.
These coarse deposits are channel deposits of the Wami River, which now closely follows the eastern boundary of the basin.
Geo-electrical measurements carried out over the deepest parts of the basin and the deep structural troughs along the western margin, indicate good prospects for medium-depth and deep ground water.
These parts of the basin were down-faulted probably in a relatively short period and mainly filled up with sandy deposits.

Boreholes, drilled down to 100 m, deep into the alluvial depostis along the western margin of the basin, show alternating sands and clays; the sands making up about 25 to 50% of the sequences.
The individual sand layers usually are 4 to 8 m thick.
Outside the areas underlain by alluvial fan deposits, the upper 100 m of sediments are much more clayey; sands generally make up less than 10% of the sequences and individual sand layers are 3 up to 5 m thick.
Ground water occurs in these sands under confined conditions.
Ground water levels vary from a few m. below ground level along the western margin, to more than 15 m below ground level in the central parts of the basin. From data of static water levels in boreholes drilled between 1938 and present, measured at their time of drilling, iso-piezometric lines of ground water occurring in the upper 50 m could be constructed in the areas east of Kimamba and north of Kitete-Dakawa.
Although the ground water levels represent the piezometric surface of aquifers at different depths, the countours show a very regular piezometric surface, sloping towards the west in both areas. This indicates that probably the aquifers that occur at different depths, are all more or less interconnected hydraulically.

The yields of wells, drilled in sediments of the basin are relatively high. The average yield of the existing boreholes was 4.0 l/s; 17% of the existing wells yield less than 1 l/s, 34% less than 2 l/s, 60% less than 5 l/s and 12% of the wells had yields of more than 10 l/s.
However as was already stated in 3.1.1., the yields of wells sunk in these sediments would have been much higher if proper combinations of wire-wound screens and gravel pack had been used for completion.

This statement is confirmed by the results of boreholes drilled by the MDWSP.

Table D 4.2-8 shows that the specific capacities of these boreholes are relatively high and that the optimum yields of these boreholes are much higher than the yields of boreholes drilled and completed previously in the Mkata-Wami sediments.

Table D 4.2-8 - Hydrualical data calculated from pumping tests in MDWSP boreholes

borehole	135/78	151/78	162/78	173/78	28/79	41/79
specific capacity	1.4 l/s/m	0.4 l/s/m	6.6 l/s/m		5.5 l/s/m	0.8 l/s/m
optimum yield	14 l/s	14 l/s	48 l/s		48 l/s	12 l/s
permeability	80 m/day	8 m/day	125 m/day	30 m/day	125 m/day	
transmissivity	650 m^2/day	50 m^2/day	2000 m^2/day	150 m^2/day	2000 m^2/day	

The transmissivity and permeability of the aquifers varies considerably from place to place but as is demonstrated by the results of borehole 151/78, even of an aquifer that has a relatively low permeability and transmissivity, the yield of wells may still be considerable if the well is properly designed and constructed.

Ground water level fluctuations have never been measured in any of the existing boreholes.
From 11-10-78 up to 21-4-1979, water levels have been measured at regular intervals in some of the MDWSP boreholes.

Table D 4.2-9 summarized these data.
Within approximately 4-5 months, the water levels in the first four boreholes rise about 2.5-3.5 m. The water levels in boreholes 27/79 and 28/79 also rise considerably in approximately one month time.
This, obviously seasonal rise of water levels in all boreholes, as well as the hydraulic gradients 1/135 in the area east of Kimamba and 1/250 in the area north of Kitete-Dakawa, point to the existence of active ground water systems, recharged directly by rainfall.
Most flow will be in the upper section, where recharge is rapidly discharged.
The ground water in the upper aquifers (upper 50 m) of these areas, is therefore thought renewable, with the potential equivalent to the recharge rate.

The EC of the ground water in the Mkata-Wami Basin aquifers varies from 22 to 300 mS/m but usually is between 50 and 150 mS/m, and 90 mS/m on an average.

After examination. the geo-electrical profiles (fig. D 3.2-38 to D 3.2-47) show the following prospects for medium-depth and deep ground water.

Profile A-A'

Prospects for medium-depth ground water	(25 - 50 m)
Prospects for deep ground water along W. Margin of basin	(50 100 m)

Profile B-B'

Prospects for medium-depth ground water	(25 - 40 m)

Profile C-C'

Prospects for medium-depth ground water	(40 - 50 m)
Locally prospects for deep ground water	(50 - 70 m)

Profile D-D'

Prospects for medium-depth ground water	(10 - 20 m)

Profile E-E'

Prospects for medium-depth ground water	(up to 50 m)
Prospects for deep ground water	(50 - 70 m)

Profile F-F'

Prospects for medium-depth ground water	(up to 30 m)
Prospects for deep ground water	(up to 400 m)

Profile G-G'

Prospects for medium-depth ground water	(up to 50 m)

Profile H-H'

Prospects for medium-depth ground water	(up to 50 m)

Profile K-K'

Prospects for medium-depth ground water	(up to 50 m)
Prospects for deep ground water	(up to 130 m)

Profile L-L'

Prospects for medium-depth ground water	(up to 50 m)
Prospects for deep ground water	(up to 230 m)

From this summary it is clear, that everywhere along the profiles, the prospects for mediumdepth ground water are better, than those for deep ground water.

Taking also into account the fact that recharge of medium-depth aquifers most probably is better than that of deep aquifers, it is recommended therefore, to construct wells in aquifers at medium-depth, preferably in the upper most of the medium-depth aquifers.

4.2.12.3. Shallow ground water

Information on the occurrence of shallow ground water in the Mkata-Wami Basin was obtained by:

- measurements in existing shallow wells and hand-dug holes
- carrying out hand-drilled exploration holes and pumping tests in these holes

In many shallow wells and hand-dug holes in the basin water levels and EC's of the ground water were measured at regular intervals.
If possible, data were collected on the type, thickness, extend, and hydraulic characteristics of the shallow aquifers. These field data are presented in table DD 1.

Near most of the villages in the basin, hand-drilled exploration holes were carried out as map D 4 shows.
Thus, data on aquifer depth and thickness, lithology of the aquifer, water levels and EC's of the ground water were collected.
Pumping tests carried out in many of the hand-drilled holes, give an idea of the yields and drawdowns that can be expected, and the calculation of permeabilities and transmissivities of the aquifers. Data on the hand-drilled exploration holes are listed in table DD 4.

From the many data thus collected, the conclusion can be drawn that shallow ground water is abundant in the basin.
Aquifers are not continuous and therefore not found everywhere but the drilling of exploration holes proved that near most villages it is possible to find locations where shallow ground water occurs.

The total aquifer thickness in the upper 12 m of sediments varies from 0.5 up to 6.5 m and is about 2.0 m on an average throughout the basin. Often more than one aquifer was encountered in the exploration drillings. The thickness of the individual aquifers varies from 0.1 to 6.0 m. In some villages it was found that shallow wells dry out during the dry season.
The reason for this is, that mostly only the uppermost aquifer is tapped by the shallow wells in question; lack of proper construction material and pumps prevented the deeper excavation of these wells.
Exploration holes, drilled near such wells often revealed the presence of a second or even third aquifer at slightly greater depth. These deeper aquifers generally do not run dry during the dry season.

The aquifers material varies from fine to coarse sands.
Generally the sands are well sorted and free of clay but occasionally they contain small amounts of clay or silt.
In some parts of the basin, sandy loams and loamy sands are the only aquifers present.

The tested yields of the exploration wells were between 1000 and 1600 l/hr and 1300 l/hr on an average; these figures are quite high, indicating good permeabilities of the aquifers. The drawdowns usually are less than 1,5 m. The transmissivities and permeabilities calculated from the pumping tests range from 10 to 400 m^2/day and 2 to 200 m/day respectively.

The EC of the shallow ground water in the basin varies between 15 and 150 mS/m but usually is less than 100 mS/m.

The very low EC values in the northern part of the basin 15 up to 35 mS/m, point to active ground water flow systems, recharged by runoff from the Nguru Mountains.
Ground water level fluctuations measured elsewhere throughout the basin, point to the existence of active flow systems also. Part of the ground water, infiltrating into shallow aquifers will drain towards aquifers at medium depth.

Up till now, only one area was found, where virtually no ground water is present in the upper 12 m. This area, situated around the villages Mabana, Mbigiri, Magole, and Mandela is mainly underlain by loams and clays which are not water bearing.
These sediments represent flood plain deposits of the Mkundi River.
In the area between Mugudeni-Mvomero and Mirama, saline ground water with EC's between 200 and 400 mS/m was found to occur in some water-bearing zones, while other aquifers in this area contain fresh water.

4.2.13. Ground water in alluvium

Outside the Mkata-Wami Basin, shallow ground water occurring in alluvial aquifers, often offers the best if not the only prospects for successfull exploration, in terms of availability, yield of wells and quality of ground water. The reason for this is, that alluvium is found always in the topographically lowest parts of an area, where logically ground water is being concentrated.
Besides this, alluvial aquifers mostly are well sorted clean sands with a good porosity and permeability thus offering exellent possibilities for good yielding shallow wells. Alluvium is defined here, as all fluvial sediments that occur in a river valley, hence the deposits include: recent channel fills (river beds), floodplain deposits, point bar deposits as well as older terraces, locally bordering the present floodplains.
The riverbeds of many rivers and streams are often good aquifers, but where floodplains or older terracces offer possibilities for the construction of shallow wells also these locations are preferable to the riverbed locations because:

- the wells can be constructed on higher grounds which reduces the chance of flooding or washing away of the well
- the bacteriological quality of the ground water is better

Three major river systems drain the Ukaguru and Usagaran Mountains towards the east and three rivers flow in southern direction as can be seen on Map D 4.
Alluvium is present in these six valleys.
A special study was carried out to study the ground water in the alluvial deposits of the Berega Basin (DA 5).
The aquifers in this river system are coarse to very coarse sands which have high porosities and permeabilities.

