THE SURVEY REPORT
FOR
AGRICULTURAL COOPERATION PROJECT
IN
KILIMANJARO REGION, TANZANIA
(GROUND WATER SURVEY)

MARCH 1976

JAPAN INTERNATIONAL COOPERATION AGENCY

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Preface

In keeping with the desire to expand technical cooperation projects in the field of agriculture beyond the Asian Region, the Government of Japan dispatched the project finding team to four East African countries in March 1973. As a result of that team's work, it was determined that agricultural development in the Kilimanjaro Region, Tanzania, was the most highly feasible of the possible projects identified. The Tanzanian Government had previously requested Japan to cooperate in the comprehensive development of the Kilimanjaro Region, and the Japanese Government, considering world wide significance of our cooperation for agricultural development in Tanzania, started the preparations.

As the first step, the implementation planning team was dispatched in November 1973, with the objective of formulating the basic concept to underlie Japanese cooperation for agricultural development in Tanzania. Then, in November 1974, a team was dispatched to Tanzania for the purpose of preparing the design of the Project. The team succeeded in formulating the outline for cooperation plans in greater detail than the preceding team had done, and a Record of Discussions with Tanzanian Government officials was prepared. In this Record of Discussions, as a preliminary phase for the implementation of cooperation, mention was made of (1) a survey for development of water resources, (2) cooperation for experimentation and research, and (3) a basic study of agriculture, as the three main subjects of future effort.

In the presnet field study, on the basis of this Record of Discussions, a survey was implemented for the development of groundwater primarily in the Kahe-Miwaleni Area of the Kilimanjaro Region which is believed to have the greatest development potential with regard to groundwater in the Region, by means of electrical soundings, pumping tests, and other methods.

It is believed that this report which summarizes the results of this work will be of high values in the second step of formulating to develope the projects for agriculture in the Kilimanjaro Region.

It is hoped, furthermore, that this report will also contribute to the strengthening of amicable ties between Tanzania and Japan.

Finally, in addition to expressing my appreciation for the efforts of Mr. Isozaki, Team Leader, and the members of his team, I wish to thank all the officials of the Tanzanian Government, of the Japanese Embassy in Tanzania, and the experts who have aided in various ways to implementate the work.

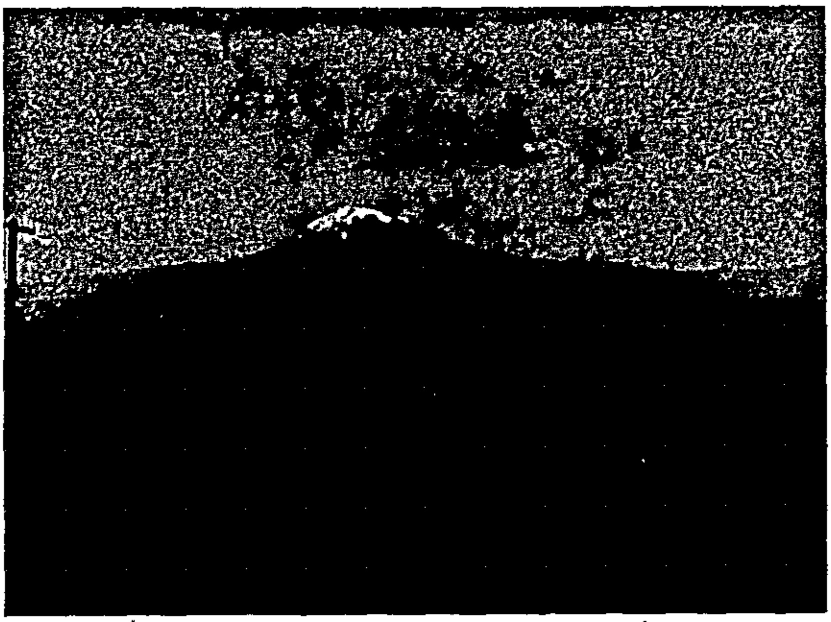
Shigekatsu Watanabe

Director
Agricultural Development
Cooperation Department

JAPAN INTERNATIONAL
COOPERATION AGENCY

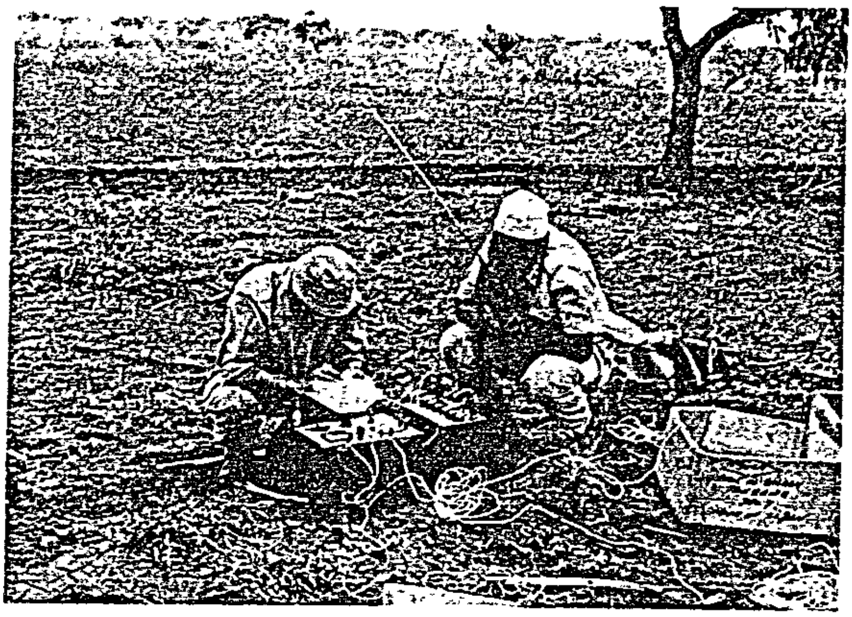
March 1976

PHOTOS OF THE FIELD SURVEY

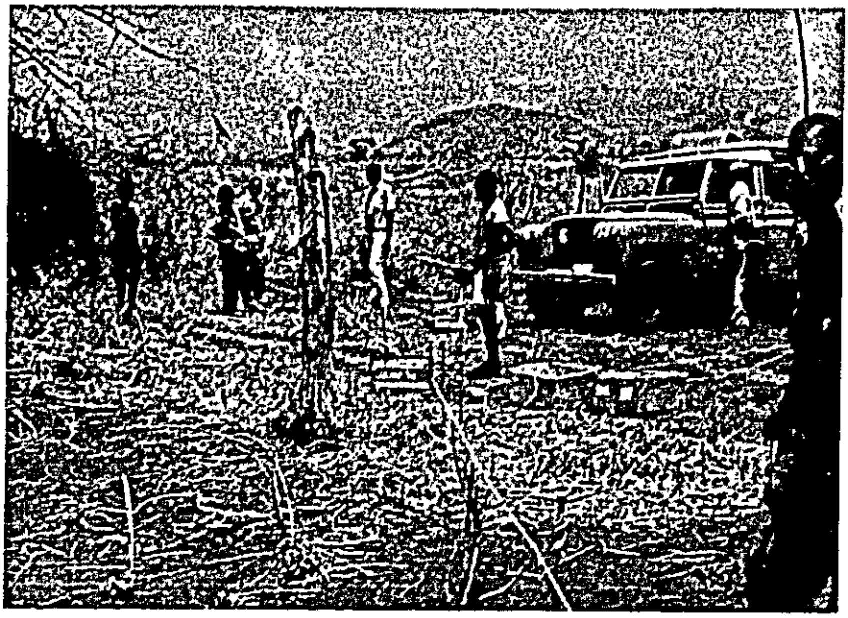


View of Mt. Kilimanjaro from Miwaleni Area

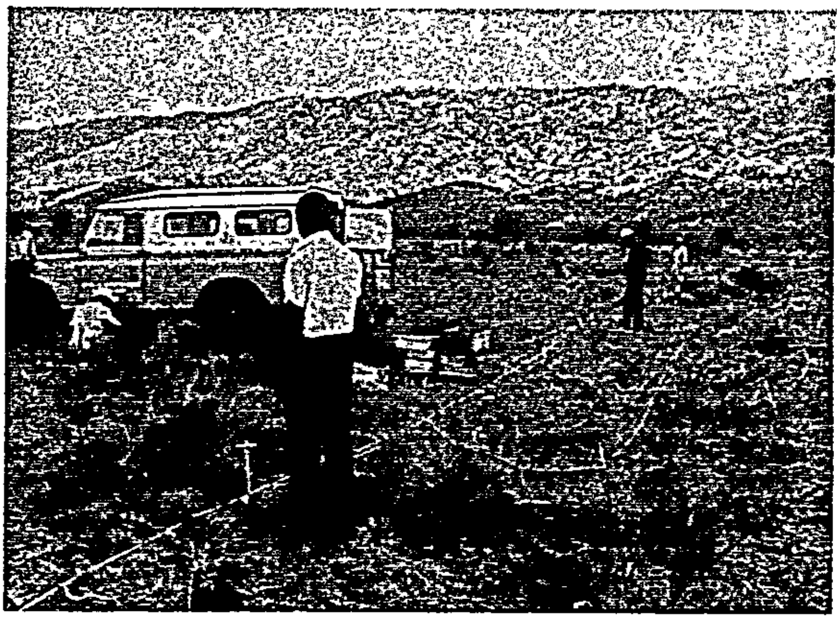
Electrical Sounding (Type ES-GI)



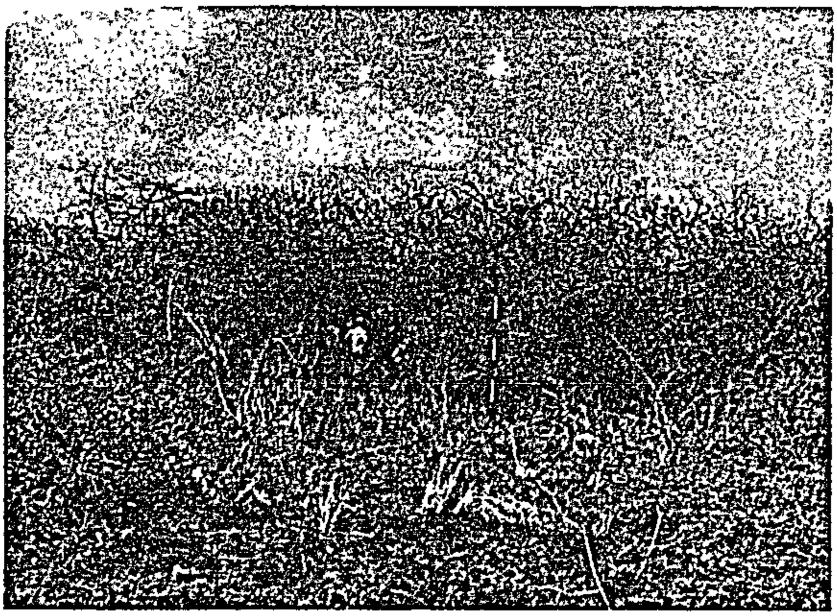
Electrical Sounding (Megger Type 3244)



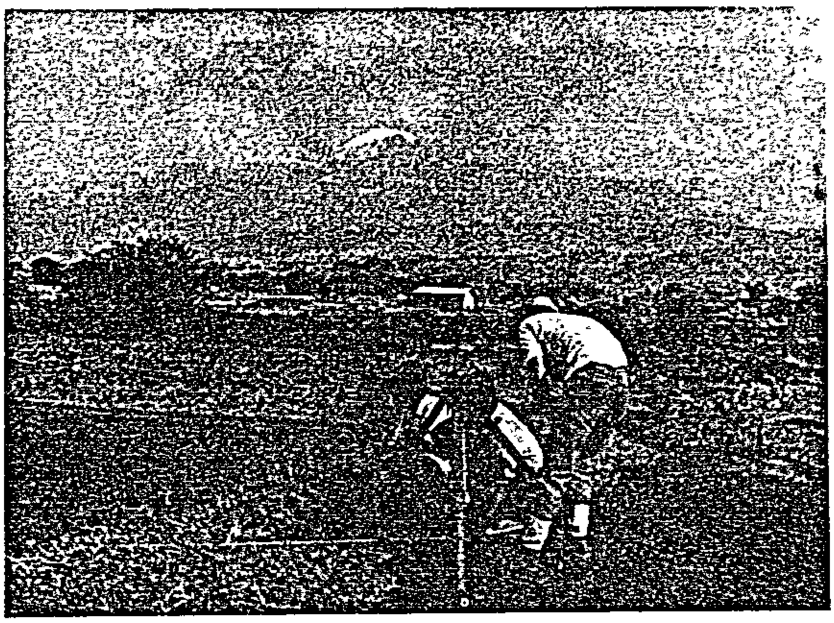
Electrical Sounding in the Kahe-Miwaleni Area



Electrical Sounding in the Mkomazi Area

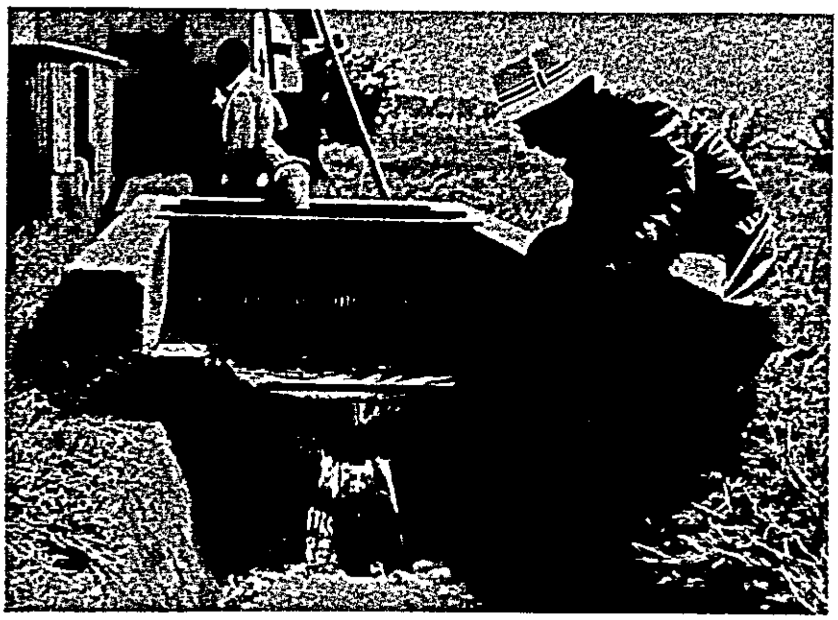


Cutting bush for Electrical Sounding



Selection of Electrical Sounding Points

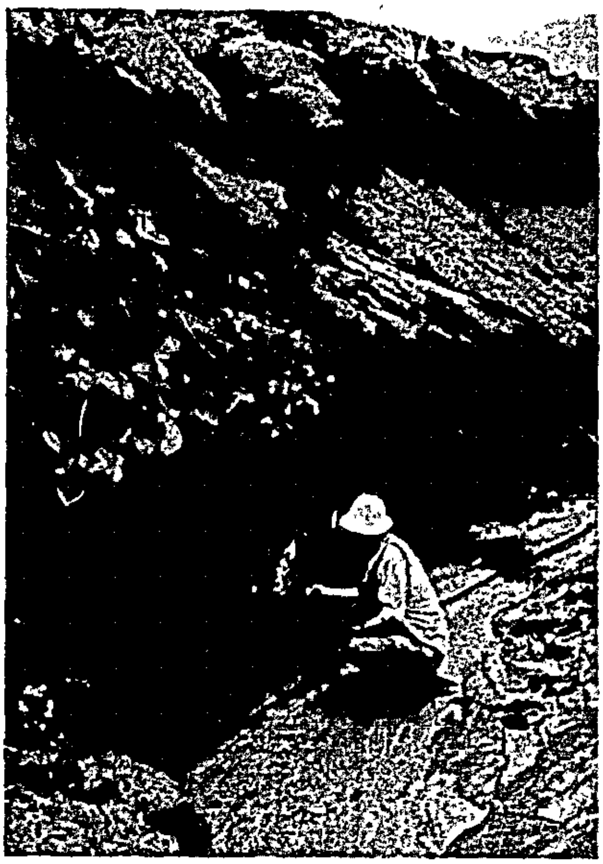
Pumping Test - Miwaleni No. 1 Borehole



Pumping Test - Observation of Yield

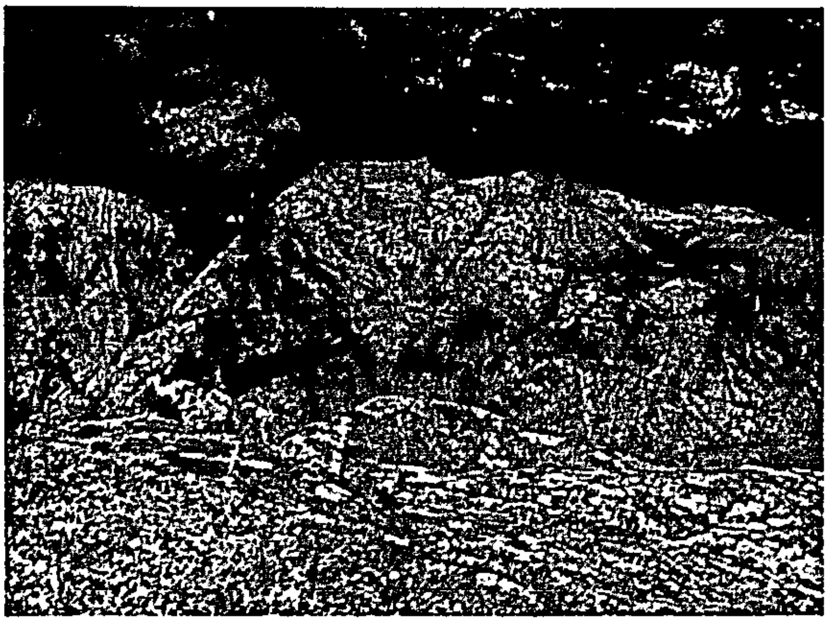
Miwaleni Spring

Njoro Spring

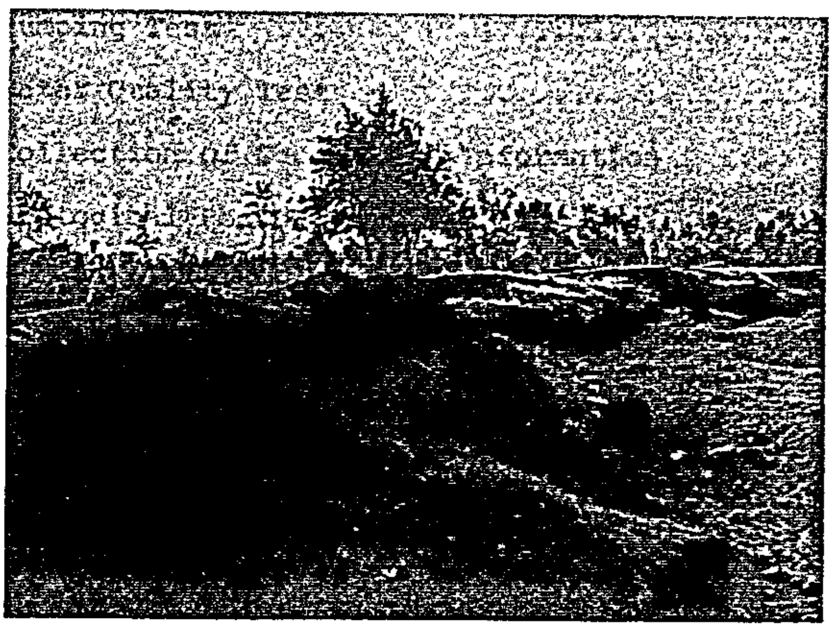


Geological Reconnaissance

Geological Reconnaissance - No perenial flow except for the Rau and Mua River in the Kahe-Miwaleni Area



Granulite near Gonja in the Mkomazi Area



Lava and Pyroclstics near Moshi-Himo Road
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Foreward

Several mission have been dispatched to the Kilimanjaro Region since 1973 in connection with the development of agriculture, and efforts have been made for both planning and implementation of development projects.

The objectives of the present team was, as one aspect of those efforts, to determine the feasibility of the development of groundwater as a source of water for agriculture and, to an extent to examine specific methods of the development and use of groundwater.

To achieve these objectives, 60 electrical soundings, pumping tests at existing wells, surface geological reconnaissance, as well as the collection of hydrological and meteorological data were performed in the Upper Miwaleni Area for which an irrigation project is now being planned and the adjacent Kahe-Miwaleni Area. In addition, for these two areas, mode of occurrence of groundwater as well as groundwater balance were studied, and guidelines for future development and the use of groundwater were examined. Further, concerning Mkomazi Area east of the South Pare Mts. in the southern part of the Region, the mode of occurrence of groundwater was estimated and some observations have been made regarding the feasibility of its development.

Concerning the groundwater in the Kahe-Miwaleni Area, some reports have been prepared by Tanzanian Government and FAO experts. These report, however, are preliminary ones, and give not so enough data on guantitative evaluation of aquifers, the selection of suitable well side and groundwater balance. In that sense the results of this field survey are considered to comprise some effective, and fumdamental informations which will be of value for future water resources development projects.

Concerning the Mkomazi Area, we have not heard that any survey report on groundwater exists. Therefore, while the present survey report is still preliminary, we believe it to be the first to deal with this particular subject.

Because of limitations imposed by the schedule and equipment at hand, there are many subjects which still remain to be studied at an appropriate time in the future. These future studies are recognized to be of considerable importance.

The present survey was conducted from the latter part of January 1976 through the end of February; as this was the hottest season of the year at the region studies, the mission's work was greatly hampered. We wish to acknowledge our gratitude to all the people who cooperated in the work, and the Tanzanian Government counterparts, who performed admirably despite the heat. Also, in expressing thanks to those who helped us, we could not overlook the officials of the Japanese Embassy in Dar es Salaam who greatly supported our work through their efforts in having equipment transported and in maintaining liaison with local government officials. All members of the mission join me in saying that without the untiring efforts of all these people, the field survey could not have yielded the results actually obtained.

Y. Isozaki

Yoshimasa Isozaki

Leader, Kilimanjaro Agricultural
Development Design Survey Team

March 1976

Part 1 Introduction

The Kilimanjaro Region is in Tanzania's north-east and borders on Kenya. It lies within the tropical zone of 3° to 4° south latitude and there is little difference in year-round temperatures. Sunlight is intense throughout the Region which is composed of highlands and mountains where humidity is low and environmental conditions are severe.

The well-known African Great Rift Valley extends to the north and south of eastern Africa, and is to the west of this Region. It is known that the Kilimanjaro Volcano is closely related to the activity of the East African Rifts (R. Girdler, 1972).

Mt. Kilimanjaro, the highest vlcano of the world (5,895m), occupies the northern part of the Region and about half of its expansive slopes, being favored with good meteorological and water conditions, has been used for agriculture since long ago, and the population density is high. However, in the lowlands of the Pangani River basin to the south as well as in the eastern region of the Pare Mts. with the exceptions of mountain slopes, agricultural development is still retarded and the land remains in the condition of swamps and steppes. The reason for retardation of agricultural development is the growth of swamps in lowlands during the rainy season and the tropical arid climate.

The major objective of the present survey was to study the feasibility of the development of groundwater as a source of water which could be used for agricultural development projects in these Middle and Lower Lands.

There is no lack of earlier reports on groundwater in these regions. The Dutch engineering geologist Coster who has 30 years of experience in Tanzania has summarized what is known about Tanzanian groundwater in his 1960 publication (Reference 3). In this, Coster makes reference to groundwater in the skirt of Kilimanjaro volcano, and cites records of the volumes and quality of water pumped up from existing bore holes.

Since that publication appeared, during the early 1960s, Tanzania Geological Survey has published 1/125,000 scale geological maps and their explanatory texts including some comments on groundwater and wells (References 9, 10, 11, 12). In particular, in the explanatory notes on the Kilimanjaro geological maps, there are some explanations of the hydrogeology, the modes of occurrence of groundwater and actual yield of wells in the Mt. Kilimanjaro plateau area (Reference 13). Reports on groundwater in the southern plateau of Mt. Kilimanjaro by Whittingham (1963) and Ramsey (1965) have also be published (References 5 and 7). All of these studies used surface geology and existing wells as data sources and do not include study of the extent and volume of aquifers, their hydrological characteristics, groundwater balance and other aspects of quantitative evaluation of groundwater.

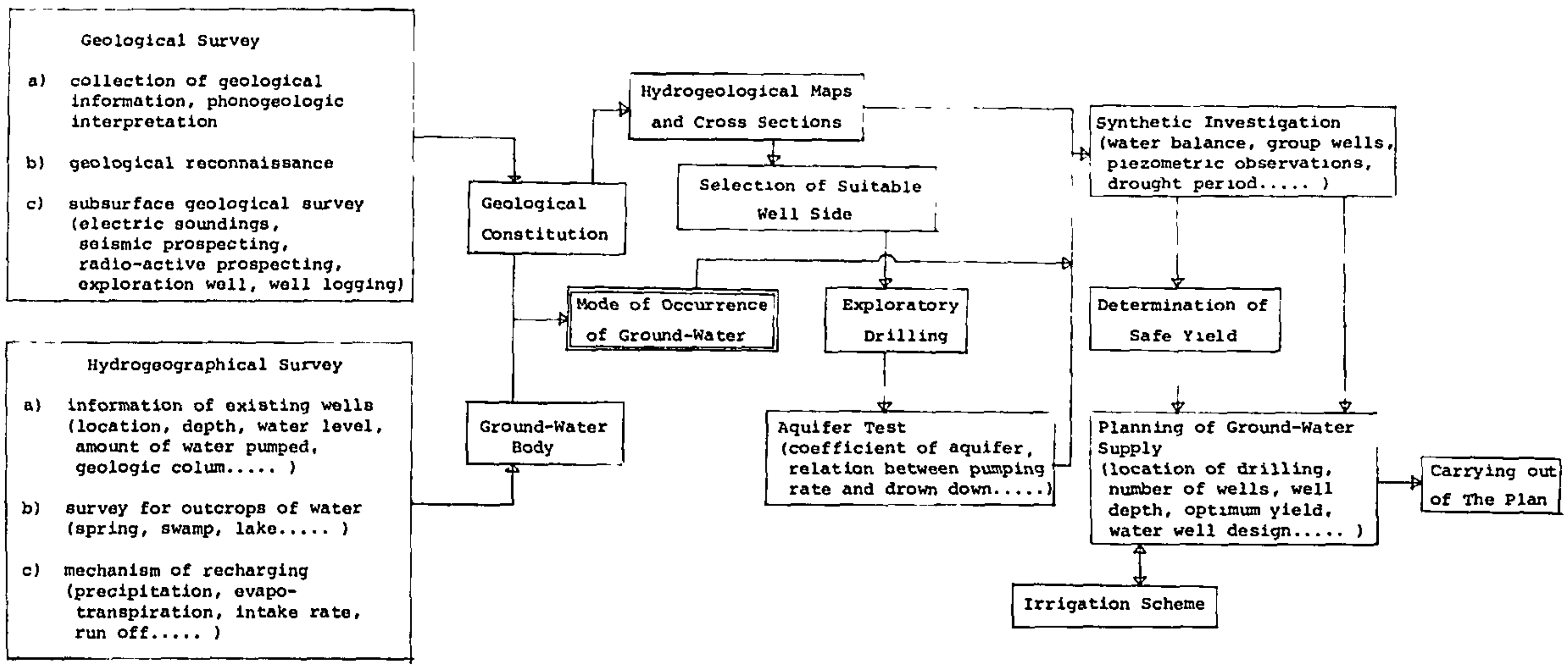
Main object of the present survey was to get some quantitative evaluations of groundwater which have been successfully done.

This report, by summarizing the results of geological reconnaissance, electrical soundings, hydro-meteorological studies, pumping tests, the collection of information, etc., gives information on the hydrogeological structure, form of occurrence of groundwater, hydrological characteristics of aquifers, water balance within groundwater basins, future development of groundwater, and related matters in the Project Area.

The methods and procedures used in the survey are shown in Fig. 1-1.

While the Kahe-Miwaleni Area in the southern plateau of Mt. Kilimanjaro was the objective of the study, a preliminary survey was also made of the Mkomazi Area on the eastern side of the South Pare Mts.

Fig. 1-1 METHOD OF EXPLORATION FOR GROUND-WATER DEVELOPMENT



Part 2 Outline of Survey Team

Part 2 Outline of the Survey Team

2.1 Background of the Survey

The Tanzanian Government had requested cooperation of Japan for comprehensive development planning in the Kilimanjaro Region, a development objective to which Tanzania has assigned high importance for the last several years. In keeping with the trend for Japan to expand the geographic scope of cooperation for agricultural development, beyond Southeast Asia to Far East, Africa and Latin America. The request was accepted and in 1971 the International Development Center of Japan (IDCJ) was commissioned by the Japanese Government to examine possibilities of Japanese cooperation for the development of Tanzania, especially for the development of Kilimanjaro Region.

On the basis of the IDCJ's recommendation, in March 1973, a project finding mission was sent to East Africa for a 13-day study, to examine what the objectives of Japanese cooperation for agricultural development should be and how the cooperation should be furnished. As a result, this mission reported that the Kilimanjaro Region, being favored with good natural and social conditions, is the most hopefull in regard to the development of agriculture. At the time of the team's visit, Tanzanian officials showed deep interest in cooperation which Japan might extent.

On the basis of the report of the project finding mission, a field survey mission was dispatched in November 1973 for 35 days, for the purpose of formulating a detailed plan for agricultural cooperation. This mission made detailed observations of the Kilimanjaro plateau area, land under cultivation, and undeveloped lowland areas, and further examined water utilization, crop conditions, soil improvement and other problems related to the present survey. And after that, the mission earnestly discussed with Tanzanian officials on concrete plan of the project.

In 1974, in order to complie a Record of Discussions, a field survey mission was dispatched, and agreement was reached on the following.

1. Cooperation would be provided in two stages, of which the first stage would be preliminary cooperation for a period of two years on the basis of the Record of Discussions, and the cooperation proper would be provided after that;

2. A survey of water resources necessary for agricultural development, comprising the collection and processing of hydrological data and a groundwater field survey would be carried out;

3. Research and study would also be made on the improvement of alkaline soils and the selection of crops suitables for such soils;

4. A survey of agricultural infrastructure including land use and markets would be carried out.

2.2 Purpose of the Survey

According to the Record of Discussions of December 2, 1974, the water resources survey for agricultural development is of vital importance for the development of agriculture in the Kilimanjaro Region; the greatest possibilities regarding the development of groundwater resources in Kilimanjaro Region would primarily involve the Kahe-Miwaleni Area; and the development of groundwater in the Region should be assigned highest priority. Therefore, the purpose of the survey which concentrates on the Kahe-Miwaleni Area is to use electrical soundings, pumping tests and geological reconnaissance and other methods, to analyze the extent of usable water resources and to formulate the basic design for the development of groundwater in the area.

2.3 Schedule of the Survey

Month	Date		Schedule
January 1976	22	Tue.	Left from Tokyo at 9:15 (BA911), arrived at Dar es Salaam at 24:00
	23	Fri.	Courtesy call on the Japanese Embassy and discussed on Technical Survey and Schedule of the Project with Mr. Inagawa (First Secretary)
	24	Sat.	AM - Courtesy call on the Tanzanian Government (Ministry of Water Development Power and Mineral) PM - Negotiated on the equipment with Ministry of Finance and Custom Office, left from Dar es Salaam at 16:00 (EC), arrived at Kilimanjaro at 17:00
	25	Sun.	Discussed on Technical Survey and Schedule of the Project with Mr. Tohgo and Mr. Hayasaka (Japanese Experts)
	26	Mon.	AM - Courtesy call for Kilimanjaro Regional Development Director, Mr. Semikiwa and discussed on Technical Survey and Schedule of the Project

Month	Date		Schedule
January 1976	26	Mon.	PM - Surveyed and selected electrical soudning sites in Miwaleni Area
	27	Tue.	AM - Discussed and surveyed by air photograph with Mr. Tohgo and Mr. Hayasaka (Japanese Experts) PM - Visited for collecting data at T.P.C. Ltd. (Tanganyika Planting Company)
	28	Wed.	AM - Regulated and discussed on data collected at T.P.C. Ltd. with Japanese Experts PM - Analyzed the data and air photographs and also prepared for electrical sounding
	29	Thu.	Received, examined and regulated the equipment
	30	Fri.	Electrical sounding in Miwaleni Area
	31	Sat.	Electrical sounding in Miwaleni Area, had meetings of the Schedule of the project with Japanese Experts
February 1976	1	Sun.	Electrical sounding and geological reconnaissance of Rau River Basin, Kahe Area and Precambrian near Kifumo

Month	Date		Schedule
February 1976	2	Mon.	Electrical sounding
	3	Tue.	- ditto -
	4	Wed.	- ditto -
	5	Thu.	Electrical sounding, geological reconnaissance and analysis of water quality at the upper stream of Rau River and Njoro River
	6	Fri.	Electrical sounding
	7	Sat.	1. Electrical sounding 2. Prepared for pumping test
	8	Sun.	1. Analyzed the data of the electrical sounding 2. Pumping test (step test)
	9	Mon.	1. Electrical sounding 2. Pumping test (step test)
	10	Tue.	- ditto -
	11	Wed.	1. Electrical sounding 2. Analyzed the geological data
	12	Thu.	1. - ditto - 2. Team Leader left from Tokyo at 9:00 (BA911), arrived at Dar es Salaam at 24:00

Month	Date	Schedule
February 1976	13 Fri.	1. Electrical sounding 2. Surveying points of electrical sounding 3. Regulated the data 4. Team Leader made courtesty call on Japanese Embassy at Dar es Salaam
	14 Sat.	1. Regulated the data and collected of the interim report 2. Discussed on Technical Survey and Schedule with Team Leader 3. Team Leader arrived at Kilimanjaro
	15 Sun.	Had meeting on the Schedule of the Project with Japanese Experts (Leader Mr. Kan, Mr. Tohgo, Mr. Hayasaka and Team members) 1. Interim Report and determined a plan of investigation for the future 2. Discussed on the second half of the schedule
	16 Mon.	1. Electrical sounding 2. Surveying 3. Team Leader made courtesy call for Kilimanjaro Regional Government, and discussion with Regional Development Director, Mr. Semikiwa after surveyed in Miwaleni Area
	17 Tue.	1. Electrical sounding 2. Geological reconnaissance in Miwaleni Area and Moshi Springs

Month	Date	Schedule
February 1976	17 Tue.	3. Regulated the data
	18 Wed.	1. Electrical sounding 2. Geological reconnaissance in Moshi Area, Rau River Basin and Kahe Area
	19 Thu.	1. Electrical sounding 2. Geological reconnaissance in the recharging area around Mt. Kilimanjaro 3. Regulated the data
	20 Fri.	1. Electrical sounding 2. Geological reconnaissance in Mkomazi Area and made a preliminary examination of Base Camp
	21 Sat.	1. Electrical sounding 2. Geological reconnaissance in the west-wide Moshi 3. Regulated the data
	22 Sun.	1. Electrical sounding 2. Regulated the data
	23 Mon.	1. - ditto -
	24 Tue.	1. Analyzed of the data of electrical sounding 2. Regulated the data of hydrology 3. Technical guidance for boring (drilling)

Month	Date		Schedule
February 1976	25	Wed.	1. Moved from Moshi to Mkomazi 2. Electrical sounding in Kisiwani village, Mkomazi Area
	26	Thu.	Electrical sounding and geological reconnaissance in Gonja and Kihurio villages in Mkomazi Area
	27	Fri.	AM - Reported and discussed on the result of the investigation PM - Left from Mkomazi, arrived at Moshi at 17:00
	28	Sat.	Prepared for the report of field survey for Kilimanjaro Regional Government
	29	Sun.	Discussed on the Report of field survey for Kilimanjaro Regional Government with Japanese Experts
March 1976	1	Mon.	Reported on the survey results for Kilimanjaro Regional Government and discussed with R.D.D. Mr. Semikiwa on the Report
	2	Tue.	Left from Kilimanjaro at 9:45 (EC613), arrived at Dar es Salaam at 10:40
	3	Wed.	Courtesy call to Japanese Embassy and reported to Tanzanian Government (Ministry of Water Development Power and Mineral)

Month	Date	Schedule
March 1976	4 Thu.	Left from Dar es Salaam at 12:45 (BA0(
	5 Fri.	Arrived at Tokyo at 14:45

2.4 Member List of the Survey

(1) Dr. Yoshimasa ISOZAKI Team Leader	Vice Director (Senior Hydrogeologist), Kanto Regional Administration Office, Ministry of Agriculture & Forestry
(2) Mr. Akihisa TONOMURA Senior Engieering Geologist	Chief Engineer (Registered Engineer of Japan), Comprehensive Development Division, Japan Engineering Consultants Co., Ltd.
(3) Mr. Tadao MITSUNAGA Geologist (Electric Prospecting)	Engineer, Comprehensive Development Division, Japan Engineering Consultants Co., Ltd.
(4) Mr. Kinzo NARITA Geologist (Electric Prospecting)	Engineer, Comprehensive Development Division, Japan Engineering Consultants Co., Ltd.
(5) Mr. Fumio TAMURA Geologist	Engineer, Overseas Division, Japan Engineering Consultants Co., Ltd.
(6) Mr. Masakatsu ISHII Coordination	Technical Cooperation Division, Agricultural Development Cooperation Department, Japan International Cooperation Agency

Part 3 Outline of Groundwater Propsecting

Part 3 Outline of Groundwater Prospecting

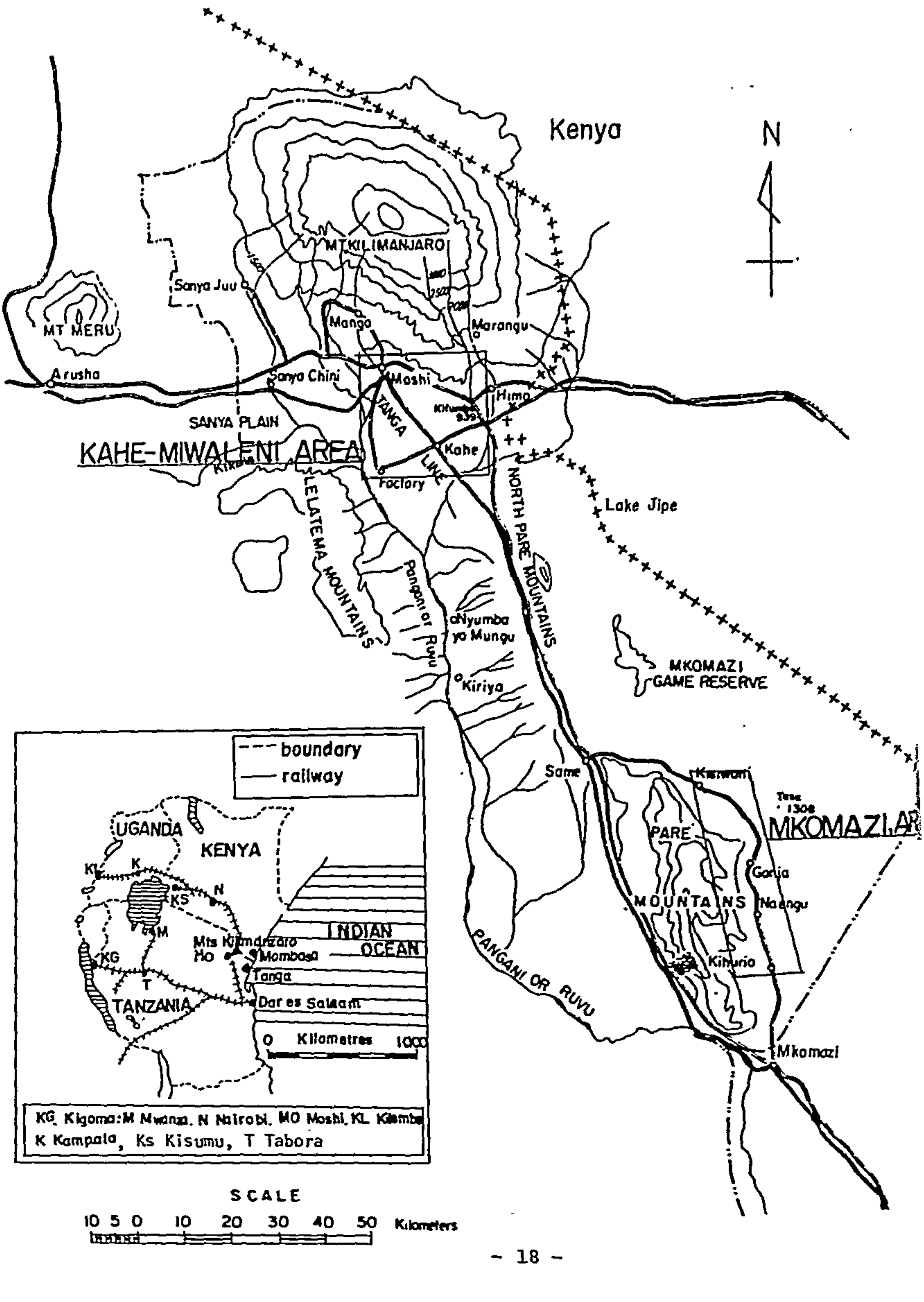
3-1 Location of Surveyed Area

The Kilimanjaro Region is in the northeastern part of Tanzania, at about 3°30' south latitude and 37°30' east longitude, and is on the border with Kenya. The Region's seat of government is Moshi, which is about 600 km from the capital, Dar es Salaam. The Region is provided with rail and highway links with other regions, and with air transport service by the Kilimanjaro International Airport.

The Region has its longest axis on the north-south direction and may be divided into three major areas: in the north is the high mountain-plateau region which includes Mt. Kilimanjaro and mountains in its range, while in the south is the North Pare Mts. and South Pare Mts. region, as well as the lowlands of the Pangani River basin. The north region including Mt. Kilimanjaro possesses relatively favorable natural conditions. The degree of land utilization and density of population are high, and a differential in all aspects of development may be seen compared to the south. Within the north region such as the Moshi area, the degree of land utilization, particularly for agriculture, is relatively high. However, except by the Tanganyika Planting Co., Ltd. and some other estates, still little progress is being made in regard to land utilization, although efforts are being made to improve land utilization through the Ujama program.

The scope of the present survey is, as shown in Fig. 3.1-1, the Kahe-Miwaleni Area near the Mt. Kilimanjaro and the Mkomazi River basin at the east of the South Pare Mts.

Fig.3·1-1 Location Map of the Project Area



The Kahe-Miwaleni Area is a plateau of about 700 m in elevation located to the southeast of Moshi. The surveys were mainly made in the Miwaleni, about 20 km from Moshi, and in the Msaranga Mandaka in order to understand the conditions of the whole part of Kahe-Miwaleni Area. About 80% of the survey schedule was made in the Kahe-Miwaleni Area.

In the Mkomazi Area, although detailed studies were not conducted, efforts were concentrated in Kisiwani, Gonja and Kihurio, east of the South Pare Mts.

Base camp for the survey was in Moshi for the Kahe-Miwaleni Area's investigation and the Mkomazi Game Lodge, 15 km south of Same, was for the Mkomazi Area.

3.2 Scope of the Survey

Hydrological surveys, geological field surveys, geophysical prospecting, boring surveys and pumping tests are needed in order to get enough data on the modes of occurrence of groundwater. In the case of the present survey, the hydrogeological structure was studied by means of meteorological and hydrological surveys, surface geological reconnaissance, electrical soundings, pumping tests and the collection of data on existing wells.

Location of the measurement site is as in Figs. 3.2-1 and 3.2-2. The methods, quantities and equipment employed are as below.

3.2.1 Electrical Sounding

Electrical sounding is a method to study the hydro-geophysical underground structure of the surveyd area by the combination with geological data obtained from field exposure and the record of well-boring. Resistivity method was adopted in this survey.