Unconfined ground water occurs both in river beds and in adjacent terracces.
Seasonal ground water level fluctuations are in the order of 0.5 m.
The EC of the ground water varies from 70-150 mS/m and is 100 mS/m on an average. The ground water in the residual soils and weathered basement alongside the valleys was found to be saline, with EC's varying from 100 up to 700 mS/m.
Proper siting for shallow well locations that are not liable to the danger of salinization, is necessary therefore.
Because of similarities in geology and hydrology of the six river systems draining the western mountains, the hydrogeological characteristics of the alluvium deposited in these valleys probably are identical to the characteristics described above.

Confined ground water occurs in the alluvium of streams draining the western parts of the Ulugurus. The average aquifers thickness in these deposits is about 3 m, water levels vary between 1.5 and 6.0 m below ground level. The EC of the ground water in these aquifers is high but usually below the maximum standard of 200 mS/m.

A special study was carried out also, to study the ground water in the alluvium of the Ngerengere River and its tributaries (DA 4). The ground water in the Ngerengere valley north of the Uluguru Mountains was found to be highly saline, with EC's up to 2000 mS/m. The situation along the Ngerengere River, downstream of Ngerengere village is similar as along the Berega River; saline ground water occurs in the residual soils and weathered basement along the valley deposits.

In the gneiss area NE of the Uluguru Mountains alluvial deposits of modest extend of the Ngerengere, Lukonde and Mikese Rivers, form the only possible ground water sources.

The few data that are available on the occurrence of ground water in the alluvial deposits of the Ruvu and Mgeta River systems, point to the occurrence of ground water of low salinity (EC up to 75 MS/m) in both riverbed aquifers as well as in the alluvial along the present riverbeds.

5. GROUND WATER POTENTIAL

5.1. Introduction

The hydrogeology of the project area was studied on the basis of the undermentioned data.
Existing data:

- existing geological maps and reports
- data on existing boreholes
- aerial photographs
- topographical maps

Data collected by MDWSP:

- Landsat Imagery studies
- hydrogeological and geological field data
- geo-electrical investigations
- seismic investigations
- hand drillings
- drilling of deep wells
- well loggings

Evaluation of these data is presented in chapter D3: Data Collection and Evaluation.
The combined studies resulted in the hydrogeological description of the project area (chapter D4) and in the compilation of a geological map of the project area (Map D3), a map showing the prospects for medium-depth and deep ground water (Map D3) and a map showing the prospects for shallow ground water (Map D4).
With respect to the hydrogeology, the project area has been divided into areas where the prospects for ground water are good, fair, poor and extremely poor.

The prospects for medium-depth (12 - 50 m below ground level) and deep ground water (deeper than 50 m below ground level) are:

Good (0.5% of area)

- in parts of the Mkata-Wami Basin	(unconsolidated sediments)

Fair (20% of area)

- in parts of the Mkata-Wami Basin	(unconsolidated sediments)
- in the Karroo area south of Mikumi	(sandstones)
- in the Karroo areas in the S.E.	(sandstones)
- in a narrow zone, south of Kidugallo	(limestones)
- in two areas east of the Ulugurus	(crystalline dolomites)

Poor (10% of area)
- in parts of the Mkata-Wami Basin (unconsolidated sediments)
- in the area north of the Ulugurus (partly decomposed metamorphic rocks)

Extremely poor (69.5% of area)
- in the rest of the project area (metamorphic rocks, sandstones)

The prospects for shallow ground water (less than 12 m below ground level) are:

Good-fair (15% of area)
- in most of the Mkata-Wami Basin (unconsolidated sediments)
- in alluvium in many river valleys (unconsolidated sediments)

Fair-poor (50% of area)
- in small parts of the Mkata-Wami Basin (unconsolidated sediments)
- in the Karroo area south of Mikumi (sandstones)
- in the alluvium S.E. of the Ulugurus (unconsolidated sediments)
- in the Jurassic area (sandstones)
- in two areas east of the Ulugurus (crystalline dolomites)
- in the area north of the Ulugurus (soils, decomposed gneiss)
- in the Ukaguru and Usagaran Mountains (gneisses)

Extremely poor (35% of area)
- in the Nguru and Uluguru Mountains (granulites)
- in the S.W. part of the project area (gravels)

In the areas where the prospects for ground water have been classified as poor to extremely poor, ground water is only locally present, not present at all and/or saline.
Because of this, these areas are not of interest for exploitation of ground water and are not considered further.

In the areas where the prospects for ground water have been classified as fair to good, the maximum amount of ground water theoretically available is equivalent to the recharge.

5.2. Renewable ground water

5.2.1. Mkata-Wami Basin

Seasonal water level fluctuations measured in boreholes and shallow wells, which are in the order of 2 - 4 m, must be a result of recharge of the aquifers.
From water levels measured in boreholes at their time of construction (between 1938 and present), the phreatic surface of the ground water in medium-depth aquifers in parts of the basin could be constructed; the hydraulic gradient is small, 2.5 x 10^{-4} to 4 x 10^{-4} and with moderate permeabilities the regional flow will be slow.
Ground water flows are in an eastern direction, towards the Mkata and Wami rivers.
Most recharge occurs in the western part of the basin, where sands are at the surface and where streams are influent.

In summary: hydrogeological active flow systems exist in the Mkata Wami Basin, with most movement occurring at shallow and medium depth, where recharge appears to be balanced by discharge.
The various shallow and medium-depth aquifers are interconnected locally.

The ground water potential in the Mkata-Wami Basin is equivalent to the recharge throughout the area.
Assuming that approximately 10 mm of the rainfall replenishes the aquifers, then 0.01 x 1.000.000 = 10.000 m^3/year per km^2 ground water is available for withdrawal.
This amount is equivalent to 27 m^3/day per km^2, which is sufficient for 675 people/km^2 per day if the daily demand is 40 l/c/d.

Withdrawals would change the present equilibrium and flow patterns, resulting in a decrease of natural discharge.
An increase in the amount of recharge may also be induced both directly from the infiltration of rainfall and from streams.

5.2.2. Alluvium

Although alluvial deposits (outside the Mkata-Wami Basin) make up less than 1% of the project area, they are amongst the most important aquifers of the area because the ground water is renewable and permeabilities are moderate to high.
Water level fluctuations have been observed in a number of wells, holes and piezometers in alluvial deposits throughout the project area.

Seasonal water level fluctuations of about 0.5 - 2.0 m have been measured, clearly indicating actual recharge of the alluvial aquifers.

The ground water potential of the alluvium in the Berega area was assessed during a special study (DA 5). The average ground water discharge through the riverbed aquifer is amply sufficient to cope with the domestic water demand in 1991 and just a fraction of the annual rainfall in the catchment area (less than 0.01%).
Assuming that the hydrogeological conditions in other alluvial areas are approximately similar to those in the Berega area, then the order of magnitude of the ground water potential in other alluvial valleys can be estimated from the size of the catchment area and the annual rainfall.
In particular the ground water potential of riverbed aquifers in the western mountain ranges can be estimated in this way.

5.2.3. Jurassic limestone zone

It has been demonstrated (DA 4) that probably considerable amounts of water infiltrate into the permeable limestone.
The discharge of the Ngerengere River, measured upstream from the limestone area is higher than the discharge downstream from the limestone area (see C 4.2.2., Volume III), which also points to recharge of the aquifer through the alluvial fill of the Ngerengere River.
The volumes of the ground water infiltrating into the limestones through the riverbed cannot be calculated because in between the two gauging stations, many small streams enter the Ngerengere River.
Recharge conditions in the limestone area are not known from observations of ground water levels.

5.2.4. Crystalline dolomite area

The many springs that occur in the area where crystalline limestone and dolomite crop out, point to the existence of active ground water flow systems, with ground water tables close to the surface.

The ground water is recharged by non-perennial streams descending from the Uluguru Mountains, west of the area.
The EC of the surface water is low; less than 10 mS/m. The EC of the ground water in the crystalline limestone and dolomite area is invariably between 45 and 50 mS/m. This is an indication that the average rate of flow through this karst area is not so high.

5.3. Non-renewable ground water

5.3.1. Mkata-Wami Basin

Geo-electrical soundings indicate the existence of sediments, 100 m up to 400 m thick, in the western parts of the basin.
Logs of boreholes drilled in these parts of the Mkata-Wami Basin indicate the presence of sand and gravel layers at depths between 50 and 200 m.
Data on deeper aquifers are not available.

Sands make up from 10% to 25% of the sequences between 50 and 200 m depth.
Assuming an average aquifer thickness of 25 m, and a storage coefficient of 5×10^{-3}, the ground water potential would be $1000 \times 1000 \times 25 \times 5.10^{-3}$ = 125.000 m^3/km^2 of area, for the deep aquifers.
However, withdrawals of ground water from deep aquifers can largely be considered as mining operations because these aquifers most probably do not receive recharge.
Although pumping from wells in deep aquifers might induce recharge of the aquifers, it is recommended to install wells in medium-depth aquifers where possible.

5.3.2. Other areas

Data on ground water flow in the weathered parts of the basement, and in the Jurassic sandstones are not available.
The very low yields of boreholes in these rocks (<1 l/s) point to very low permeabilities, and the high salinity of the ground water is an indication that the retention period of the ground water is very long.
It thus may be concluded that ground water flow through these rocks is almost non-existent.
The only exceptions are fault zones, through which ground water might move at considerable flow rates as is demonstrated by relatively high yields of boreholes drilled in fault zones.

5.4. Ground water potential of hydrological sub-areas (see Fig. D 3.1-1)

5.4.1. General

As has been pointed out in Chapter 2, the main objective of the hydrogeological investigations was to assess the ground water potential throughout the project area, and in its rural areas in particular.
The prospects for ground water throughout the project area have been indicated in paragraph 5.2. Areas have been distinguished where ground water is, or is not available and for those areas where ground water is available (throughout the year), the potential has been roughly calculated or estimated.
In the following paragraphs, the ground water potential of the rural areas is concentrated on.
Those rural areas where no ground water is available (e.g. the Uluguru and Nguru Mountains), are not considered further.

Not all rural areas where ground water is available, could be investigated.
Priority was given to the assessment of the ground water potential of those areas, identified in the First MDWSP report as areas contending with serious water supply problems:

- the northern part of the Kilosa District (sub-area I)

- the area between Mandela and Manyinga (sub-areas II and III)
- the Ngerengere area (sub-area IX)

Besides these priority areas, other sub-areas have been investigated. The hydrogeological sub-areas described in the next paragraphs are considered to be representative for the various hydrogeological conditions prevailing in the project area.

5.4.2. Hydrogeological sub-area I: The Berega area

5.4.2.1. Introduction

The Berega Basin has been the subject of a special study on the occurrence of ground water (DA 5).
A brief description of the area, the executed fieldwork, and the ground water potential is given here.

5.4.2.2. General description

The Berega River Basin drains the central part of the eastern Ukaguru Mountains. The basin is about 80 kilometres long, down to the junction with the Chogowale River, one of the main tributaries of the Mkindu River.
The basin drains moderately arid to semi-arid terrain between elevations of 1500 and 600 metres above MSL.
The catchment area has a surface area of about 1760 km^2 of which roughly 5% is the main valley floor, 15% is rugged mountains and the remaining 80% is upland terrain.

Slopes are moderate, 4-10% with some inselbergs reaching elevations of 300 to 800 metres above their surroundings.

The valley is a NW-SE oriented depression bounded by faults. To the NE the Nguru Mountains rise steeply, forming a drainage divide at elevations up to 1500 metres. To the SW the divide follows elevations of up to 1400 m of the Kaguru Mountains.

The Nguru Mountains mainly consist of granulites. The Kaguru Mountains are composed of tightly folded gneiss, amphibolite, meta-gabbro and quartzite, locally invaded by granite.

The Berega River Basin itself is underlain by Precambrian biotite gneiss of sedimentary origin, folded into a NW-SE striking broad syncline.
In many places the weathered or unweathered bedrock is covered with some metres of red-brown, sandy soil, derived from the biotite gneiss.

Remnants of fluvial and colluvial depositional terraces, locally up to several hundreds of metres wide and a few metres thick, are found in the main valleys.

These sediments are well-graded, consisting of dark brown sandy loams, loamy sands and coarse sands to fine gravels, most probably deposited during early Quaternary periods. The top of these terraces is situated at elevations of a few metres above the present river beds.
The present river beds of the Berega River itself and its main tributaries, the Kibedya, Magera and Kinyolisi Rivers, are 5 up to 50 metres wide.
They are cut into the old terraces or bedrock and filled up with some metres of coarse to very coarse sands. Geo-electrical measurements carried out during the special study indicate the presence of a fairly thick, weathered zone beneath these alluvial deposits. Finely textured flood plain deposits are not present in the catchment area.

5.4.2.3. Field data collection

Activities started in June 1978, with a hydrogeological reconnaissance survey of the area.
During this survey, data collected within the scope of the identification of conditions and problems of rural water supply in the northern part of the Kilosa District, dealt with in the first MDWSP Report, were quantified and qualified.
Hydrogeological fieldwork was carried out around 40 villages.
Various water-bearing formations could be distinguished.
Shallow ground water occurs in:
- alluvial sands and gravels filling up the river beds of the Berega River and its main tributaries
- sand and gravels of higher level fluvial terraces

Ground water at greater depth is occasionally present in:
- weathered zones, faults and shear zones of the gneissic basement rocks

Tables D 4.2-2 and DA 5.4.6-1 show that ground water in the basement rocks is invariably highly mineralized and unsuitable for domestic use. In addition, yields of boreholes are very low.
For this reason it was decided to concentrate the detailed study on the occurrence of shallow ground water. Since all problem villages are situated within the catchment area of the Berega River, it seemed logical from a hydrogeological point of view to confine the investigations to this basin.

Thus, the aim of this detailed study was:
- to assess the quantity of potable ground water at shallow depth (0-12 m), available for domestic water supply throughout the year
- to find hydrogeological reasons for the occurrence of saline ground water in the basin
- to locate suitable shallow well sites

To determine the ground water potential of the river bed aquifer the following fieldwork was executed:

- as close as possible to a problem village cross-sections were drilled in the river beds
- at a depth of one metre in the boreholes, soil samples were taken for examination
- 1 inch diameter PVC-piezometer tubes have been installed in every borehole

Geo-electrical soundings, along the alignments of the hand-drilled profiles, were carried out in the river beds themselves and on the older terrace deposits, where present. The soundings were made in order to obtain more information about the thickness of the weathered zone and to establish the depth to the fresh bedrock.

Boreholes drilled in the vicinity of geo-electrical soundings were well-logged in order to gather resistivity data which might be of use during the interpretation of the geo-electrical sounding curves.

All profiles, drilled boreholes, locations of geo-electrical soundings and installed piezometer tubes were levelled.

Water samples were taken to get an impression of the chemical quality of the ground water. Extraction of water samples from the observation wells was not possible. Therefore water samples were taken from hand dug holes close to the cross-sections.

In 20 villages, mainly in the eastern part of the basin, more than 100 hand-drillings were carried out.

5.4.2.4. Ground water potential

With regard to the possibilities of shallow ground water, exploitation the Berega River Basin can be divided into two parts.
A western part where the river bed aquifer is either dry or highly saline during the dry season, and an eastern part where exploitation of ground water present in river beds and terraces is possible.
Villages where shallow wells can be constructed are:
Ibindo, Mwandi, Berega, Mabula, Magera, Italague, Kinyolisi, Makuyu, Iyogwe, Idobo, Leshata, Madege, Ndogomi.
In the villages Ibindo, Mwandi, Berega, Mabula, Magera, Kinyolisi, Idobo, Leata, Madege and Ndogomi the ground water potential could be calculated.
This has been done by:

- Estimating the permeability of the river bed sands after the samples were studied.
  Permeability values are high and vary from 200 to 450 m/day.
- Calculating the cross-section areas from the hand-drilled profiles.
- Determining the hydraulic gradient of the river bed aquifers from the topographic maps.

Table 5.4. -1 - Ground water potential and water demand

cross-section	village	population 1978	population demand 1978 m^3/day	population demand 1988 m^3/day	population demand 1998 m^3/day	k m/day	i -	A m^2			Q m^3/day		
								BDS	EDS	E EDS	BDS	EDS	E EDS
165/1-1	Berega	2890	116	174	232	450	.014	340	300	290	2150	1880	1825
165/1-2	Mabula	1069	43	65	86	300	.015	225	170	160	1010	765	720
3						225	.014	360	320	310	1135	1000	875
165/1-4	Magera	1567	63	95	126	200	.014	260	145	125	725	406	350
5						250	.014	190	120	95	800	420	332
165/1-6	Kinyolisi	800	32	48	64	350	.015	72	50	40	378	263	210
165/1-7	Ndogomi	1434	57	86	114	275	.015	65	43	38	267	177	157
165/1-8	Madege	2050	82	123	164	300	.015	89	68	63	400	306	283
165/1-9	Nguyami	1792	72	108	144	350	.015	138	107	100	725	562	525
165/1-10	Idibo	2715	109	164	218	400	.015	110	80	60	660	480	360
165/1-11	Mbili	821	33	50	66	400	.026	10	7	-	104	72	-
12						300	.026	7	-	-	55	-	-
165/1-13	Mawandi	2558	102	153	204	400	.014	390	370	350	2185	2075	1960
165/1-14	Ibindo	1558	62	93	124	350	.014	475	435	420	2327	2130	2055
146/3-1	Leshata	2285	91	137	182		.016	150	105	90	600	420	360
	Total		862	1296	1724								

BDS = Beginning dry season
EDS = End dry season
EEDS = End extreme dry season

A = Area in m^2
Q = Discharge in m^3/day
i = hydraulic gradient
k = permeability in m/day

5.4.3. Hydrogeological sub-area II: The Msowero-Dakawa-Dibamba area

5.4.3.1. General description

This area, enclosed by the Nguru Mountains to the West and the Wami and Mkata Rivers to the East, is gently sloping towards the South-East. It is underlaid by 40-200 m of unconsolidated sediments, deposited by the Wami and Mkata Rivers and their tributaries during periods from upper Tertiary up to Recent times. The depth to the basement varies considerably from place to place and the thickness of the sediments covering the gneissic basement varies accordingly. Because of the great horizontal and vertical variation in sedimentation of sandy and clayey deposits, withdrawable ground water occurs at various depths.
There are 18 villages in the area with a total population of 32,200.

5.4.3.2. Field data collection

Hydrogeological fieldwork in this area was carried out between June and August, 1978.
Shallow ground water is being exploited by means of hand-dug holes in river beds (Kitete, Dumila, Mkundi, Mugudeni) and concrete-lined shallow wells (Mkata Ranch, Mfulu, Madudu, Makuyu, Mandela, Mirama and Mvomero). However, the shallow wells are few in number and most of them run dry during the dry season.
Ground water is present at depths between 3 and 20 m below ground level. The quality of the shallow ground water, expressed by its EC value, in most of this area is good (EC 40-100 mS/m). Water of poor quality (EC 125-200 mS/m) was found in wells and holes at Dibamba and Mugudeni.