The Resistivity Method comprises a comprehensive evaluation of the results of measurement of variation in the resistivity of the earth. Vertical prospecting method was used in this survey.

(1) Points of Measurement

Measurements were made in two areas, as shown on Figs. 3.2-1 and 3.2-2. In all, 71 measurements were made.

<u>A. Kahe-Miwaleni Area</u>

[Miwaleni]

No. of Measured Points	Number	Investigation Depth	Method
34	E-1 - E-33 E-40	150-200 m	Schlumberger
15	E-34 - E-39 E-41 - E-49	50-100 m	4-pole Wenner

[Mandaka, Msaranga, Moshi]

No. of Measured Points	Number	Investigation Depth	Method
15	E-50 - E-64	50-100 m	4-pole Wenner

B. Mkomazi Area (Kisiwani, Gonja, Kihurio)

No. of Measured Points	Number	Investigation Depth	Method
7	E-65 - E-71	50-100 m	4-pole Wenner

(2) Equipment Employed

In consideration of the arid climate and local conditions, the following equipment was selected and used.

Equipment	Type & Characteristics	Quantity
AC/DC geoelectric sounder	Model ES-G1; 600V 3A; usable to 500m depth	1 set
Ground specific resistivity measurement instrument	Megger type 3244; 12V; usable to 150m depth	1
Electrode bars	Steel bar ϕ18mm ℓ=800mm	10
Dry celles	BM-1; 45V	50
Storage batteries	12V; 50AH	3
Electric cable	Single-strand ϕ0.75mm	5,000m
Measuring rope		1,000m
Transceivers		3
Electric megaphone	With alarm attachment	1
Theodolite		1
Level		1
Staff and pole		1
Field vehicle	Jeep	1 each day in field

The distances between the neighbouring two measurement points in the Miwaleni Area were adjusted in accordance with survey objectives, and were 200 m, 400 m, 600 m, 1,000 m and more. For other areas, the distances were 500 to 1,000 m. In the Miwaleni Area, for soundings of the depth of 150 - 200 m, the ES-Gl unit and Schlumberger method were used, and for works at the depth of 50 - 100 m in the Miwaleni Area and in other areas as well as for all work in other areas at 50 - 100 m, the Megger unit and four-pole Wenner method were used.

In the analysis of sounding data, the Schlumberger's double layer standard curve were used for Schlumberger method, and Sundberg's standard curve and Ono's auxiliary curve were used for Schlumberger method and Sundberg's Standard curve and Hummer's auxiliary curve were used for Wenner method.

3.2.2 Pumping Tests

With the purpose of determination the pumping conditions and the coefficient of aquifer etc. in the Kahe-Miwaleni Area, an existing well at Miwaleni was used for pumping tests.

There exist three wells in Miwaleni of about 1,000 m apart, and the western-most well (No. 1) was used for pumping tests.

The pertinent characteristics of the well and equipment used were as follows:

Well diameter	I.D. 250 mm casing pipe
Pump type	submersible

Pump characteristics	I.D. 157 mm, 27 HP
Pump depth	35 m
Well depth	67 m
Water gauge	Tester type, 2 units

There are two methods of pumping test, one is the step draw down type and other is the constant yield type. The step draw down test is separated into two methods, the draw up test in gradually increasing yield and the draw down test in gradually decreasing yield.

The yield was chekced by triangular weir and the water table were measured by tape (electric wire and tester). The water table resulting from the one step of pumping was measured during one hour for two days as a rule. For the constant yield type test, draw down and time were recorded.

3.2.3 Water Quality Tests

Water quality tests were made at each water outcrop, surface water, groundwater, and springs in the Kahe-Miwaleni Area, in order to obtain the data of examination for water use and hydrogeological analysis. Tests were made at 16 points in and around the Kahe-Miwaleni Area including the south slope of Mt. Kilimanjaro. The locations of these points are shown as A-P in Fig. 3.2-1.

The characteris_ics tested and equipment used were:

Temperature and electric conductivity:	EST-3 electric quality meter, made by Toho Dentan Co.
pH:	ph test paper, made by Toyo Roshi Co.
Salinity:	FHK salt analyzer, made by Fujihira Kogyo Co.

3.2.4 Collection of Geological Information

Government officials, officers of the Tanganyika Planting Company (TPC) and others provided the mission with materials on topography, geology, meteorology, hydrology, groundwater and other subjects. The major subjects for which informations were obtained are:

1. Meteorology, rainfall, river discharge
2. Geological columnar sections, deep well pumping data, water quality
3. Yeild of groundwater
4. Geological and hydrogeological survey reports (by FAO and others)
5. Geological maps and explanatory notes

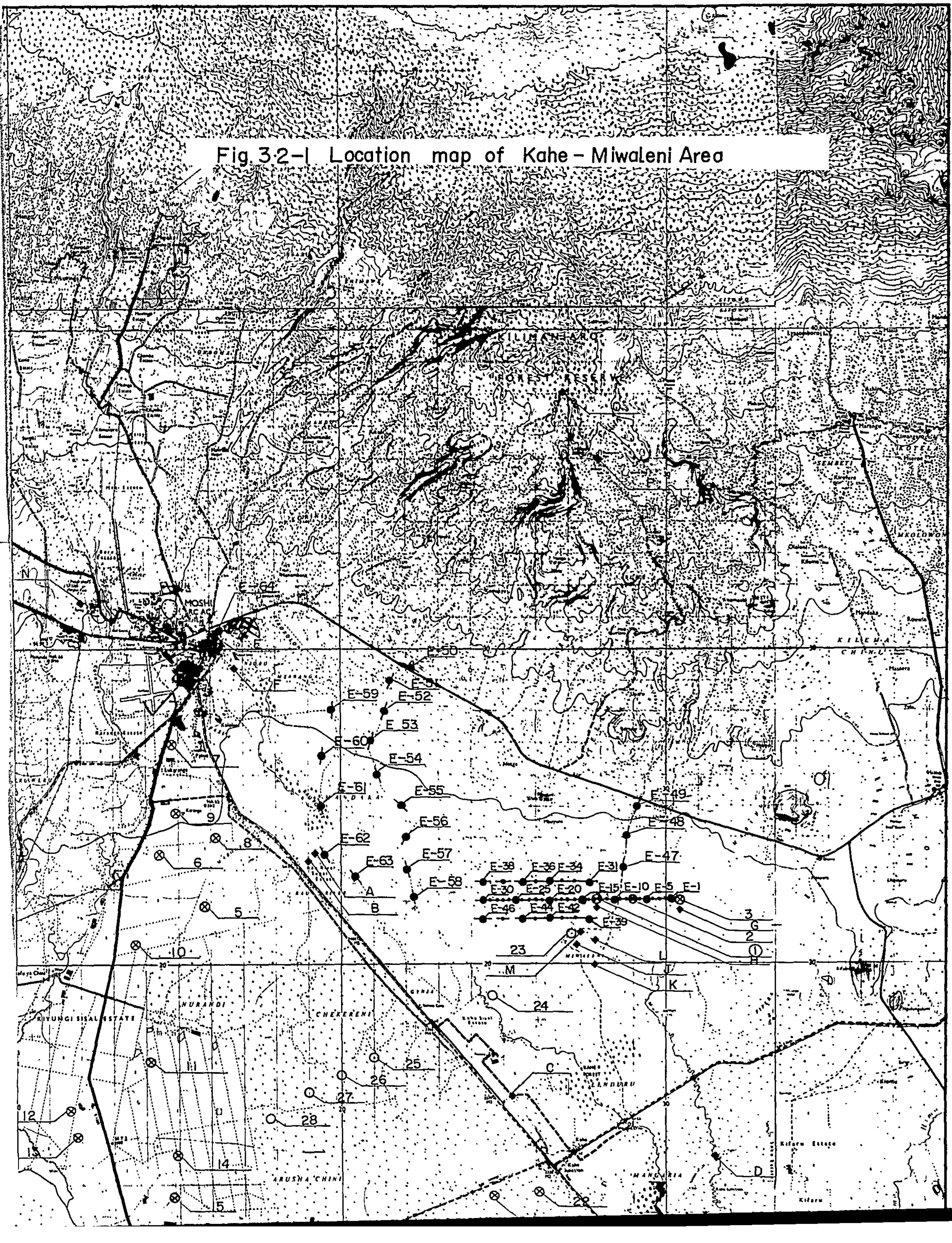
3.2.5 Surface Geological Surveys

Reconnaissance was undertaken in the Kahe-Miwaleni and Mkomazi areas to observe topography, geology, water outcrops and other features.

In addition to the Kahe-Miwaleni Area, surveys were also made on the southern slope of Mt. Kilimanjaro including a part of the Forest Zone which is thought to be the recharge area of groundwater. Therefore, the observation of outcrops and reconnaissance were carried out in an area of about 900 km^2, with Kiwoso, Old Moshi, Lindima and Kirua of the southern slope of Mt. Kilimanjaro to the north, Arusha Chini and Kahe to the south, Kikafu Ya Chini to the west and Kifumbo to the east.

In the Mkomazi Area, a wide areas from Same along the eastern foot of the South Pare Mts. to Kisiwani, Gonja, Kihurio and other areas were also observed.

Fig. 3.2-1 Location map of Kahe - Miwaleni Area



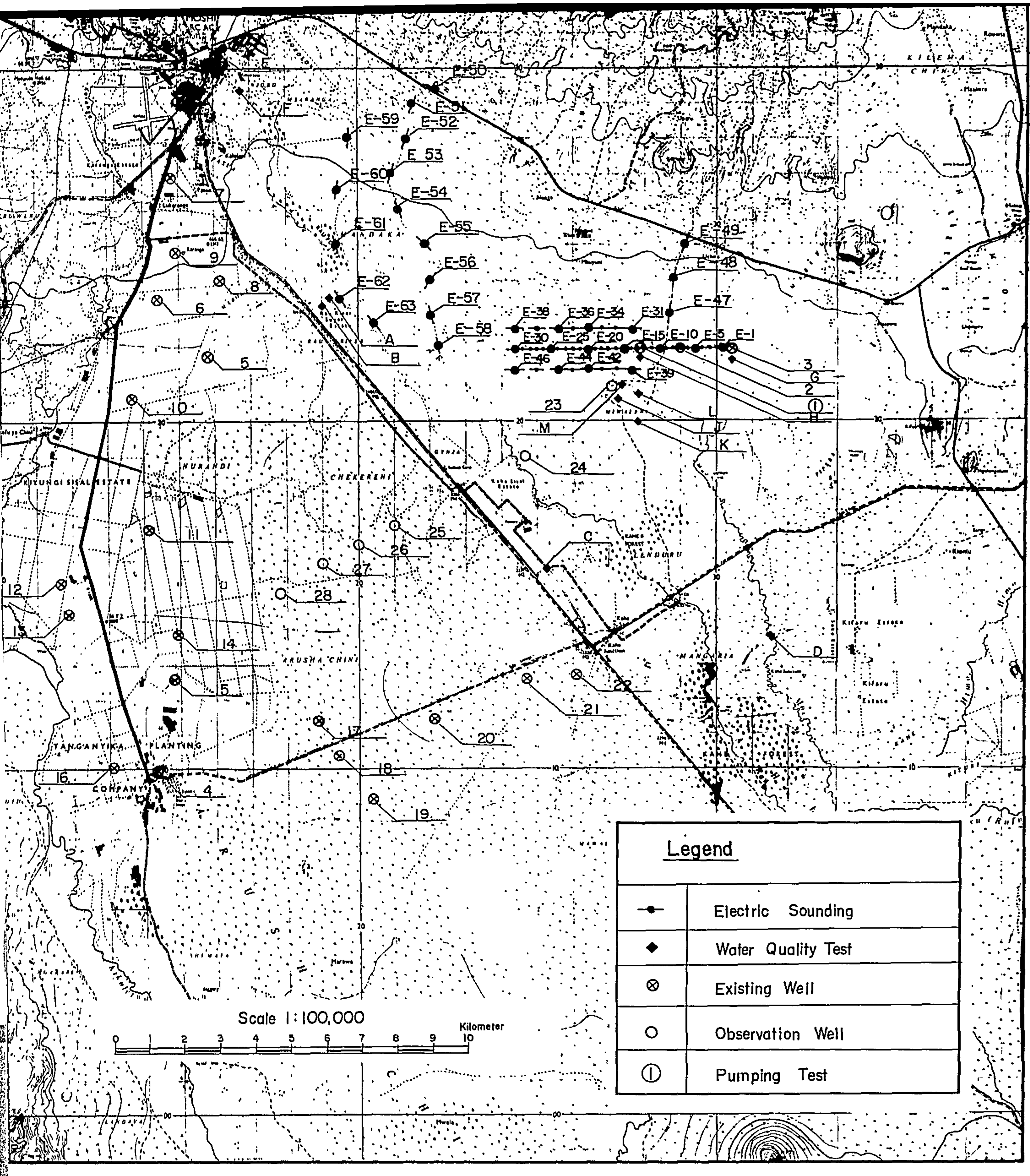
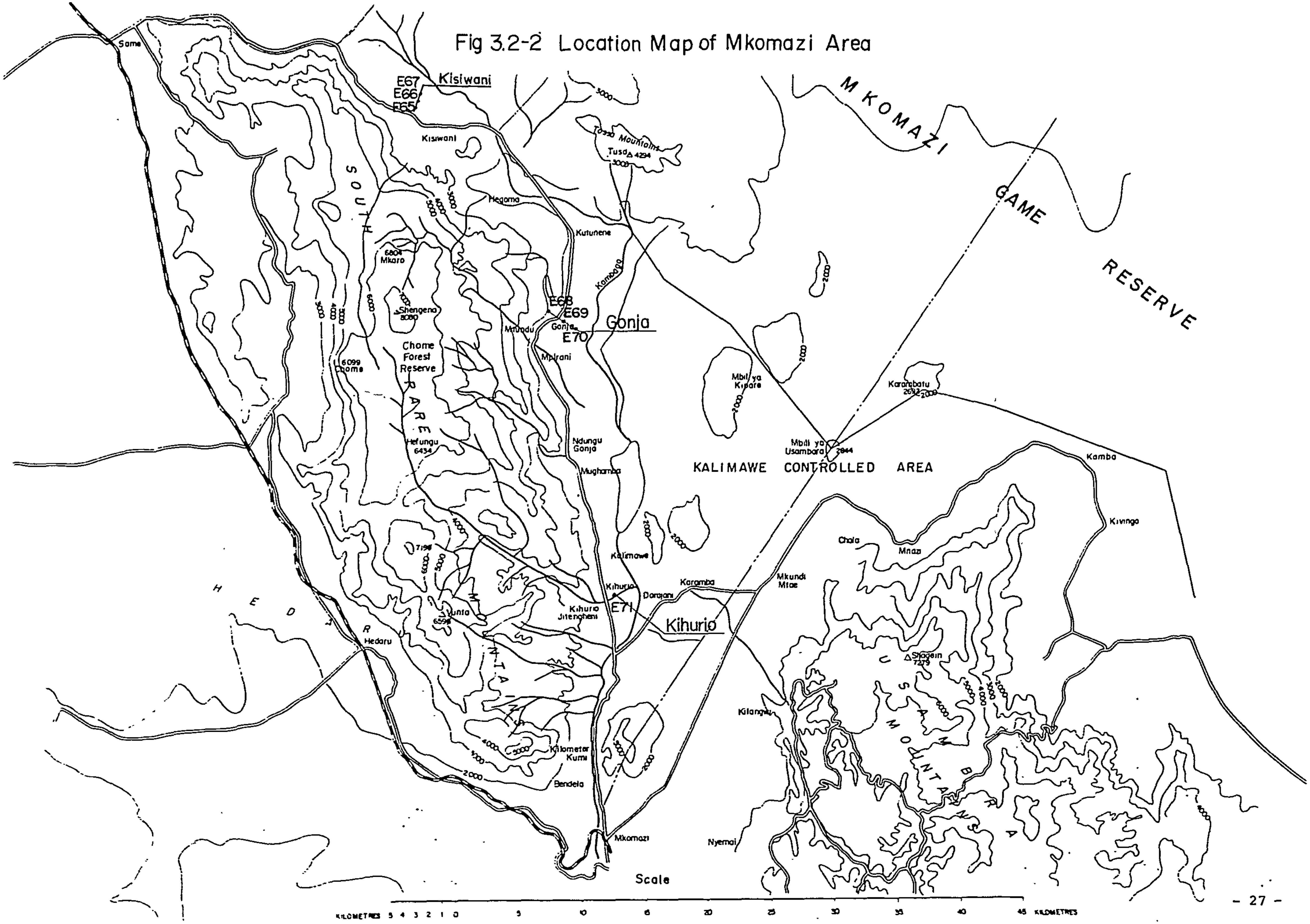

Legend
Electric Sounding
Water Quality Test
Existing Well
Observation Well
Pumping Test
Scale 1:100,000
0 1 2 3 4 5 6 7 8 9 10
Kilometer
NURANDI
KIVUNGI SISAL ESTATE
CHEKERENI
ARUSHA CHINI
TANGANYIKA PLANTING COMPANY
LANDURU
MANGARIA

Fig 3.2-2 Location Map of Mkomazi Area



Part 4 Results and Analyses of the Survey

4.1 Kahe-Miwaleni Area

4.1.1 Topography and Geology

The Kahe-Miwaleni Area is a large plains at the south foot of Africa's tallest peak, Mt. Kilimanjaro (5,895m) and is bounded by mountains -- the Lelatema Mts. (1,600m) to the west and the North Pare Mts. (2,000m) to the east -- and the basin lowlands of the Pangani River to the south.

Mt. Kilimanjaro's highest peak is Kibo (5,895m); the other two peaks are Shira (4,005m) to the west and Mawenzi (5,148m) to the east. The southern foot of the mountain leads into plains at 30 - 50 km from the summit, and the point where the foot of the mountain meets the level and coincides with the Moshi-Himo road. To the north of the road is the slope of Mt. Kilimanjaro and to the south is level land at the elevation of 700 - 750 m; the latter corresponds to the Kahe-Miwaleni Area.

West of Mt. Kilimanjaro are Mt. Meru (4,300m) and Mt. Monduli (2,660m), also volcanic mountains, and further to the west is the Rift Valley which traverses the African continent from north to south. These volcanic mountains are oriented east-and-west, and it is said that both volcanic activity and the tectogenesis of the Rift Valley follow a structural weak line.

Further, the topography in this area is dominated by geologic structure the characteristics of which are clearly evident. The North Pare Mts. to the east of the plains, and the Lelatema Mts. to the west, are connected by a fault scarp, and the level surface of the Kahe-Miwaleni Area forms a graben. Changes in tropography due to differences in rock are evident on the south slope of Mt. Kilimanjaro, and in the deep valleys radiating from the summit it may be seen valleys, in the area of Old Moshi, where dissection is advanced and the weathering of lava, differences in the timing of volcanic eruptions and differences in rocks have developed collapse-structure forms, and relatively eroded small valley forms having scattered hard rocks, to the north of Moshi.

Almost all river systems in the Kahe-Miwaleni Area have their origin on Mt. Kilimanjaro. They show dissection in a radial manner on the slopes of the mountain. They may be broadly separated into the easternmost Mua River system, the Rau River system, and the Kikuletwa River system. All collect many tributaries and flow southward, and flow into the Pangani River in the southern part of the plains. Also found in the Kilimanjaro range are springs typical of volcanic mountains; typical springs are the Njoro Springs in the Moshi, the group of springs at Kenya, Lake Chala, as well as large springs at Miwaleni.

Mt. Kilimanjaro, while close to the equator, is so tall that the peak is perpetually capped with snow. Terminal moraines indicative of glacial topography are recognized at elevations up to 3,000 m. The mountain's slope may be divided according to topography, meteorology, and elevation as follows.

(a) Ice and alpine desert
    El. 4,000 m and higher; perpetual snow; alpine slopes

(b) Heath or moorland zone
El. 3,000-4,000 m; alpine heath

(c) Mountain rain forest zone
El. 2,000-3,000 m; dense rain forest

(d) Cultivated temperate zone
El. 1,200-2,000 m; tropical to sub-tropical temperatures; cultivation of crops; densely

(e) Semi-arid stepps
El. 750-1,200 m; stepps

According to this classification, the Kahe-Miwaleni Area belongs to (e), the semi-arid stepps zone. Concerning the present land use, the most highly developed zone is (d) which is favored by good meteorological conditions and is a source of bananas, coffee and vegetables. Zone (e) where there is a large-scale sugarcane plantation and some other estates, has been developed for the cultivation of crops. At Nyumba Ya Mungu on the Pangani River 30 km south of Kahe there is a dam, and the reservoir region is to the north. The Pangani River basin in southern part of the Kahe-Miwaleni Area is included in this reservoir region and the future development is restricted.

In broad terms, geologically Mt. Kilimanjaro is composed of volcanic rocks, alluvial (superficial) deposits which make up the plains, and Precambrian gneiss. General aspects of these geologic formations are given in Table 4.1-1 and a geological map is given in Fig. 4.1-1.

[Precambrian Rocks]

The oldest layer underlying the survey area is Precambrian gneiss and granulite, which in addition to being visible at a hill east of Kifumbo are distributed in the North Pare Mts., to the southeast, the Lelatema Mts. to the west and the Nyumba ya Mungu area along the Pangani River, to the south. The structure of this basement rocks in the survey area gradually subsides from the Nyumba ya Mungu area diping to the north, and is presumed to be distributed down far from the surface in the Kahe-Miwaleni Area. The Kahe-Miwaleni Area thus forms a basin which contacts the Precambrian mountains by faults at the east and west sides and has shallow Precambrian strata as a basement to the south.

This Precambrian basement, according to the Mt. Kilimanjaro geological map is composed of garnet-quartz-feldspar granulite, quartzite, garnet-sillimanite granulite, hornblende gneiss, biotoite gneiss, crystalline limestone, etc.

[Kilimanjaro Volcanic Rocks]

Kilimanjaro's volcanic activity began in Miocene, as is confirmed by measurement of isotopes, and continued through Pleistocene to the Recent. The activity is now limited to local fumaroles.

The geologic histroy of early activity is not evident because the widely exposed recent volcanic deposit. Three peaks, Shira, Kibo and Mawenzi, are the centers of volcanic activity. In addition to these three, small parasitic cones are present, in a WNW-ESE orientation.

Shira the oldest peak, which is a westernmost of the three and is almost entirely covered by volcanic rocks of the Kibo group is composed of lava and pyroclastics.

Mawenzi, which was active following Shira, had lava flow mostly on the southern to eastern side, and is mostly basaltic rocks. Tuff breccia and agglomerate are also recorded.

The highest peak, Kibo, is the newest, and lava flow was mostly to the south and north. Activity began in Pleistocene and continued until recent times. Kibo's lava is mostly composed of porphyry group having feldspar phenocrysts, and this type of rock is relatively resistant to erosion. The urban area of Moshi is located in the region where Kibo lava is distributed, and water which reaches the surface through gashes in the lava, emerges as the Njoro Spring, the spring within the prison, Nsere Spring, Shiri Spring and others.

Southeast of Moshi, in the northern part of the western side of the Kahe-Miwaleni Area, Kibo lahar is distributed. It is composed of pebbles of porphyry of 1 - 10 cm in size. Lahar was created by debris flow and it is thought that it was formed accompanying the development of the Kibo peak.

Nearly 300 parasitic cones, associated with the volcanic activity of Kilimanjaro are known to exist. Their parasitic cones are about 100 m in diameter and about 100 m in height. They are composed of scoria and ash with small amount of lava flow. The activity is most strongly recognized in a NWN-SES line which crosses the row of main peaks.

Also, while it is geologically classified among parasitic cones, thick volcanic clay formation covers the region around Old Moshi north of the Moshi-Himo road, north and northeast of Narangu, and the Masama and Kyuu area northwest of Moshi. This formation is composed of much weathered lava, agglomerate, scoria etc. This area is easily eroded in places, and some fragmented landscope are recognized.

These volcanic rocks appear to be covered by Kibo lava at the north of Moshi and by Mawenzi lava at the north of Himo. Judging from the degree of weathering and extent of erosion, they seem to be fairly old volcanic rocks.

[Superficial Deposits]

In the plains of the Kahe-Miwaleni there are alluvial deposits came from the Mua, Rau and Kikuletwa Rivers. They are formed of wash-out deposits, clay, sand, gravel, as well as limy clay and other deposits.

The wash-out deposits are brown loam clay which is covering limy deposits in the transitional area between the area of volcanic rocks and the alluvial deposit area where clay, sand and limy deposits are exposed. Small volcanic gravel (1-5mm) are included in these wash-out deposits. The thickness is judged to be about 5 - 10 m on the basis of observation of surface outcrops.

In the lower portion of the wash-out deposits, a weakly solidified formation of clay, sand and gravel including limy clay is widely distributed, mostly from Miwaleni south and in the area around Kahe. The characteristic of this formation is that the gray limy clay has stratification and moreover is accompanied by round gravel. The round but flat gravels are 1 - 3 cm or less in diameter and are composed of basalt, porphyry and other volcanic rocks presumed to have the Kilimanjaro volcano as their origin. The limy clay has a greyish color, and includes fossils. They may be lacustrine deposits and are thought to indicate the depositional environment of this region. Alluvial deposits including this formation were widely observed at Miwaleni Spring, downstream of the Rau River, downstream of the Mua River and elsewhere, and moreover there are records of their presence in well drilling information from TPC (Arusha Chini), so they are believed to be widely distributed below the surface in the Kahe-Miwaleni Area. The clay, sand and gravel, judging from observations of outcrops, must have been deposited in an environment in which sorting effect was poor; clay and sand are present even in the gravel formation, and there can be observed poor horizontal continuity.

Further, some lava flows and other type of volcanic rocks are intercalated within this formation. Consequently, this alluvium formation forming the Kahe-Miwaleni sedimentary basin, more than 150 m thick, in view of existing well drilling information seems to have very complicated sedimentary structure.

Further, the fan deposits which is composed chiefly of round gravel of about 10 cm in diameter are recognized as an alluvial deposit at the end of the valleys opening up from the flanks of the volcano. Rocks are all volcanic and are judged to be distributed only in a very narrow pattern along the valleys.

[Soil]

The surveyed area is near the equator and is characterized by high temperature conditions and strong weathering. The surface soil indicates a characteristic distribution pattern reflecting the geologic nature of mother rocks.

The southern flank of the Kilimanjaro volcano, north of the Moshi-Himo road, is composed of brown to dark-brown volcanogenous soil of weathered lava, and this thick surface soil is widely used for cultivation. The distribution area of the wash-out deposits south of the road comprises soil of weathering clay having small brown gravel as is found on the flank of the volcano.

Because the southern part of the plains from the area of Miwaleni is a region where limy deposits are distributed, the soil is pale-gray to gray and is generally thin. This characteristic is reflected in the vegetation at the south of the Kahe-Taveta rail line.

In the east where the Precambrian rocks are exposed, reddish brown sandy clay came from weathered gneiss is widely distributed. In hill area the topsoil is think and large trees are few.

[Geologic Structure]

The most important geologic structure of this area is the Rift Valley of north-south direction. The west side of the Pare Mts. and the east side of the Lelatema Mts. are both contact with the plain area to form the Kahe-Miwaleni sedimentary basin including the Pangani Trough by faults.

The Kilimanjaro volcano is on the tectonic line of the east-west-direction. Mt. Meru is also on this tectonic line. As this tectonic line crosses the Gregory Rift Valley in the west, it is thought that this tectonic line is related to the tectogenesis which formed the Rift Valley.

The Precambrian formations which are thought to be the base of the studied area is cut by an east-west fault, deeply buried by volcanic rocks in the north and gradually approaches to the surface in the south at Nyumba ya Mungu along the Pangani River. Therefore, the Kahe-Miwaleni Area is judged to have a graben-like basin structure.

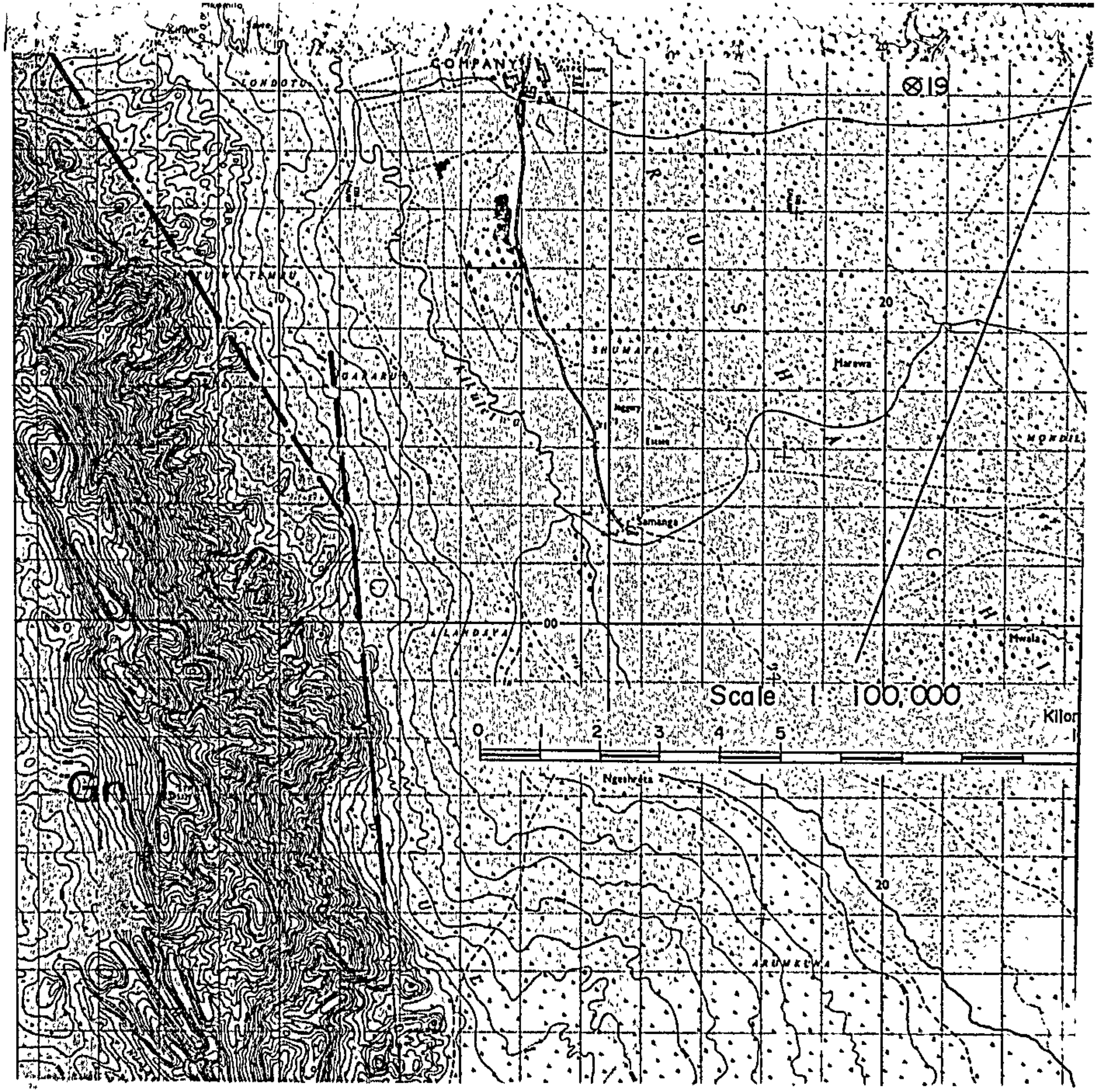

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Fig. 4·1-1 (1) Geological Map of Kahe-Miwaleni Area

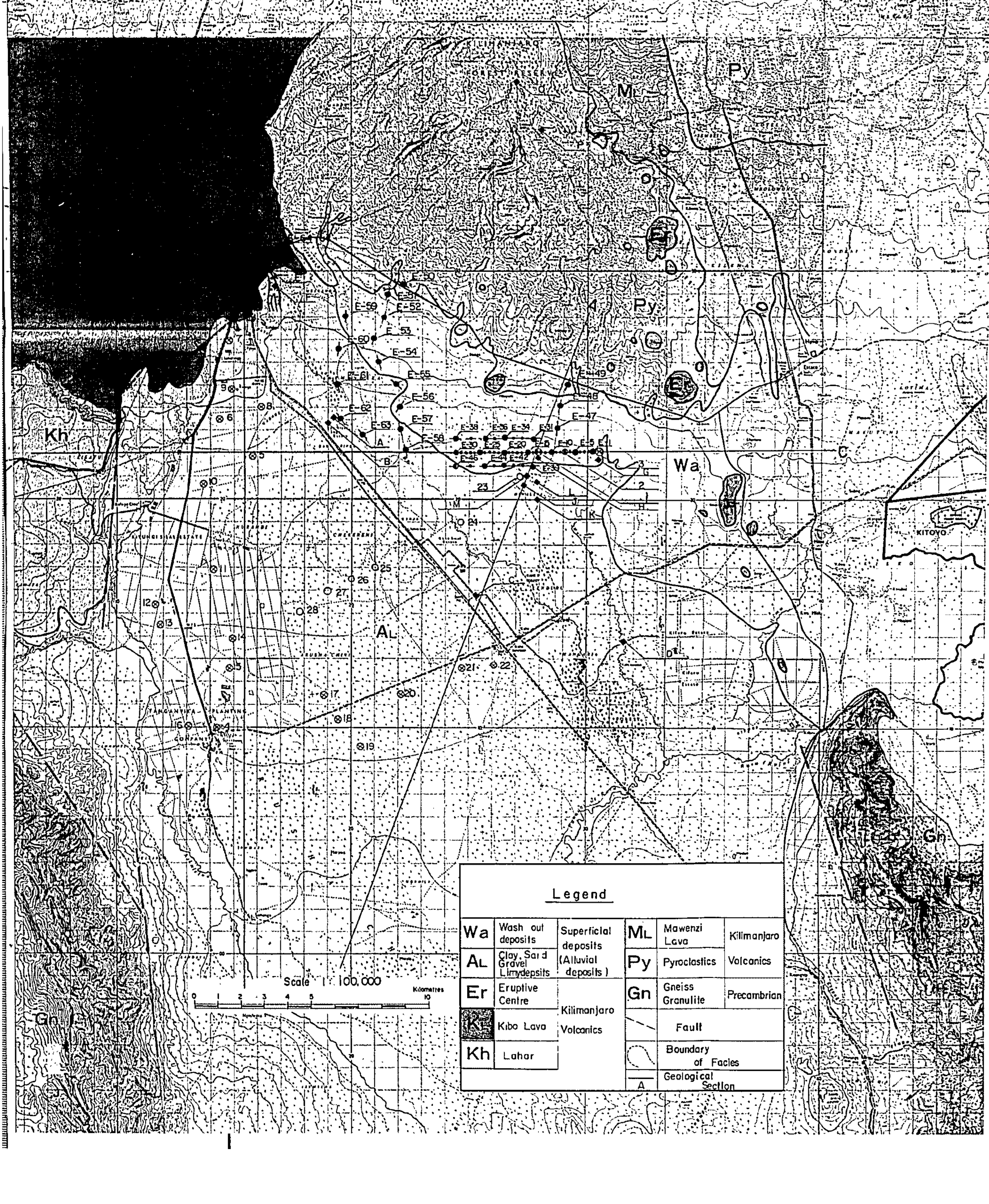


Fig 4·1-1 (2) Geological Cross Section of Kahe-Miwaleni Area

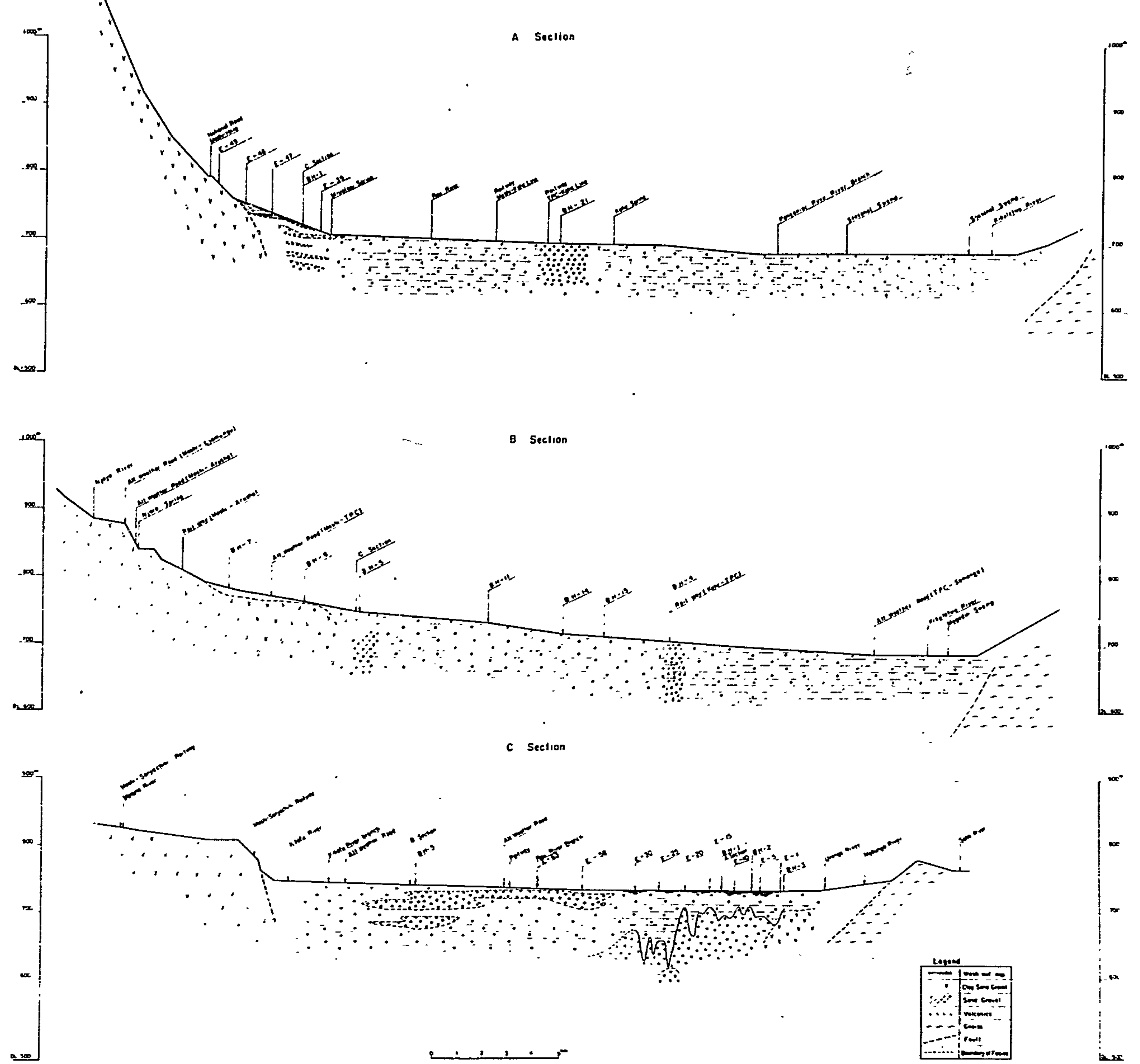


Table 4.1-1 Geological Formation

Era	Formation	Facies
Neogene	Superficial deposits (Alluvial deposits)	Wash out deposits (Loamy clay) Alternation of clay, sand, gravel & limy deposits Sand & gravel Alluvial fan deposits
	Volcanics (Kilimanjaro group)	Parasitics (Scoria & ash) Kibo (Lahar, Porphyry) Mawenzi (Trachybasaltic lava, Agglomerate) Shira (Trachybasalt, Agglomerate)
Precambrian	Usagaran of Mozambiquian Orogenic Belt	Gneiss, Granulite

4.1.2 Hydrology and Meteorology

(1) River Systems

The river systems of the Kahe-Miwaleni Area have their origin at Mt. Kilimanjaro and have radial shapes with deep gorges. There are three systems: the Mua River, Rau River and Kikuletwa River systems. Each system has many trubutaries, flowing to the south and converge at the southern part of the plains to form Pangani River which flows south into the Indian Ocean.

Mua River is in the eastern portion of the plains and has its origin on the south flank of Mawenzi. There is almost no surface flow during the dry season, and it is thought that almost all surface water of Mua River near the railway bridge of Kahe-Taveta Line comes from Miwaleni Springs.

Rau River has its origin on the southern flank of Mt. Kilimanjaro, flows south, passing through east of Moshi and the center of the plains. Of the three river systems this is the only one having a surface flow during the dry season. At the south of Moshi it converges with Njoro River which has its origin at springs east of Moshi, flowing along the Tanga Line railway tracks. It has the Rau Forest of 5 km long.

The surface flows noted above are valuable as sources of irrigation water although there is virtually no surface flow at the south of Kahe.

The Rau and Mua River flow into the Pangani (Ruvu) River 28 km at the south of Kahe and the Pangani River crosses the Tanga Line and flows south.

The main stream of Kikuletwa River comes from the south flank of Mt. Meru and is joined by streams which came from the southwest flank of Mt. Kilimanjaro merging into the Pangani (Ruvu) River at 40 km south of Moshi. The Pangani River reaches to the Indian Ocean at the south of Tanga port through the dam at Nyumba ya Mungu.

The Karanga, Werumeru and Kikafu River systems have their origins at the south slope of Kibo and Shira, and the Kware and Sanya River systems come from the west-southeast flank of Shira. Of these two, the one which is thought to bear a relation the Kahe-Miwaleni Area is the former which have a surface flow even during the dry season. All three sub-systems of it coverage the area between south of Moshi and the Kikafu ya Chini area and flow southward east of the plain to join the Kikuletwa River at 8 km south of Kikafu ya Chini. Two rivers which come from the west-southwest flank of Shira flow into the Kikuletwa River which originates from Mt. Meru at the south of Ngulu before entering the plain.

(2) Springs

Many springs are observed in the environs of Mt. Kilimanjaro. In the southern range of the mountain, which was studied in this survey, large springs such as Miwaleni Springs, Njoro Spring which rise through the fissure of lavas and the spring within the Prison are found in the area round Moshi.

There are also many springs in the southeast and north ranges of Mt. Kilimanjaro. In particular, it is recorded that large springs exist in Kitovu, Taveta, Ziwani and Loitoki in Kenya. Mt. Kilimanjaro is also the source of Lake Chala's water.

The water of all these springs first fall as snow or rain on Mt. Kilimanjaro and permeate through volcanic rocks and then some come to the surface through cracks in lava, while some passes from lava strata through alluvial deposits to surface as springs.

(3) Precipitation

The seasons are distinguished in the Kilimanjaro Region as the major rainy season, in March through May; the minor rainy season, in November and December, and the dry season, in July to September. More than 60% of the annual rainfall is concentrated in the major rainy season, and there is almost no rainfall during the dry season. However at high evaluations areas there are light rainfalls even during the dry season.

Observations of rainfall near the Kahe-Miwaleni Area are made at the Moshi meteorological station, Lyamungu agricultural research institute and its Miwaleni branch, and elsewhere, including schools and estates. Because a reasonable amount of data is available, it has been possible to prepare the following table for sites near the area surveyed.

Table 4.1-2 Annual Precipitation at Selected Sites in the Kahe-Miwaleni Area

Site	Elevation	Precipitation
Lyamungu	1,250 m	1,560 mm
Miwaleni branch	725	630
Moshi Met. Station	870	880
Kilewa Mission	1,113	1,940
Old Moshi School	1,067	960
Kiyungi Sisal Estate	747	680
Kahe Estate	710	530
Arusha Chini Estate	716	550
Himo Sisal Estate	792	720
Kibosho Mission	1,370	1,900

The location of raingauge stations is as in Fig. 4.1-2; monthly precipitation is as shown in Figs. 4.1-3 to 4.1-5. Further, according to "The Survey Report for Agricultural Cooperation Project in Kilimanjaro Region, Tanzania, 1974 (J.I.C.A.)", precipitation varies with elevation as shown in Table 4.1-3.