Regular measurements of water levels and EC's were taken in Mandela, Makuyu and Madudu during the period from May, 1978 until April, 1979. Seasonal water level fluctuations vary from 0.5 to several metres; most shallow wells run dry during the dry season. The EC of the shallow ground water in the three villages mentioned above did not change during the period of the dry season.

Based on the recent results of a hand-drilling programme carried out in a number of villages from December 1978 until January 1979, the sub-area has to be divided into two parts with regard to the possibilities for shallow ground water exploitation.
The two parts are:
IIa the southern part of this sub-area, situated between Msowero-Mandela and the Mkata River (13 villages, 23,800 people)
IIb the northern part of this sub-area, between Mugudeni, Dibamba and the Wami River (5 villages, 8,400 people)

IIa

Hand-drillings were carried out in and around Mbigili, Mabana, Dumila, Magole, Mandela, Makuyu. Maximum drilling depth was 11 m. No aquifers were found in these upper 11 m.
Mainly clays, sandy clays and loam were found. Some thin sand layers (0.2-2.0 m) present in drillings at Magole and Madudu were not water-bearing.

IIb

Hand-drillings were carried out at Mirama, Mugudeni, Mvomero, Dibamba and Dakawa. Except in Dakawa, it proved to be difficult to find proper shallow well sites in this sub-area. About 75% of the hand-drilled holes had to be rejected.
As in sub-area IIa, the upper 11 m are principally clayey and loamy and not water-bearing. Saltish ground water was found in drillings at Mugudeni and Mvomero. (EC up to 500 mS/m). Nevertheless, sufficient quantities of shallow ground water, though of poor chemical quality (EC 125-200 mS/m), were found in a number of the drillings; at Mirama the EC's were good (40 mS/m).
Sandy aquifers were found between 2.0 and 10 m below ground level. Thickness of these mostly loamy or clayey sands varied from 0.5-3.0 m. Tested yields were moderate: 0.8 to 1.2 m^3/hour could be pumped with drawdowns of 0.5 to 4.9 m.
In Dakawa the shallow ground water situation is somewhat different. Thick, coarse-grained, clayey sands were found in drillings from about 5.0 m down to 10.0 m below ground level. The EC's varied between 30 and 100 mS/m. Yields were moderate: up to 0.9 m^3/hour was pumped with drawdowns up to 1.0 m.

Ground water at greater depths has been exploited by boreholes at Magole (17/60) and Mvomero (6/62). The Magole borehole is still producing. The yield is 2-3 l/s; the borehole is pumped for 8 hours/day. Drawdown is 8 m approximately. The EC of the ground water is 72.5 mS/m. The Mvomero borehole has been abandoned since 1970, because of an increase of the salinity of the ground water. From 1962 to 1970, the EC changed gradually from 62.5 mS/m to 260 mS/m. The yield at the time of operation was approximately 4 l/s, with a drawdown of only 1.5 m.

Boreholes were also drilled by Maji Morogoro in Kitete (33/78) and Dumila (226/77); they are not yet in operation.
Several aquifers, varying in thickness from 2 to 14 m, were found at depths between 15 and 80 m. The water-bearing formations are medium-coarse to very coarse, sometimes gravelly sands. The EC of the ground water in these boreholes is between 75 and 125 mS/m. Most probably due to faulty constructions tested yields were low (2-3 l/s) with a drawdown in the well of 40 m at Dumila.

Between September 1978 and January 1979, MDWSP boreholes were drilled at Dakawa (135/78), Dibamba (151/78), Mandela (162/78). Makuyu (173/78), Mugudeni (6/79) and Mirama (4-5/79).
Detailed data on these wells are presented in sub-par. 3.3.3.

Several water-bearing sand layers, 4 up to 25 m thick, were found in the boreholes at Mandela, Makuyu and Dibamba between depths of 25 and 66 m below ground level.
Tested yields were 10.0 l/s at Mandela, 7.7 l/s at Makuyu and 10.0 l/s at Dibamba with respective drawdowns of 1.5 m, 15 m and 25 m.
The chemical quality of the ground water is very good, EC's were below 50 mS/m.

In the boreholes drilled at Mugudeni (110 m deep) and Mirama (66 m deep), only clays and clayey sand and gravel were found, no aquifers were present here.

The Dakawa borehole is very different from the others. Thick, well-rounded, coarse sands to fine gravels were found between 3 m and 30 m below ground level. These sediments are considered to be channel deposits of the Wami River. The permeability of the sands and gravels, calculated from pumping tests, was 80 m/day. The EC was very low (17 mS/m).
Water levels have been measured at regular intervals in the MDWSP boreholes in this sub-area, since the time they were completed.
Table D 5.4-2 summarizes these data.

Table D 5.4-2 - <u>Water level fluctuations in sub-area II</u> (m below ground level)

Borehole location	11-10-'78	27-10-'78	10-11-'78	24-11-'78	9-1-'79	17-1-'79	30-1-'79	8-2-'79
Dakawa	7.33	-	-	-	6.68	6.65	5.46	-
Dibamba		8.56	-	-	6.78	6.69	6.79	6.32
Mandela			15.15	-	14.00	13.92	13.81	13.32
Makuyu				11.63	9.26	-	-	-

Within approximately 3 months the water levels in the boreholes rose about 2 m. This is a clear indication of recharge. The tritium content of the ground water has been determined from six of the MDWSP-boreholes (see table D 5.4-3). The tritium content is a measure for the period passed since it precipitated as rainfall.

Table D 5.4-3 - <u>Tritium content of ground water</u>

Borehole	depth of screen (m)	GT$^-$ lab. no.	tritium A^3 (TU)
Dakawa	17.4 - 22.3	1542	2,1 ± 0,8
Madoto		1543	3,7 ± 0,8
Mandela	25.0 - 34.7	1544	1,8 ± 0,8
Dibamba	60.9 - 65.8	1545	<1,4
Makuyu	42.0 - 46.9	1546	2,1 ± 0,8
Mbwade		1547	2,5 ± 0,8

The very low tritium contents indicate an age of more than 40 years of the ground water in the upper 65 m of the Mkata-Wami Basin. Moreover, the denterium content of the ground water virtually precludes any evaporation during the time that the water was at the surface.
The above-mentioned isotope data suggest that the infiltration of that part of the rainfall that recharges the ground water happens soon after precipitation (no evaporation) and that the retention period of the ground water in the Mkata-Wami aquifer is relatively long.

At any rate ground water flow is extremely slow, as gradients are very low (2.5 x 10^{-4} to 4 x 10^{-4}). It is not improbable that the recharge areas of the Mkata-Wami aquifer system are situated along the western border of the basin or even outside the basin.

5.4.3.3. Ground water potential

Shallow ground water potential sub-area IIa

Prospects for shallow ground water in this sub-area are very poor.
The upper 11 m of the Wami-Mkata sediments are predominantly clayey and loamy. Existing shallow wells in Mandela and Madudu, tapping loamy aquifers, run dry during the dry season.

Ground water of good chemical quality (EC < 125 mS/m), but having a very poor bacteriological quality, occurs in river bed sands of the Mkundi and Kitete Rivers. The aquifers are 15-30 m wide, approximately 5 m thick, and made up of coarse to very coarse-grained sand.
Water levels vary from 0.0 m at the beginning of the dry season to-1.5 m at the end of it. Because of the poor bacteriological quality, exploitation of this ground water cannot be recommended.

Shallow ground water potential sub-area IIb

As in the area IIb, the upper 11 m of this sub-area are predominantly clayey and loamy, and water occurs only locally in loamy sands situated at depths between 2.0 and 10.0 m below ground level.
Thickness of these aquifers is 0.5-3,0 m.
There is a great variety in the salinity of shallow ground water in this sub-area.
Water of poor but acceptable quality (EC 125-200 mS/m) is found close to water of high salinities (EC up to 500 mS/m).
Because of the limited extent of the aquifers and the great variety in salinities, pumped supplies from shallow wells are not thought to be feasible.
The relatively high EC's most probably indicate low ground water flow velocities.

* Potential of ground water at greater depths in sub-area IIa, b

On the basis of the geo-electrical investigations and borehole data, sub-area IIa, b, has been divided into a NW part, where prospects for deep ground water are fair to good, a middle part where prospects are poor and a narrow SE zone, along the Mkata-Wami Rivers, where prospects are good again.

In the NW part of this sub-area ground water occurs in medium-depth aquifers (between 25 and 66 m below ground level).
The aquifers are medium-coarse to coarse, sometimes slightly clayey or loamy sands deposited most probably in alluvial fan and braided river systems.
Aquifer thickness is from 3 m to 25 m, but tends to be not more than 5-6 m on an average. Calculated permeabilities are between 10 and 100 m/day. Water quality is good; EC's do not exceed 50 mS/m. The low EC's as well as an average ground water level rise of 2 m in 3 months, indicate active flow systems.
It is impossible to make a quantitative estimate of the ground water potential of the area, as no recharge data are available.
Should the exploitation of medium-deep ground water be intensified, ground water levels must be scrutinized carefully on a regional scale, to prevent overdraft and depletion of the aquifers.

5.4.4. Hydrogeological sub-area III: The Musufini-Dihinda area

5.4.4.1. General description

This area comprises a 35 km long, narrow zone following the major fault which forms the transition zone from the Nguru Mountains to the Wami Valley. Along the upthrown side of the fault the terrain is hilly and underlain by gneissic rocks, covered with some loamy soil or colluvium.