Table 4.1-3 Annual Precipitation at Different Altitudes

Elevation	Annual Precipitation
5,000 ft = 1,524 m	1,950 mm
4,600 = 1,402	1,980
4,500 = 1,372	1,830
4,300 = 1,310	1,600
4,200 = 1,280	1,800
4,000 = 1,219	1,300
3,300 = 1,006	1,350
2,900 = 884	850
2,500 = 762	650
2,300 = 701	430

As can be understood from the above figures and tables, precipitation is concentrated at high elevations and decreases from the mountains to the plains.

(4) Temperature

The survey area, being in the southern hemisphere, has its lowest temperatures during June-August, and its highest temperatures during January-March. The annual range is small and, as may be expected, the daily range is greater than the annual range. Temperature observations are available for the Lyamungu agricultural research institute, its Miwaleni branch, the Moshi Meteologiral Station and the

Kahe Estate, all near the survey areas. Mean monthly temperatures are as in Figs. 4.1-3 and 4.1-4.

(5) Evaporation and Transpiration

Observations of pan evaporation are made at the Lyamungu agricultural research institute and its Miwaleni branch. Mean annual evaporation recorded there are 860 mm at Lyamungu and 2,390 mm at Miwaleni. Observations were made by use of a Class A Pan (4 ft ϕ).

Monthly evaporation are as shown in Fig. 4.1-3; the evaporation is greatest during October-March when temperatures are high, and smallest during April-September.

There are no records of direct observation of transpiration, but calculations may be performed using evaporation data. Because bananas, coffee and other crops are cultivated at highland below the Forest Zone and north of the national highway, it may be considered that there is good vegetative growth. Because rainfall is low (500-600mm) and temperatures are high at the south of the national highway, vegetative growth is sparse and many thorny plants can be seen, and the only crops are maize, beans and some others, which are rainfed. Therefore the ratio of transpiration to pan evaporation (E/Ep) is thought to be about 0.7 at the north of the national road including the Forest Zone, and about 0.6 in the plains to the south (both means annual values).

(6) Runoff

Almost all of the rivers which flow into the Kahe-Miwaleni Area except the Rau and Mua Rivers are seasonal rivers which show to surface flow during the dry season. Even in the case of the Rau River, although there is surface flow from Mt. Kilimanjaro (including the Forest Zone), it also collects water from the Njoro Springs east of Moshi. Almost all of the water of the Mua River is from the Miwaleni Springs. The annual runoff rate for this area calculated by comparison with precipitation and outflow at IDC3A (Kahe Forest, the Rau River) is about 12%. Therefore although it may be thought that there is some storage of water in the Forest Zone, it is thought that the average annual runoff rate is about 10%, and, in the Upper Zone north of the national road about, 15%.

The locations of discharge measurement stations near the Kahe-Miwaleni Area are shown in Fig. 4.1-2, and monthly discharge is as in Table 4.1-4.

Fig 4·1-2 LOCATION MAP of RAINGAUGE &
DISCHARGE MEASURMENT STATI

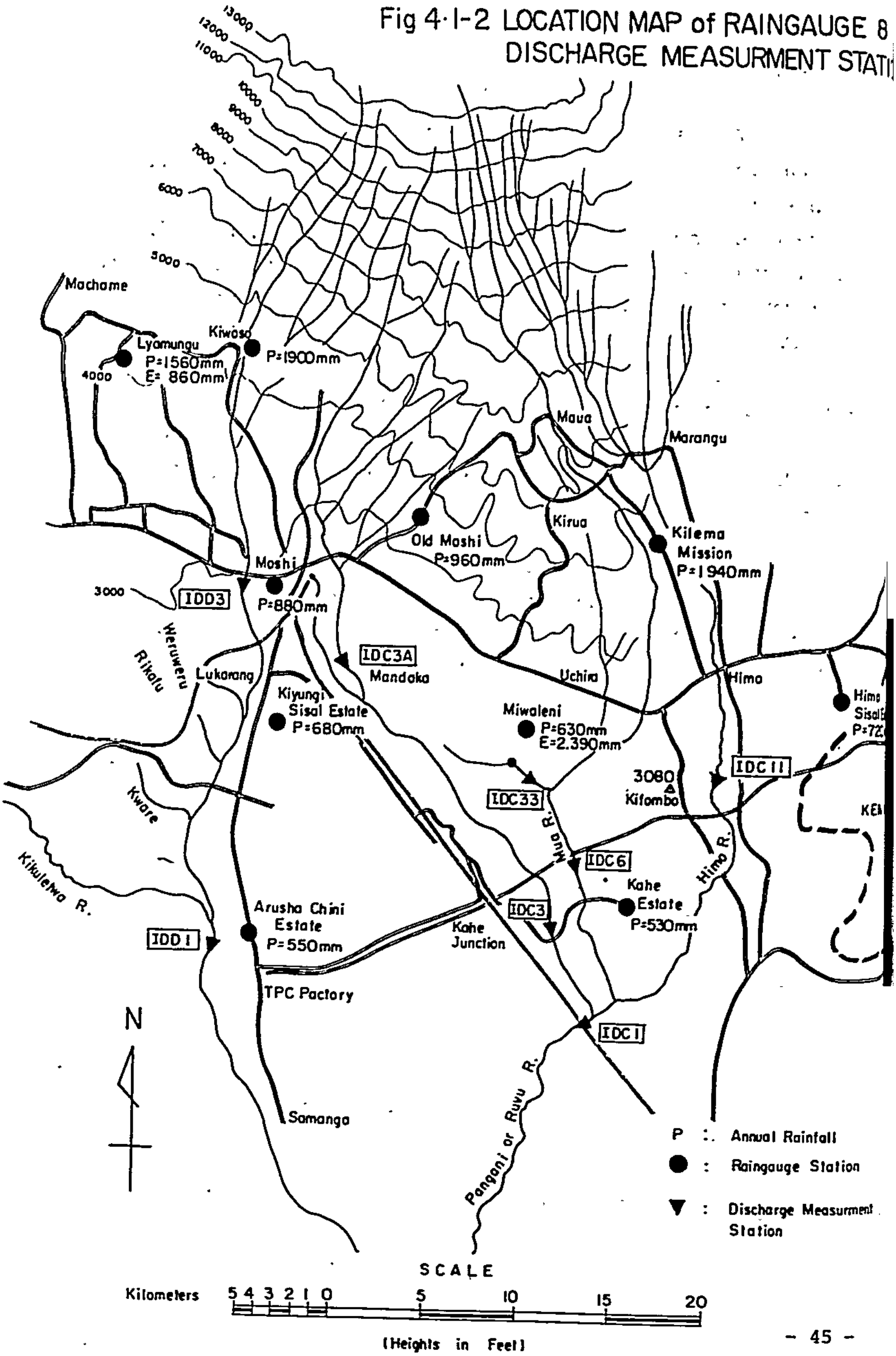
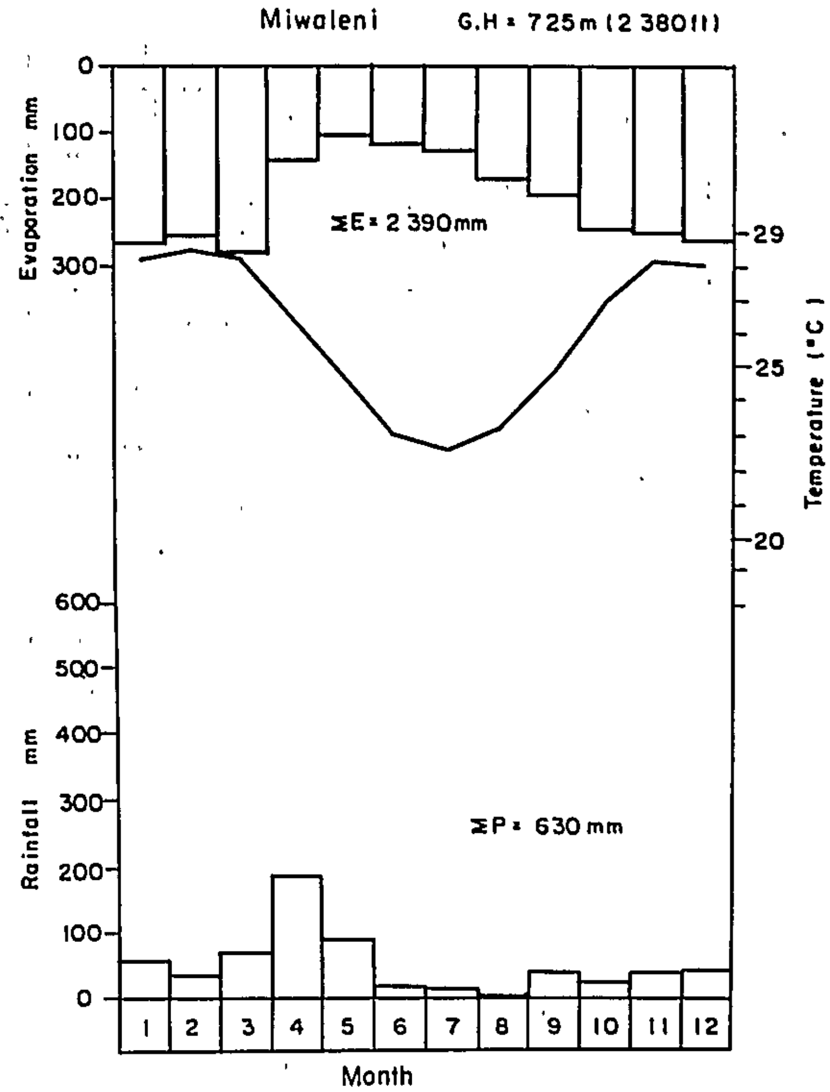


Fig. 4·1-3 Meteorological Data (1)



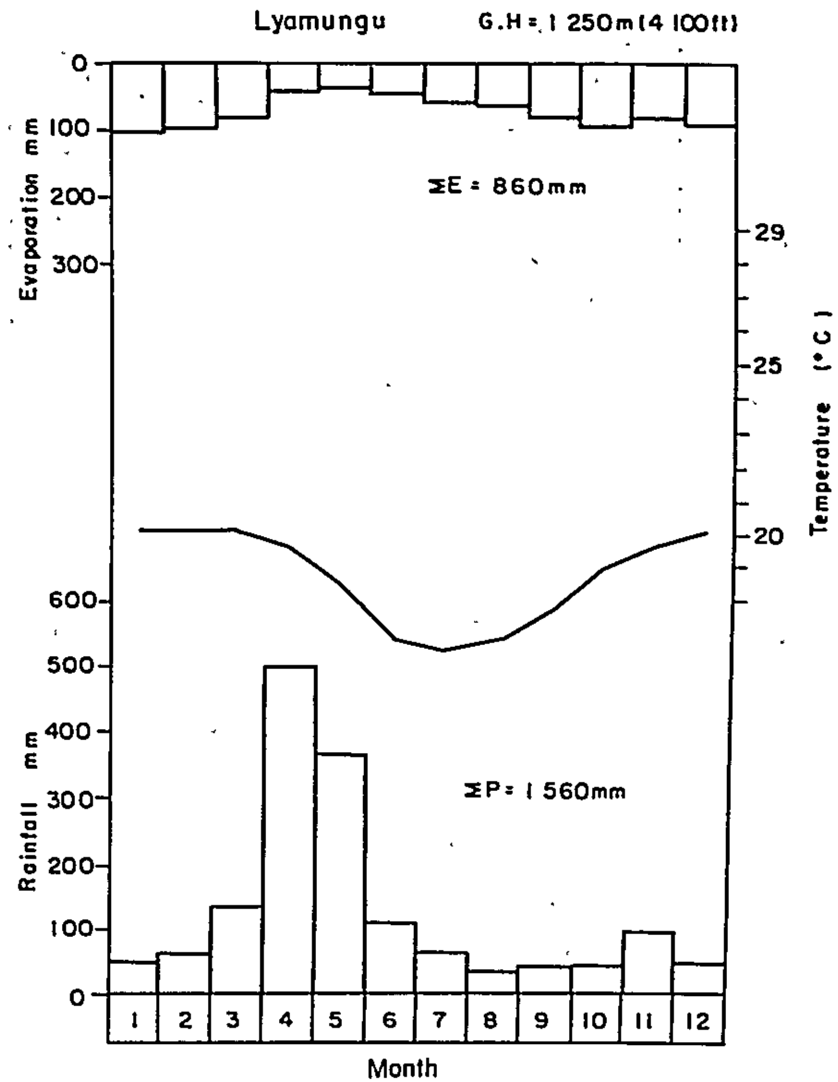


Fig. 4-1-4 Meteorological Data (2)

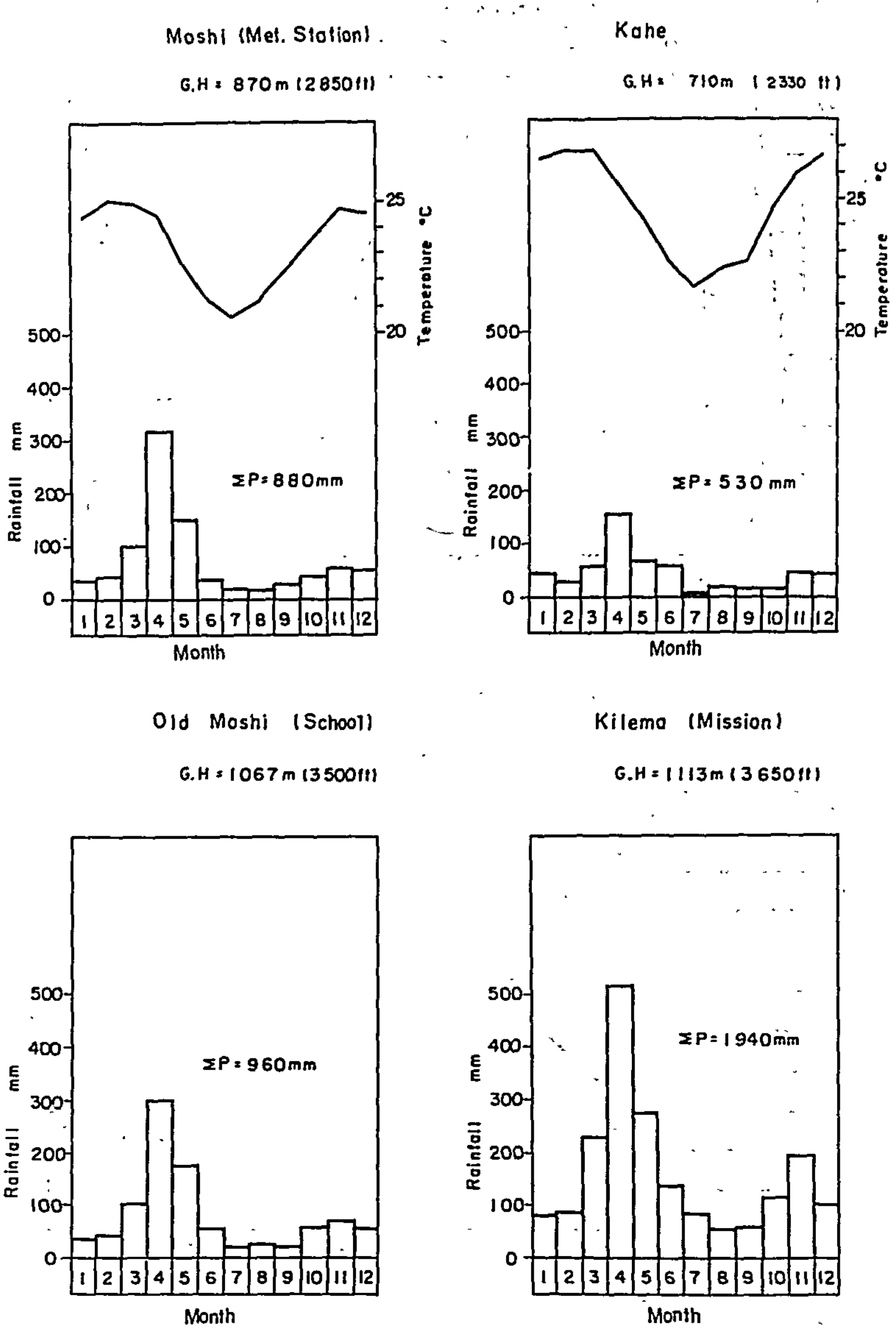
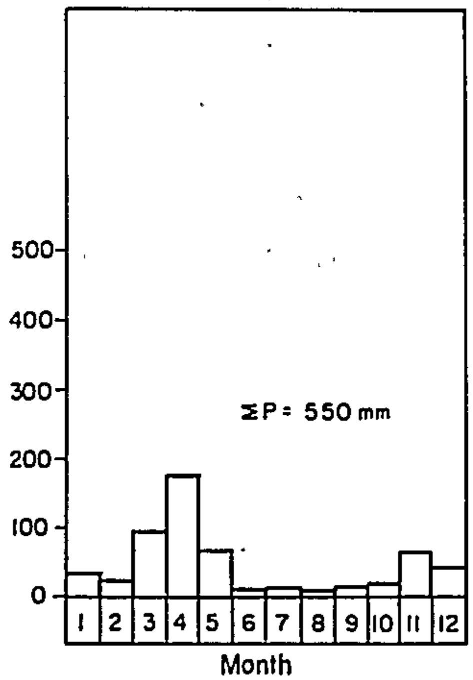


Fig. 4·1-5 Meteorological Data (3)

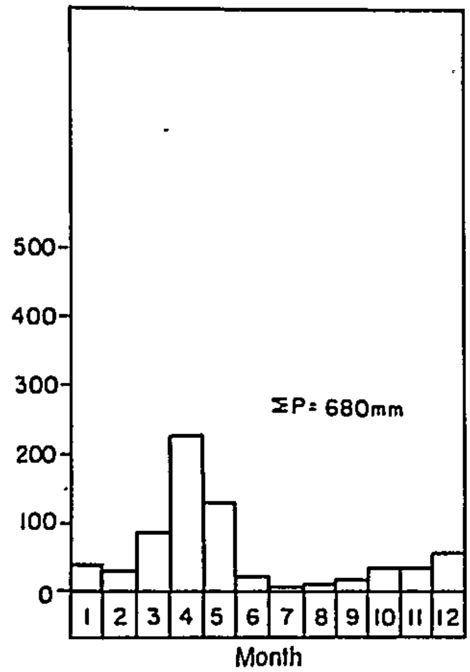
Arusha Chini Estate

GH = 716 m (2350 ft)



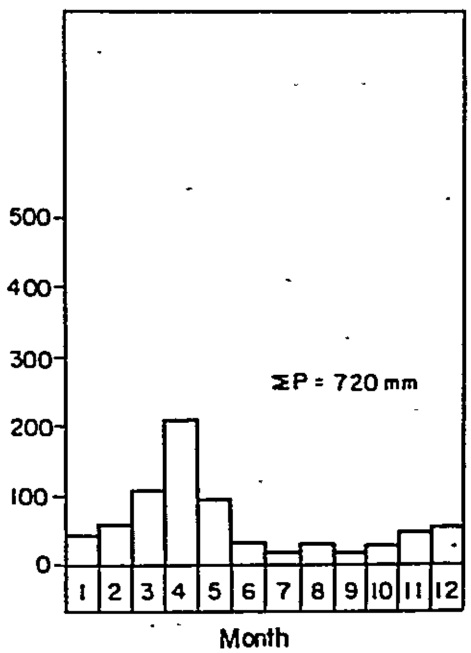
Kiyungi Sisal Estate

G.H = 747 m (2450 ft)



Himo Sisal Estate

G H = 792m (2,600 ft)



Tabl4 4.1-4 Monthly Mean Discharge of Rivers in Kahe-Miwaleni Area

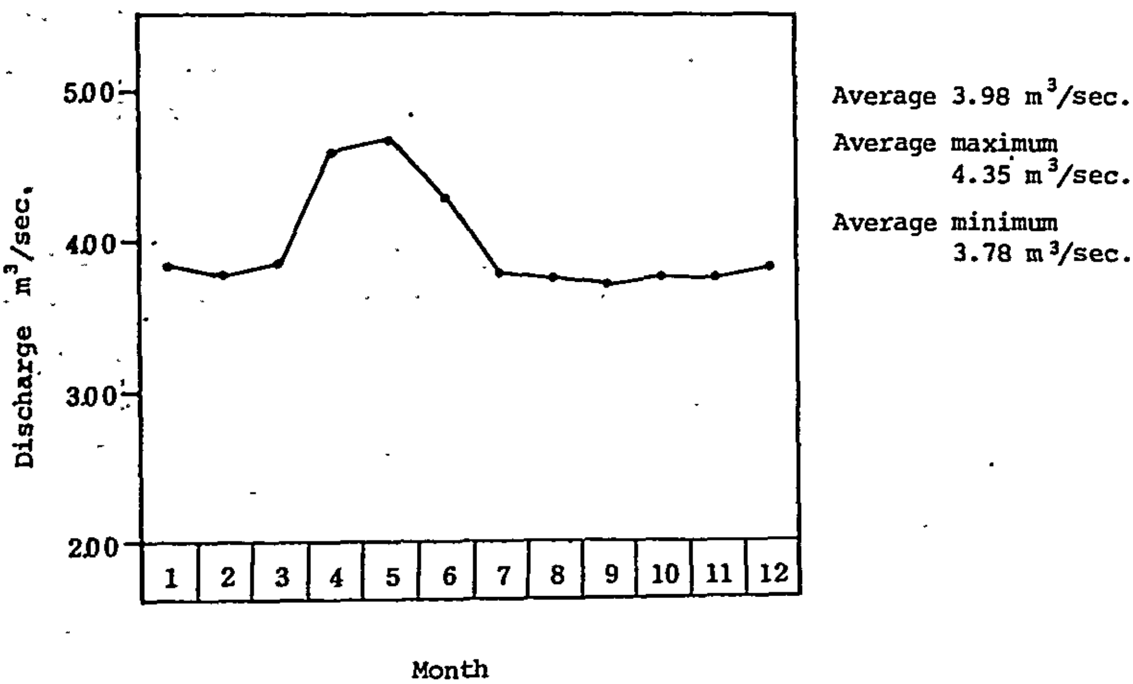
m^3/sec

Station No	Location	Name of River	1	2	3	4	5	6	7	8	9	10	11	12	Annual Mean	Remarks
IDC 3 A	Kahe Forest	Rau	0.72	0.77	1.20	0.73	1.07	1.19	0.96	0.60	0.51	0.44	0.38	0.34	0.72	1969~70
IDC 3	Kahe	"	0.51	0.56	0.47	0.66	1.46	1.37	1.32	0.94	0.77	0.67	0.88	0.95	0.88	1957~59
IDC 33	Miwaleni	Miwaleni Springs	3.86	3.80	3.89	4.54	4.65	4.32	3.84	3.76	3.71	3.79	3.79	3.85	3.98	1966~70
IDC 6	Railway Bridge	Mua	3.55	3.52	3.55	3.74	7.58	5.62	3.92	3.47	3.44	3.47	3.60	4.02	4.12	1957~59
IDC 11	Himo	Himo	1.24	0.90	0.90	2.10	7.45	5.50	3.00	2.15	1.68	1.13	0.84	0.89	2.32	1958~59
IDC 1	Railway Bridge	Ruvu	16.35	11.57	10.16	16.07	20.44	14.90	12.88	12.06	10.81	10.61	13.68	16.93	13.87	1959~65
IDD 3	Arush-Moshe Road	Karanga	0.63	0.93	0.47	4.33	10.63	6.46	3.13	1.37	0.43	0.27	0.43	0.74	2.49	1954~59
IDD 1	Londotu	Kikuletwa	16.94	18.32	16.38	44.27	56.40	34.96	27.33	20.83	15.57	13.40	16.87	14.05	24.61	1969~75

(7) Discharge of Miwaleni Springs

The average annual discharge of Miwalnei Springs for the five-year period 1966-1970 is shown in Fig. 4.1-6. Further, concerning the base discharge of the springs, according to a report (Kahe Irrigation Scheme, Miwaleni Springs Discharge Analysis) by T.H. Mather (Nov. 1964) and informations collected by Japanese experts, there is some fluctuation from year to year, but the annual average of recorded observation for 1958-1970 is 3.5 m^3/sec., and even allowing for fluctuation the value does not go below 3.0 m^3/sec.

Fig. 4.1-6 Monthly Mean Discharge of Miwaleni Springs at IDC33 (1966-1970 average)



4.1.3 Subsurface Geology

1. Results of Electrical Soundings and Comparision with Geological Characteristics

Electrical soundings were carried out in the north of the Kahe-Miwaleni Area from the Miwaleni district to the Msaranga Mandaka district. Geologically, these districts are the contacts of Mt. Kilimanjaro volcanic rocks and recent alluvial deposits of the plains. Kilimanjaro volcanic rocks include, in addition to lava, pyroclastics and these pyroclastics are inserted between new alluvium deposits. New deposits include loamy clay which came from the volcanic rock areas, clay which is dominant throughout most of the plains, sand, gravel, and gravel bed of fan deposits.

As the major purpose of the electrical soundings was to gain an understanding of the structure of the strata containing groundwater, work was performed with the objective of comparing resistivity values with existing geologic information.

For the comparison of resistivity values obtained by means of analysis with geologic information, reference was made to geologic information obtained at boreholes Nos. 1-3 in the Miwaleni Area as well as observations made at points of lava flow, etc. Concerning the correlation between resistivity values and geology, distinct differences in resistivity values for clayey strata, gravely strata and lava strata are found.

(Correspondence of resistivity values and geologic information from borings)

ρ = 4 - 7 Ω-m   Strata mostly of clay

ρ = 40 - 80 Ω-m Strata mostly of gravel
ρ = 110 - 130 Ω-m Volcanic rocks (lava)

(Resistivity values of other lava)

ρ = 135 - 190 Ω-m At E-48 and near E-49
ρ = 400 Ω-m At E-50
ρ = 250 Ω-m At E-64

It is thought that high porosity of scoriaceous lava is the reason for the high value at E-50.

The interpretation of the results of the analysis of electrical soundings was based on such comparisons of resistivity and geologic information as given above.

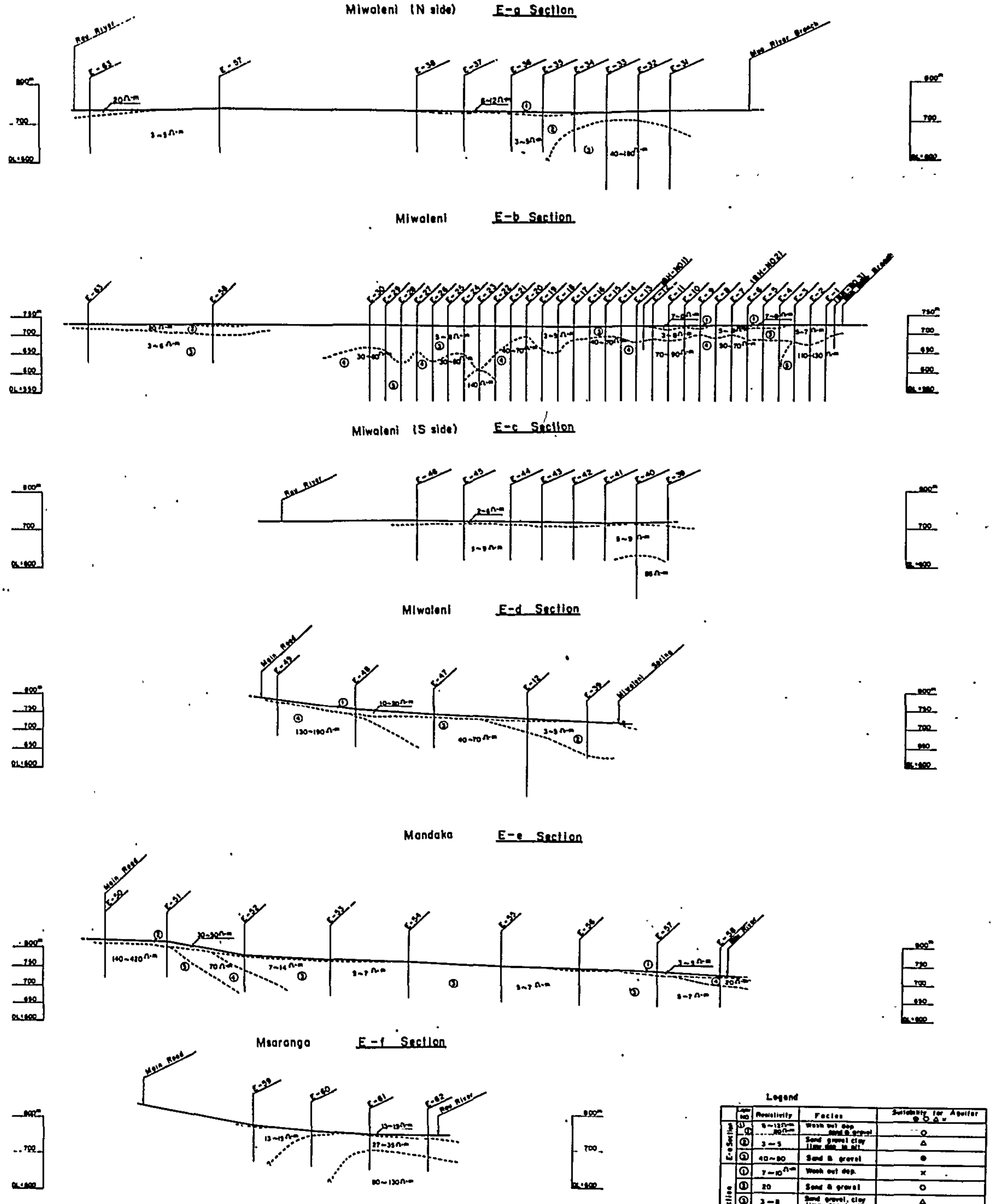
(Results of Soundings)

Results of analysis for each sounding line are shown by Fig. 4.1-7. The location map of electrical soundings is given as Fig. 4.1-8, and sounding lines are summarized in Table 4.1-5.

Table 4.1-5 Sounding Lines Data

Section	Area	Direction	Notes
E-a	Miwaleni	E-W	Northernmost
E-b	"	"	600m south of E-a
E-c	"	"	600m south of E-b
E-d	"	N-S	Eastern Miwaleni
E-e	Mandaka	"	
E-f	Msaranga	"	About 1.5km west of E-e

Fig 4·1 − 7 Cross Section of Kahe-Miwaleni Area (After Electrical Soundings)

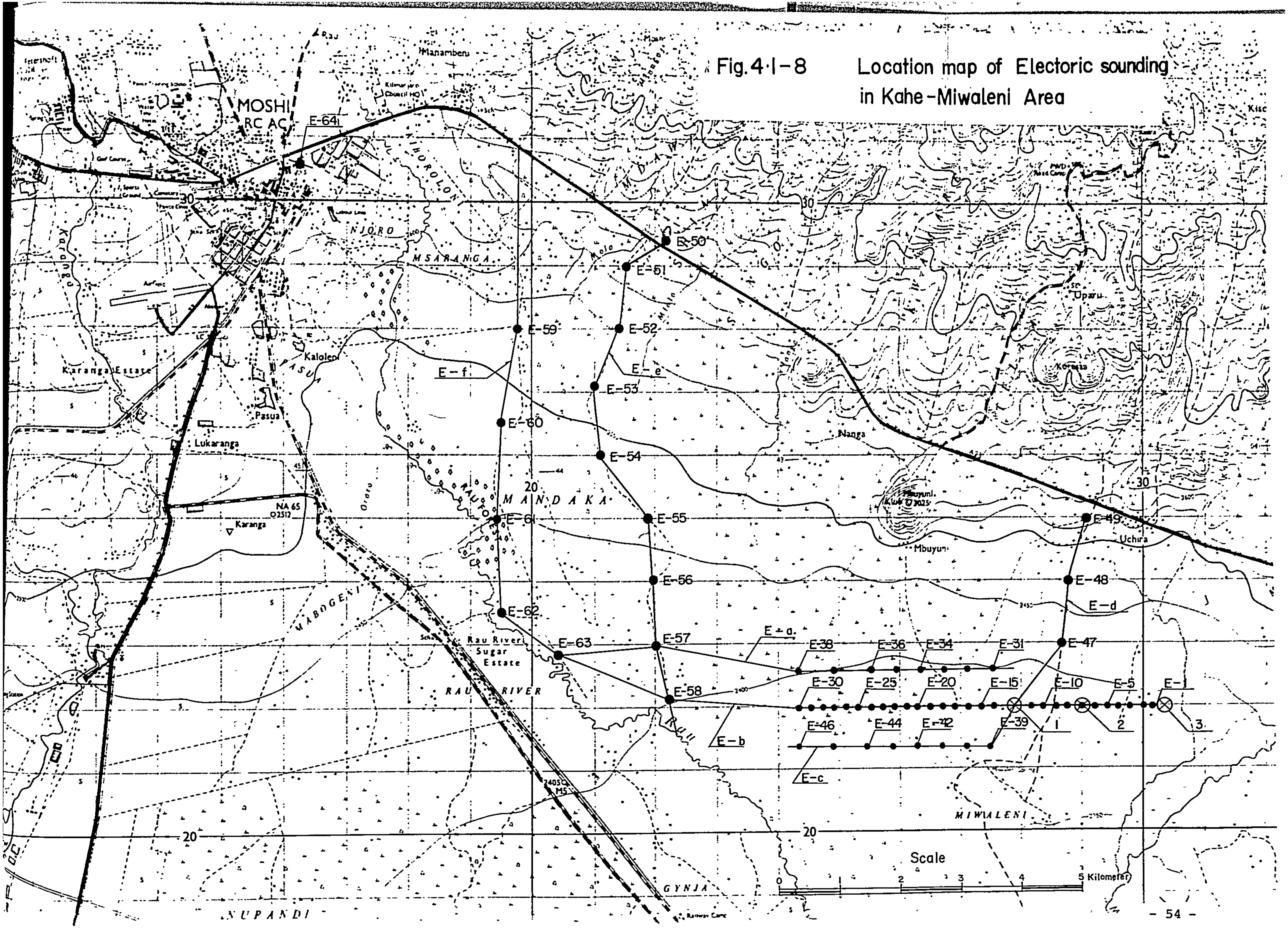


Legend

	Layer No	Resistivity	Facies	Suitability for Aquifer ● ○ △ ×
E-a Section	①	6~12Ω-m	Wash out dep.	
	①	20Ω-m	Sand & gravel	○
	②	3~5	Sand gravel clay (limy dep. in alt.)	△
	③	40~80	Sand & gravel	●
E-b Section	①	7~10Ω-m	Wash out dep.	×
	②	20	Sand & gravel	○
	③	3~8	Sand gravel, clay (limy dep. in alt.)	△
	④	30~90	Sand & gravel	●
	⑤	110~130	Lava & other volcanics	○
E-c Section	①	2~6	Limy dep.	×
	②	5~10	Sand gravel clay (limy dep. in alt.)	△
	③	95	Sand & gravel	●
E-d Section	①	10~30	Wash. zone of volcanic wash out dep.	×
	②	3~5	Sand gravel clay (limy dep. in alt.)	△
	③	40~70	Sand & gravel	●
	④	130~190	Lava & other volcanics	○
E-e Section	①	3~5	Limy dep.	×
	②	30~50	Weathered zone & wash out dep.	○
	③	5~14	Sand gravel clay limy dep. in alt.	△
	④	70 20	Sand & gravel	●
	⑤	140~400	Lava & other volcanics	○
E-f Section	①	15~20	Wash out dep.	×
	②	27~35	Sand & gravel	●
	③	80~130	Lava & other volcanics	○

0 1 2 3 4 5km

Fig. 4·1–8 Location map of Electoric sounding in Kahe-Miwaleni Area



Information for each section is given below.

a) E-b Section

This section is the one with the shortest interval between sounding points and the three boreholes used to obtain information for comparison of relative resistivity with geologic information on this line. The location is at the center of the Miwaleni Area.

In the area 500 m west of the eastern boreholes No. 3, high resistivity (ρ=110-130Ω-m) was recorded at 30 - 50 m, and in view of information from borehole No. 3, this formation is judged to be lava. At the 3 km area to the west, some irregularities are found at 30 - 50 m and deeper, and a formation having somewhat low resistivity (ρ= 40-90Ω-m) is distributed there. The information from boreholes No. 1 and 2 indicate that this is a gravel stratum. Further west, this gravel bed generally becomes deeper to 80 - 100 m.

The upper parts of these lava and gravel formations generally have low resistivity, and the value of ρ = 3 - 8 Ω-m corresponds to clay-rich bed. Further, a formation of the thickness of 2 - 5 m covering the surface and having a value of ρ= 7 - 5 Ω-m was found; this corresponds to weathered sand which was washed out from mountain areas. At the western parts of this section, near the Rau River, a formation where ρ = 20 Ω-m was recognized to the depth of 20 - 30 m, and at lower depths, ρ = 3 - 6 Ω-m. All of these formations are probably mostly clay but it is probable that considerable amounts of gravel are also present in the upper part.

b) E-a Section

This section is at the 600 m north of and is parallel to E-b.

In the east, A formation having ρ = 40 - 80 Ω-m was recognized at about 20 m depth of the eastern part. It is highly possible that this formation is composed of sand and gravel. In the west, this formation gradually becomes deeper, and is distributed at the depth over 100 m. The upper formation where ρ = 3 - 5 Ω-m show low resistivity and is thought to be composed at mostly clay with little amounts of sand and gravel.

c) E-c Section

This section is parallel to and 600 m north of E-b.

A formation having low resistivity (ρ= 5-7Ω-m) is present in the entire area at the depths of up to about 100 m. Almost all of it is mostly clay, and even where sand and gravel beds are present, they are probably thinly inserted between clay formations. In one part, at about 90 m in depth, a formation where ρ = 85 Ω-m is recognized; this is thought to correspond to sand and gravel bed.

d) Summary of the information on the above three sections

A formation which is regarded as sand and gravel bed is widely distributed at 30 - 50 m along the section E-b. Along the section E-a to the north, this formation is less deep of about 20 m, but its distribution is limited to be extremely narrow.

Along section E-c, the continuity of this porous bed is not very clear but it seems that it becomes as deep as nearly 1 - 0 m.

e) Section E-d

This section has north-south direction and is located east of the Miwaleni district. This section was measured to measure the resistivity of lava flow at the foot of Mt. Kilimanjaro.

The resistivity value of strata near the surface changes from the north to the south and gradually decreases, from ρ = 130 - 190 Ω-m to 3 - 5 Ω-m through 40 - 70 Ω-m. These are thought to correspond to lava flow, sand-gravel bed, clay-sand bed respectively. The boundaries between these beds gently dip toward the south. There seems to be interfingering of sand and gravel bed at the edge of the lava distributed on the side of the mountain, and that sand and gravel bed gradually passes to the bed chiefly composed of clay.

f) Section E-e

This section is oriented north-south in the Mandaka district and is located at the edge of lava flow area.

The geologic structure is about the same as that of section E-d in the Miwaleni district. To the north is a lava distribution zone where ρ = 140 - 420 Ω-m, so that resistivity is greater than it is in the Miwaleni district. Lava in this region is of scoria nature and has many voids. The high-resistivity beds at the south, although small in scale, show ρ = 70 Ω-m and may corresponds to a sand and gravel bed. Further south, as far as the neighborhood of the Rau River, practically all beds to the depth of about 100 m has low-resistivity (ρ = 5 - 7 Ω-m). This low resistivity beds are mostly clay and sand, and even if there are any gravel beds, they must be thinly intercalated within clay and sand. In the Rau River basin area to the south, a bed having ρ = 20 Ω-m is recognized from the surface to about 30 m depth; it is thought to be a sandy bed.

g) Section E-f

This section is west of E-e, oriented north-south.

At the southern end, resistivity ρ = 90 - 130 Ω-m is high at the depths of 50 - 60 m. This value may indicate the presence of lava, and there is a possibility that a portion of the lava distributed in the urban area of Moshi penetrates with the form of a tongue within this area (E-61, E-62). The upper part of that which seems to be lava has a resistivity of 300 Ω-m, and, although there may not be much gravel, may be a sand and gravel bed. This high resistivity bed becomes thicker toward the north. The northern end of this section is near the mountain, but no lava-like formation is recognized and there is occupied by mostly clay and sand became of low resistivity (ρ=13-15Ω-m).

h) Summary of soundings in the region of lava distribution

The sounding sections related to the area where lava is distributed near the surface are E-d, E-e and E-f. In addition to these, the resistivity of the lava zone of the upper regions of the Njoro Spring were measured (E-64); the average value for ρ was 255 Ω-m. Resistivity values for lava in the environs of this region vary somewhat from point to point due to the differences in the type of lava rocks and to the influence of other type of bed intercalated with it, but for the most part ρ = 100 - 400 Ω-m.

It must be noted that in the environs of the boundary of the foot of the mountain sand and gravel beds are developed at the edge of lava.

2. Hydrogeological Structure

The hydrogeological structure of the area has been determined as a result of electrical soundings, geological field surveys and study of information collected in Tanzania as shown by sections A, B and C in Fig. 4.-1.

As the characteristic of this region's hydrogeological structure, it is noted that, in the Kilimanjaro range, there is a large-scale alluvial sedimentaly basin. This basin is filled with deposits of clay, sand, sand and gravel, and limy clay, etc., which present a complicated geologic structure in which Kilimanjaro volcanic rocks are intercalated within the deposits.

The base of this structural basin is Precambrian gneiss, which is distributed at the depths exceeding 200 m in the area studied and becomes deeply buried from the environs of Nyumba ya Mungu along the Pangani River at the north.

The east and west of the basin are limited by faults as is observed in section C. The region thus comprises the structural basin between the two mountain ranges, and almost all of the river systems which obtain water on Mt. Kilimanjaro flow into this basin and become to the Pangani River in the south of the basin.

Electric resistivity values, roughly though, indicate the depth and thickness of coarse-grained and fine-grained beds forming the alluvium deposits. However, horizontal continuity and stratigraphical correlation of these alluvium beds at different localities or lines have not been fully clarified by electric resistivity measurements.

The size of gravel in the Miwaleni environs is generally relatively small (1-3cm) and flat, but, along the river of the volcano range, much larger volcanic-origin gravels (10-20cm) of round to oval shape constitute alluvial fan deposits. Such fan deposits are characteristically well distributed near the boundary of volcanic mountain and alluvial basin deposit area.

Volcanic rocks of the Kilimanjaro volcano in the northern part of the basin are oriented east-west which is the direction of the peak's elongation, and Kibo's most recent lava flow was primarily on the south and on the north flanks. Volcanic rocks related to the basin comprise Kibo lava, Mawenzi lava, lava thought to be older than both of these, as well as pyroclastics, and in particular the old volcanic rocks, in addition to forming the framework of Kilimanjaro, are presumed to be distributed in the deep portion of the structural basin.

Therefore, the geologic factors related to the formation of the plains of the Kahe-Miwaleni Area related to the volcanic activity, the deposition of alluvial deposits, and the tectogenesis to form the Rift Valley must be quite complicated.

4.1.4 Hydrogelogy

1. Mode of Occurrence of Groundwater

Hydrogeologically, the base of the Kahe-Miwaleni Area is Precambrian gneiss and granulite, both of which are impermeable rocks. In view of this structure of the base rock, it is judged that the Kahe-Miwaleni structural sedimental basin, with regard to sub-surface hydrology, forms a groundwater basin. The groundwater basin is covered by recent alluvial deposits of clay, sand and gravel, and lavas. All of these recent deposits are unsolidified formations which correspond to the strata in which groundwater occurs. The lavas came from Kilimanjaro Volcano have many cracks and play the role of nice aquifers.

Hydrological characteristics of this area are the semi-arid zone designated as stepps, annual precipitation of the order of 650 mm, and evaporation exceeding precipitation. While the western and eastern parts of the region are mountains of 1,500 to 2,000 m, they too have also the same climatic conditions, and the south is a plain which is a part of the stepps of the Pangani River basin. To the north of the area is Mt. Kilimanjaro (el. 5,895m) the summit of which is perpetually covered with snow. In the middle zone of the mountain is the Forest Zone. The southern flank of the mountain receives heavy rainfall and the natural environment of the intermediate zone between the Forest Zone and the plains is favorable and land usage, especially for agriculture, is advanced. Almost all of the swamps and valleys which dissect the southern slope of the mountain drain or flow into the Kahe-Miwaleni groundwater basin. There are three major river systems, of which the Mua River system, east of the basin, shows no surface flow during the dry season, while the Rau River has almost no surface flow from upstream into the groundwater basin, and its surface flow in the plains is dependent on water from springs. The volume of water is greatest in the Kiluketwa River. If these characteristics of the river systems are compared to the geology, it can be said that the Kikuletwa River having an abundant volume of water has as its catchment area in Kibo which is Kilimanjaro's highest peak and the southern side of Shira. Especially, the Karanga and Weruweru Rivers flow over Kibo lava. The Rau River, which flows on the eastern part of the Kibo lava flow, has some volume of surface water, although this volume is lower than compared to the Kikuletwa River. The catchment areas of the eastern flank of the Rau River and the river system of the Mua which has no surface flow, consist of greatly weathered lava, or pyroclastics etc. Regarding these river systems from the viewpoint of the relation to geology, it must be considered that rivers flowing over the relatively hard, dense, porphyry lavas of Kibo in which relatively little water infiltrates have the surface water whereas in the case of rivers such as the Mua having catchment areas of a highly permeable base of weathered lava and pyroclastics with many voids, rain and surface water easily infiltrate into the ground and little surface flow can be observed. These hydrogeological differences can be observed along the national highway in the area of Moshi.

When we consider the above-noted hydrological environment, it is easily said that the area of recharge of groundwater is limited to the southern flank of Mt. Kilimanjaro, especially to the area where weathered lava and pyroclastics are distributed between Kibo and Mawenzi. This area shows greater dissection than the fresh Kibo lava area. Regarding the rainfall, there is a data of over 1,500 mm/year at the side-slope of Mt. Kilimanjaro and moreover the rainfall must

Fig. 4.1-9 Hydrogeological Map of KaHe-Miwaleni Area

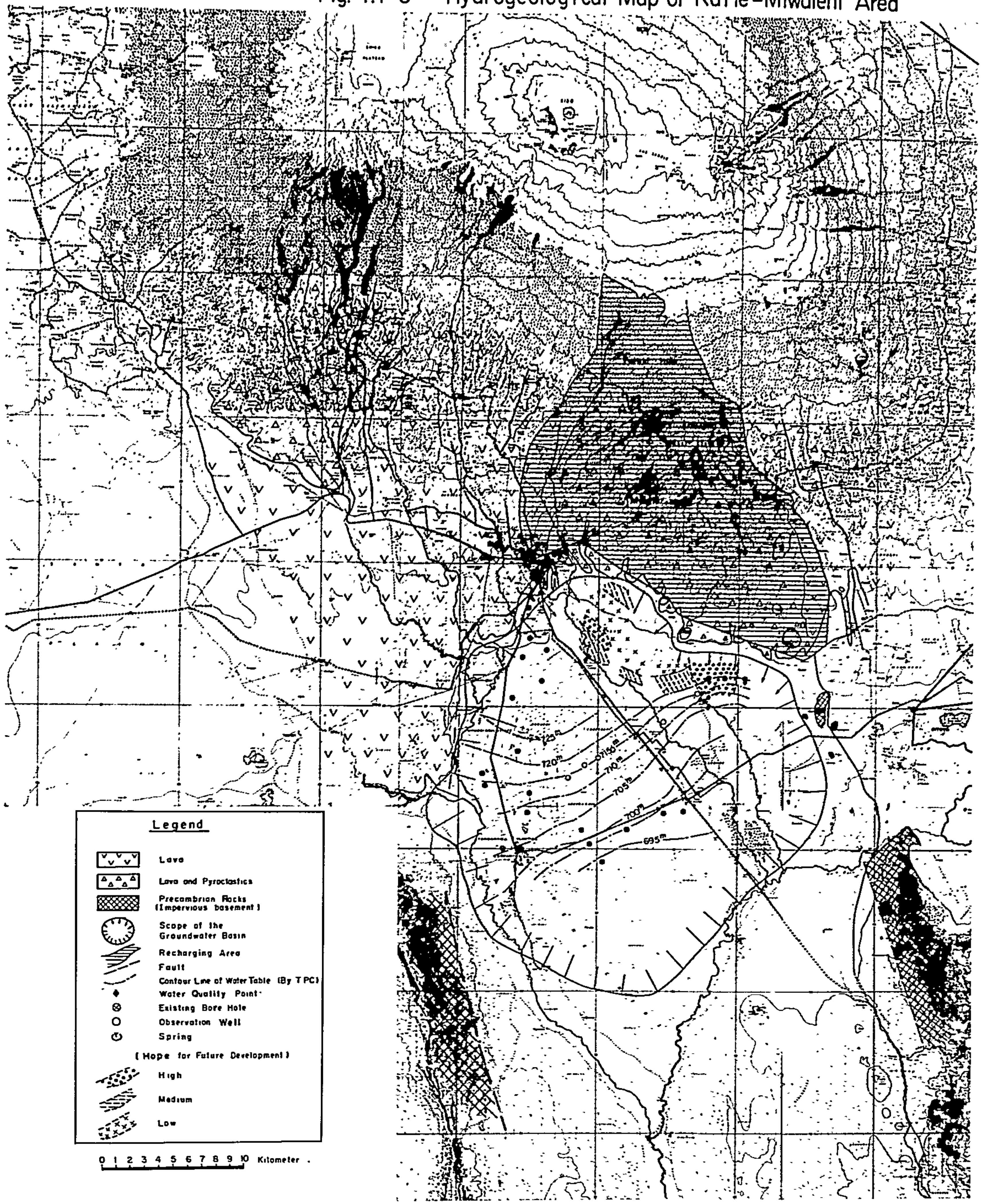
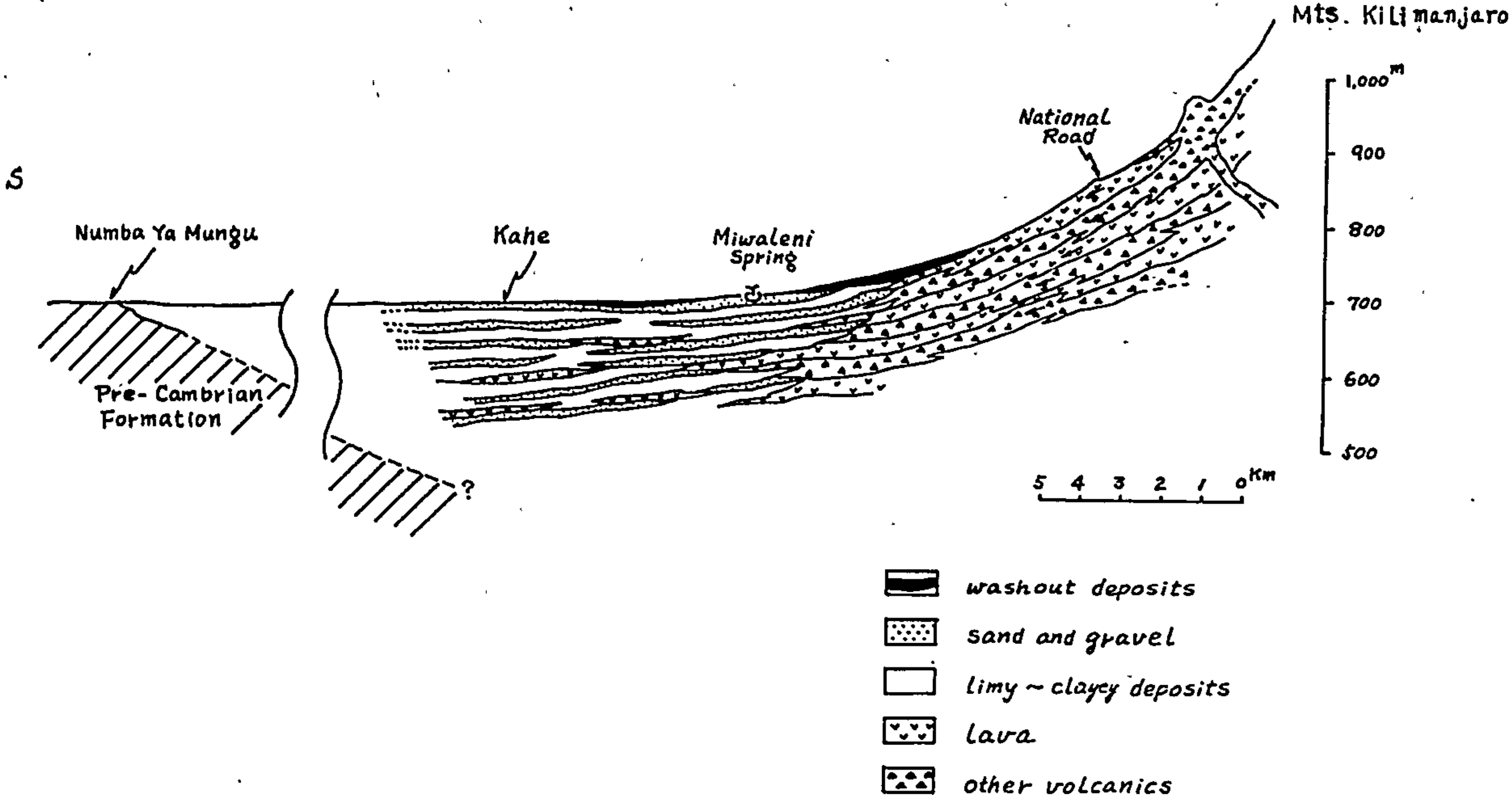


Fig. 4.1-10 Schematic Hydrogeological Cross Section of the Kahe-Miwaleni Basin.



be greater in the Forest Zone. Water which has permeated into the ground from the Forest Zone and 1,000 to 1,500 m high intermediate zone must come to the alluvial deposits through the cracks of lavas.

The mechanism whereby groundwater is formed may be analogized by the Njoro Spring in the suburbs of Moshi and the spring within the prison at Moshi, which appear at the edges of lava flow. Sub-surface hydrology may be summarized as in Fig. 4.1-9 which is a hydrogeological map of the Kahe-Miwaleni Area, and Fig. 4.1-10 which is a schematic profile of the Kahe-Miwaleni basin.

As is indicated in the schematic profile, various aquifers are recognized, of which sand and gravel formations are the best aquifers. The springs in the Moshi environs and the flowing water at borehole No. 3 indicate that lava having may play as an aquifer, even though the lava flow seems not to be a major aquifer. It is nevertheless clear that in this area the high mountain area which is lava is very important as recharging area of groundwater. From these points, if there is a sand and gravel beds, especially of large scale and in contact with lava, conditions are favorable for the occurrence of groundwater. The results of electrical soundings attest to the presence of relatively large sand and gravel beds from the eastern part of the Miwaleni and the Mandaka along the Rau River. These beds are in contact with lava and are good aquifers. In Miwaleni in particular there is the large Miwaleni Spring in the south, and it is thought this spring is an overflow from a part of a large sand and gravel beds in the northern part. The water level contour of the groundwater in the Miwaleni Springs environs, according to existing data, the flow of groundwater from east and west is suggested. It is very probable that the structure of the broadly distributed sand and gravel beds bears a strong relationship to the formation of the Miwaleni Spring pool.

Further, it was found to be just under 4 m from Borehole No. 1 in Miwaleni and other information indicates that the elevation of the water level in this area is near the surface and is confined water.

Groundwater development has already been begun in Kahe and Arusha Chini, and observation of the elevation of the groundwater level is being carried out on an-going basis, with consideration the influence of the Miwaleni Spring.

In the Kahe-Miwaleni Area, good aquifers primarily composed of sand and gravel beds are distributed at the depths of up to 100 m, and the use of the land for cultivation; by the use of groundwater is advanced in the west and south region. It is thought that there is also a favorable occurrence of groundwater in the survey region, and it is anticipated that it may be beneficially developed in the future.

2. Current Situation of Groundwater Utilization

With regard to overall water usage in the area including the southern flank of Mt. Kilimanjaro and the urban area of Moshi, it may be noted that Mt. Kilimanjaro swamp water is being used for agriculture on the south flank of the mountain and some is being diverted to dams and channels for use as drinking water, all being so effectively used that hardly any water flows further downstream.

Table 4.1-6 List of Existing Well

Kahe - Miwaleni Area

Location	Locality	Depth	Yield	Amounts of Groundwater	Columnar Section	Condition of Aquifer
1	Miwaleni	67.1 m	104 m^3/h	832 m^3/d	o	
2	Miwaleni	74.7	0	0	o	
3	Miwaleni	59.5	0	0	o	
4	T.P.C.	91.5			o	
5	T.P.C.	91.5			o	
6	T.P.C.	97.6	255	2,040	o	
7	T.P.C.	91.5			o	
8	T.P.C.	91.5	255	2,040	o	
9	T.P.C.		0	0	o	
10	T.P.C.		510	4,080	x	Dry hole
11	T.P.C.				x	
12	T.P.C.		611	4,888	x	
13	T.P.C.		765	6,120	x	
14	T.P.C.		611	4,888	x	
15	T.P.C.		510	4,080	x	
16	T.P.C.		550	4,400	x	
17	T.P.C.		510	4,080	x	
18	T.P.C.		204	1,632	x	
19	T.P.C.		357	2,856	x	
20	Kahe	54.9	173	1,384	o	
21	Kahe	54.9	100	800	o	
22	Kahe	61.0	100	800	o	
23	T.P.C.	30.0	0	0	o	Observation hole
24	T.P.C.	30.0	0	0	o	Observation hole
25	T.P.C.	30.0	0	0	o	Observation hole
26	T.P.C.	30.0	0	0	o	Observation hole
27	T.P.C.	30.0	0	0	o	Observation hole
28	T.P.C.	30.0	0	0	o	Observation hole

In the Kahe-Miwaleni Area, the utilization of water is particularly outstanding at TPC in Arusha Chini, and there is also some usage at the Kahe Estate and Miwaleni farms. The groundwater, in addition to water from Miwaleni Spring and the surface flow of the Kikuletwa River, is used for this agricultural water.

The survey of the present time discloses that most of this groundwater is being pumped from the depth of 100 m of the Kahe-Miwaleni alluvial basin. Table 4.1-6 which gives the yields, amounts of groundwater and other information is summarized from existing information. TPC makes the greatest use of groundwater of about 1.5 m^3/sec, and 41,000 m^3/day.

Miwaleni has three wells, but only one is in use. The amount of water used at present is judged to be about 1,080 m^3/d. At Kahe about 3,000 m^3/d is being pumped from three wells, and it is thought that for the Kahe-Miwaleni Area as a whole the amount of groundwater for use is about 45,000 m^3/d. Information furnished by TPC gives extremely high figures, and judging from data from pumping tests at wells and other reports, (see references 3 and 5), it is thought that those figures exaggerate reality.

3. Pumping Tests

Pumping tests were performed at well No. 1 in Miwaleni; construction at the other two prevented tests there. There is no observation well. Tests performed were quantitative tests and step drawdown tests.

For the tests, the triangular notch in place was used to measure the discharge by the conversion the 100° angle notch to 90° using an H-Q curve (see reference No. 5).

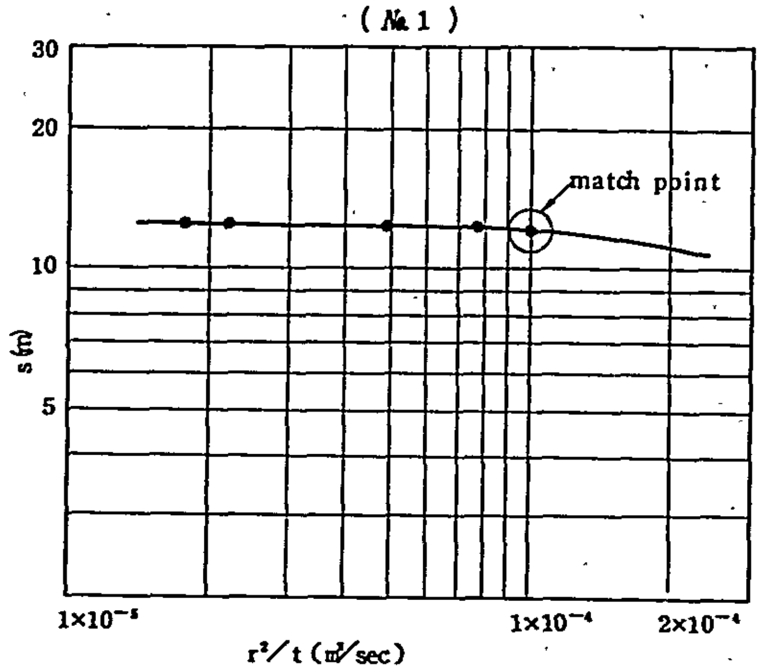
(Quantitative Tests)

Quantitative tests were performed with the well discharge of Q = 0.0234 m^3/sec. The coefficient of transmissability was sought by applying the nonequilibrium equation of Theis.

From the records of the tests and calculation which are shown in Annex 6 and 7, the relationship s - r^2/t was made.

From the graph in Fig. 4.1-11 and the W(u)-u standard curve, the following values were obtained as matching points.

Fig. 4.1-11 S - r^2/T



s = 12.0 $r^2/t = 1.0 \times 10^{-4}$

W(u) = 11.0 $u = 1.2 \times 10^{-5}$

These values were used in the Theis equation to calculate the coefficient of transmissability.

$$T = \frac{Q}{4 \cdot \pi \cdot s} W(u) \quad \ldots\ldots\ldots \text{(1) [Theis equation]}$$

T = coefficient of transmissibility
Q = well discharge (m^3/sec)
W(u) = well function
s = drawdown

From Equation (1).

$Q = 0.0234$ m^3/sec, $s = 12.0$ m, and
$W(u) = 11.0$, so that $T = 1.70 \times 10^{-3}$ m^2/sec

From this coefficient of transmissability the coefficient of storage is sought.

$$S = 4 \cdot u \cdot T \cdot t/r^2$$

Here

$T = 1.70 \times 10^{-3}$ m^2/sec, $t/r^2 = \frac{1}{1.0 \times 10^{-4}}$ sec/m^2
and
$S = 8.16 \times 10^{-4}$

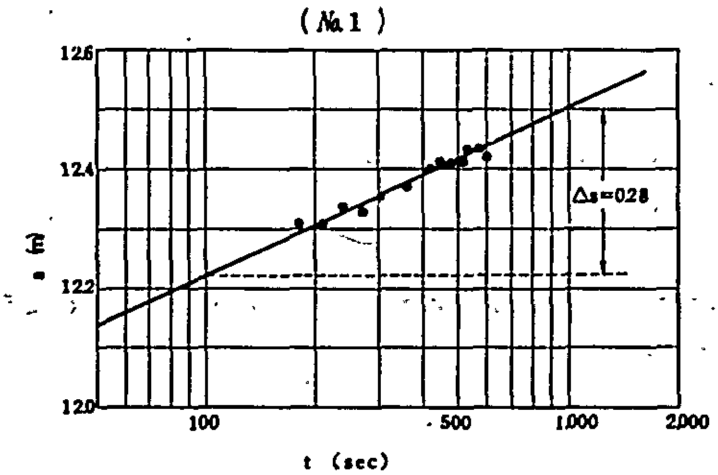
Concerning the coefficient of storage, S, must be excessively low, and does not adequately represent reality, because the observation well was not used.

Further, the coefficient of transmissability was calculated by the Jacob's method as follows:

$$T = \frac{2.30\ Q}{4 \cdot \pi \cdot \Delta s}$$

Fig. 4.1-12 is a graph showing the relationship between the continuous pumping time (t), and drawdown (3). From this we may obtain 0.28 m as the value of Δ s.

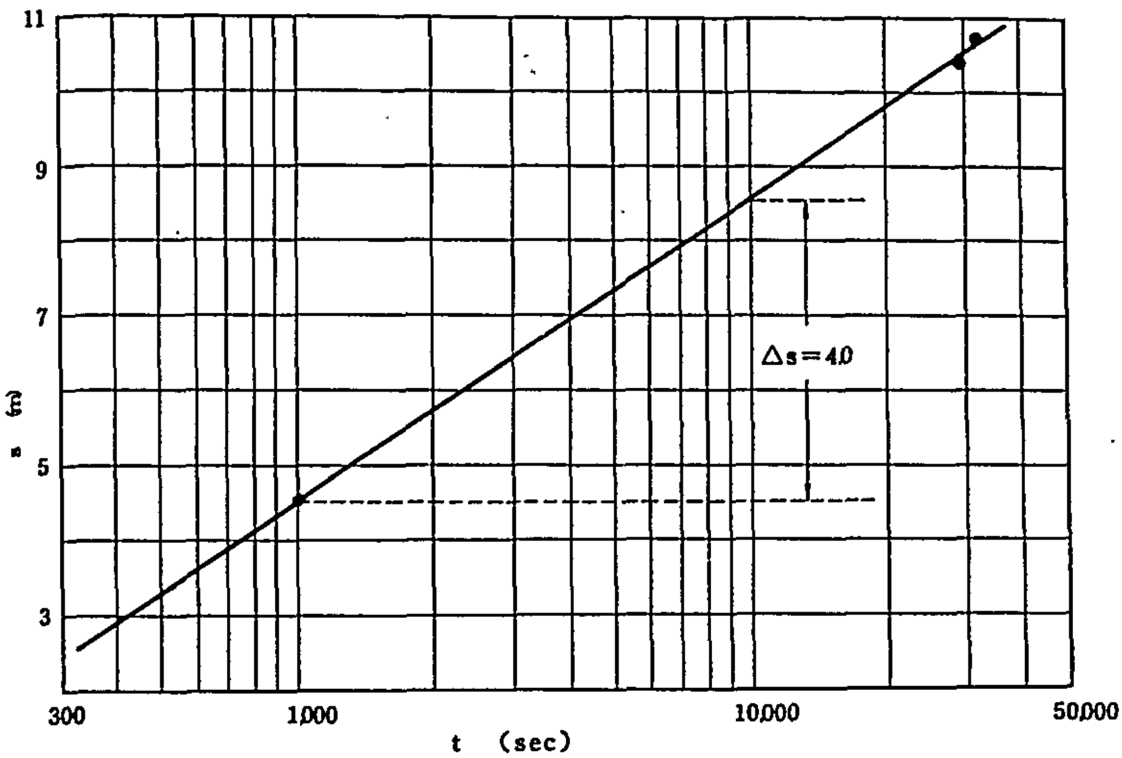
Fig. 4.1-12 s - t



Therefore, $T = 1.53 \times 10^{-2}\ m^2/sec$

The value thus obtained by the Theis solution is 1.70×10^{-2} m^2/sec, while that obtained by the Jacob solution is $1.53 \times 10^{-2}\ m^2/sec$. For reference purpose the aquifer conditions of other wells were also calculated by past data using the Jacob solution as follows:

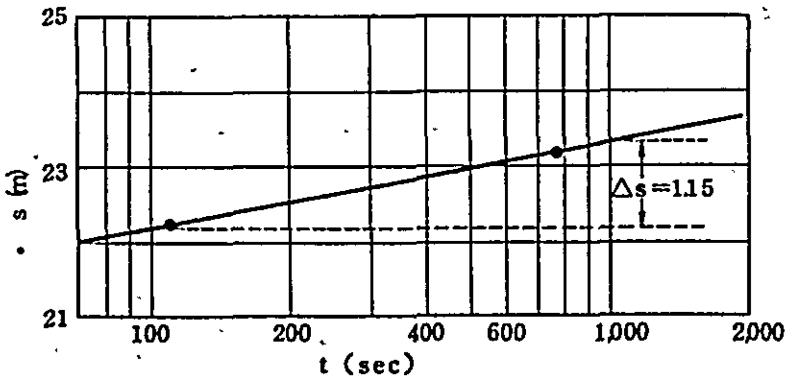
Fig. 4.1-13 s-t (Bore Hole No. 2)



At No. 2, from the graph in Fig. 4.1-13, $\Delta s = 4.0$, at which time well discharge Q is 0.0273 m^3/sec, so that

$$T_2 = 1.25 \times 10^{-3} \ m^2/sec$$

Fig. 4.1-14 s-t
(Bore Hole No. 3)



At No. 3, from the graph in Fig. 4.1-14, $\Delta s = 1.15$, $Q = 0.0218\ m^3/sec$ and therefore

$$T_3 = 3.46 \times 10^{-3}\ m^2/sec$$

Both T_2 and T_3 are $\alpha \times 10^{-3}\ m^2/sec$. Judging from the geological data, it is presumed that represents an aquifer of No. 3 is in the fissures of basaltic rock.

No. 2 may represent the groundwater in sand, or in gravel bed as in the case of No. 1. Probably water in No. 2 is being obtained from the same sort of aquifer as in No. 1.

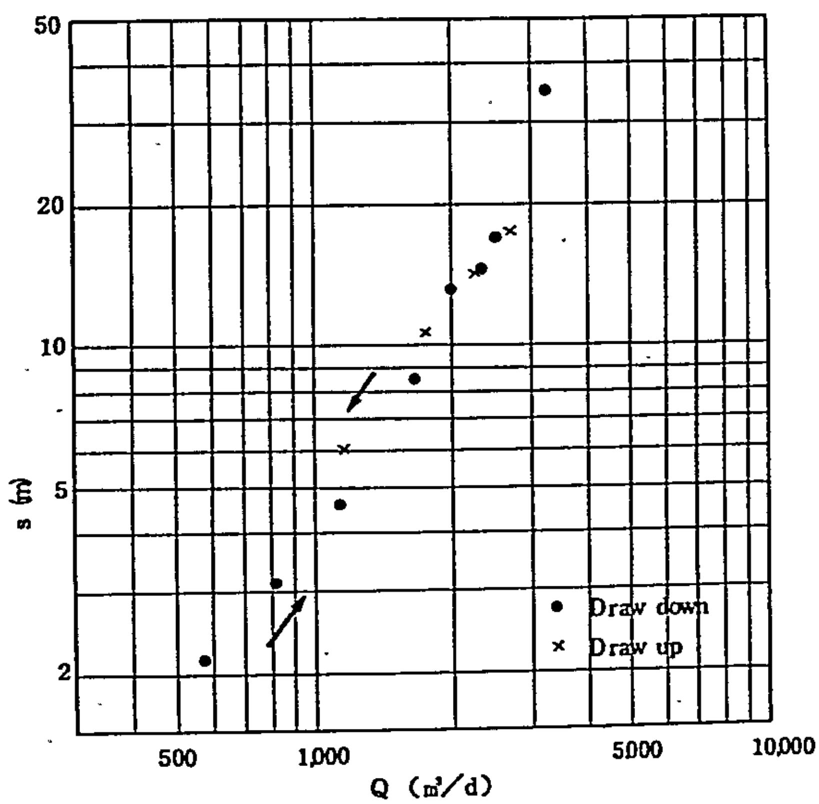
Judging from the results of the field study of the size of the sand and gravel, it is thought suitable that the coefficient of transmissibility be taken as $T = 1.70 \times 10^{-3}$ m^2/sec in the case No. 1 and No. 2.

(Step Drawdown Tests)

With the purpose to establish the relationship between pumping discharge and drawdown, step drawdown tests were carried out over a two-day period. Drawdown tests were in eight steps and until the hydraulic level was stabilized the level was observed for one hour after each step of pumping. The results (see Fig. 4.1-15) are that at discharge $Q = 2{,}700\ m^3/d$ (31 liters/sec) drawdown was 17.5 m; at $Q = 3{,}100\ m^3/d$ (36 liters/sec) drawdown greatly increased, to 33 m. Therefore 2,700 to 3,100 m^3/d is judged to be the critical discharge value, and the optimum yield, as judged from the graph in Fig. 4.1-15, is 2,500 m^3/d (29 liters/sec) or less.

Fig. 4.1-15 S-Q

(No. 1)



It is frequently thought that the advisable discharge should be 80% of critical discharge. However, it must be noted that such recommendation should not be immediately given without consideration regarding the diameter of the well, the duration of continuous pumping, the distance between wells the number of wells and sub-surface hydrological conditions. The final pumping plan should be made up considering the above noted whole conditions.

4. Water Quality Tests

Results of water quality tests, primarily consisting of electric conductivity tests results, are given in Table 4.1-7 and 4.1-8.

Table 4.1-8 Water Quality for Different Types of Water

Type of Water Outcrop	Classification	Water Temperature	PH	Electric Conductivity	Notes
Surface Water	Rivers	15.7-22.4°C	-	77-335 μν/cm at 25°C	
	Dam	22.1		27	
Groundwater	Deep well	22.5-24.7	7.2	382-389	
	Shallow well	-	7.0	238	
Springs	Kibo lava	18.2-19.5	7.0	115-146	
	Alluvial	21.2-23.5	7.0 -7.6	220-928	High values for PH(7.6) and conductivity (928) are due to limy deposits

Table 4・1−7 Measurement of Water Quality

No.	Location	Kind of Water	Water Temperature(℃)	Electric Conductivity(μ℧/cm)		pH	Salinity Cl'(ppm)	General Geology
				Measurement	at 25℃			
A	Rau River	River	20.2	185	204	7.2	—	
B	Rau Sugar Estate	Well(shallow)	28.0	252	238	7.0	—	Alluvial
C	Kahe Irr. Scheme Canal	River	21.2	310	335	7.4	—	
D	Mua River	River	22.4	324	342	7.2	—	
E	Njoro Spring	Spring	18.2	99	115	7.0	—	Kibo Lava
F	Njoro River	River	19.1	100	113	7.0	—	
G	Miwaleni B・H No.3	Well	24.7	380	382	7.2	—	
H	Miwaleni B・H No.1	Well	22.5	370	389	7.2	12.4	
I	Moshi Hotel	Water Supply	21.0	139	151	7.0	—	
J	Miwaleni Springs	Spring	21.2	203	220	7.0	10.6	Pebble
K	Kahe Irr. Scheme Intake	River	22.0	310	330	7.2	10.6	
L	Miwaleni Springs	Spring	22.2	390	413	—	12.4	Pebble
M	Miwaleni Springs	Spring	23.5	900	928	7.6	124.1	Limy deposits
N	Prison Spring	Spring	19.5	130	146	—	—	Kibo Lava
O	Nanga River(Upstreem)	River	15.7	63	77	—	—	Pyroclastics
P	Mworoworo Dam	Dam	22.1	25	27	—	—	—do—

The temperature of surface water, with the exception of upstream waters in valleys, is 20 - 22°C. The temperature of the water of the Miwaleni deep well, 22 - 24°C, is high, and the springs in the Moshi suburbs which have Kibo lava as mother rock are low, at 18 - 19°C, while the Miwaleni Spring is 21 - 23°C.

In regard to electric conductivity, low values of 27 - 77 μν/cm were obtained for surface water, upstream, while at almost all places downstream in the plains the values are 200 or greater. Concerning groundwater, the Miwaleni well yielded a value of 380 μν/cm, which is considerably high in comparison to the Moshi Spring and other sites. Among the springs, values in the suburbs of Moshi where the mother rock is Kibo lava are low, but the values obtained at Miwaleni Spring, 220 - 400, are thought to be typical. Water of a spring having its origin in a limy deposits is so high as 928 μν/cm and PH is also characteristically high (7.6).

For reference, Table 4.1-9 gives results of water quality tests at TPC wells.

Table 4.1-9 Water Analysis of T.P.C. Well

Item		Kiyungi No. 1	Kiyungi No. 3	Remarks
PH		8.2	7.3	
Conductivity	μν/cm	522	110	
Ca ++	ppm	Tr	Tr	
K +	ppm	23	13	
Na +	ppm	65	42	
SO_4 ++	ppm	Tr	Tr	

Regarding the quality of groundwater in the southern Kilimanjaro range, it may be said that the temperature of spring water having lava as its mother rock is low and the electric conductivity is also low, making the water good in quality. However, if comparison is made with the water of springs such as at Miwaleni which have alluvial deposits as the mother rock, it is found that in the latter case the temperature and conductivity are both somewhat high. Further, the groundwater which has as its major aquifer alluvial deposits has almost the same temperature and conductivity as the Miwaleni Spring water. Probably, the groundwaters in alluvium deposits change their characters by permeating through alluvial deposits from recharging areas of lava and volcanic rocks.

5. Quantitative Evaluation of Groundwater Refill

The following is a general consideration of the groundwater balance of the Kahe-Miwaleni Area alluvial basin.

From the viewpoint of hydrogeologic structure, the rain fall on the southern flank of Mt. Kilimanjaro is the most important source of the groundwater in this area. In the environs of the groundwater basin in the semi-arid zone, annual rainfall is only about 650 mm, and evaporation greatly exceeds this, so that the direct supply of groundwater from the rain in the Same area is not possible. Regarding surface water, there is almost no flow in whole stream of the Mua River during the dry season, and the water of the river came directly from springs even in downstream. The Kikuletwa River is the westernmost in the Kahe-Miwaleni alluvial basin, but taking the entire basin macroscopically it may be said that the recharge from river-bed water of these rivers can not be expected. The recharge of groundwater in this basin must take place basically in the mountainious areas.

In the area of eastern and western sides of the basin having a hard and impermeable Precambrian rocks, season rainfall is low. However annual rainfall is heaviest in the intermediate zone of Mt. Kilimanjaro, north of the basin (see Tables 4.1-2 and 4.1-3). Mt. Kilimanjaro is compressed of lava, agglomerate and pyroclastics.

Older pyroclastics and lava have suffered weathering making them permeable and thereby forming a valuable recharging area. In the Kibo lava flow, the groundwater move through cracks in the lava, although the permeation is not thought to be as great as in the former case. There is a Forest Zone on the side of the Kilimanjaro. The Forest Zone should be considered to be the most important recharging area. Almost all groundwater in the Kahe-Miwaleni Area must have been originated from the Forest Zone on the southern flank of Mt. Kilimanjaro.

The following equation is ordinarily used to derive the annual amount of recharging with consideration of groundwater balance.

$$Q_R = \{P - (D + E)\} \times A_R$$

where

Q_R = Volume of recharge as groundwater (volume peameating to below the surface)

P = Volume of precipitation

D = Volume of run-off

E = Volume of evaporation

A_R = Area of recharging region

In order to determine the volume of groundwater which can be expected to be supplied to the Kahe-Miwaleni Area from the southern flank of Mt. Kilimanjaro by means of equation (1), the values of P, D and E are calculated by the technique given in above noted Section 4.1.2.

The volumes of rainfall are as follows:

Forest Zone	2,000 mm/year
Intermediate Zone	1,500 mm/year

The volume of run-off, D, can be calculated as follows, using the coefficient of run-off for the Forest Zone (C=0.10) and of the intermediate zone (C=0.15).

Forest Zone	200 mm/year (2,000x0.10)
Intermediate Zone	225 mm/year (1,500x0.15)

Evaporations in the Forest Zone and the intermediate zone are 700 mm/year, and 860 mm/year respectively. 70% of these figures are used for E:

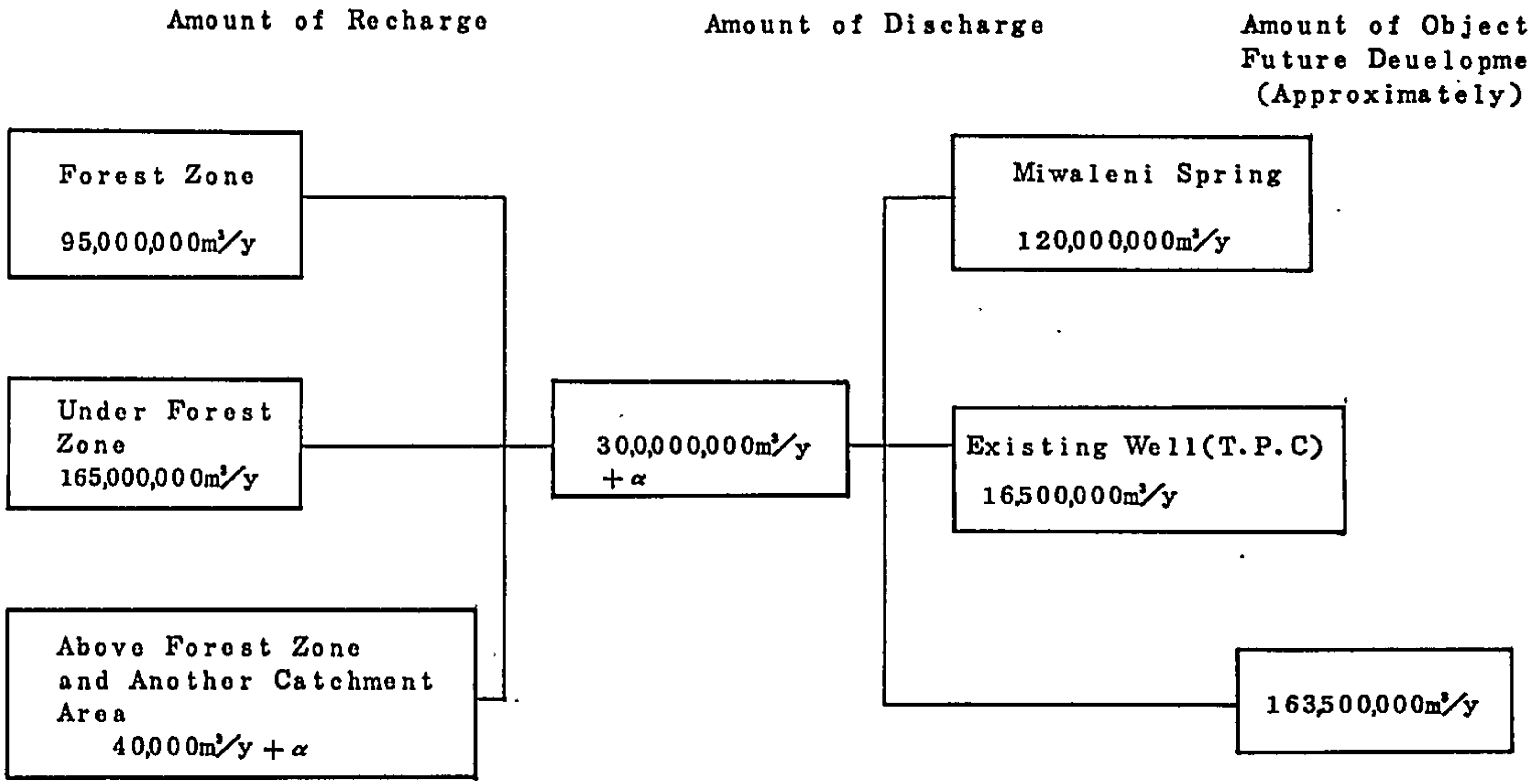
Forest Zone	490 mm/year
Intermediate Zone	600 mm/year

The calculated results in the Rau and Mua River systems on the basis of these values are as given in Table 4.1-10.

Table 4.1-10 Calculation of Recharging of Groundwater

Recharging Area	Area A_R (km^2)	Rainfall P (mm/y)	Run-off D (mm/y)	Evaporation E (mm/y)	Permeation G (mm/y) G=P-(D+E)	Volume of Recharging Q m^3/y $Q=A_R \times G$
Forest Zone	72	2,000	200	490	1,310	$94,320x10^3$
Intermediate Zone	245	1,500	225	600	675	$165,375x10^3$
						$259,695x10^3$

Fig 4.1 − 16 Groundwater Balance of
The KAHE ~ MIWALENI Basin



Thus calculated minimum volume of recharged groundwater is 260,000,000 m^3. However, it is thought that there is some permeation to this area through cracks in rocks in Shira and pre-Shira lava and pyroclastics distributed below the Kibo lava. Moreover, the upstream region of the Kikuletwa, is also the area of high permeability. The recharging from these sources can be estimated to be 40,000,000 m^3. Therefore, adding these volumes and water which may be acquired from the Rau and Mua Rivers, the total volume of recharging of groundwater in the whole region of this basin can be expected to be 300,000,000 m^3.

Pumping up from wells by TPC, in addition to natural flow out from Miwaleni Spring water is the major run off from the Kahe-Miwaleni groundwater basin.

The groundwater balance for the region, including the mean annual flow of 3.78 m^3/sec for the Miwaleni Spring (see 4.1.2) and the utilization of groundwater of the order of 45,000 m^3/day (see 4.14) is as in Fig. 4.1-16.

Thus, the utilization and run-off of groundwater in the Kahe-Miwaleni Area seems to be about 50% of the rechargeable groundwater volume. It must be kept in mind, however, that this is only an approximation and was made without reliable data of rainfall and evaporation in the Forest Zone. It is urgently necessary to examine this value on the basis of really recorded functions.

6. Pumping Conditions and Area of Influence

Conditions related to pumping at all wells in the Kilimanjaro Region are summarized in Table 4.1-11; the location of the wells are given in Fig. 4.1-17.

It may be seen from this table that the conditions are much better in the Kahe-Miwaleni Area than in other areas of Kilimanjaro Region, such as the eastern range of the Kilimanjaro, the Same Area in the North Pare Mts. and the Mkomazi Area on the east flank of the South Pare Mts.

In the groundwater basin of the Kahe-Miwaleni Area, there are many wells with the specific capacity of about 200 m^3/D/m. It is possible to pump 2,000 m^3/day in some parts of much better groundwater conditions. In other areas, however, the specific capacity is low and barely reaches 200 m^3/day. Therefore, it is only the Kahe-Miwaleni Area where a large-scale pumping program may be carried out.

Below is a consideration of the pumping conditions and area of influence in the Miwaleni, using the results of pumping tests.

A = 29 liters/sec (economic marginal discharge as obtained by step tests)

$T = 1.70 \times 10^{-3}$ m^2/sec

$S = 8.16 \times 10^{-4}$

Q = discharge; T = coefficient of transmissibility;
S = storage coefficient

This value for S differs from that obtained by drawdown tests, and does not match actual conditions because it is a calculated value obtained without use of an observation well. S, therefore, can be calculated by the Theis equation using measured values of discharge (Q) and drawdown (S) as follows:

$T = 1.70 \times 10^{-3}$ m^2/sec

$Q = 0.0234$ m^3/sec (actual observation)

$s = 12.50$ m (actual observation)

$t = 43.200$ sec

with s = drawdown and t = time of continuous pumping

From the above, S value derived from the well function W(w) which is calculated by the above noted functions is as follows:

$S = 1.10 \times 10^{-1}$

The storage coefficient of $S = 1.10 \times 10^{-1}$ is acceptable because the well's aquifer is a sand and gravel beds.

If the pumping conditions as follows; s and u values can be calculated as shown by (1) and (2).

$Q = 1,880$ m^3/day/well (18 hrs/day of operation, unit discharge, 29 liters/sec)

$T = 147$ m^2/day ($1,70 \times 10^{-3}$ m^2/sec x 86,000 sec)

$S = 1.10 \times 10^{-1}$

$$s = \frac{Q}{4\pi \cdot T} W(u) = 1,018W(w) \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$u = \frac{S\, r^2}{4 \cdot T \cdot \pi} = 1.87 \times 10^{-4} \cdot \frac{r^2}{t} \quad \ldots\ldots \quad (2)$$

Using five steps (1 day, 30 days, 60 days, 90 days and 180 days) for t in equation (1) and (2), the relationship between the interval between wells (r) and drawdown (s) is obtained as shown by Table 4.1-12 and Fig. 4.1-18.

It is probable to think from Fig. 4.1-18 that when drawdown is 1,880 m^3/d, the area of influence is 600 m to 1,000 m.