East of the foothills, where the basement is downfaulted, the terrain is flat and swampy and underlain by sediments deposited in alluvial fans, streams and backswamps.

There are 8 villages in this area, all situated in the lower foothills. The flat area underlain by alluvial deposits is used mainly for crop growing. The total population is 12,200.

5.4.4.2. Field data collection

Fieldwork in this area was carried out during August 1978. It appeared that ground water was hardly being used here.
Many streams descending from the Nguru Mountains are at present used for domestic water supply. Some of the streams are perennial.
Because of this, large areas along the downfaulted side of the main fault are swampy the whole year round. The EC of the surface water of both streams and swamps is very low; 10 mS/m on an average.
It has been observed that sands are being deposited along the downthrown side of the fault. The sand is very angular and consists mainly of quartz; grain size is fine to very coarse (up to 2 mm). This material is washed down the mountains during heavy rains and high run-off. Because of the difference in slope between the foothills and the alluvial plains the sands are deposited just along this transition.
During periods of high run-off, streams running parallel to the fault zone spread the sands sheet-wides over this area. The width of the sand deposits varies from 100 to 300 m; the length of the deposits is up to a few km. The rest of the alluvial area is clayey at the surface.
The description may be indicative of the geological structure of the sub-surface and may be of help to explain the results of the hand-drillings.

During July and August, as well as December, 1978, hand-drillings were carried out in the area by a MWCP survey team in order to find proper sites for shallow well construction. Depth of the drillings was 3 to 9 m. In the holes drilled in the lowest parts of the foothills, red/orange, sometimes sandy to gravelly loam was found.
Most of these holes were dry and in some of them saline ground water was found (EC 240-600 mS/m). The hand drillings carried out in the alluvial plain were more successful. Although much clay was found, water-bearing sands were also struck.
The sands are 0.5 up to 3.0 m thick and are covered with and alternate with 0.5 to 5.0 m thick clay layers.
The sands are fine to coarse, angular and almost free of clay, strongly resembling the sands found at the surface. Water levels at the time of drilling varied between 0.5 and 1.5 m below ground level.

Data on seasonal ground water level fluctuations could not be collected because there were no wells in the area, tapping the aquifers just described. They are expected to be small however, because of a permanent recharge of the shallow ground water in the swamp areas.
The chemical quality, expressed by its EC value, is very good; on an average the EC is 30 mS/m. These low values probably indicate recharge of the aquifers not far from the area surveyed.

Pumpings tests carried out in a number of the exploration drillings gave good yields: more than 1200 l/hr could be pumped in most cases at an average drawdown of 0.3 to 0.9 m.
Average transmissivity as calculated from these figures is 40-120 m^2/day.

Data on deeper ground water are available from MDWSP geo-electrical soundings carried out near Dibamba, Dihombo and Kigugu.
The prospects for deeper ground water in the area between Dibamba and Dihombo, comprising the villages Msufini and Hembeti, have been classified as fair to good (see Map D4).
Depth to basement in this area was interpreted to be 200-300 m and in MDWSP borehole 151/78 at Dibamba (see sub-par. 3.3.5.) drilled to 110 m depth, two 4-6 m thick aquifers were found.

No sufficient data are available on the occurrence of fresh ground water in deeper aquifers in the area between Dibamba and Dihinda.
Explorations for deeper ground water by means of geophysical survey or drilling is hampered by the swampy character of the terrain.
However, borehole 14/66 in Turiani was successful and is still in operation.
Water is extracted from fissured basement material, probably the zone of the major fault.
The yield is more than 3 l/s and the EC is about 85 mS/m.

5.4.4.3. Ground water potential

Confined, semi-confined and unconfined shallow ground water occurs in alluvial sands, deposited alongside the foothills as 0.5-3.0 m thick, 100-300 m wide and 1 to 3 km long bodies.
The sands are angular, fine to coarse-textured and almost without clay.
Water levels measured during the first part of the dry season (July, August 1978) were 0.5-1.5 m below ground level.
The very low EC (30 mS/m on an average) of the ground water may indicate recharge of these aquifers. Permeabilities, estimated on the ground of the texture of the sands as well as calculated from short pumping tests vary from 50 to 200 m/day.

The shallow ground water potential per village may be calculated by using the following figures:
- since the villages are approximately 1-2 km long, one sand aquifer with average dimensions of 2 m x 250 x 2500 m may be present within reasonable distance of the village
- storage coefficient is 5 x 10^{-3}

Taking into account a certain amount of recharge, the ground water potential of such an aquifer could be $2 \times 250 \times 2500 \times 5 \times 10^{-3} = 6250$ m^3. Based on a daily water demand of 40 l/c/day the yearly water demand for a village with 430 inhabitants, could probably be satisfied. Unconfined aquifers may yield considerably more water, because for unconfined aquifers the storage coëfficient may be substituted by the specific yield, which may easily amount to 0.1. Unconfined aquifers are, however, more susceptible to pollution.

Summing up, it may be stated that the shallow sandy aquifers along the foothills of the Nguru Mountains present interesting possibilities for the construction of shallow to medium-deep wells. The quality of the ground water is very good. Detailed assessment of the quantities available would require the mapping of the extent of the aquifers or prolonged pumping tests.
Since sufficient shallow ground water is available and permeabilities are moderate to high, pumped/piped water supplies from shallow wells seem to be possible.

Ground water at greater depths occurs in the sediments that filled up this downfaulted part of the Wami Basin as well as in fissured parts of the basement, most probably the major fault zone. With only a few geoelectrical soundings and two (successful) boreholes in the area, it is not possible to quantify the potential.
However, the available data point to moderate to good possibilities. Exploitation of deeper ground water is hampered by the inaccessibility of this swampy area.

5.4.5. Hydrogeological sub-area IV: The area east of Turiani

5.4.5.1. General description

The area is flat with a slight slope towards the Wami River. It is underlain by 20-60 m of sediments, deposited in alluvial fans, swamps and river systems. The area comprises 6 villages, all situated around the Mtibwa Sugar Estate, with a total population of approximately 10.000 people.

5.4.5.2. Field data collection

Hydrogeological fieldwork in the area was carried out during the second half of August, 1978.
In this area people mainly depend on shallow ground water which is exploited by means of many hand-dug holes (more than 10 in most villages) and some concrete-lined shallow wells.
The depth of the hand-dug holes and wells varies from 1.7 m to 6.8 m and is only 4.3 m on an average. Depth to ground water, measured in August, 1978, varied from 1.0 to 6.7 m and was 3.6 m on an average.

The EC of the shallow ground water in most holes and wells is very low; values vary between 19 mS/m and 54 mS/m.
Only in Kunke and Kidudwe Ujamaa, were EC values between 100 and 200 mS/m measured.
Between August and October 1978, regular measurements of water levels and salinities were carried out. Within a period of approximately two months, the water levels declined 0.3 m on an average.
The EC values did not change during this period.
Hand-drillings have not been carried out in this area. Lithological profiles of some hand-dug holes could be compiled from field observations and information supplied by well-diggers from the villages.
From the ground level down to 6-8 m depth, brown, medium-coarse, somewhat cemented sands occur.
Sometimes the upper 0.5-1 m is loamy or clayey due to soil formation.
Below these upper sands there is an impermeable clay layer of unknown thickness.

A geo-electrical survey was carried out in this area to investigate the possibilities for ground water at greater depths. Some data on deep ground water are available from 5 boreholes drilled on the Mtibwa Sugar Estate. Depth to basement in the boreholes varied from 24-40 m. Mainly loamy and clayey unconsolidated sediments were found, alternating with some sand layers.
The EC of the ground water varied between 50 and 90 mS/m. The boreholes were abandoned because of their low yields. However faulty construction might well be the reason for the low yields.

5.4.5.3. Ground water potential

In this areas shallow ground water occurs under water-table conditions in an approximately 7 m thick sand layer. Thickness of the satured zone varies from 4.0 m in the wet season, to 3.0 m in the dry season.
On the basis of an examination of sand samples, a permeability between 10 and 100 m/day has been estimated.

The ground water potential of this aquifer per km^2 at the end of the dry season is: 1.10^6 (area) x 3 (thickness satured zone) x 10% (specific yield) = 3.10^5 m^3

If a yearly recharge of 10 mm is assumed, the recharge per km^2 would be 10,000 m^3 which is sufficient, for instance, to supply 685 people with water.

The above figures show that the shallow ground water potential in the area is more than sufficient for exploitation by means of shallow hand-pumped wells or motor-pumped supplies.

With pumping rates of 2-3 l/s for a hand-drilled shallow well, drawdown would probably be too high.
Therefore concrete-lined storage wells will probably be necessary for the construction of pumped/piped supply systems.

The bacteriological quality of the shallow ground water has to be examined carefully because contamination of the water is very easily possible.
Therefore it is also advised to further examine the possibilities of confined aquifers at medium depth in this area.
Data on medium-depth ground water will mainly have to be collected by drilling.

5.4.6. Hydrogeological sub-area V: The Kilosa-Kimamba area

5.4.6.1. General description

This area forms part of the Mkata-Wami Basin; its surface slopes gently towards the East.
Along its western margin, its area is bounded by the Usagara Mountains.
Geo-electrical investigations indicated the presence of two major faults, the Wami Rift Fault which is partly concealed in this area, and the Ilonga Fault.
Both faults coincide just south of Rudewa-Batini.
Less important faults were found north of Rudewa-Gongoni and south of Tindiga.
In between the Ilonga Fault and the Wami Rift Fault, the sediments covering the down faulted basement are approximately 100 m thick. East of the Wami Rift Fault, depths up to 400 m of the sediments are indicated by the geo-electrical soundings.
The sediments have been deposited most probably during upper-Tertiary to Recent times, by the Myombo and Mkondoa Rivers and some smaller streams, descending from the Usagara Mountains.
In this part of the basin, relatively large quantities of coarse-textured sediments (sands, gravels) were deposited and ground water is abundant in various aquifers at various depths.
There are 13 villages in this sub-area, with a total population of 32,000.
Kimamba (10,000 people) and Kilosa (30,000 people) have both been excluded from the study.