When this pumping condition of 1,880 m^3/d is used for planning agricultural water supply in the Miwaleni, and 800 ha are to be irrigated with water at 0.5 m^3/sec, it would be necessary to have 23 wells of 70 - 80 m depth and with diameters of 250 mm. At this time, the interval between these wells should be at least 600 m. For the discharge of 1,500 m^3/d, 29 wells the interval of which is 525 m is measuring

Therefore when operation is continued for 60 days (two months) it is possible to pump up 1,880 m^3 per day. However, it must be noted that this calculation was done in the case of quite favorable aquifer conditions. Moreover, by the lack of observatioln well, the accuracy is not as high as is desired. It is dangerous to think that pumping conditions and the number of aquifers are the same as for No. 1. Above noted pumping conditions-should represent the most favorable conditions to be encountered.

Pumping conditions calculated above are not considered to represent whole part of the area under study because of the limitations of the accuracy of the tests, the location of the tests, and other reasons. It is now necessary to conduct pumping tests for groundwater in lava as well as in gravel areas where low resistivity values were obtained, and to compare these with the results of electrical sounding and also to determine the hydrological characters of aquifers by means of pumping tests accompanied by the use of observation wells just like the Miwaleni No. 1 well. Final plan of the groundwater utilization should be made after such detailed tests are completed.

Fig. 4·1-17 Location Map of Existing Well in Kilimanjaro Region

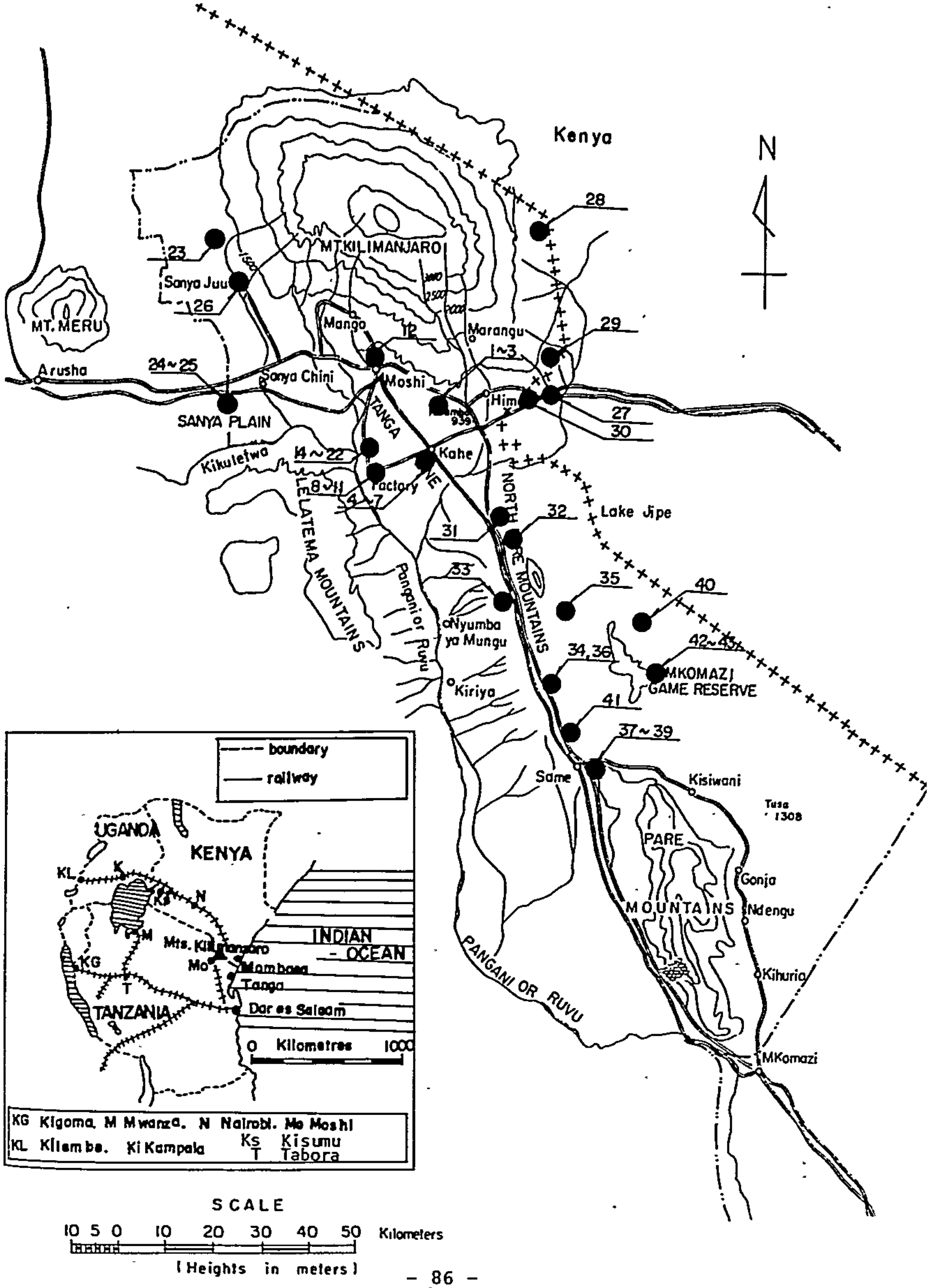


Table 4.1-11 Existing Well of Kilikanjaro Region

Location	BH No.	Locality: Area	Locality: Locality	Depth	W.S.	Water Level	Draw Down	Yield	Specific Capacity	Qualit etc.
				m	m	m	m	m^3/h		
1	36/34	Kahe-Miwaleni	Miwaleni	60.0	23-35 35-open	3.7	12.5	104	199	good
2	27/65		"	74.0	14,36 55,67	8.0	15.0	120.4	192	"
3	29/65		"	67	22.5-50	2.1	25	94.4	90	"
4	8/65		Kahe	61	9.15	7.93	10.68	100.32	225	"
5	12/65		"	53	9.15	6.89	10.98	100.32	219	"
6	22/65		"	55	7.63	6.41		173.8		"
7	31/71		"	61		4.30		12.77		"
8	21/72		Arusha Chini	91.5	4.90	1.40		22.2		"
9	249/73		"	91.5	1.80	0.92		12.62		"
10	47/70		"	161.7	2.1	2.9		161.70		"
11	52/71		"	87	4.6	5.5		-		"
12	/51	Moshi	Moshi	69.2	6.10	3.97		7.11		"
13	126/71		Tanzanite Mine Moshi	213.5	178	63.7		0.046		
14	146/72	Arusha Chini	T.P.C.	97.6		1.4	3.8	22.2	140	"
15	8/71		"	91.5		3.3		not tested		
16	80/70		"	30.5		0.61		"		
17	260/73		"	91.5		0.98		10.03		
18	202/73		"	91.5		4.70		10.14		
19	201/73		"	91.5		1.0		12.62		

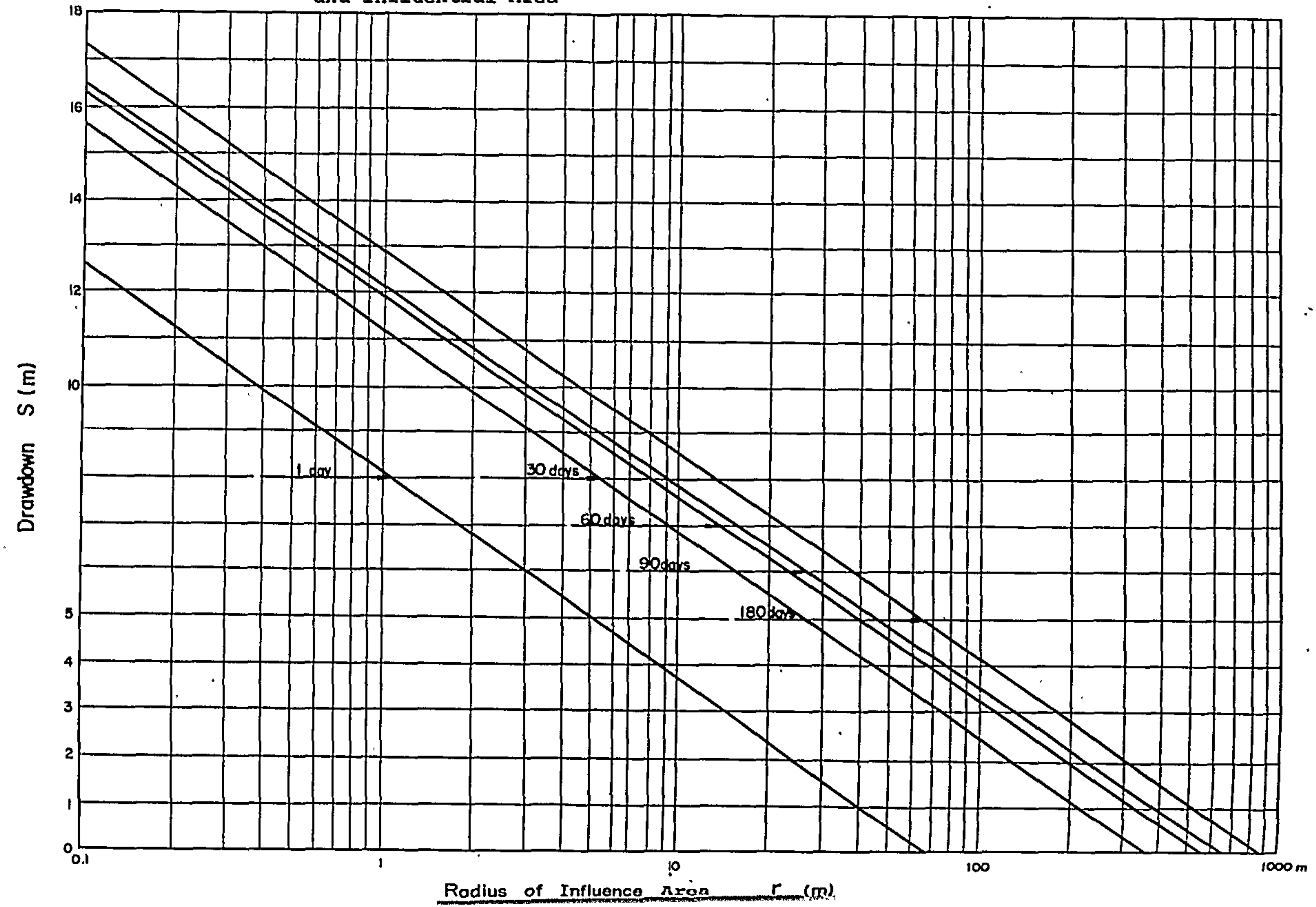
Loca-tion	BH No.	Locality Area	Locality	Depth	W.S.	Water Level	Draw Down	Yield	Specific Capacity	Quality etc.
				m	m	m	m	m^3/h		
20	64/73	Arusha Chini	T.P.C.	91.5		0		14.40		
21	87/69			156.2		2.1		95.76		
22	73/69			61		7.0		47.10		
23	28/70	West of Moshi	Sanya Juu Airport	89.4	24.4 70.2	28	28.2	45.6	39	good
24	104/70		Inter-national Airport	91.5	82.4	49.7		8.2		bad
25	82/69		"	91.5	24.4,36.6 82.4	30.7	54.6	38.76	17	
26	12/58		Sanya Juu	61.0	4.9	2.1		10.94		
27	51/67		Taveta	154.6	91.8-147.6	79.8		5.44		good
28	7/65	Rombo	Shoshoro -Rombo	91.5	74.7 79.3	68.3	85.4	9.58	2.7	bad
29	8/64		Chala -Rombo	160.1	134 151	132.2		6.02		good
30	1/64		Latema	58.5	47.6	46.4		9.12		"
31	21/63	North Pare	Kisangiro	58.3	28.7 45.7	28.6	-	7.87		"
32	12/61		Mwanga		9.8,17.1 23.4,25.6			9.12		"
33	7/54		Lembeni	27.8	10.7	8.2		10.94		"
34	43/70		Mgagao	152.5	86.1,122 152.5	53.74	128.3	2.84	0.5	"
35	24/61	Same	Kimori Same	94.6	61.0	55		100.32		"
36	2/58		Ngagan Same	91.5	83.5	73.2	-	50.16		"

Loca-tion	BH No.	Locality Area	Locality	Depth	W.S.	Water Level	Draw Down	Yield	Specific Capcity	Qualit etc.
				m	m	m	m	m^3/h		
37	80/69	Same	Same	140.3		43.6	53.7	14.53	6.5	
38	17/56		Same	80.8	46.1 74.7	35.4		8.21		
39	17/52		Same	82	50.6 77.8	40.0		11.40		
40	28/61		Ndea Same	106.8	80 94	61.0		13.68		
41	13/61		Njoro Same	65.6	48.8 62.6	47.3		9.12		
42	20/63	Mkomazi	Mkomazi	91.2	81.7	80.8				dry
43	7/63		Mkomazi	141.8	73.2 85.4	73.2		0.14		bad

Table 4.1-12 Relation between Pumping Operation Time and Drawdown

Pumping Operation Time	Distance from the Well	u	W(u)	s	Remarks
1 day	r_o = 0.125 m	3.02×10^{-6}	12.50	12.725 m	
	r_1 = 10 m	1.87×10^{-2}	3.50	3.563	
	r_2 = 50 m	4.675×10^{-1}	0.63	0.641	
30 days	r_o = 0.125 m	1.00×10^{-7}	15.50	15.78	
	r_1 = 100 m	6.23×10^{-2}	2.40	2.44	
	r_2 = 200 m	2.493×10^{-1}	1.10	1.12	
60 days	r_o = 0.125 m	5.00×10^{-8}	16.00	16.29	
	r_1 = 100 m	3.12×10^{-2}	3.0	3.05	
	r_2 = 200 m	7.79×10^{-1}	0.34	0.35	
90 days	r_o = 0.125 m	3.35×10^{-8}	16.20	16.49	
	r_1 = 100 m	2.08×10^{-2}	3.40	3.48	
	r_2 = 500 m	5.19×10^{-1}	0.60	0.61	
180 days	r_o = 0.125 m	1.68×10^{-8}	17.00	17.31	
	r_1 = 100 m	1.04×10^{-2}	4.20	4.27	
	r_2 = 500 m	2.60×10^{-1}	1.05	1.07	

Fig.4.1-18 Relation between Pumping Operation Time, Drawdown and Influential Area



7. Recommendation for Future Development

According to the trial calculation of the data described in "4.1.4 - 5 Quantitative Evaluation of Groundwater Refill", the rechargeable volume of the groundwater is estimated at approximately 300,000,000 m^3.

Hence, we consider, on the basis of the yield conditions of the groundwater basin, what is the approximate volume of the groundwater that can be exploited. The volume of flowing groundwater Qf is formulized by the following equation (1):

$$Qf = A \cdot S \cdot h$$

A: areal dimension of the basin
S: average storage coefficient
h: average drawdown

If S, the average storage coefficient of the whole basin, is 50% of the calculated value of Miwaleni basin,

$$S = 1.10 \times 10^{-1} \times 0.5 = 5.5 \times 10^{-2}$$

$A = 480$ km^2 and $h = 5$ m.

Therefore, $Qf = 160 \times 10^6$ m^3

Thus calculated volume of flowing groundwater (160,000,000 m^3) is almost a half of the total recharge and is nearly equal to the annual recharge except the flow-out of Miwaleni Spring (Fig. 4.1-16). The water of this volume, however, is not all drawable. In view of the recharge source, the hydrogeological conditions of the strata and the capacity of the pumping facilities, the yield is estimated at approximately 80,000,000 m^3, a half of the calculated volume.

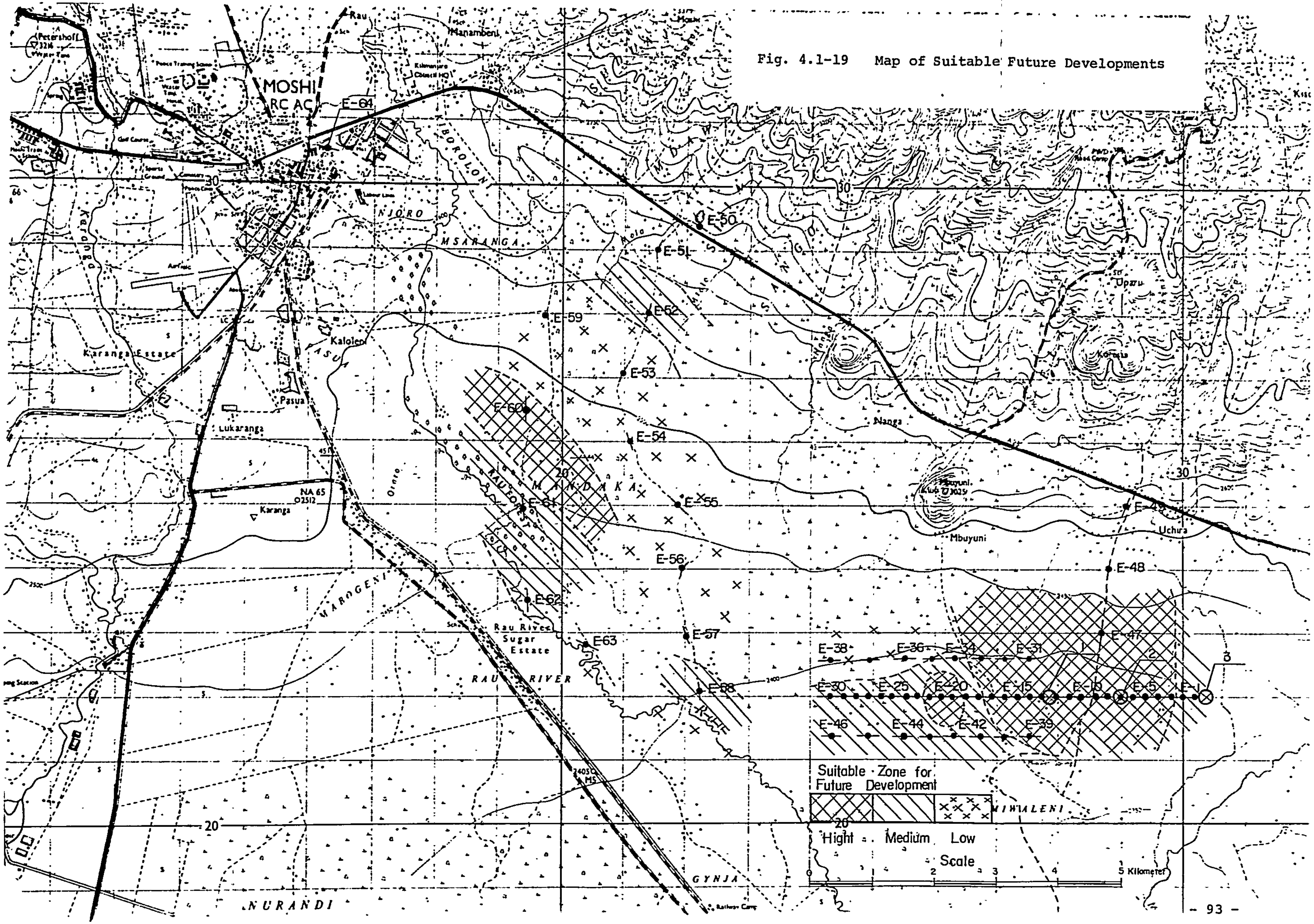


Fig. 4.1-19 Map of Suitable Future Developments

Current annual yield at the Kahe-Miwaleni ground-water Basin is estimated at slightly less than 17,000,000 m^3 including TPC's (according to "4.1.4-2 Current Situation of Groundwater Utilization"). If this figure is balanced, the volume that can be exploited in the future can be estimated about 50,000,000 - 60,000,000 m^3, although the value is a rough estimation. The yield plan should be made through precise surveys at various districts because hydro-logical characters of the groundwater would be somewhat different by district. In planning exploitation, groundwater reservation should be sufficiently considered since a large yield at a spot and the discharge of more than the recharge may cause groundwater pollution beyond recovery such as land subsidence.

Exploitation has been progressed in the southern part of the basin. This survey was made in and around the northern part which is behind the development. The districts of the northern part classified by the yield conditions are illustrated in Fig. 4.1-19.

Some advices for the future survey will be given as below:

(1) Miwaleni

Electrical soundings and pumping tests have been done in this survey for the Upper Miwaleni Scheme. As the result, good aquifers were determined to be distributed around the No. 1 well which has comparatively good discharge conditions. If the yield is approximately 1,900 m^3/d, the area of its influence must be within 600 m - 1,000 m. The extent of good aquifers discovered by the electrical sounding is shown in Fig. 4.1-19. As shown in this illustra-tion, there must be two types of nice aquifers: excellent and good aquifers, in this basin area. This area, therefore, is considered to be most hopeful in future groundwater exploitation. It goes without saying that in exploitation work, pumping tests should be made for wells provided with some apparatus by which hydrological characters of each horizon of groundwater estimated by electrical sounding method can be measured. The relation between the yield and the influential area should be examined with the use of the hydrogeological coefficients. Aquifer horizons should be ascertained by core boring as well as by the comparison with the results of electrical sounding.

The annual flow-out of a large spring called the Miwaleni Spring is 120,000,000 m^3. Large yield at the Upper Miwaleni Scheme may affect the spring since the source of water may exist in the same sand and gravel beds even though the depth from the surface is different. Therefore, proper well distribution and control of the yield should be made, in accordance with the scale of aquifer and recharge over a wide area for either the economics or the reservation of the groundwater. Further, the earth-surface water coming out from the spring should be fully utilized if it is available to reserve groundwater resource as much as possible.

(2) Msaranga Mandaka

The ground hydrogeological survey of this area between Miwaleni and North-Western Moshi was made only by electrical sounding since there was nothing else to be referred. This area is also located near the southern slope of Mt. Kilimanjaro which is believed to be the recharge source. There is a large possibility of groundwater exploitation since its geological structure is believed to be characterized by relatively thick sand and gravel beds just like the best aquifers in Miwaleni (Fig. 4.1-19).

The area around Mandaka, especially an excellent aquifer can be expected. These aquifers must be distributed within the range of 100 m depth from the earth surface so far the groundwater exploitation would be so easy. In the eastern part of Mandaka, some good aquifers of 100 m or more in depth will also be found by future survey. The survey of this area of this time was rough as a whole with distance interval of 500 - 1,000 m. In future, more precise survey should be made with combined application of electrical sounding, core boring and pumping test. The proper yield plan would be made after these date are analysed.

(3) Kahe

Judging from data obtained from wells in the vicinity of Kahe, nice hydrogeological conditions substantially equal to Miwaleni is expected in the area ranging from the southern part of Miwaleni and Kahe.

Field survey indicates the wide distribution of sand and gravel beds in the area ranging from Miwaleni to the southern part of Kahe. Most of this area has already been exploited as indicated by the existence of wells at Kahe and only a small part in the southern part of Miwaleni to the Rau River is considered as left for further exploitation. When we consider the planning of the development of this area, detailed examinations of pumping tests, drawdown and well distance are desirable.

(4) Arusha Chini

Many wells are now being used by TPC in this area. The TPC's wells are distributing over a wide area from Lukaranga (6km south from Moshi) to Arusha Chini. Groundwater movements are being precisely examined by means of observation wells. TPC is using these wells by keeping their mind to hold the nice yield conditions and to reserve groundwater. It is considered that further exploitation of groundwater in this area may be difficult. Particularly, the southern part of this area has little room for further water utilization and for land development since it is situated near the Precambrian stratum and the water of Nyumba ya Mungu Dam covers a large part of the area.

In this report the possibility of future groundwater exploitation in the Kahe-Miwaleni Area has been described. Most hopeful region in this area is the plain region ranging from Miwaleni to the Rau River located in the south-east of Moshi. Even in this region, good balance between the utilization and the reservation of the water resource should be ensured with the careful considerations of hydrogeological conditions of the region and its surrounding area.

4.2 Mkomazi Area

4.2.1 Topography and General Geology

The Mkomazi Area exists about 150 km south-east of Moshi on the east skirt of the South Pare Mts. The South Pare Mts. with the heights of 1,750 - 2,500 m above the sea level form a long chain ranging for 60 km. Small rivers dissecting the eastern side of the mountains run into the Kisiwani and Kambaga River with the trend of north and south along the Pare Mts. and finally come into Mkomazi River.

The Mkomazi Valley is a basin-shape plain along the Mkomazi River dissecting the plain. There is a hill area of the Kisiwani Mts. (1,000m above the sea) and the Tossa Mts. (1,300m above the sea) on the eastern side of this Valley. Small monadonocks and seasonal swamps are distributing within the Valley. The height of the plain is about 650 m above the sea in the neighbourhood of Kisiwani, 550 m at Gonja, 500 m at Kihurio in the southern part, and 450 m at Mkomazi. Consequently, the gradient over a distance of 60 km between Kisiwani and Mkomazi is about 200 m.

A dam lake has been made between Ndungu and Kihurio where the valley becomes narrow. It serves as a water source for agricultural purposes such as rice field in the vicinity of Kihurio.

The source Mkomazi River came from the southern end of the North Pare Mts.

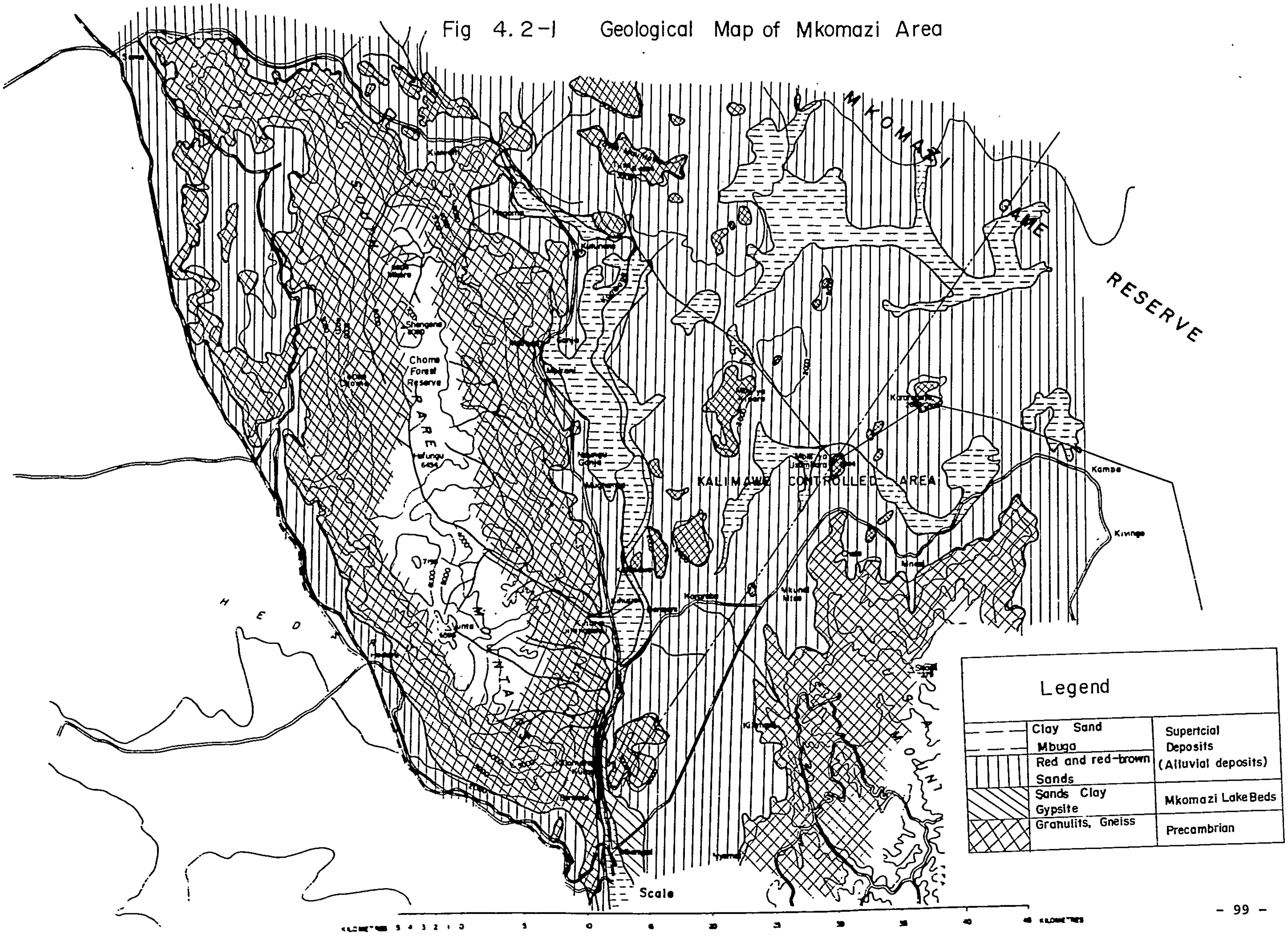
The Usambara Mts. (2,000m above the sea) is in the south-east of the South Pare Mts. The width of the valley developed between the South Pare Mts. and the Usambara Mts. is about 10 km at Mkomazi.

The geological structure of this area is roughly divided into two parts, the basement of metamorphic rocks and superficial deposits (Fig. 4.2-1).

The Precambrian basement rocks are exposed in the North Pare, the South Pare, the Usambara Mts., Kisiwani Mts. and Tossa Mts. and small monadonock-type hills within the Mkomazi Valley plain. It is composed of garnet-biotite-granulite.

The younger alluvial deposits mostly composed of clay and gravel, is distributed all over the Mkomazi River

Fig 4.2-1 Geological Map of Mkomazi Area



Basin. These younger deposits also have intercalation of dark-gray clay deposits and lake deposits probably accumulated in wrong drain conditions. Most of clay and gravel in these deposits are the weathering products of granul tes. Sandy clay which was piled up on the plains near the mountains has characteristic reddish brown color. Similar red soil is found on high mountains of the South Pare and the Usambara Mts. This is also considered as weathered residual soil of granulites. The lake deposits described at Mkomazi Town must have been accumulated under the dry climate in the closed system which is wrong in drainage.

4.2.2 Hydrology and Climate

(1) River Systems

The Mkomazi Area is located on the east side of the South Pare Mts. There are three large rivers, Kisiwani, Gonja and Zaseni, in the north-to-south order, running down along the east side of the South Pare Mts. These rivers have surface flow even in the dry season. All of them came from Mt. Shengena, the highest peak of the South Pare Mts. Kisiwani runs to the north, Gonja to the north and then to the east, Zaseni to the south and then to the east and, finally, all of them flow into the moor area along the east side of the South Pare Mts. The Kambaga River takes a course through the moor into a reservoir, the Dam Lake Kalimawe. Below the lake, the water which is called the Mkomazi River runs further to the south and flow into the Pangani River near the upper stream of Korogwe.

The Mkomazi River collects waters from the east river systems of the South Pare Mts., the south river systems of the North Pare Mts., the river systems belonging to the Kisiwani and the Tossa Mts., and the north-west river systems of the Usambara Mts.

(2) Precipitation

At the Mkomazi Area, similarly to Kahe-Miwaleni, the period of March-May is the heavy rainfall season, November -December is the light rainfall season, and July-September is the dry season. Practically there is no rainfall in the dry season. The rainfall of the east side of the South Pare Mts. is larger than the west side because of characteristic wind direction. This area does not have so many rainfall observation points as the skirt area of the Mt. Kilimanjaro (Fig. 4.2-2).

The monthly average rainfalls at each observatory are shown in Fig. 4.2-1.

Table 4.2-1 Annual Precipitation at Selected Sites in the Mkomazi Area

Site	Elevation	Annual Precipitation
Gonja Estate	549 m	940 mm
Kalimawe	503	300
Same	869	630
Hassani Sisal Estate	488	570

The rainfalls at different altitude are shown in Table 4.2-2 (Survey report for the Agricultural Cooperation Project in the Kilimanjaro Region, Tanzania, 1974 (J.I.C.A.)).

Table 4.2-2 Annual Precipitation at Different Altitude

Elevation	Annual Precipitation
4,500 ft = 1,372 m	1,300 mm
4,000 = 1,219	1,190
2,900 = 884	500
2,500 = 762	500
2,200 = 670	460

Fig.4·2-2 LOCATION MAP of RAINGAUGE STATION

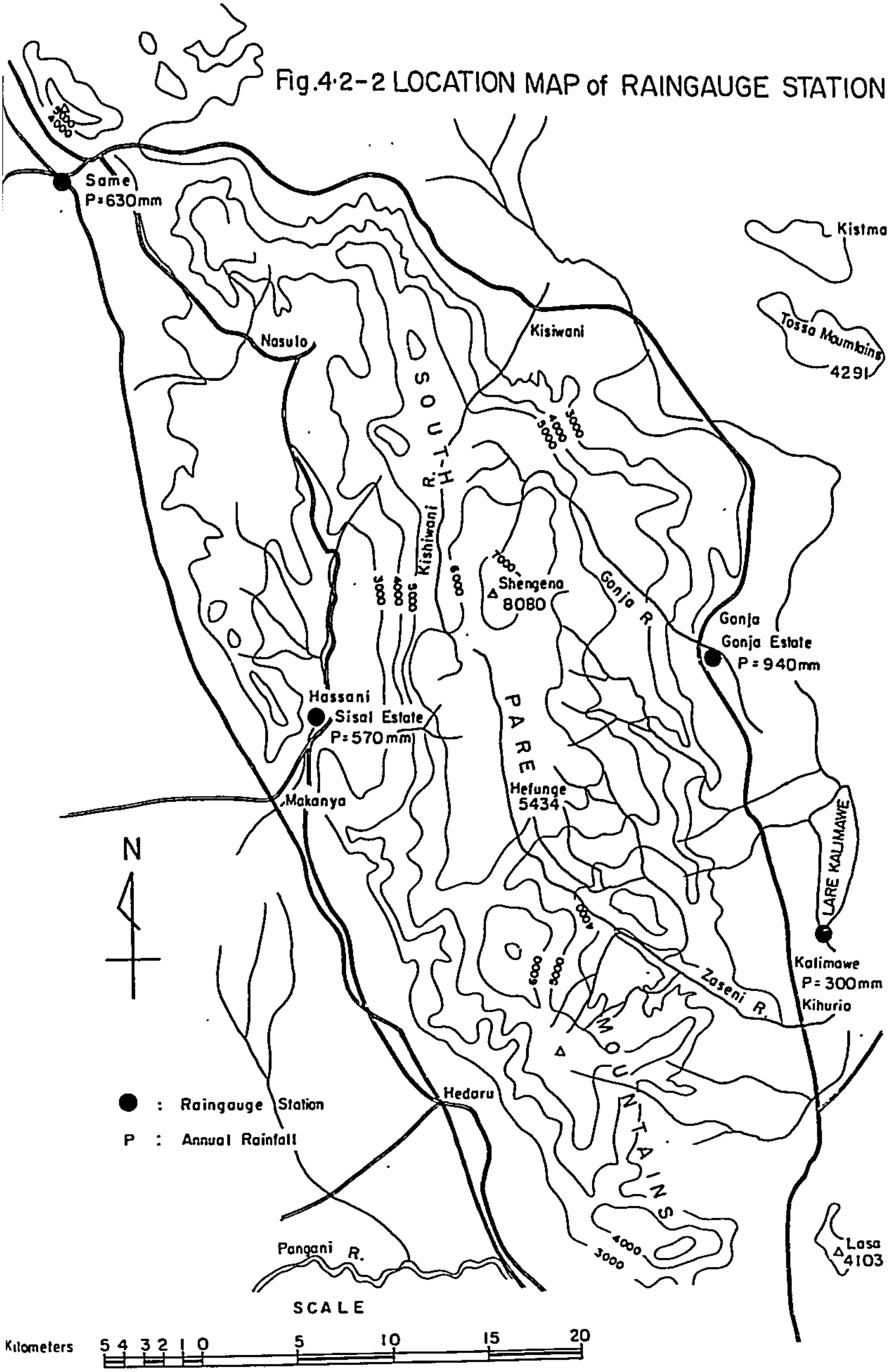
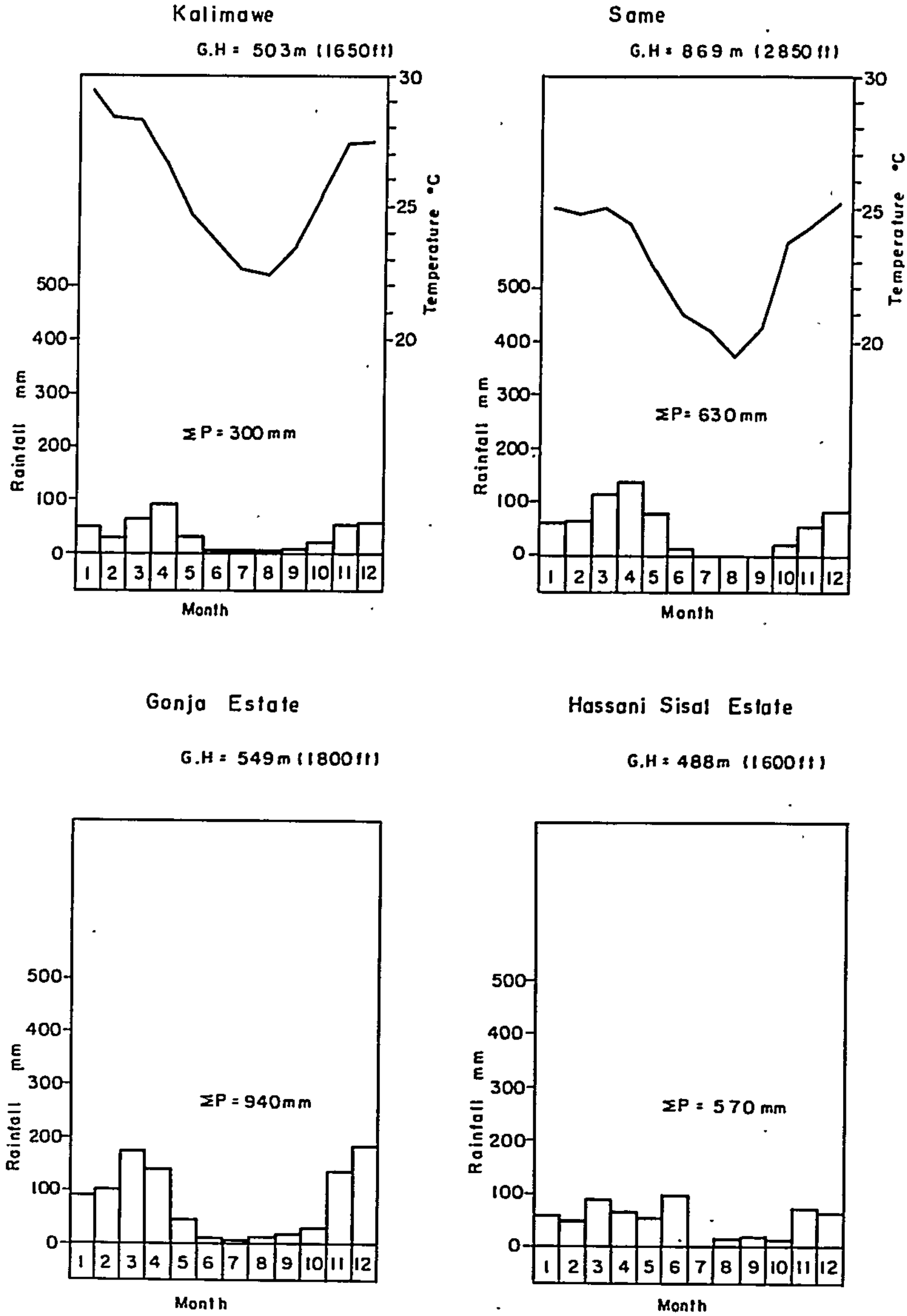


Fig.4·2-3 Meteorological Data



(3) Temperature

The temperature is low in the period of June-August and high in January-March. The monthly average temperatures are shown in Fig. 4.2-3.

(4) Evaporation

There is no datum of evaporation except the evaporation at Kalimawe (W.D. & I.D.) in October as follows:

Ep = 190.6 mm (class A Pan)

Judged from the comparison of this to the previously described evaporation at the Miwaleni Area, the whole year evaporation of this area Kalimawe can be estimated to be 1,880 mm or so.

4.2.3 Hydrogeology

The hydrogeological structure is shown in Fig. 4.2-4. The estimations of the subsurface geology of Kisiwani, Gonja and Kihurio Area were made from the data obtained in electrical sounding and areal survey at the Mkomazi Area.

The resistivities were measured at and around the measuring points E65 and E68 in the Kisiwani and the Gonja areas where the basement of the Precambrian stratum is exposed in neighbourhood. As the result, a value of ρ = 40 - 100 Ω-m was obtained as showing the resistivity of the basement granulite. At some points far from the basement, the resistivity shows low values of 4 - 18 Ω-m. In Kisiwani, the bed of over 100 m thickness having a resistivity of ρ = 4 - 5 Ω-m is considered to lie on the basement rocks. At the piont E70 close to the center of the Gonja Valley, the resistivity value was 18 Ω-m, a little higher than that at E69. The variation of resistivity by the depth, however, is extremely small. At Kihurio, a stratum having the resistivity ρ = 17 Ω-m is distributed with more than 100 m thickness.

As far as observed on the land surface, dark-gray clay is dominating and white shells are observed in the surface stratum of the Kisiwani Area. The boulders of gneiss and granulite were also found there. At Gonja, the pebbles of Precambrian rocks was observed in talus deposits on the slope of the mountains. At the outcrop along the small valley, biotite-garnet-granulite are exposed and surface water flow are observed. Flat plains along some valleys are filled with clay and sand of light gray of gray color and wild lands and small moors also exist there. There is the Fall Thernton at 3 km west of Gonja. The surface flow at the Fall is utilized for agricultural purposes in the neighbourhood. The Zaseni River runs in the south of Kihurio, having comparatively rich flow, and its valley plain is utilized as paddy fields, etc. The fields are fully provided with facilities to irrigate the water from the Kalimawe Dam located at the upper part of the river.

The geological structure of the Mkomazi district as inferred from the results of electrical soundings and areal survey is as shown by Fig. 4.2-4. The alluvial deposit which shows a low resistivity becomes suddenly deep at the edge of the mountains.

The granulite body of the South Pare Mts. is an impermeable mass. The aquifers are considered to be within the not-solidified alluvial bed deposited on the Precambrian basement. The resistivity value of this alluvial bed shows that the bed is composed of fine-grained soil. Especially, the alluvium deposits at Kisiwani must be chiefly composed of clay. Sand and gravel are mixed in the clay at Gonja and Kihurio areas. Consequently, it is possible to presume that moderate amounts of groundwater can be obtained from some sandy and gravel beds in the alluvium deposits developed in the area at the middle of Mkomazi River. Such large scale groundwater recharge as seen in the Kahe-Miwaleni Area, however, can not be expected here. This is because, according to resistivity data, the aquifers, if there are, must be of smaller scale and the rainfall in the mountain consisting mainly of impermeable granulite as recharge source is much less. Further, as the alluvium deposits are made up mainly of clay, the flow down of surface water can not be expected to be so free. Therefore, the yield condition of this area is much inferior to that of the skirt areas of Mt. Kilimanjaro which have been previously described.

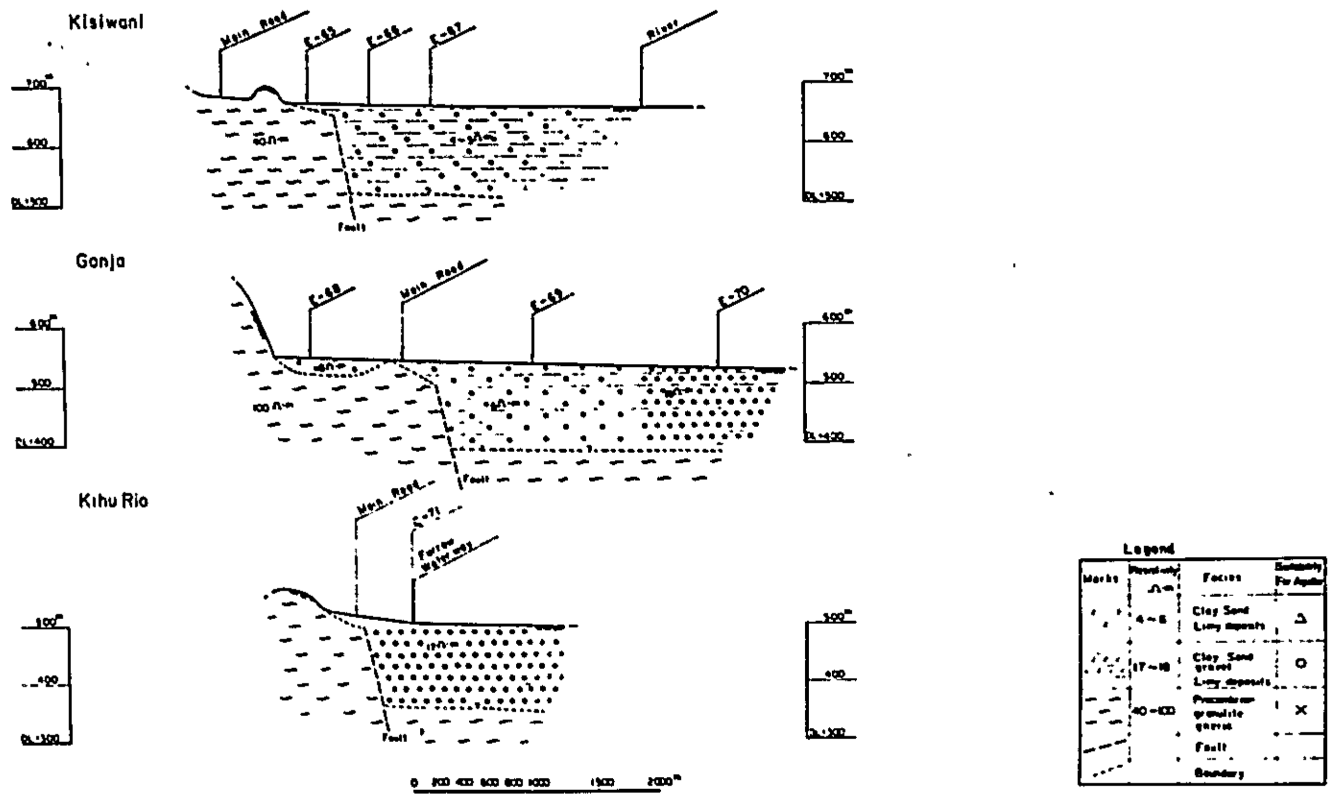
The existence of the groundwater is expected in the fault fractural zone at the foot of the Block Mountains. It may be difficult, however, to prospect the exact location of the storage.

4.2.4 Recommendation for Future Development

In the valley area along the Mkomazi River, there are two types of groundwater, the one is in the aquifers within the alluvial deposits and the other may be stored in the fault fractural zone in the skirt area of the South Pare Mts. In the latter case, the prospecting will be technically difficult because of its complicated mechanism of the stored groundwater. Seismic and radioactive methods of propsecting are recommended.

According to the results of the survey, the finding of groundwater from coarse-grained part of alluvium deposits is possible in the vicinity of Gonja. The survey of this time was not sufficient to say anything exact and conclusive. Electrical sounding and core boring should be done to much deeper part to prospect the basement depth and to examine the horizon of aquifers, component near the basement. Anyway it can be said that groundwater conditions of this area is much worse than those of the Kahe-Miwaleni Area. Large-scale groundwater exploitation can not be expected here. The utilization of groundwater will be confined to the general water service such as household.

Fig 4·2-4 CROSS SECTION OF MKOMAZI AREA
(After Electrical Soundings)



Part 4 [illegible]

[illegible]

[illegible] present survey will [illegible] the research and [illegible] other areas of the [illegible] principally from the point of [illegible]

Part 5 Conclusion

5.1 [illegible] Area

5.1.1 Conclusion

This Area, as [illegible] structure, surrounded by [illegible] The basin is filled by [illegible] sands, gravels, clays and [illegible] amounts of lavas and pyroclastic [illegible] [illegible] These [illegible] in the [illegible] thicker toward [illegible] area.

It must be impossible to [illegible] tation area without taking into consideration [illegible] balance within the alluvium deposits of the [illegible]

[illegible] the total [illegible] water [illegible] estimated to be [illegible] and the [illegible]

Part 5 Conclusion: Comments on the Results of the Survey and Advices for Future Progress

In this chapter, conclusions from results of the present survey will be summarized and some opinions regarding the research and progress of exploitation in future will be given. The possibility of finding groundwater resources in other areas of the Kilimanjaro Province will also be discussed principally from the point of topo-geographical view.

5.1 Kahe-Miwaleni Area

5.1.1 Conclusion

This Area, as shown in Fig. 4.1-1, has a basin structure, surrounded by faults or Precambrian basement rocks. The basin is filled by alluvium deposits chiefly composed of sands, gravels, clays and calcareous deposits, with some amounts of lavas and pyroclastic rocks originated from Kilimanjaro Volcano. These deposits which are roughly estimated at more than 130 m in thickness in the south and seem to become thicker toward north are major aquifers in this area.

It must be impossible to make a groundwater exploitation plan without taking into consideration the water balance within the alluvium deposits of this basin.

As shown in Fig. 4.1-16, the total quantity of water recharged in the Kahe-Miwaleni groundwater basin is estimated to be 300,000,000 m^3/year and the quantity of water consumed by surface runoff (mainly from the Miwaleni Spring) and pumping works is estimated 110,000,000 m^3/year. About half the quantity of recharge may be regarded as the object of the future groundwater exploitation. However, it is still dangerous to think that all of 190,000,000 m^3/year can be exploited in future. It is technically impossible to pump out all the potential quantity due to hydrogeological restrictions and power limit of the pumping facilities. The quantity of water that can be practically drawn up should be estimated at most 50,000,000 m^3/year, less than half the potential quantity.

The aquifers of the Upper Miwaleni area and its surroundings where irrigation works are under way can be divided as shown in Fig. 4.1-7. A plan showing the drawing conditions in this area is given by Fig. 4.1-19.

By the pumping tests at already bored holes, the coefficient of aquifers having the best drawing character is calculated as follows:

Transmissibility	$T = 1.70 \times 10^{-3}$ m^2/sec
Storage Coefficient	$S = 1.10 \times 10^{-1}$

From the result of the step draw down test, the maximum economical yield of a bore hole (about 250 mm in diameter and 70-80 m in depth) is estimated to be 1,800 - 2,000 m^3/day. The proper bore hole distance must be 600 - 1,000 m, if continuous water pumping for about 2 months and 12 m down of water table are considered.

5.1.2 Some Problems and Basic Policies for Future Survey

1) In this survey, the pumping test could be carried out with only one bore hole showing the best aquifer condition. No observation well could be newly provided for the test. Therefore, various hypotheses and assumed conditions had to be used to calculate various hydrological characters, such as level down of water table by the continuous pumping and the proper bore hole distance. It is extremely necessary to confirm the nature of aquifer by means of test borings at localities (at least 3 points) having different aquifer condition (Fig. 4.1-19). At the same time, it is also urgently required to obtain the coefficients of aquifer by pumping tests at two or three newly set observation wells. In this case, the pumping should be continued at least for 3 - 5 days to confirm the characters regarding the drop down of water level.

2) The electrical sounding carried out this time was a linear survey. Consequently, three dimensional shape of aquifers are partly left unknown, even though some profiles of underground structure could be drafted. It is quite necessary to carry out an electrical sounding at many additional points or along the crossed lines to get more reliable data regarding the physiographic characters of aquifers.

3) The meteoro-hydrogeological data obtained in the past were used to calculate the groundwater balance. The data of rainfall, evapo-transpiration, surface runoff and others, however, were not so enough, sometimes were not so accurate. It is also quite necessary to carry out meteological and hydrological observations at much

more stations if we wish to have definit and satisfactory future plan of the utilization of water for the development of this area.

5.2 Mkomazi Area

5.2.1 Conclusion

An alluvial deposits are developed in the Mkomazi Area on the eastern side of the South Pare Mts. composed of Precambrian metamorphic rocks. From the result of electrical soundings, the alluvial deposits are estimated to have the thickness over 100 m on Precambrian basement. Electric resistivity and geological observation of surface outcrop indicate that the alluvial sediments filling the valley are composed of comparatively fine-grained materials such as clays, sands, and calcareous matters. Therefore, such an excellent aquifer as that found in the Kahe-Miwaleni Basin can not be expected in this area. In fact, the maximum amount of water pumped through two or three wells in this area is only 100 m^3/day. It is not advisable for the Mkomazi Area to use the groundwater for irrigation because the utilization of groundwater for irrigation would not pay for the cost of sinking and upkpeeping of wells if the yield per bore hole comes to less than 100 m^3/day. Taking the technical feasibility into consideration, it would be better to construct a small dam on the east slope of the Pare Mts. having plenty rainfall.

5.2.2 Some Problems and Basic Policies for Future Survey

Although abundant groundwater can not be expected in this area, it is advisable to carry out test borings to the depth of 100 m at Kisiwani and Gonja Valleys in which thick alluvium deposits exist to confirm the nature and the possible yield of the aquifer.

It can also be expected that there exist fissure filling water contained in basement-forming Precambrian rocks. Electrical and seismic prospecting are most favorite methods to confirm the possibility of finding this type of groundwater. Before carrying out a plan to construct a dam for irrigation water, it is necessary to do careful studies on the choice of dam site, the possible pondage, hydrogeology of the reservoir area and the embankment materials by field geophysical, geological and topographical surveys and hydrogeological observations.

As the basement of dam site, Precambrian hard gneisses may offer little problem although a final survey by boring and other methods should be conducted to decide the location of dam site. In regard to the type of dam, fill type dam, using impermeable materials such as residual soils (red soils) and weathering products of the basement rocks which can be easily and abundantly obtained in this area is highly recommended.

5.3 Groundwater in Other Districts

Kilimanjaro Region in Tanzania is topographically divided into three districts: 1) Kilimanjaro Mts. and its eastern and southern slope areas, 2) the low land in the basin along the Pangani River and 3) Pare Mts. and its eastern sides.

The Kahe-Miwaleni Basin details of which are given in this report belongs to 1). In the areas on eastern sides of Mt. Kilimanjaro such as the Rombo district, there must be alluvial fan deposits of the hydrogeological characters, similar to that of the Kahe-Miwaleni, and excellent recharge storage condition can be expected. Some parts of these areas, however, may chiefly be composed of thick volcanic rocks. These volcanic rocks are generally very permeable. Consequently, if the boundary between volcanic strata and impermeable basement Precambrian rocks is so deep, the meteoric water easily run down to far depth and it would be practically impossible to pump up the groundwater except locally perched water. In fact, the explanatory notes of geological map (Kilimanjaro) on a scale of 1/125,000 indicate that in the eastern side of Mt. Kilimanjaro of Keni only one bore hole was succesful to find water and 5 bore holes in Mkuu, Mashati and other areas had no water.

In order to exploit groundwater in the slope areas surrounding Mt. Kilimanjaro, it would be necessary to carry out at first some detailed geophysical prospecting (electrical sounding and radioactive and seismological prospecting may be effective) to determine the recharge storage and then test borings for final confirmation.

Hydrogeologically, the Pangani River Basin, a low land area extending from the north to the south between Pare Mts. and Lelatema Mts. having small exposures of basement rocks (ex. Nyumba ya Mungu Dam) seems to be similar to the Mkomazi Area which was described in this report. Therefore, it is advisable to carry out a survey in the same ways as those noted in Chapter 4.2

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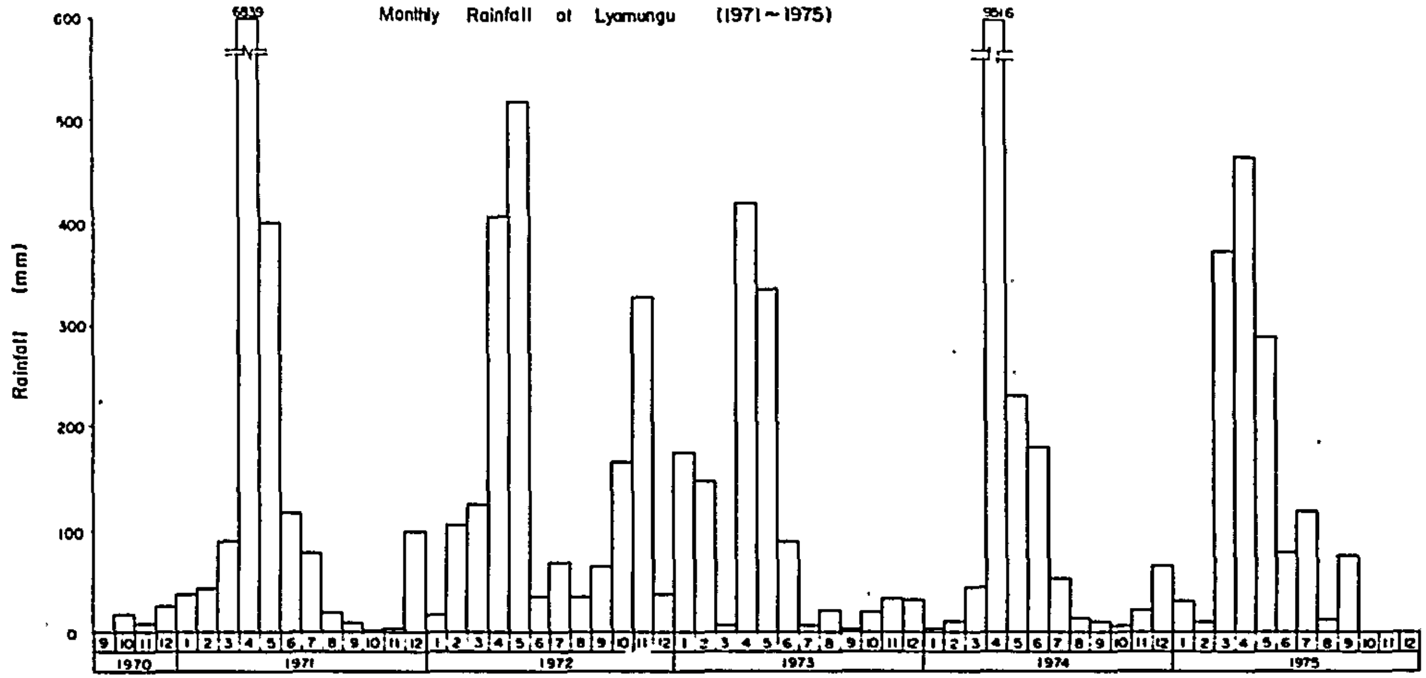
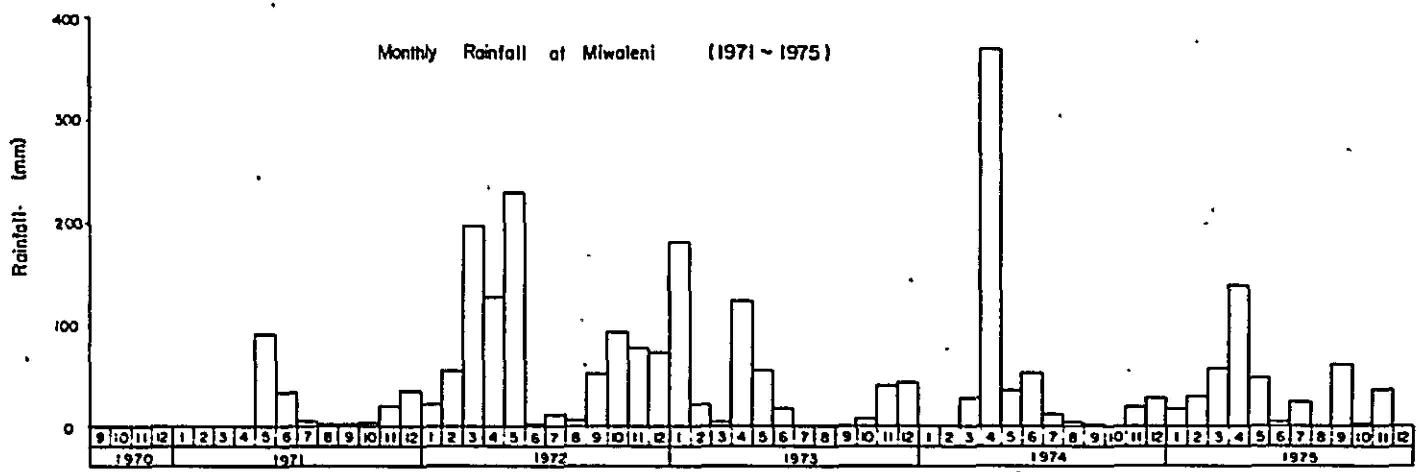
List of Annex.

Annex I



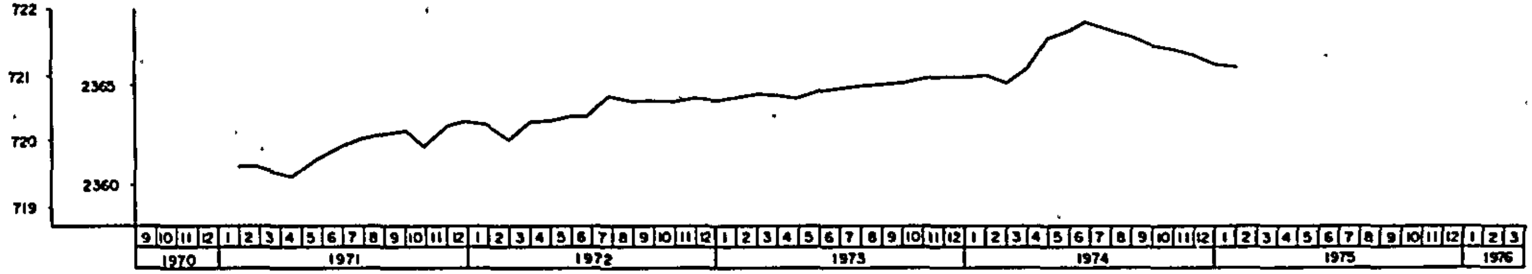
Monthly Rainfall at Lyamungu (1971 ~ 1975)
Rainfall (mm)
600
500
400
300
200
100
0
683.9
951.6
1970
1971
1972
1973
1974
1975



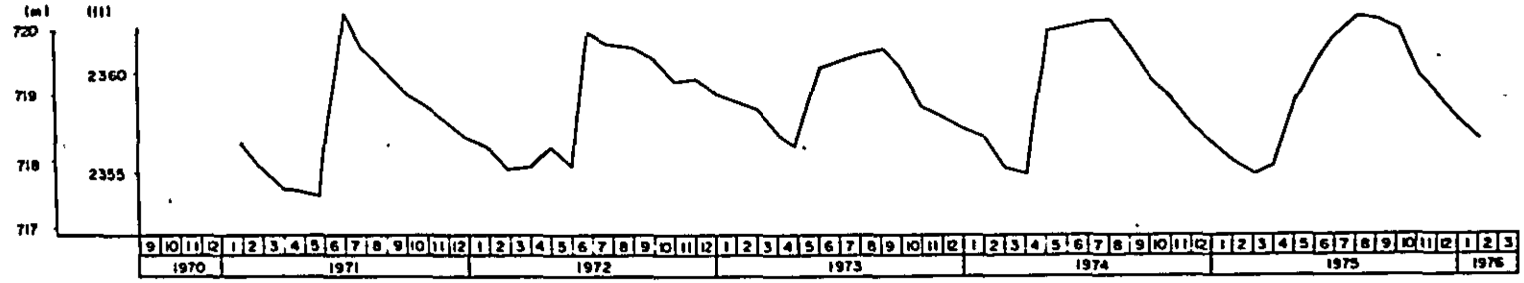
Monthly Rainfall at Miwaleni (1971 ~ 1975)
Rainfall (mm)
400
300
200
100
0
1970
1971
1972
1973
1974
1975

Annex 2 Monthly Variation of Ground Water Table (1971 ~ 1975)

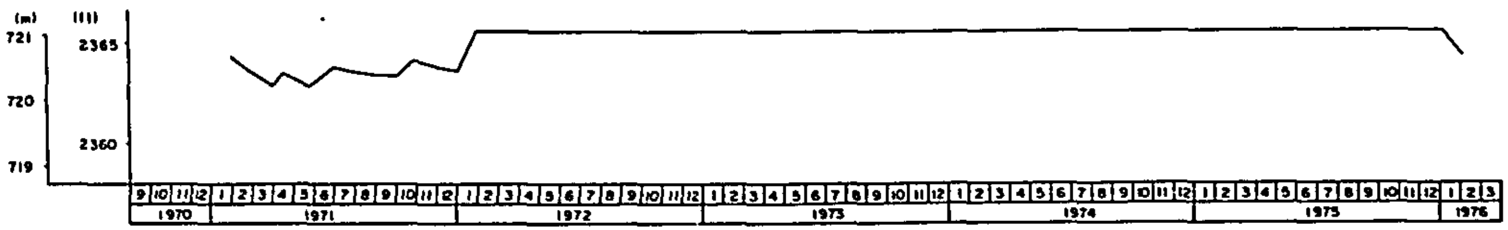
T. P. C. Observation Well № 1059 G.H. = 2381.67 ft



T.P.C. Observation Well № 1061 G.H. = 2370.00 ft

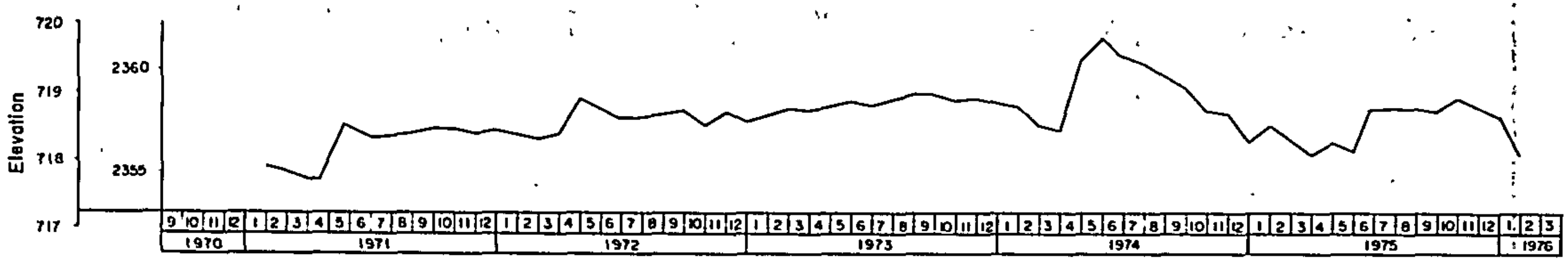


T. P. C. Observation Well № 1062 G.H. = 2365.61 ft

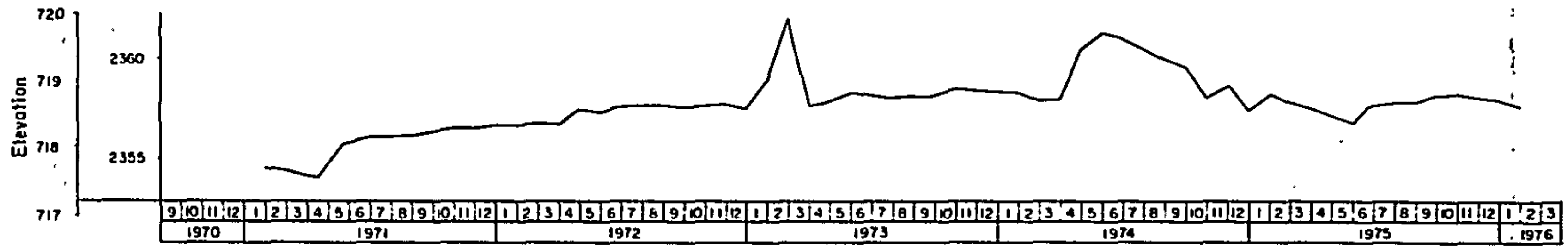


Annex Monthly Variation of Ground Water Table (1971 ~ 1975)

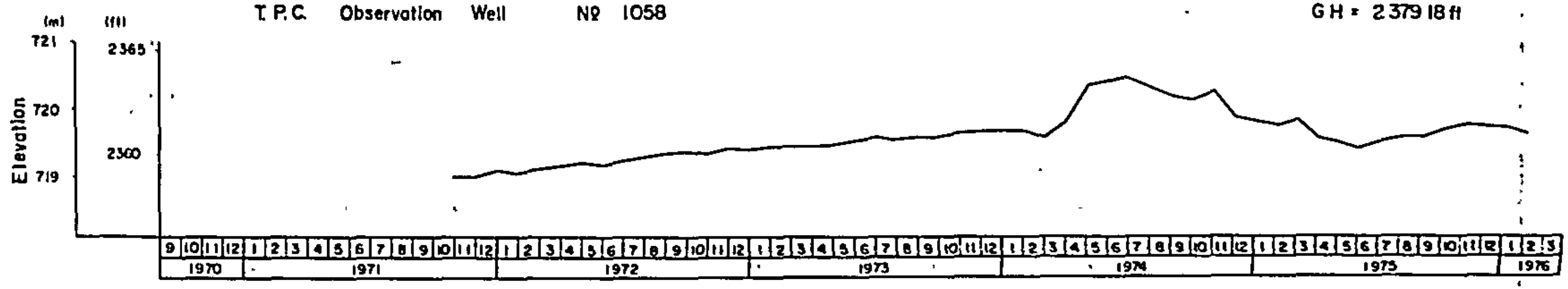
T. P. C. Observation Well Nº 1056 G H = 2373 62 ft



T P. C. Observation Well Nº 1057 G.H. = 2373.80 ft



T. P. C. Observation Well Nº 1058 G H = 2379 18 ft



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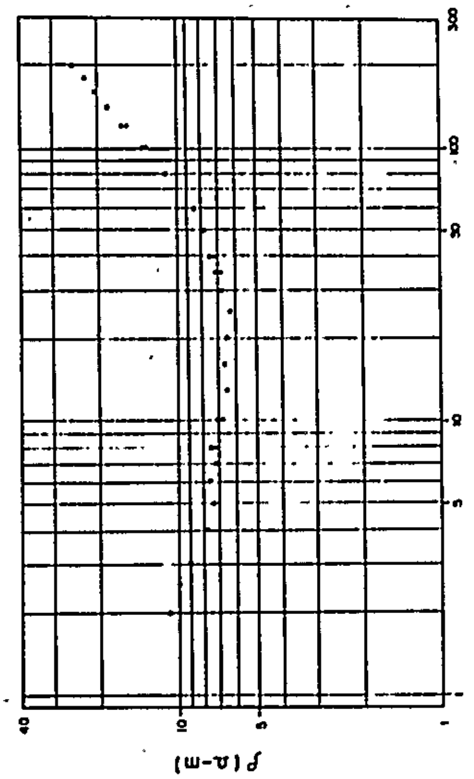

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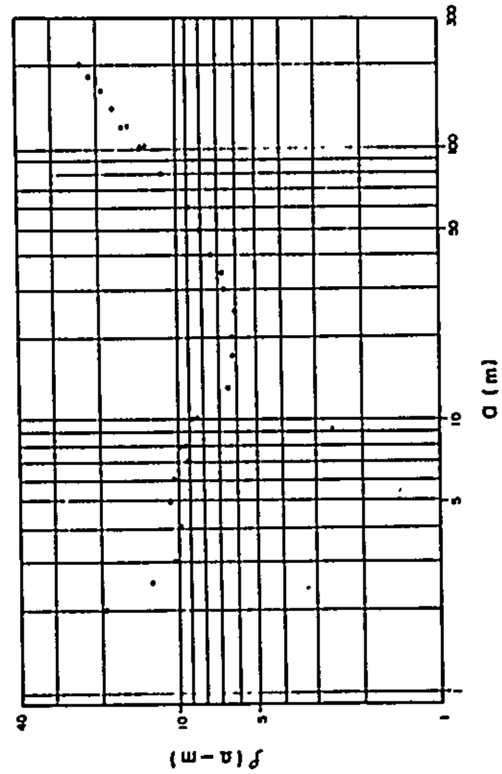

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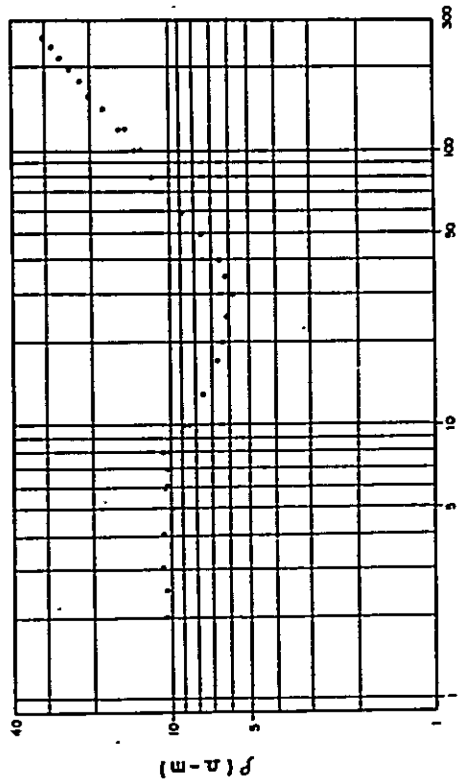

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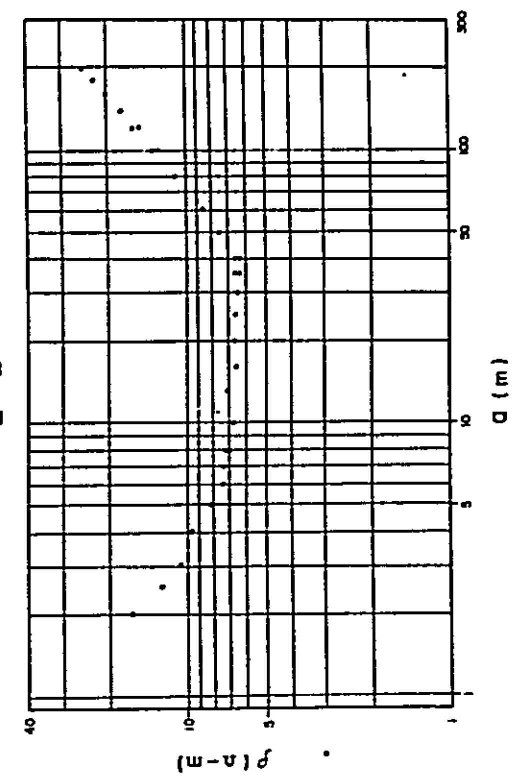
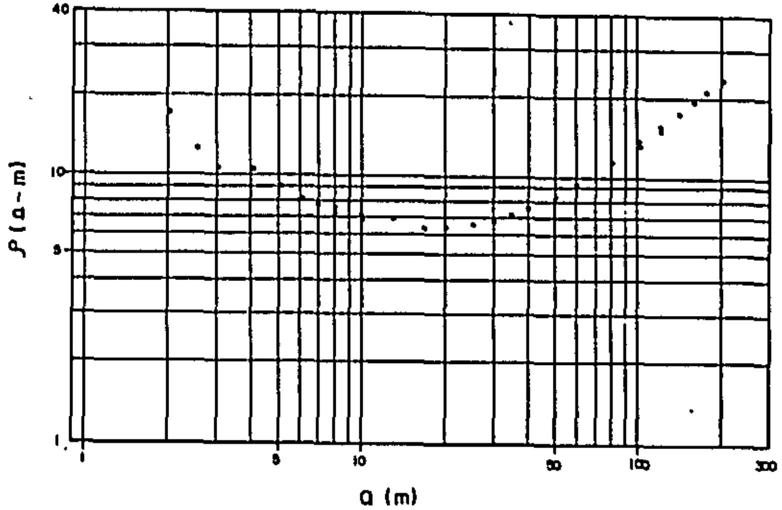


Annex ρ-a Curve (Kahe-Miwaleni Area)

E-5



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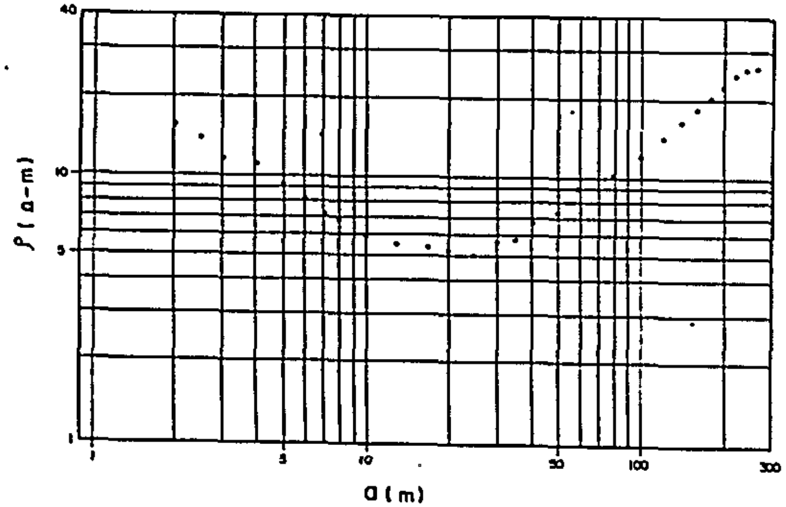
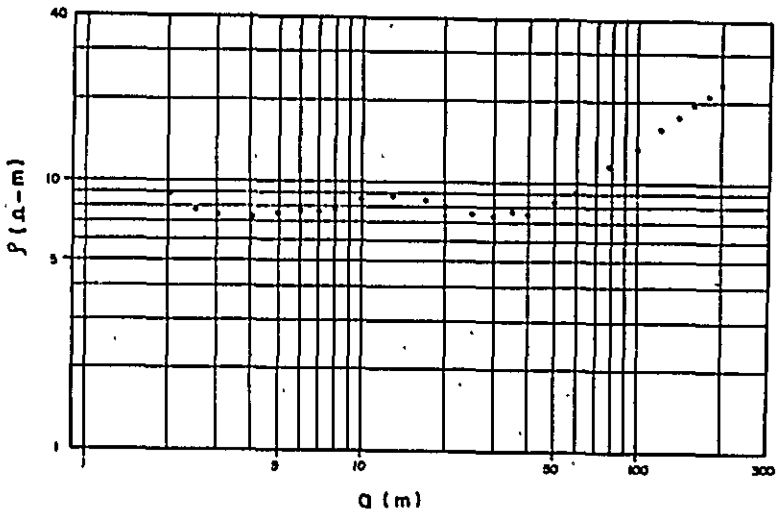
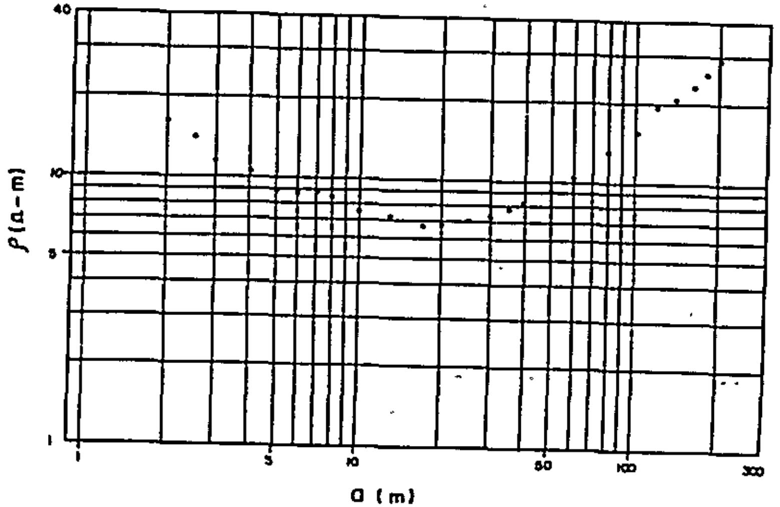


E-6

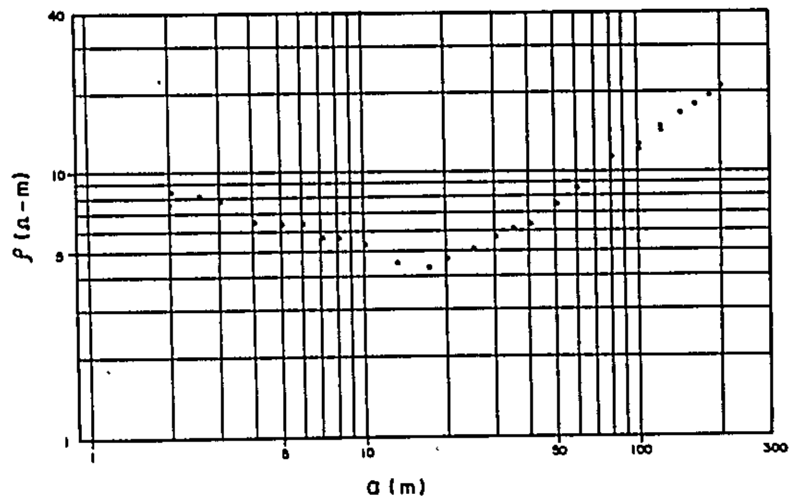


E-8

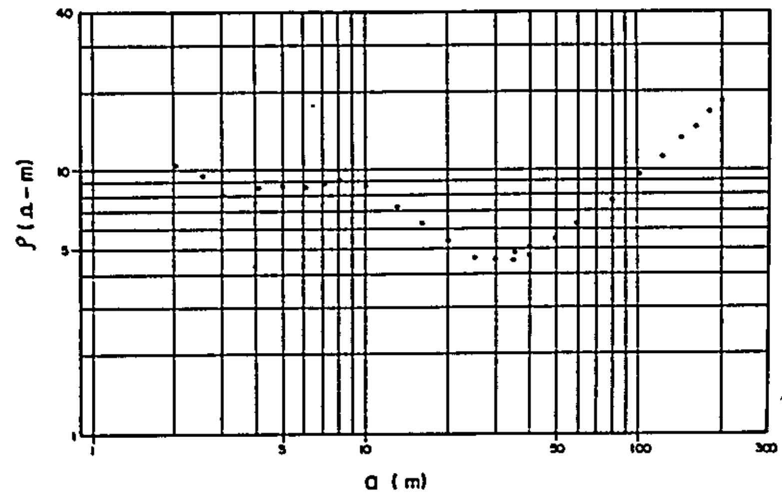


Annex ρ-a Curve (Kahe-Miwaleni Area)

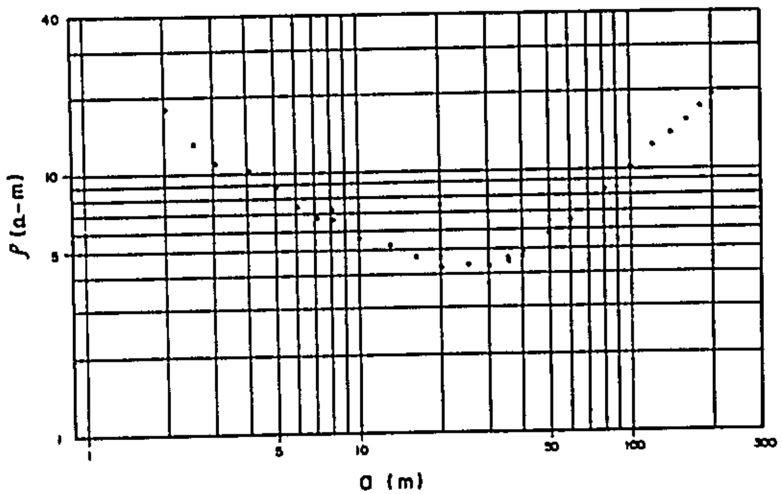
E-9



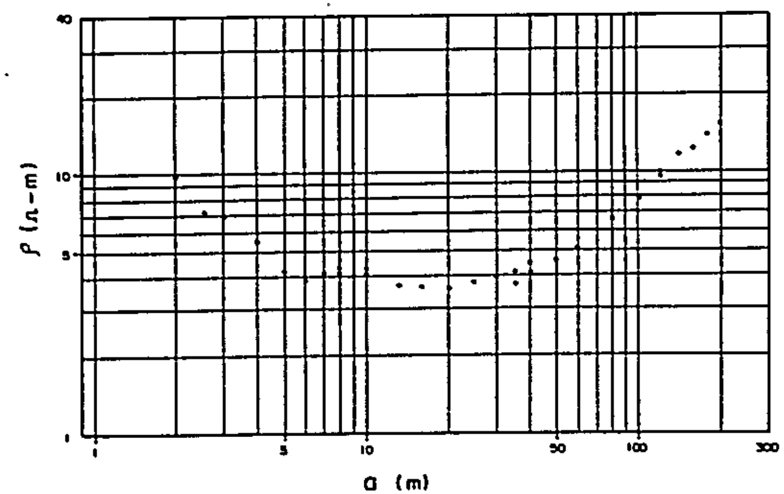
E-11



E-10

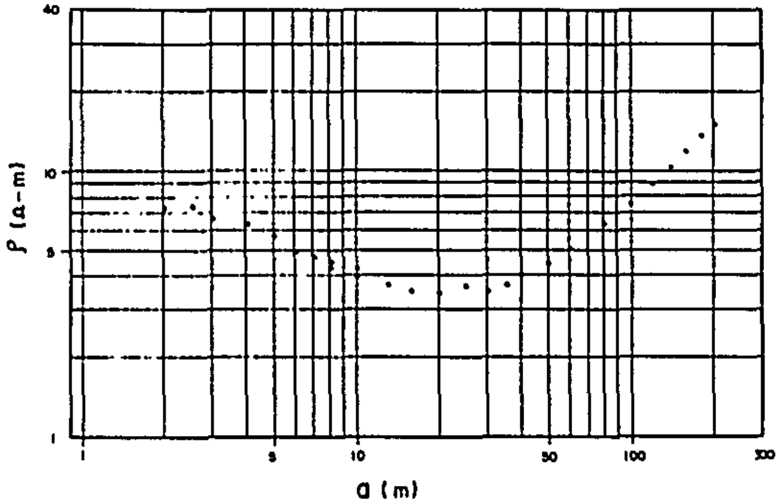


E-12

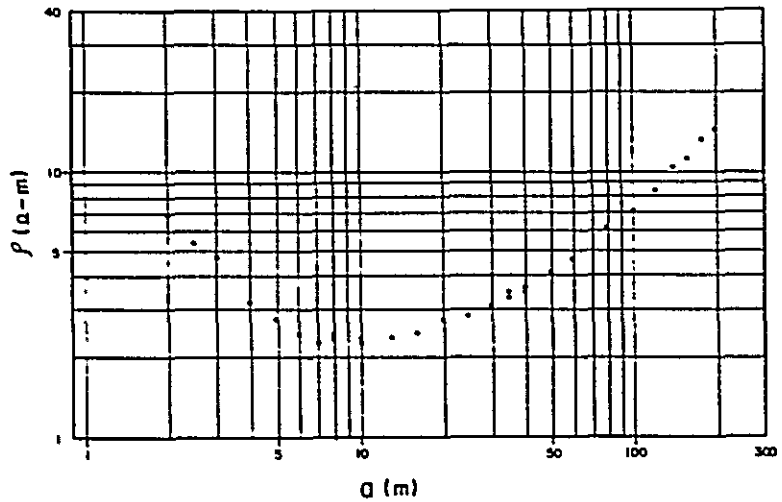


Annex ρ-a Curve (Kahe-Miwaleni Area)