5.4.6.2. Field data collection

Hydrogeological fieldwork in this sub-area was carried out between the end of July and mid-October 1978.
Shallow ground water is exploited by means of many hand-dug holes which are often lined with oil drums, and concrete-lined shallow wells of various types and diameters.

The villages Chanzuru, Kondoa, Malangali, Malui, Mamoyo in the southern part of the sub-area each have between 10 and 20 hand-dug holes and some shallow wells.
Mbwade has only one concrete-lined shallow well; Peapea some hand-dug holes and Madoto, Ilonga Rudewa-Gongoni have no ground water supplies.
Many hand-dug holes are also found in the villages Rudewa-Batini and Rudewa-Mbuyuni.
The depth of most hand-dug holes and shallow wells in the area is small: between 2.5 and 5.0 m.
Only in Mbwade and Rudewa-Batini are the depths of the wells 12 and 9 m respectively.
The water levels vary between 2.0 and 4.4 m below ground level and are only deeper in Mbwade (9.5 m) and Rudewa Batini (6.0 m).
The EC of the ground water in this area generally is not high; values between 35 mS/m and 100 mS/m have been measured. The EC of the ground water from the shallow well at Mbwade was approximately 130 mS/m.
It is apparent that there is an abundance of shallow ground water in this sub-area; aquifers do not dry up during the dry season.
Regular measurements of water levels and EC's were taken in Kondoa, Malangali, Mamoyo, Mbwade, Rudewa-Batini and Rudewa-Mbuyuni during the period of July 1978 - December 1978.
Seasonal water level fluctuations in the southern part of this sub-area are about 3.0 m; the EC of the ground water did not change during the course of the dry season. Water level fluctuations measured at Mbwade, Rudewa-Batini and Rudewa-Mbuyuni were between 0.4 and 1.1 m. Only at Mbwade, the EC value of the ground water increased from 105 mS/m at the beginning of the dry season, to 140 mS/m at the end of the dry season.

Between January and April 1979, more than 100 hand-drillings were carried out in the sub-area by survey teams of the MWCP, in order to find suitable locations for the construction of shallow wells.
The maximum drilling depth was 13.5 m and the average drilling depth was 11.0 m.
Aquifers were often found at two or three different levels.
An upper aquifer is present almost everywhere at depths between 1.5 and 5.5 m below ground level; its thickness varies from 0.5 up to 3.0 m.
A second aquifer occurs between 5.5 and 8.0 m depth; its average thickness is 1.0 m.
The deepest shallow aquifers occur locally between 8.0 and 13 m depth; their average thickness is 1.0 m.
The ground water in the upper aquifer is unconfined to semi-confined; semi-confined to confined conditions prevail in the deeper shallow aquifers.
Most aquifers consist of fine sands; medean-coarse sands occur only locally.

The water levels in the second and third aquifer are generally somewhat higher than those of the upper aquifer; the EC of the ground water in the various aquifers does not show much variation. Ground water with EC values higher than 150 mS/m has not been encountered in the area.
The tested yields of the hand-drillings were moderate to very high (between 1000 and 1600 l/hr) and only where loamy sands make up most parts of the aquifer, lower yields were obtained.
Unfortunately drawdowns have not been measured and therefore specific well capacities, permeabilities and transmissivities could not be calculated.
From examination of the samples, k-values between 5 and 50 m/day could be estimated for most aquifer material.

Between 1938 and 1978, approximately 30 boreholes were drilled in this sub-area. At present the boreholes 37/54, 37/56, 19/57, 31/57, 30/61 and 95/72 are in operation. The other boreholes have all been abandoned. Drilling depth varied from approximately 30 to 190 m and was 60 m on an average.
Several aquifers, varying in thickness from 3 to 6 m, were found at depths between 15 and 150 m. Locally aquifers of more than 12 m thick were encountered in boreholes near Kilosa. Slotted casing was generally installed in aquifers between 20 and 60 m depth, thus at medium depth. From static water levels, measured in these boreholes at their time of construction, the piezometric surface of the medium-depth aquifers could be constructed (Map D3). The ground water flows slowly towards the East; the hydraulic gradient is between 2.5×10^{-4} and 4.0×10^{-4}.

The yields of most boreholes were between 3 and 10 l/s and average yields were 6 l/s approximately, with drawdowns between 3 and 12 m and 5 m on an average.
The EC of the ground water in the various aquifers varies considerably; values between 23 and 320 mS/m have been recorded, but generally the values are between 60 and 150 mS/m.

On the basis of the geo-electrical investigations, carried out in this area, sub-areas have been indicated where the prospects for medium-depth and deep ground water are good, fair and poor (Map D3).

The prospects have been classified as good in the area between the Wami Rift Fault and the Ilonga Fault (the triangle between Magomeni, Malui and Rudewa-Batini); here the depth to basement is about 100 m.
The prospects are also good in the area east of Rudewa-Batini and Mvumi, where the depth to basement is more than 200 m.
In these areas, aquifers occur at various depths and the minimum total aquifer thickness is 15 m. EC values of the ground water generally will be below 100 mS/m.

East of the Wami Rift Fault, between Chanzuru and Mbwade, the prospects are fair. In these parts the depth to basement exceeds 400 m. Minimum aquifer thickness is 5 m and the EC of the ground water is less than 200 mS/m.

In the triangle between Chanzuru, Madoto and Rudewa-Batini the prospects are poor which means that aquifers may be absent, thin and/or saline.

Between January and April 1979, MDWSP boreholes were drilled at Mbwade (7/79), Madoto (13/79, 24/79, 27/79), Rudewa (28/79) and Kondoa (37/79, 41/79). Detailed data on these wells are presented in sub-par. 3.3.3.

In the Rudewa borehole a thick aquifer was found between 15 and 26 m below ground level. Alternating sand and clay layers, varying in thickness from 0.5 - 1.5 m make up the upper 15 m of the sequence; the sand layers offer good possibilities for shallow wells.

In the Kondoa borehole, three aquifers, each 4.3 m thick, are present between 15 and 67 m depth. Thin sand layers, offering good possibilities for shallow wells, occur in the upper 15 m.

The Mbwade borehole, which was drilled down to 85 m below ground level showed the presence of aquifers between 15-18 m, 33-43 m, 53-58 m and 66-73 m, hence the total aquifer thickness in the upper 85 m is 24 m.

At Madoto mostly clayey deposits were found, with only one thin sand layer at depths between 23 and 26.5 m.

The tested yields were 11.2 l/s at Mbwade, 0.9 l/s at Madoto, 10.4 l/s at Rudewa and 6.4 l/s at Kondoa with respective drawdowns of 5.53 m, 17.92 m, 1.83 m and 4.85 m.
The chemical quality of the ground water is good, EC's were below 75 mS/m at Mbwade, Rudewa and Kondoa, and were 135 mS/m at Madoto.

In one month time, water levels in the boreholes at Rudewa and Madoto rose 0.3 and 1.3 m respectively which is an indication of recharge.

5.4.6.3. Ground water potential

Except for the areas which have been classified as poor in Map D3, ground water is abundant in this sub-area.
The aquifers present at shallow depth vary in thickness from 0.5-3.0 m and offer good possibilities for shallow wells; the aquifers generally consist of fine to medium-grained sands.
The average aquifer thickness at medium depth is 12 m; the aquifer material is coarse to very coarse sand and fine gravel.
The shallow and medium-depth aquifers are interconnected locally.

Assuming an average aquifer thickness of 15 m for the combined shallow and medium-depth aquifers, than 15 x 1,000,000 x 5.10^{-3} (storage coefficient) = 75,000 m^3 ground water is available per km^2 on a "mining" basis.
Ground water level fluctuations as well as the contours of the piezometric surface of the medium-depth ground water, point to the existence of active flow systems, recharged by rainfall.
As the location and the extent of recharge areas are not known, the safe yield of the aquifers cannot be determined, but it may be assumed that there is sufficient ground water for domestic purposes.

Ground water also occurs in aquifers deeper than 50 m below ground level. In Mbwade for instance, the total aquifer thickness between 50 and 85 m depth, is 11 m. However, recharge of these aquifers will be less and it is recommended therefore, to install wells in medium-depth aquifers where possible.

5.4.7. Hydrogeological sub-area VI: The north-eastern foothills of the Uluguru Mountains

This zone of foothills is underlain by east-dipping calcareous and dolomitic marble, interbedded by granulites and gneiss.
To the east the area is bounded by a major fault, separating these Precambrian metamorphic limestones from the consolidated sediments of the Karroo Formation. West of the foothill zone are the massive granulites that constitute part of the core of the Uluguru Mountains.

In this area ground water is mainly extracted from alluvial deposits in the valleys and river beds. The water-bearing formations are often fine-grained, loamy and thin; hence permeabilities will be low. The EC values, varying from 20 to 79 mS/m suggest a good chemical quality of this shallow ground water. Siting for shallow well locations was executed by the MWCP team in valley deposits of the villages Kiroka, Kiziwa, Kibungi and Kikundi.
Thin sand layers, alternating with clays, were found in most of the hand-drillings. The EC value of the water-bearing sands varied from 40-80 mS/m; EC's as high as 176 mS/m were measured only in Kikundi.