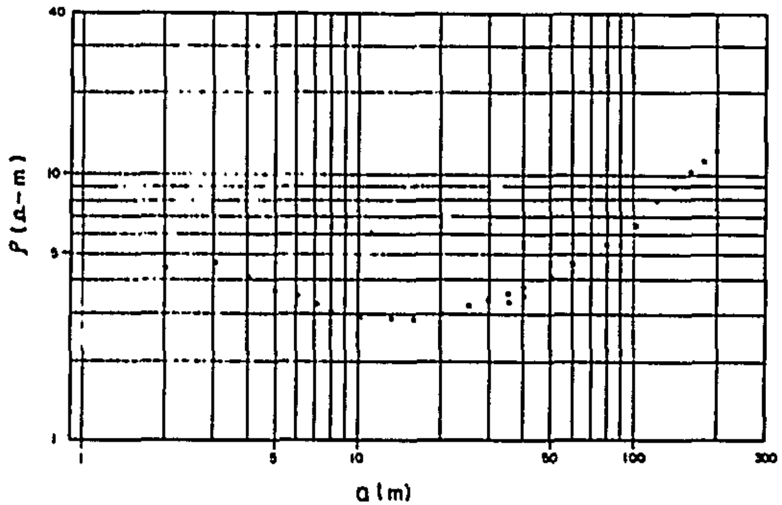
E-13



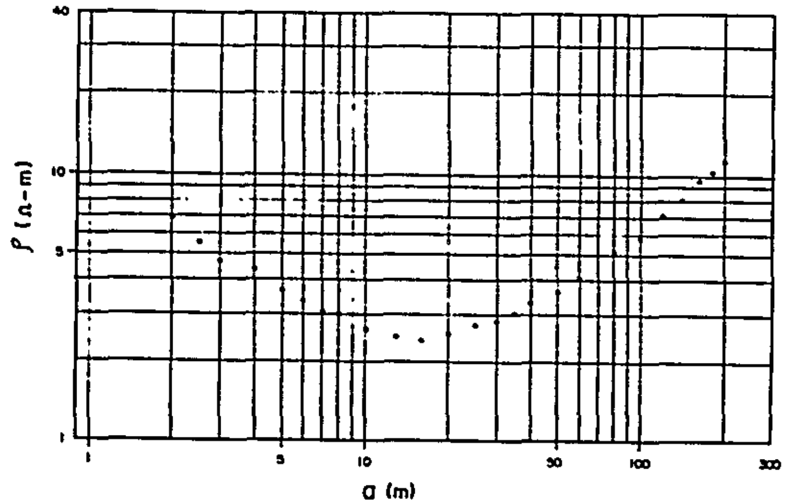
E-15



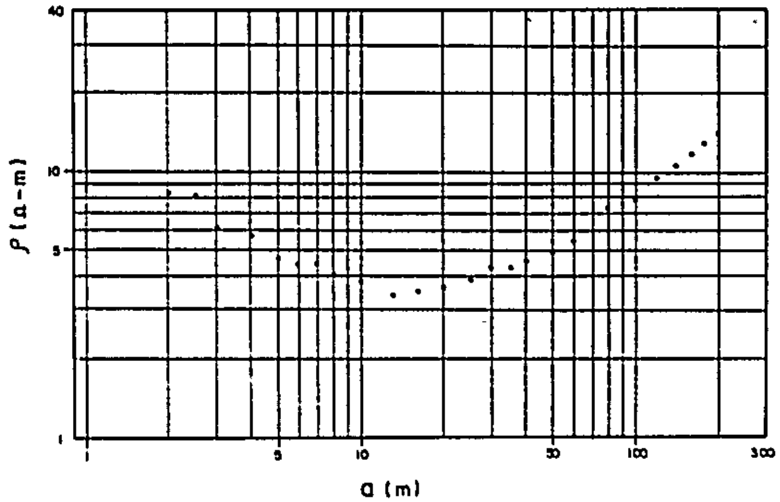
E-14



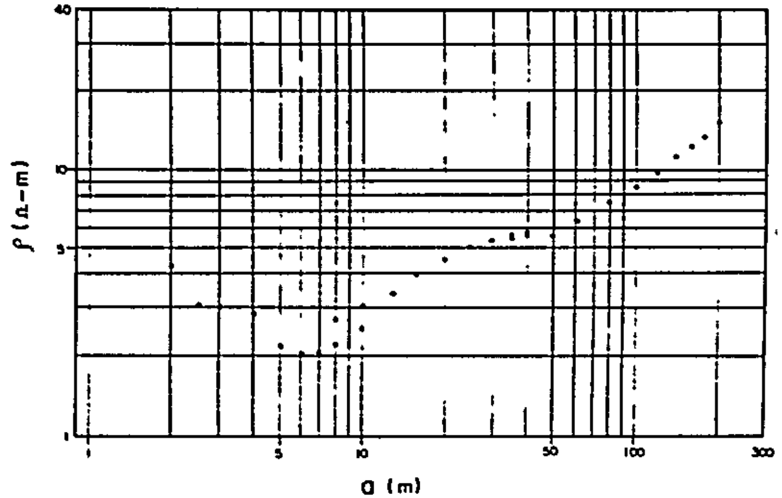
E-16



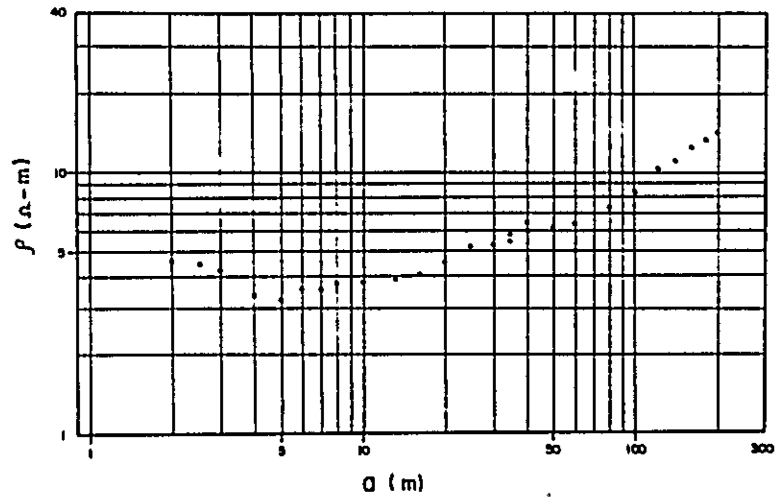
E-17



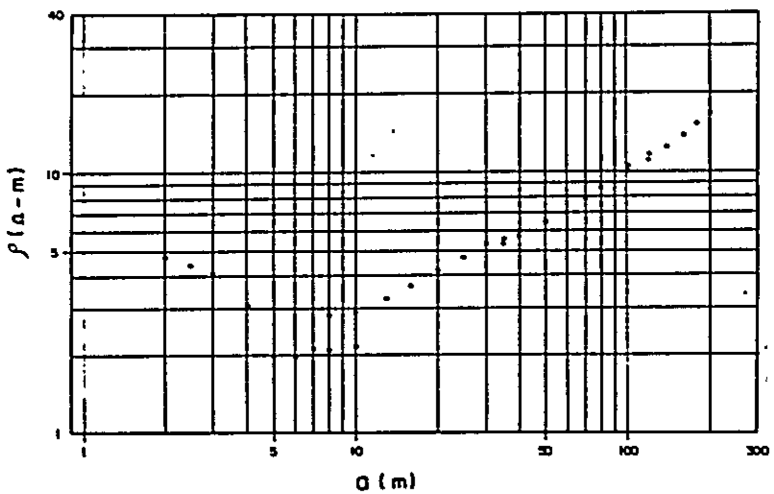
E-19



E-18

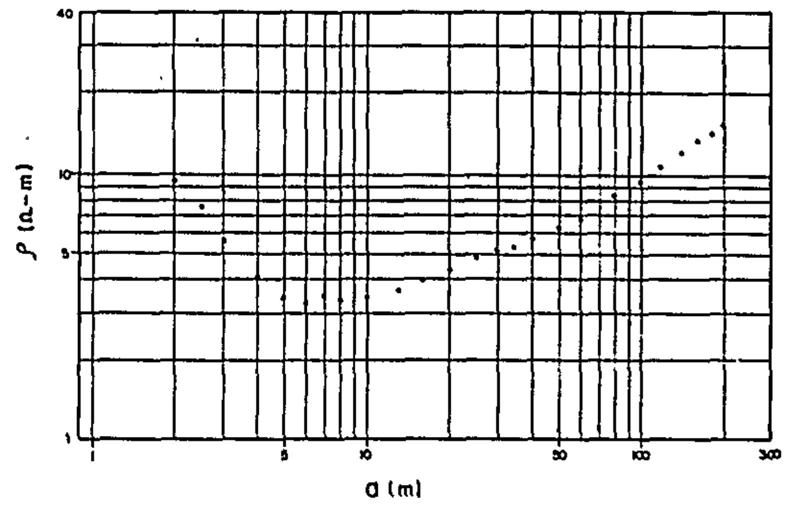


E-20

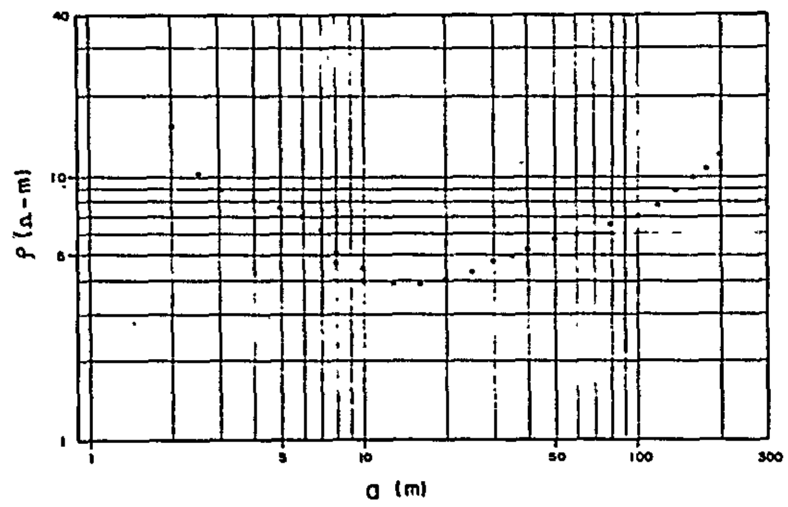


Annex ρ-a Curve (Kahe-Miwaleni Area)

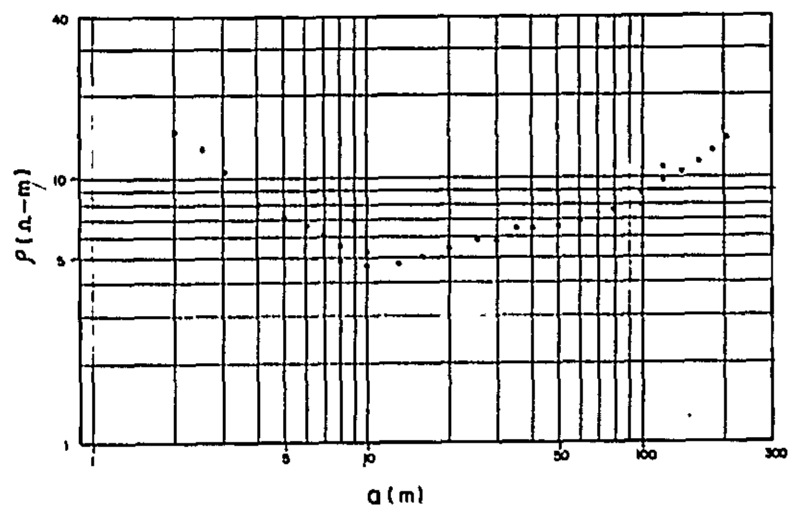
E-21



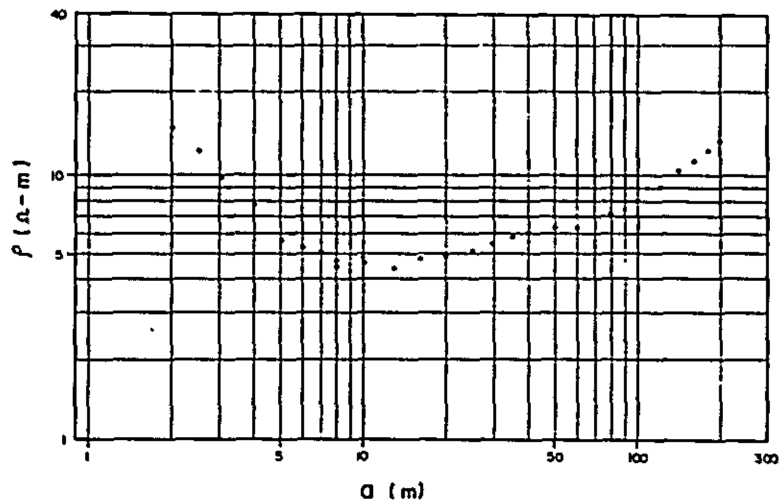
E-23



E-22

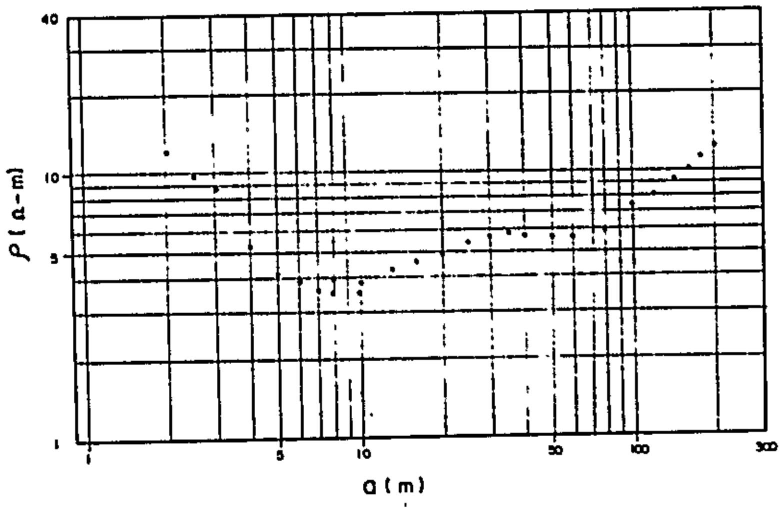


E-24

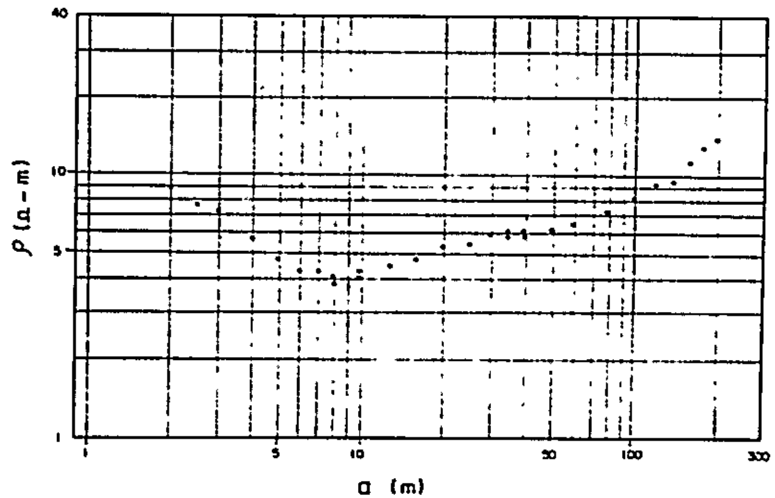


Annex ρ-a Curve (Kahe-Miwaleni Area)

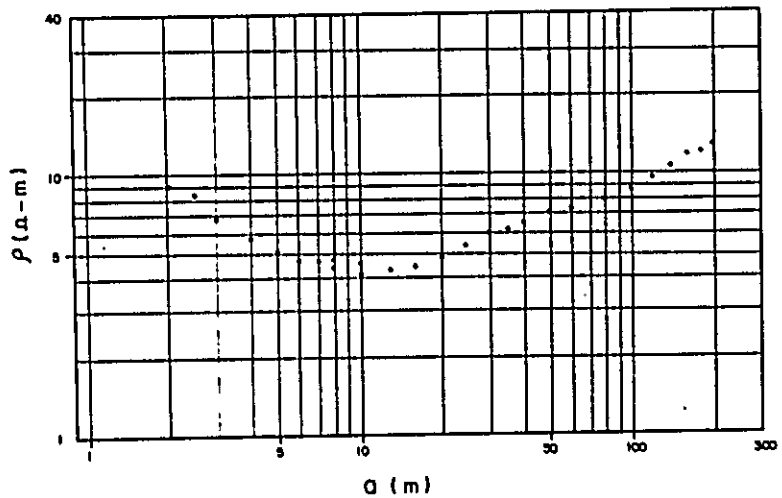
E-25



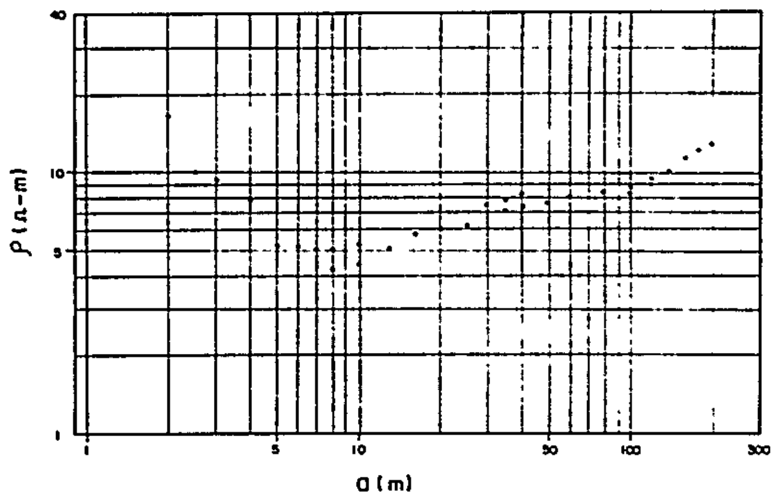
E-27



E-26

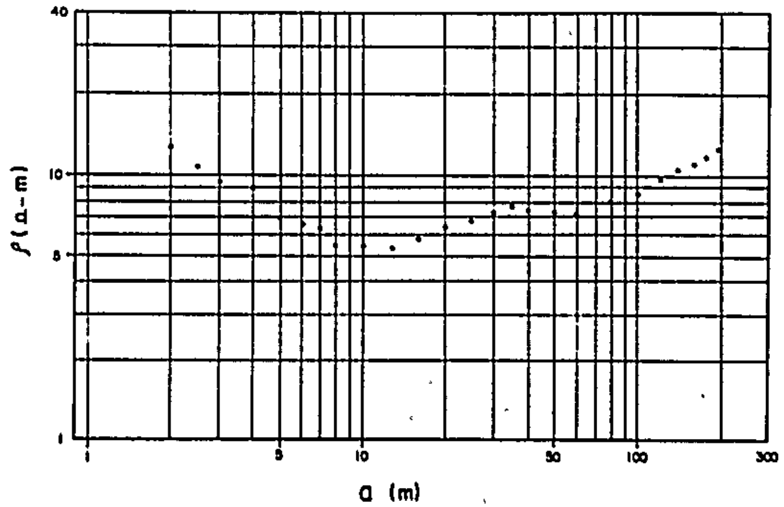


E-28

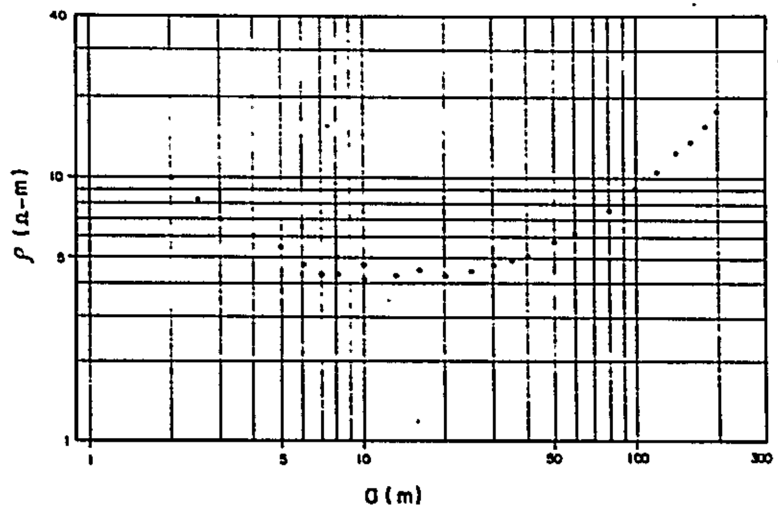


Annex ρ-a Curve (Kahe-Miwaleni Area)

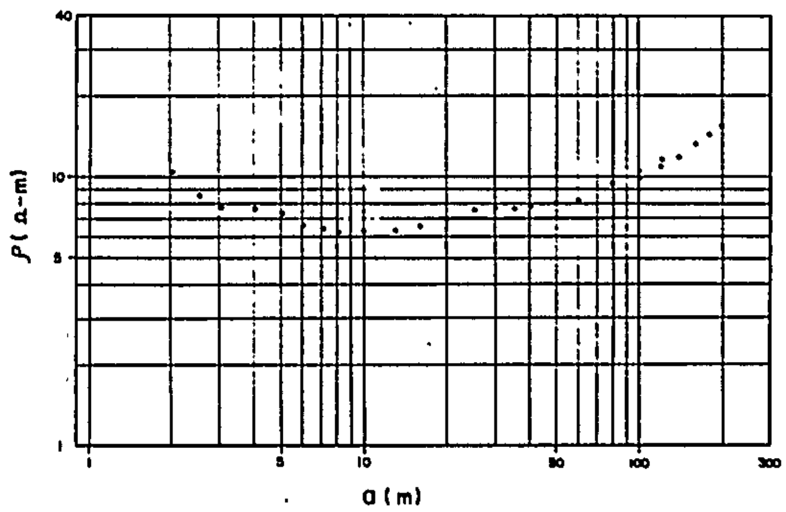
E-29



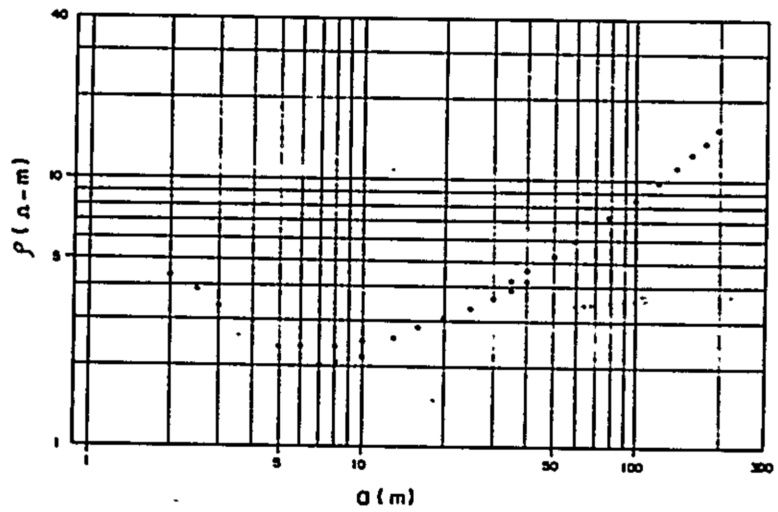
E-31



E-30

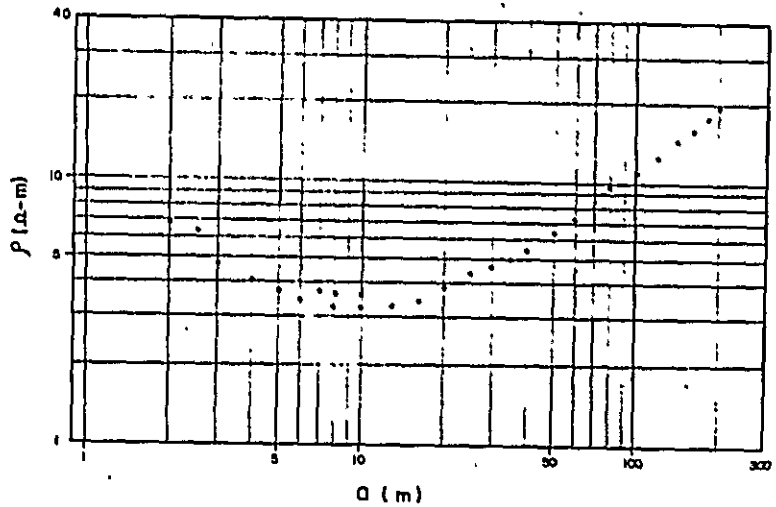


E-32

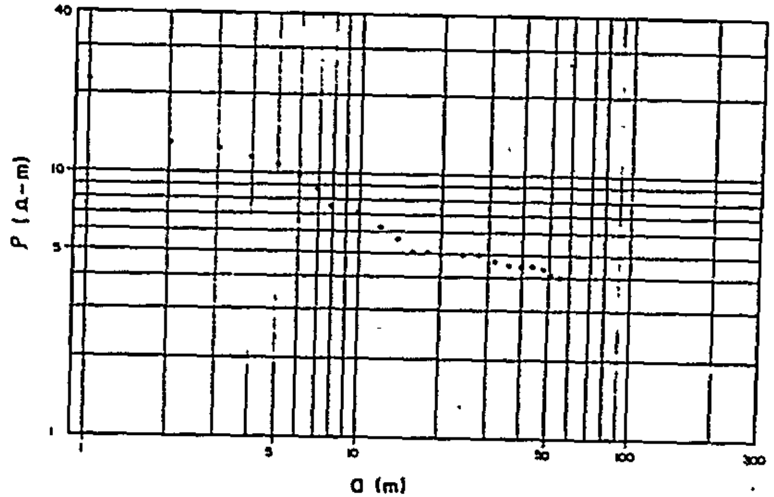


Annex ρ-a Curve (Kahe-Miwaleni Area)

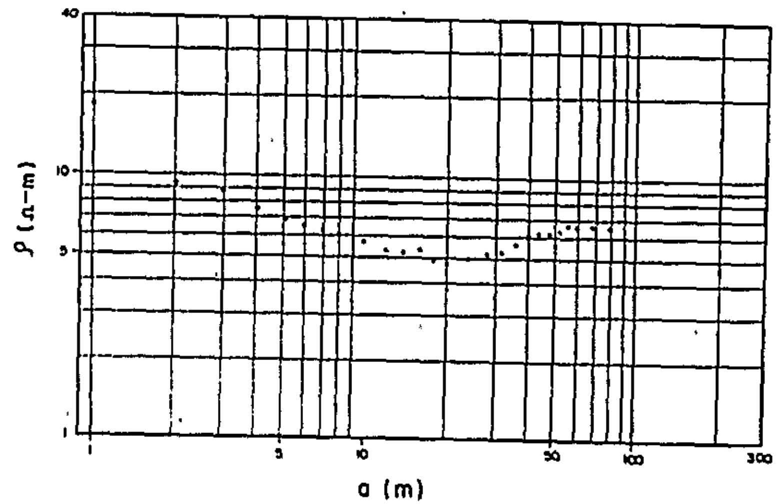
E - 33



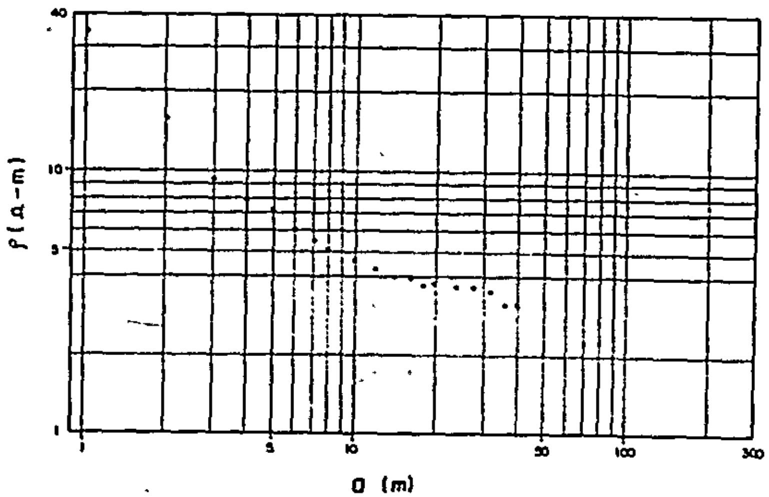
E-35



E - 34

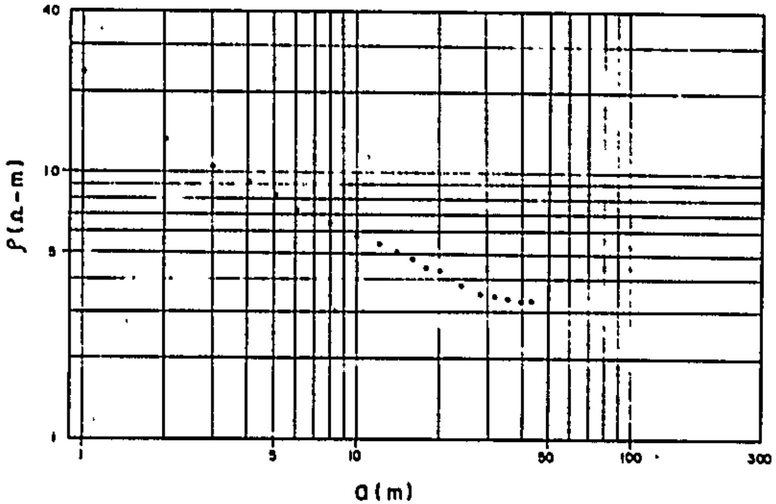


E-36

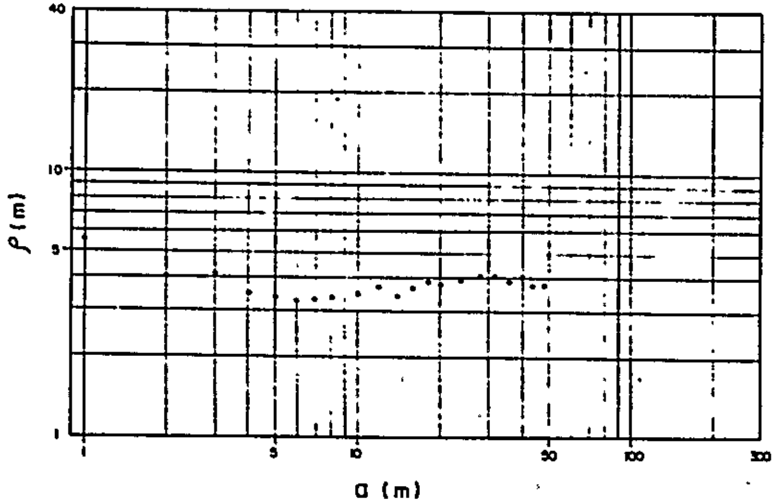


Annex ρ-a Curve (Kahe-Miwaleni Area)

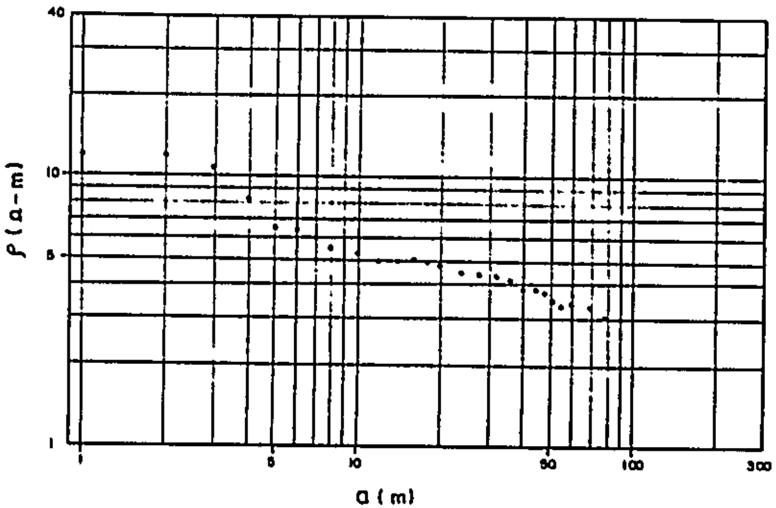
E-37



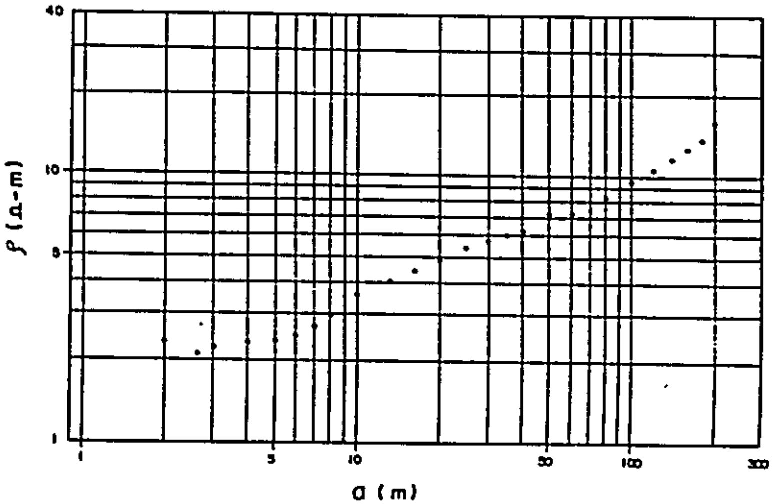
E-39



E-38

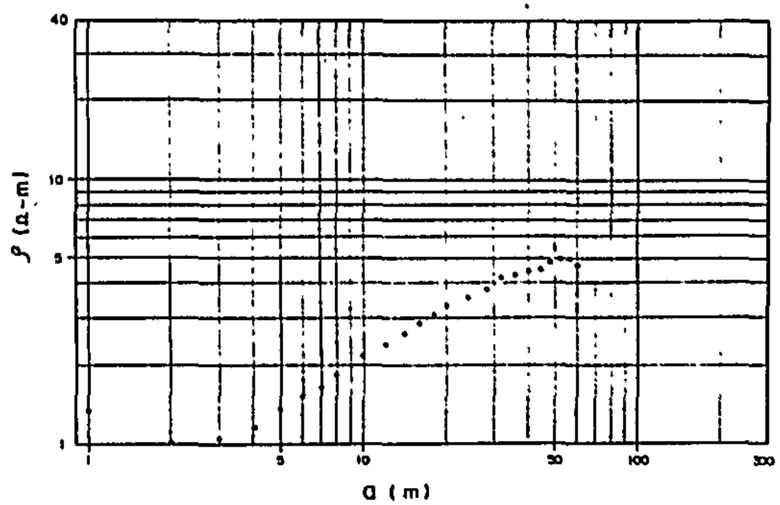


E-40

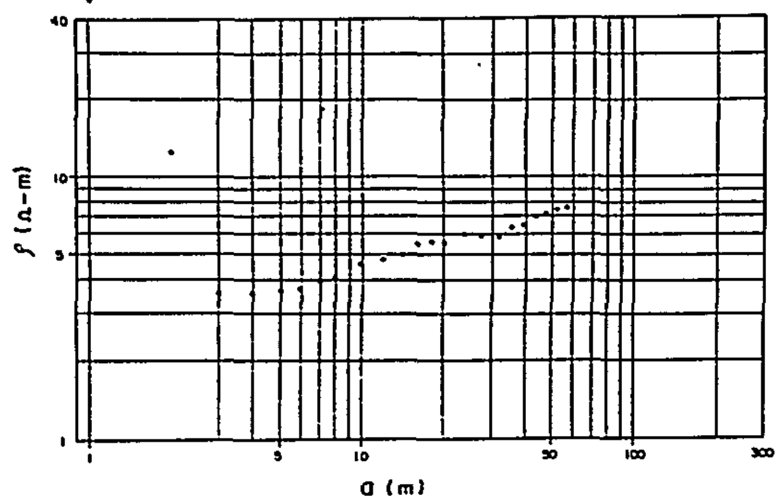


Annex ρ-a Curve (Kahe-Miwaleni Area)

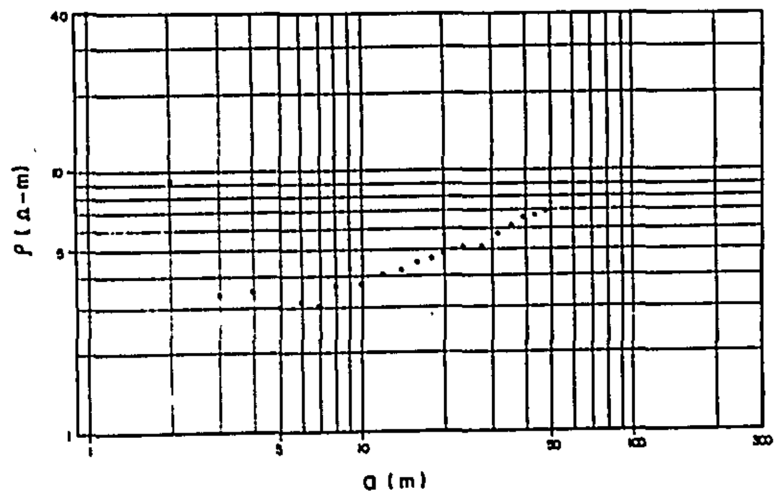
E-41



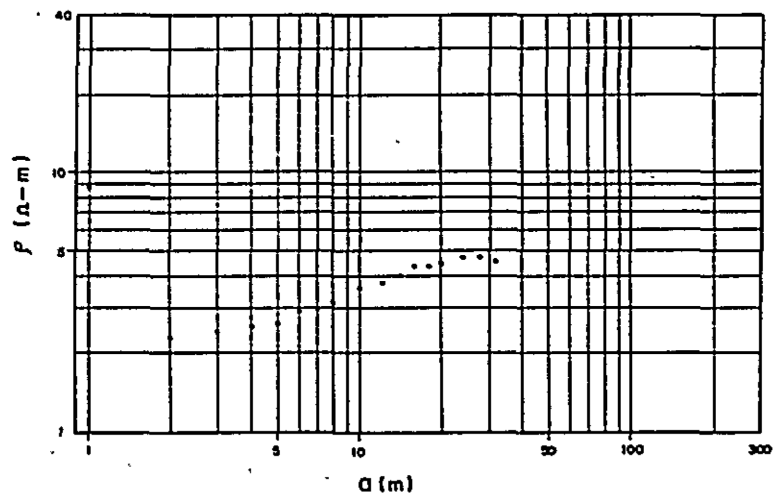
E-43



E-42

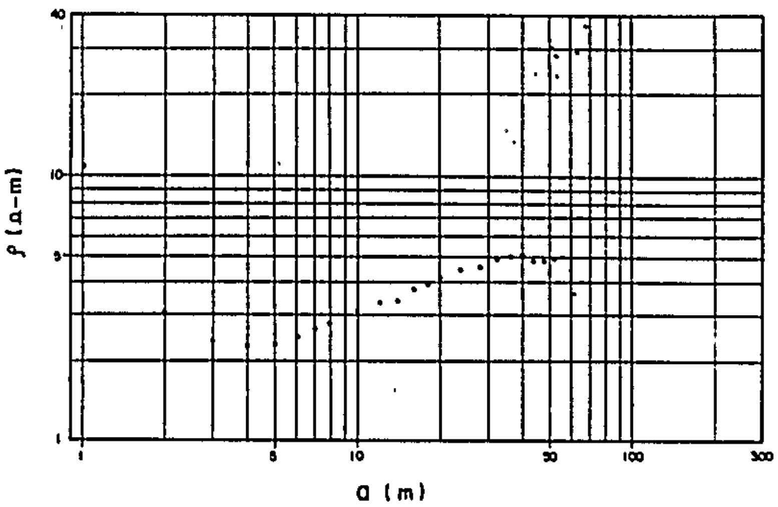


E-44

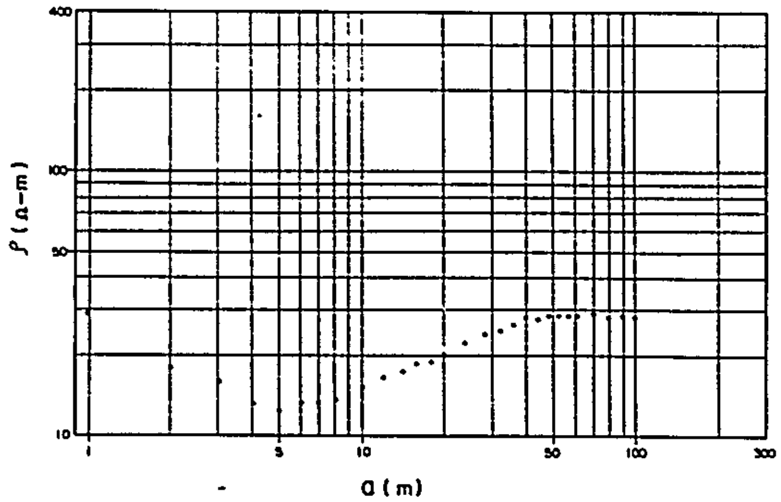


ρ-a Curve (Kahe-Miwaleni Area)

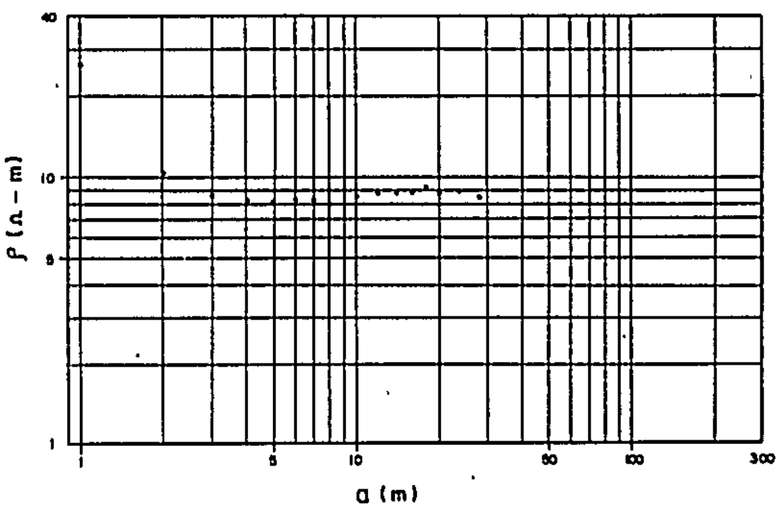
E-45



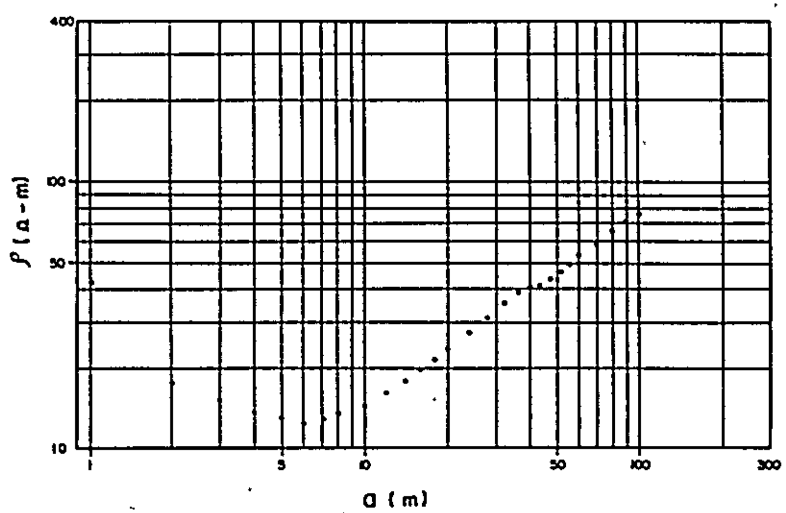
E-47



E-46

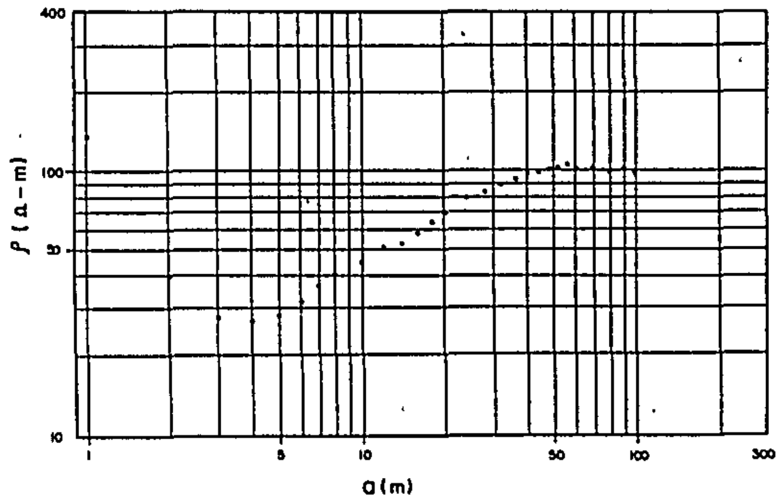


E-48

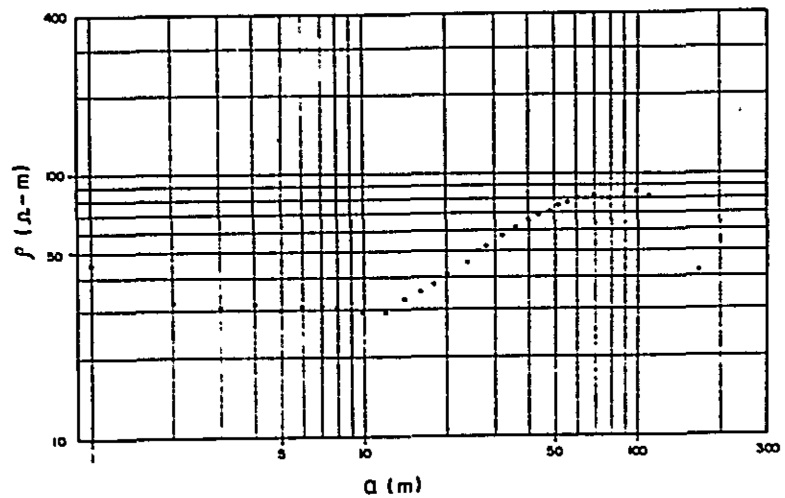


Annex ρ-a Curve (Kahe-Miwaleni Area)