The other water-bearing formation of the area is formed by the metamorphic limestones. Karst springs were found near Tambuu, Mtamba and Mkuyuni; they often occur along the boundary between the marble and gneis/granulite. Discharges of the springs vary from one to several litres per second.
The EC is very constant: 50 mS/m. No boreholes were drilled in this area.

Detailed data on occurrences, discharges and chemical quality of the Karst springs are given in sub-par. (3.3.7.2. of Volume III (Hydrology)).

5.4.8. Hydrogeological sub-area VII: The Mgeta and Ruvu valleys south and east of the Uluguru Mountains

5.4.8.1. General description

This is a flat to gently sloping area, directly south and east of the Uluguru Mountains.
The area is underlain by north-west dipping sandstone, siltstone and shale of the Karroo Formation, covered with sub-horizontal, unconsolidated sediments of unknown thickness, deposited by tributaries of the Mgeta and Ruvu Rivers during the Quaternary.
In the Mgeta catchment there are 11 villages with a total population of 21,000; along the Ruvu River there are 7 villages with a total of 9,100 people.

5.4.8.2. Field data collection

Hydrogeological fieldwork was carried out during the last week of July and the first week of August, 1978.
At present only four of the 18 villages in this sub-area make use of ground water for domestic supply. The other villages are all situated near or along a perennial river and use surface water. In Dakawa and Milengwelengwe some shallow wells and hand-dug holes have been constructed but they dry up during the dry season. In Gomero and Nyarutanga hand-dug holes in an abandoned course of the Mgeta River are used.

Between August and October, 1978, regular measurements were carried out in shallow wells at Dakawa and Milengwelengwe as well as in hand-dug holes at Gomero. Within two months ground water levels at Dakawa dropped from 7.8 m to 11.7 m below ground level; the EC of the ground water here changed from 91 mS/m to 110 mS/m. Water levels at Milengwelengwe went down 0.6 m; the EC did not change.
The ground water table in the abandoned course of the Mgeta River went down 0.5 m within two months and the EC increased slightly from 70 mS/m to 75 mS/m.

There are no boreholes in the area, hence no data are available on ground water occurring in deeper alluvial aquifers or in the Karroo Formation.

5.4.8.3. Ground water potential

At present it is not possible to describe exactly the ground water situation since there are only a few shallow wells and hand-dugs holes in the area. Aquifers will undoubtedly be present in the alluvial sediments, deposited by the Mgeta and Ruvu Rivers and their tributaries.

At most villages situated along perennial streams it is probably possible to extract shallow ground water from either terrace deposits along the present river beds or from the river bed deposits themselves.
Shallow ground water can certainly be exploited at Gomero and Sesenga. The aquifer at these places is a coarse sand to fine gravel, and the EC of the ground water is below 75 mS/m. At Dakawa and Milengwelengwe deeper aquifers have to be looked for. Ground water may be found in alluvial aquifers at medium depths, or in the Karroo. Tested yields of boreholes in the Karroo Formation in other parts of the project area vary from 0.3 to 4 l/s and the EC's from 40-300 mS/m.

It is strongly recommended that a geo-electrical survey be carried out in part of this sub-area to investigate the prospects for both shallow and deep ground water and to establish the thickness of the alluvial cover. Hand-drillings will have to be carried out here too.

5.4.9. Hydrogeological sub-area VIII: The Mlali-Doma area

5.4.9.1. General description

This area comprises the western foothills of the Uluguru Mountains. Slopes are in a NW direction toward the Mkata River. The area is underlain by partly migmatized granulites and gneisses of Precambrian age. Residual soils, covering the weathered or unweathered basement, are very thin (0.5-2.0 m). Alluvial deposits of recent age are present in some valleys draining this area.
There are 7 villages in the area with a total population of 12,000.

5.4.9.2. Field data collection

A hydrogeological field survey in this area was carried out in October 1978.
Shallow ground water appeared to be the main source of water supply throughout the dry season.
Melela is going to have an improved water supply, pumped from a shallow well, dug in weathered basement. The well is under construction. In the villages Magali, Mangae, Msongozi, Maharaka, Doma and Manza, shallow ground water is at present being exploited by means of some concrete-lined shallow wells and hand-dug holes.

Depth of the wells and water holes varies from 3.0 to 9.0 m; the depth to the water table, measured in October, 1978, varied from 1.0 m to 7.0 m below ground level. The salinity of the ground water in this area is rather high, 130-225 mS/m, but generally below the maximum acceptable limit of 200 mS/m.

At the beginning of the dry season, during the months of May and June, 1978, a survey team of the MWCP drilled about 20 exploration holes in this area in order to find shallow well sites. These holes, drilled with light hand-drill equipment, ranged in depth from 2.0 to 9.0 m.
Shallow ground water was found in alluvial deposits of the Maharaka, Msongozi, Melela and Mangae Rivers and occasionally in weathered basement, at depths between 4 and 9 m.
Static water levels were higher than the levels at which ground water was struck. The holes were tested with a hand pump. Tested yields were generally more than 1 m^3/hour with relatively small drawdowns.
The EC of the ground water was mostly between 130 and 190 mS/m. Saline ground water (EC 600-850 mS/m) was found in two holes, drilled at Msongozi.

5.4.9.3. Ground water potential

Unconfined and semi-confined shallow ground water occurs in alluvial sediments, deposited in valleys of some small rivers draining this area. Aquifers generally consist of clean to slightly clayey, medium to coarse sand layers, up to 5 m thick. Locally ground water is present in highly fissured basement. Permeabilities are moderate to high. Recharge of the aquifers is proved by the differences in water levels, measured at the end of the rainy season (0.5-3.0 m below ground level) and during the last part of the dry season (1.0-7.0 m below ground level). The chemical quality of the ground water is poor since salinities are between 130 and 190 mS/m. No noticeable increase in salinity has been found during the course of the dry season.
The shallow ground water can be exploited by means of shallow wells with hand-pumps.
It is difficult to predict whether the ground water potential of this area is sufficient for exploitation by means of pumped/piped water supply systems. The first test pumping on the newly constructed shallow well at Melela appears to have given disappointing results. Permeabilities certainly are sufficiently high, but the aquifers may be limited in extent.

The prospects for deep ground water exploitation are considered to be very poor. Yields of boreholes drilled elsewhere in Precambrian metamorphic rocks are generally very low, while the water is often highly mineralized.

5.4.10. Hydrogeological sub-area IX: The area between Mikumi and the Great Ruaha River

5.4.10.1. General description

Geologically this area resembles sub-area VII. It is underlain by rocks of the Karroo Formation, covered with alluvial deposits of the Great Ruaha and Ruhembe Rivers.
The area is very flat. There are four villages with a total population of 8,200.

5.4.10.2. Field data collection

Fieldwork in the area was done during the month of September, 1978.
Ground water is exploited by means of a few shallow wells and hand-dug holes with an average depth of 5.0 m.
Ground water levels measured in September 1978 were 3.5 m below ground level. The EC of the shallow ground water seems to increase in a northern direction; near the Great Ruaha River the EC is only 18 mS/m, while 6 km to the north the EC's are around 150 mS/m.
Regular measurements have not been carried out in this area.
According to information given by village authorities, ground water levels fluctuate not more than 0.5-1.0 m during the year.
South of the Great Ruaha River, just outside the project area, three boreholes were drilled in the Kilombero Sugar Estate area.
Down to 60 m, the sequences consist for more than 80% of water-bearing sands and gravels.

5.4.10.3. Ground water potential

The boreholes, drilled at Kilombero Sugar Estate show that the minimum thickness of alluvial deposits is 60 m here.
Further north of the river the thickness may be less, however.
The shallow wells in the area tap a fine, sandy, upper aquifer below which there is a clay layer, which is a few metres thick.
Below the clay, more than 40 m thick sands and gravels occur, alternating with thin clay layers. The yield of the boreholes is high: 15-40 l/s, with respective drawdowns of only 1.5 m and 3.6 m.
Transmissivity of the aquifer is of the order of 1000 m^2/day.
With an aquifer thickness of 40 m, the permeability is 25 m/day.

From these data it appears that ground water is abundant at both shallow and medium depths. Ground water may be exploited by shallow wells in the upper aquifer (about 6 m below ground level), but it would be better to make 9-12 m deep shallow wells, tapping the top of the second aquifer, or to make medium-depth boreholes.

5.4.11. Hydrogeological sub-area X: The Ngerengere Area

5.4.11.1. General description

The Ngerengere Area is the catchment area of the Ngerengere River, which takes its rise in the NW Uluguru Mountains and flows around the Northern Ulugurus in an easterly direction.
From its sources to the point where it leaves the project area, near Seregete, the Ngerengere River is about 100 km long.
The area is approximately 2210 km^2 and contains 42 villages with a total population of more than 50,000.
Morogoro Town, with about 75,000 inhabitants, which is also situated in the Ngerengere catchment area, is not included in this study.

The Ngerengere River takes its rise at elevations between 1200 and 1600 m in the Ulugurus and descends steeply into the 14 km wide valley SW of Morogoro, situated at elevations between 520 and 500 m above MSL. From here down to the junction with the Ruvu River, the slope of the main course is 0.25% with two kinkpoints, caused by lithological differences of the rocks underlying the valley.

West of the Uluguru Mountains the Ngerengere River follows SW-NE oriented faults, which separate the Uluguru granulites from banded migmatites north of the mountains, and then follows the SSW-NNE oriented Kingolwira Fault, which separates the migmatites in the west from a biotite gneiss complex in the east. In this part of the catchment area, the Precambrian rocks are covered with red soil of varying thickness. Between Mzumbe and Mavulu the Ngerengere River has deposited alluvial material in a 500-1000 m wide and 10-25 m deep valley.
East of the Kingolwira Fault, the catchment is underlain by biotite gneiss, intruded by a migmatized gabbro body just east of Ngerengere Darajani.

At Ngerengere the river crosses the Kiwege Fault which separates the biotite gneiss in the west from Jurassic sandstones and from limestones in the east.

5.4.11.2. Field data collection

During the hydrogeological survey of the Ngerengere area, carried out between August and November, 1978, the ground water supply problems of this area were evaluated in terms of ground water availability and salinity.

Because the geological and consequently also the hydrogeological situation throughout the area was found to vary considerably, the results of the hydrogeological survey are too general to make definite recommendations possible on the development of ground water sources.
Therefore a special study has been executed to investigate the ground water situation in this area (DA 4). This study concentrated on the occurrence of shallow ground water because the evaluation of data from boreholes drilled in the Ngerengere area (see Table DA 4.4-3) shows that the ground water at greater depth is highly mineralized and unsuitable for domestic purposes.
The purpose of the special study was:

- to study in detail the availability of ground water in the Ngerengere area and near its problem villages in particular
- to explain the poor quality of ground water in this area

The activities included:

- drilling of exploration holes with hand-drill equipment
- examination and evaluation of water sample analysis results
- study of aerial photographs

The fieldwork started in mid-December, 1978, and continued till mid-April 1979.
Hand-drilled profiles were executed near the villages:
Kihonda, Tungi, Mkambarani, Mkonowarama, Mikese, Lubungo, Ngerengere Darajani, Kinonko, Muhungamkola, Visaraka and Masimbu.

At Masimbu, Kihonda, Tungi, Mkonowarama, Ngerengere Darajani and Visaraka profiles were drilled across the valley of the Ngerengere River. Ground water occurring in alluvial deposits between Kihonda and Mkonowarama, was found to be saline. EC values varied from 220 mS/m up to 3500 mS/m.
Ground water of low salinity was found near Ngerengere Darajani and Visaraka.

At Mkambarani, Mikese, Lubungo, Kihonda and Muhungamkola profiles were drilled across small tributaries of the Lukondo River.
Ground water of low salinity was found here also in alluvial deposits. However, without pumping test data and ground water level data from the dry season it is not yet possible to recommend exploitation of this shallow ground water. Piezometers will have to be installed in a few wells to measure ground water level fluctuations.

5.4.11.3. Ground water potential

- Examination of data from boreholes, drilled in the Ngerengere area proves, that the prospects for medium-depth and deep ground water in most parts of the Ngerengere area are poor to extremely poor.

The yields of boreholes generally are low (< 3 l/s) to very low (< 1 l/s) and almost everywhere the ground water is saline. EC's up to 3800 mS/m have been measured.
Fair prospects for exploitation of medium-depth to deep ground water are only present in the narrow (2-3 km wide) N-S orientated zone, underlain by Jurassic limestones (see D 4.2-7.).

- In the Ngerengere valley upstream from Sanga Sanga settlement (Fig. DA 4.3-1), 10 m up to 30 m thick and up to 900 m wide alluvial deposits occur.
  Since downstream from Sanga Sanga the Ngerengere River cuts relatively steeply into the basement and no alluvium is present there, the valley upstream from Sanga Sanga must have undergone a relative subsidence.
  Clays and sandy clays make up more than 90% of the upper 12 m of the sediments. Sands are usually water-bearing, the ground water being confined, but the salinity of the ground water is extremely high so that there are no prospects for shallow ground water in this part of the area. Only very near to the river, shallow wells may locally be possible.

- Between Sanga Sanga settlement and Ngerengere, the Ngerengere River has cut into the Precambrian gneiss and practically no alluvium has been deposited here.
  As can be seen on Map D 4, this part of the catchment area is bounded by NE-SW running major faults, and is relatively uplifted. Alluvium occurs only locally in the valleys of the Lukondo, Matule and Mikese rivers, and some other streams. The alluvium is up to 100 m wide and 5-10 m thick.
  Approximately 80% of the sequences are clays; sands and clayey sands make up 20% of the alluvium.
  The ground water is confined and the EC's are mostly below 200 mS/m although saline ground water was found also locally.
  Exploitation of shallow ground water by means of shallow wells with hand pump might be possible in the villages:
  Mkambarani, Mikese, Muhungamkola and Kinonko.
  No data are available yet on the water level fluctuations in these aquifers; some aquifers probably will run dry during the dry season.
  The presence of saline ground water very close to the areas where fresh ground water was found, forms a potential danger. Pumping of ground water might induce the saline ground water to flow towards the wells.

- Downstream from Ngerengere, the river has deposited alluvial sediments which are more than 12 m thick and 500 m up to more than 1000 m wide.

This area is not underlain by Precambrian gneisses, but mainly by Jurassic sandstones and this probably is the reason for the abundance of sands in the alluvial deposits.
At Visaraka, medium to very coarse sands make up more than 75% of the alluvial sediments.
The sands are ground water-bearing and the EC is low (< 75 mS/m).
Saline ground water was found to occur in clays and loams on the slopes of the valley.
Shallow wells therefore will have to be located close to the river.
Because of the high permeability of the sands, and the thickness and extent of the aquifer, it is possible to withdraw a few l/s from a well.
Larger yields, however, will increase the chances of salinization of the aquifer. Carefull planning and testing of aquifers is recommended before pumped supplies from shallow wells are taken into consideration.

By extrapolation of the collected and evaluated hydrogeological data, predictions can also be made concerning the prospects for shallow ground water in other problem villages.
The prospects for shallow ground water of all problem villages in the Ngerengere area are summarized below.

Diguzi

No field data were collected on the occurrence of shallow ground water near Diguzi.
The valley, approximately 1 km south of this village was visited and alluvium was found to occur here over a width of 100 m across the valley.
Possibilities for shallow ground water are present here.
Since the EC's of the ground water in Kiwege, upstream from Diguzi, and Visaraka, downstream from Diguzi are low, low salinity of the ground water near Diguzi is expected as well.

Fulwe

The topographical location of Fulwe is very unfavourable; the village is situated almost on the water shed between the Ngerengere and Lukondo rivers.
Ground water is present in small valleys in and near the village. However, during the dry season the wells and holes dry out and the ground water is saline.
Approximately 1.5 km south of the village there is a small alluvial valley, where ground water of a low salinity (25 mS/m) occurs. The two shallow wells in this valley are hardly used, however, because of their distance to the village.
If shallow wells with hand pump are to be constructed in this valley, a road will have to be constructed first.
A borehole was drilled in Fulwe (149/77), but its yield is very low, 0.4 l/s with a drawdown of 9.3 m.

Kinonko

At Kinonko shallow wells can be constructed in the valley of the Matule River. Average depth of the wells will be 7.0 m; the aquifer thickness is approximately 1.6 m.
The EC of the ground water is generally below 200 mS/m but saline ground water occurs also and salinization of the aquifers during the dry season may be expected.

Kiwege and Mlilingwa

These villages are situated on watersheds.
Small quantities of shallow ground water occur in a few very small alluvial valleys around the villages. The yield of hand-dug holes in these valleys is extremely low; the EC of the ground water is only 9 mS/m, which points to very "young" water.
There may be some possibilities for concrete ring wells.
Yields will be very low and during the dry season there may still be a shortage of ground water.

Lubungo

Near Lubungo there are two small valleys where alluvium was deposited. The ground water in these alluvial sediments is saline. There are no possibilities for shallow wells.

Maseyu

This village is situated on a watershed.
Ground water of low salinity occurs in very small valleys, filled with sandy alluvium. The ground water occurs in pockets and many of these pockets dry up during the dry season.
A detailed study of the aquifers around this village will have to be carried out, to find out whether there are possibilities for shallow wells here.

Mikese

Shallow wells can be constructed in the valley of the Mikese River.
The EC of the ground water is 103 mS/m on an average. The seasonal water level fluctuations in this valley are considerable. Water levels vary from 1.5 to 7.0 m below ground level.

Mkambarani

Small amounts of ground water can be withdrawn from aquifers in valleys south and east of the village.
Because of the presence of saline ground water in the same valleys, there is danger of salinization of the wells during the dry season.

Mkonowarama, Kihonda, Tungi

All ground water, occurring in the alluvium of the Ngerengere Valley is extremely saline. Therefore there are no possibilities for shallow wells.

Muhungamkola

Shallow wells with hand pump can be constructed in a small valley, east of the village. There is danger of salinization of the aquifers, however.

Ngerengere

Shallow wells can be constructed along the Ngerengere River, in sandy alluvium. The EC is low; < 75 mS/m.

Ngerengere Darajani

Narrow, isolated patches of alluvium occur along the Ngerengere River. There are some possibilities of exploitation of shallow ground water from the alluvium, especially close to the river, where hydraulic connections exist between the riverbed and the alluvium along the river. Because of the presence of saline ground water, there is a danger of salinization of the aquifers as a result of their exploitation.

Seregete A and B

There are no possibilities for shallow ground water within a distance of 1.5 km from these villages. The nearest source of ground water is the riverbed and alluvium of the Ngerengere River, at distances of respectively 5 and 3 km from these villages.

Kwaba, Lubumu, Lulongwe, Magela, Matuli, Visaraka

Shallow wells can be constructed in the extensive alluvium of the Ngerengere River and its main tributaries.
There is an abundance of sandy material in the alluvium.
Yields of shallow wells will be high and the EC of the ground water is between 75 and 125 mS/m.
Because of the presence of saline ground water on the higher slopes of the valley, in weathered basement material, wells will have to be constructed quite close to the river.