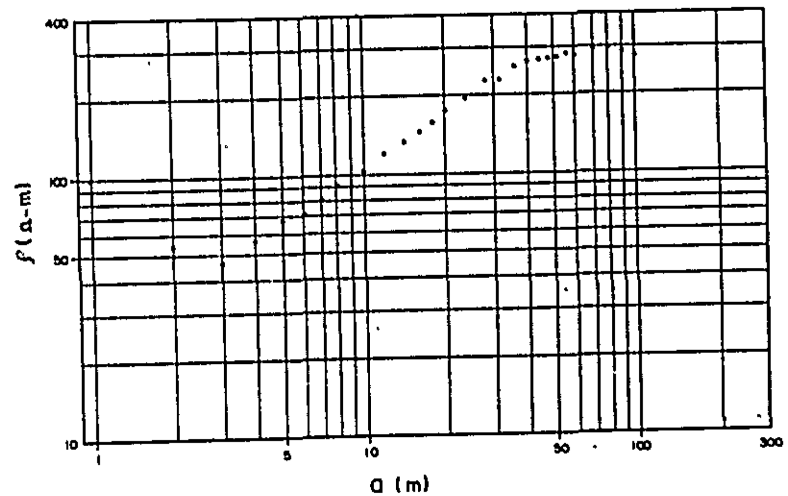
E-49



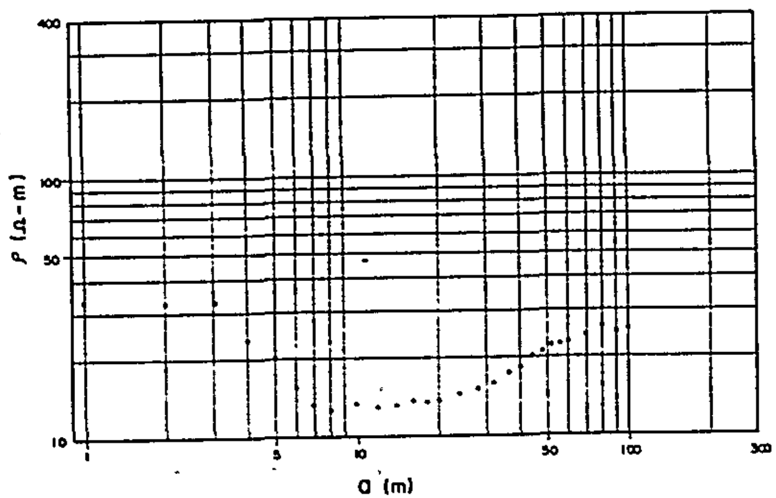
E-51



E-50

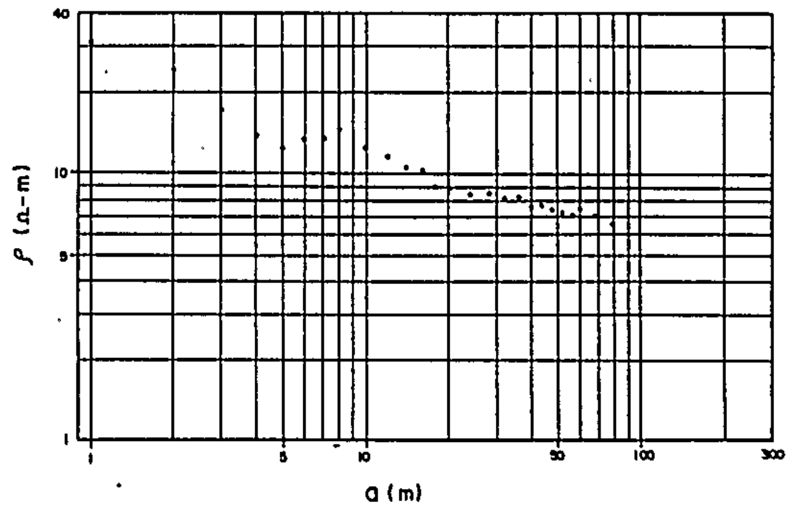


E-52

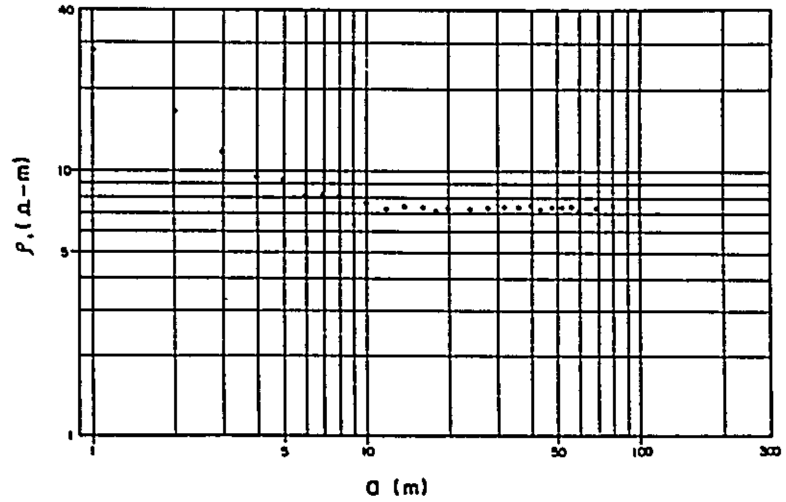


Annex ρ-a Curve :(Kahe-Miwaleni Area)

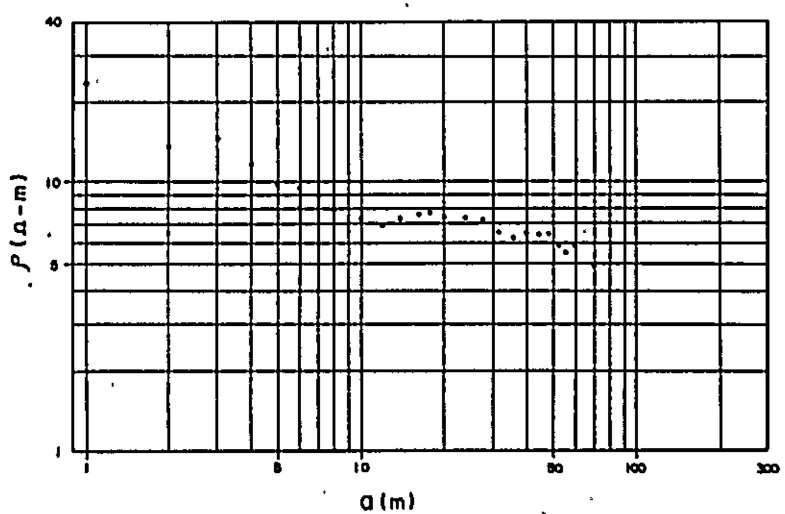
E-53



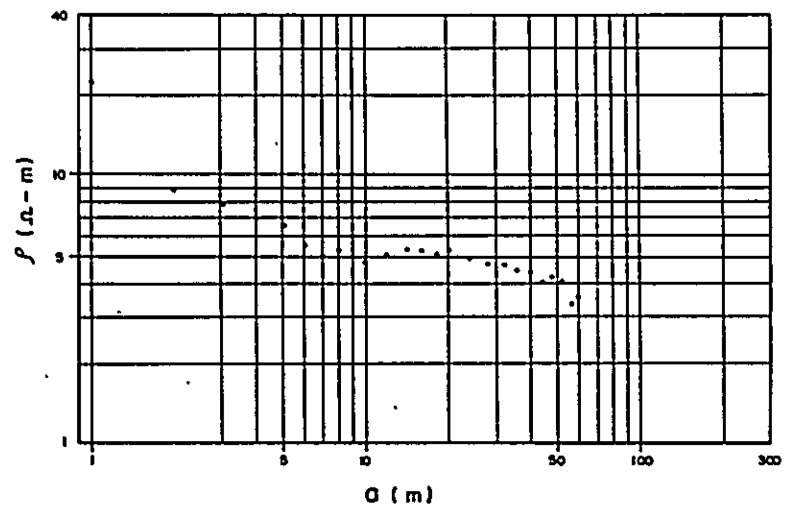
E-55



E-54

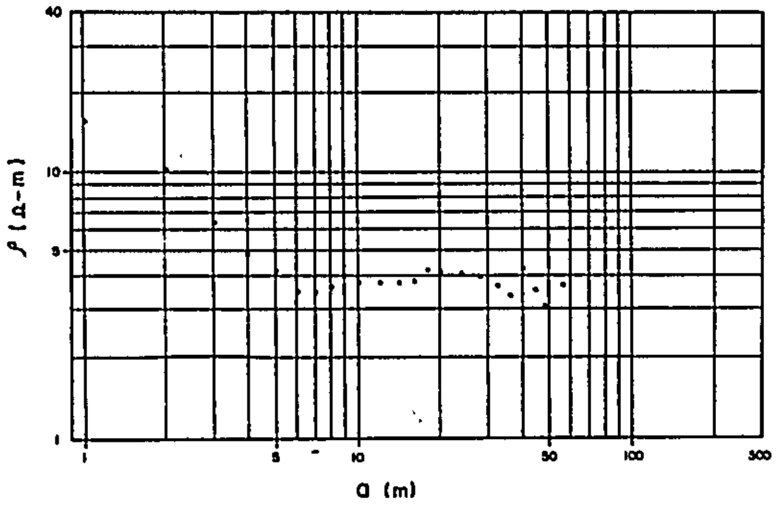


E-56

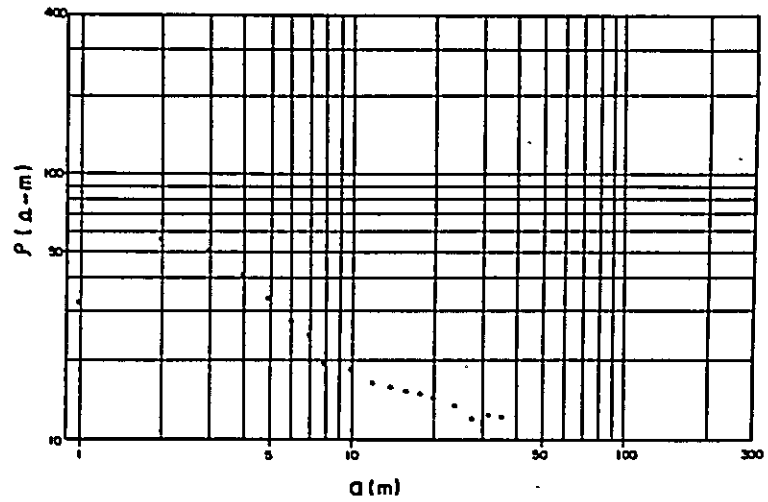


Annex ρ-a Curve :(Kahe-Miwaleni Area)

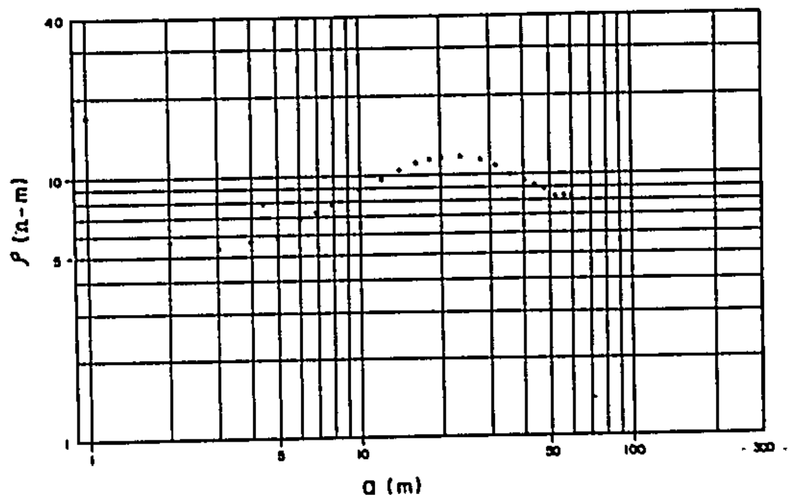
E-57



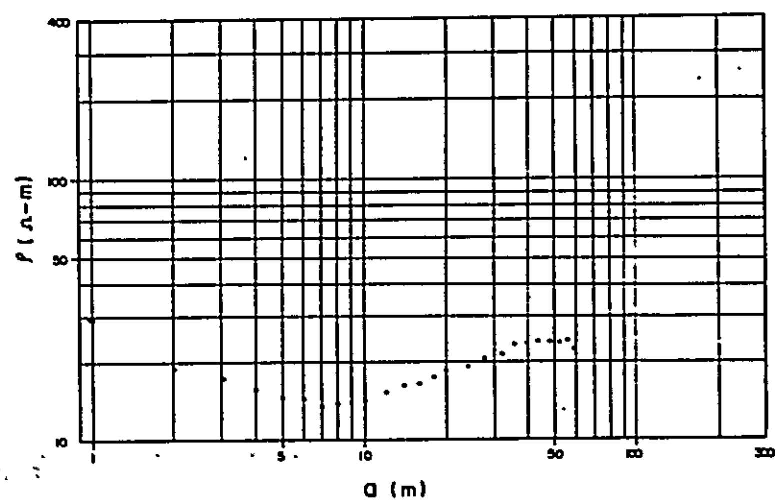
E-59



E-58

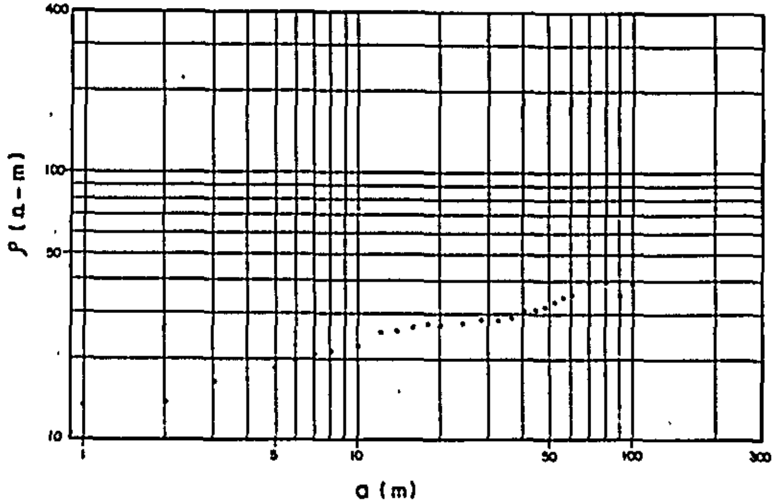


E-60

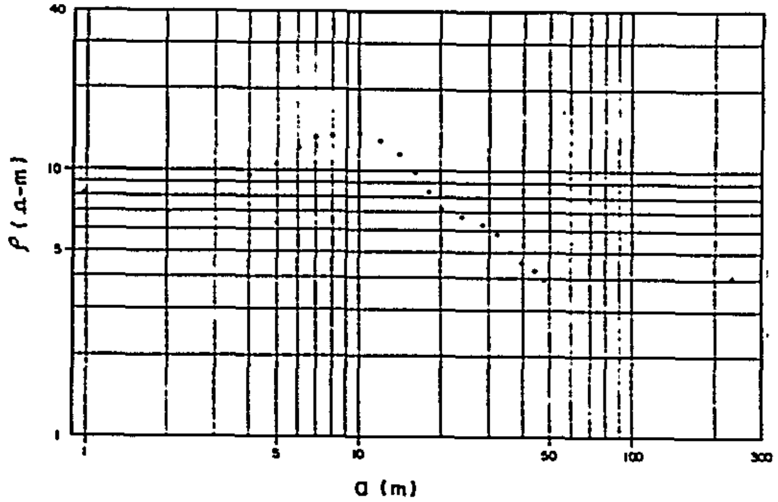


Annex ρ-a Curve (Kahe-Miwaleni Area)

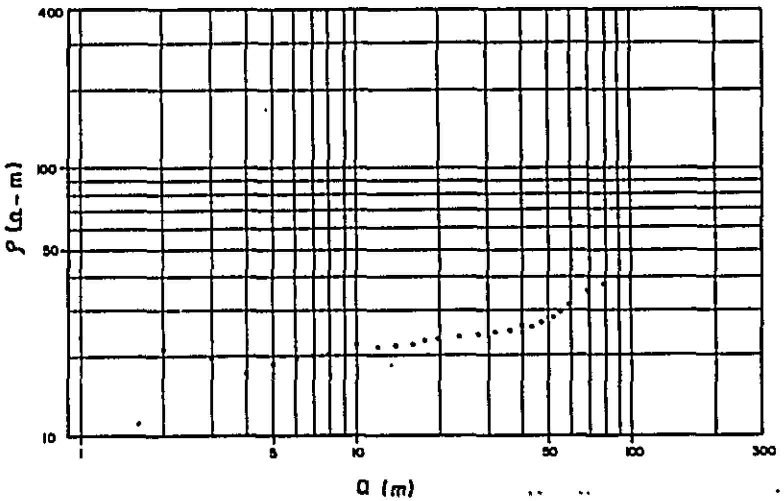
E-61



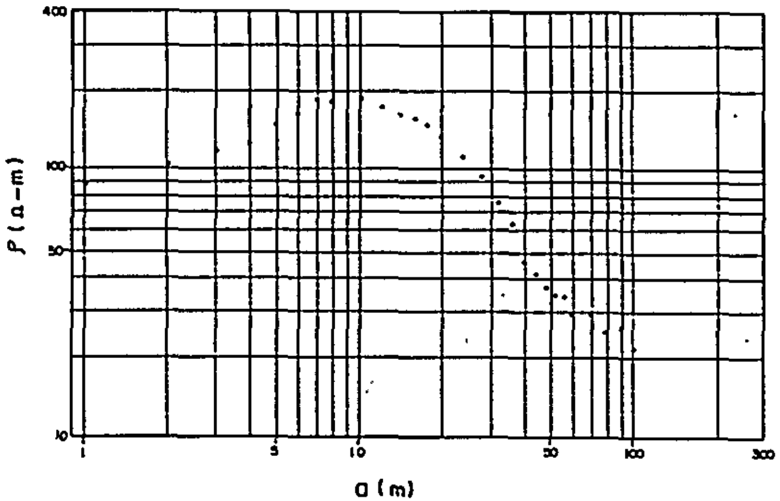
E-63



E-62

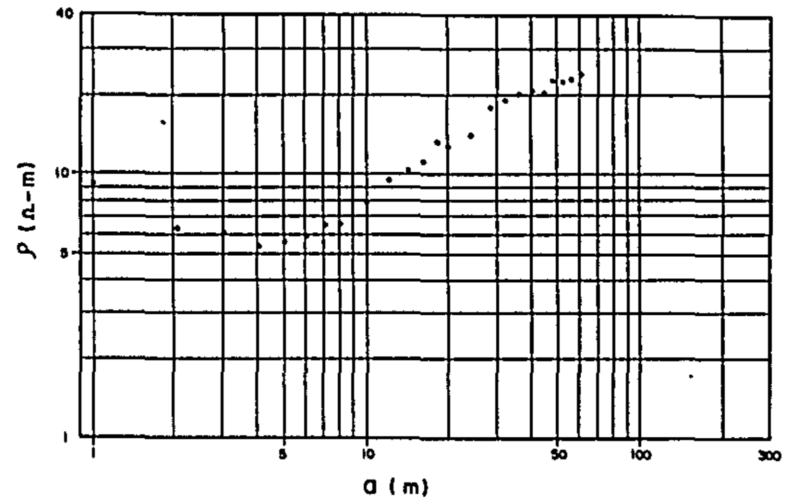


E-64

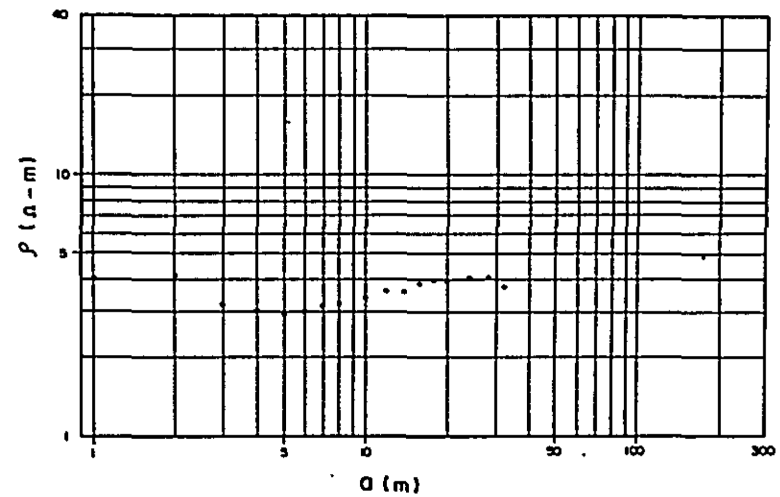


Annex ρ-a Curve (Mkomazi Area)

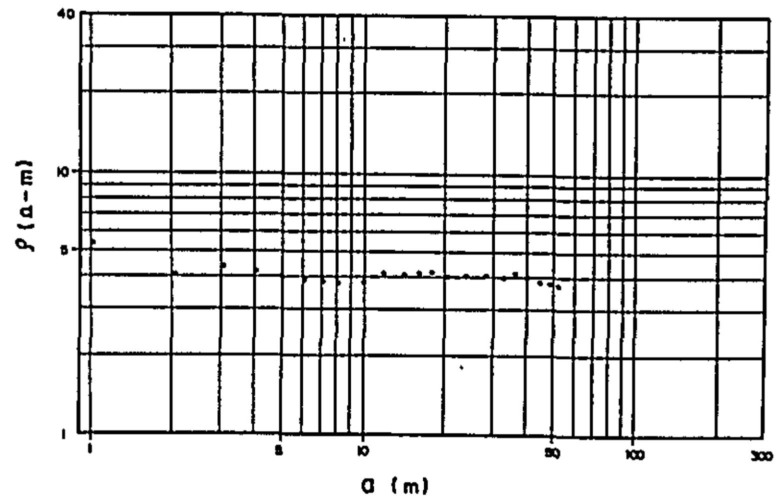
E-65



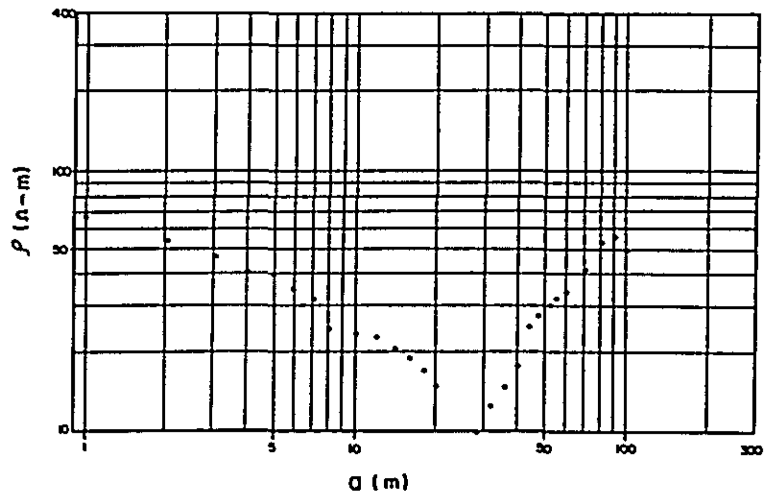
E-67



E-66

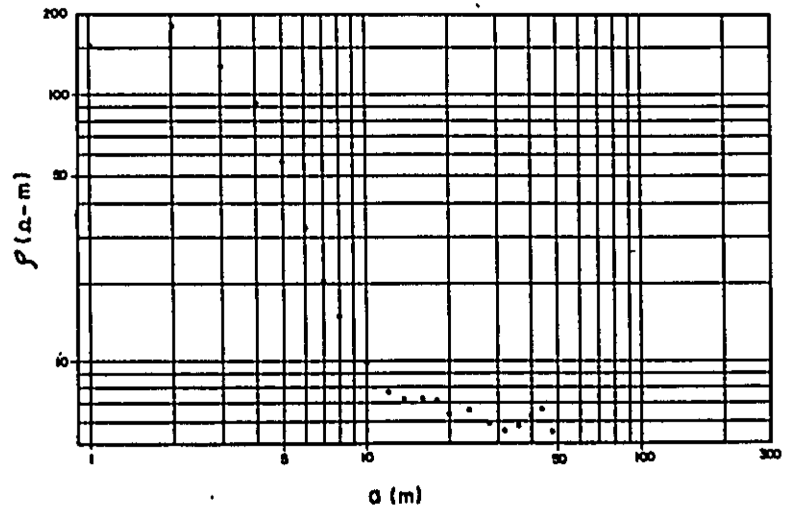


E-68

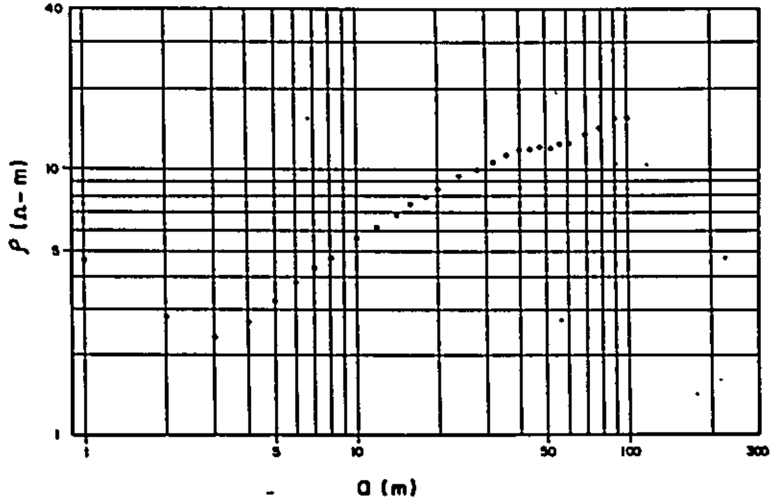


Annex ρ-a Curve (Mkomazi Area)

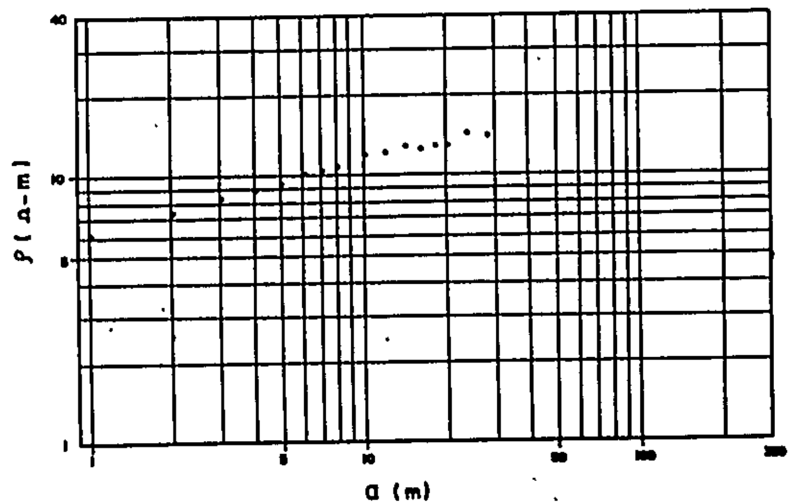
E-69



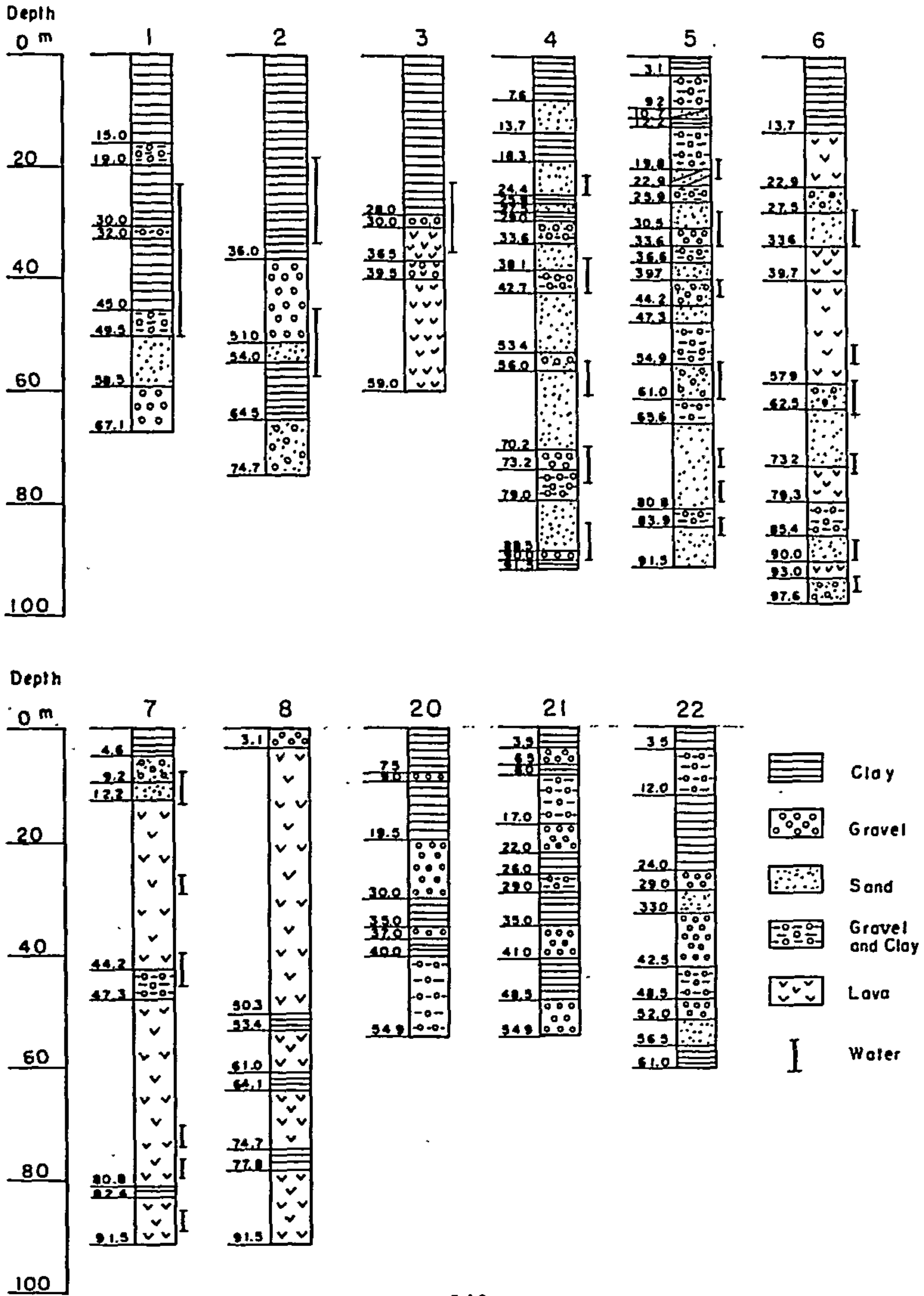
E-71



E-70

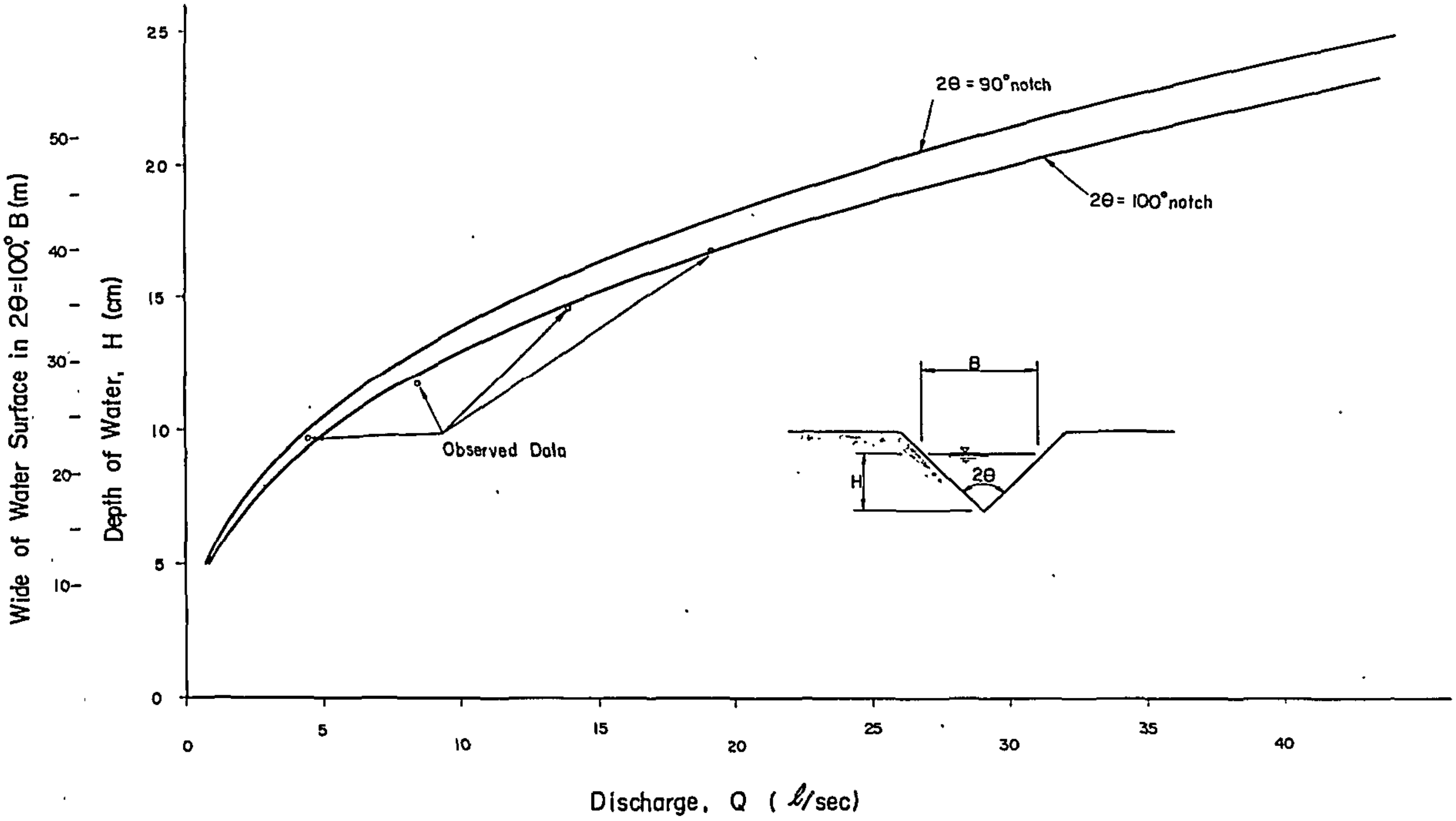


Annex 4 Columnar Section



Annex 5

Discharge Curve of Triangular Weir (2Θ = 100°)

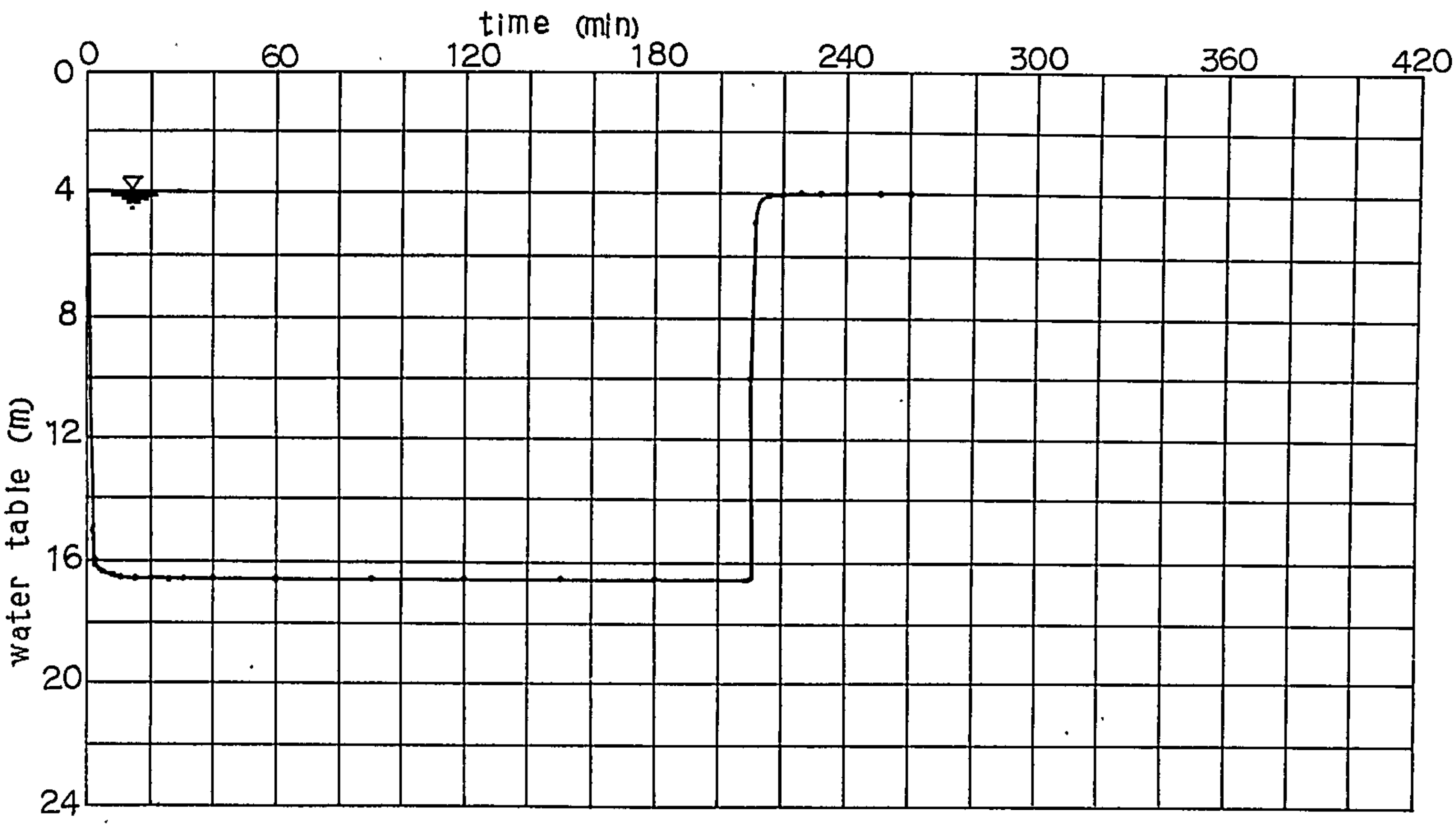


Annex 6

Data of Pumping Test (B.H. No. 1)

Time hr.	Time min.	Time sec.	Time after Pumping Started t (sec.)	Time after Pumping Stoped t' (sec.)	Depth of Water Table from Ground Surface (m)	Draw-down s (m)	t/t'	log t/t'	Radius of Well r (m)	r^2/t	Pumping Rate Q (m^3/sec.)	Remarks
10	00	00	0		4.000	0					0.0234	Pumping Start 10h
	1	15	75		15.000	11.000			0.127	2.151 x 10^{-4}	0.0234	
	3	00	180		16.310	12.310			0.127	8.961 x 10^{-5}	0.0234	
	3	30	210		16.310	12.310			0.127	7.680 x 10^{-5}	0.0234	
	4	00	240		16.335	12.335			0.127	6.720 x 10^{-5}	0.0234	
	4	30	270		16.325	12.325			0.127	5.974 x 10^{-5}	0.0234	
	5	00	300		16.350	12.350			0.127	5.376 x 10^{-5}	0.0234	
	5	30	330		16.350	12.350			0.127	4.89 x 10^{-5}	0.0234	
	6	00	360		16.370	12.370			0.127	4.480 x 10^{-5}	0.0234	
	7	00	420		16.400	12.400			0.127	3.840 x 10^{-5}	0.0234	
	7	30	450		16.410	12.410			0.127	3.584 x 10^{-5}	0.0234	
	8	00	480		16.410	12.410			0.127	3.360 x 10^{-5}	0.0234	
	8	30	510		16.410	12.410			0.127	3.163 x 10^{-5}	0.0234	
	9	00	540		16.430	12.430			0.127	2.987 x 10^{-5}	0.0234	
	9	30	570		16.430	12.430			0.127	2.830 x 10^{-5}	0.0234	
	10	00	600		16.420	12.420			0.127	2.688 x 10^{-5}	0.0234	
	15	00	900		16.450	12.450			0.127	1.792 x 10^{-5}	0.0234	
	20	00	1200		16.450	12.450			0.127	1.344 x 10^{-5}	0.0234	
	25	00	1500		16.460	12.460			0.127	1.075 x 10^{-5}	0.0234	
	30	00	1800		16.475	12.475			0.127	8.961 x 10^{-6}	0.0234	
	35	00	2100		16.460	12.460			0.127	7.680 x 10^{-6}	0.0234	
	40	00	2400		16.460	12.460			0.127	6.720 x 10^{-6}	0.0234	
	45	00	2700		16.465	12.465			0.127	5.974 x 10^{-6}	0.0234	
	50	00	3000		16.465	12.465			0.127	5.376 x 10^{-6}	0.0234	
	55	00	3300		16.460	12.460			0.127	4.888 x 10^{-6}	0.0234	
11	00	00	3600		16.460	12.460			0.127	4.480 x 10^{-6}	0.0234	
	30	00	5400		16.470	12.470			0.127	2.987 x 10^{-6}	0.0234	
12	00	00	7200		16.470	12.470			0.127	2.240 x 10^{-6}	0.0234	
	30	00	9000		16.480	12.480			0.127	1.792 x 10^{-6}	0.0234	
13	00	00	10800		16.475	12.475			0.127	1.493 x 10^{-6}	0.0234	
	25	00	12300		16.460	12.460			0.127	1.311 x 10^{-6}	0.0234	
	30	00	12600	0	16.380	12.380			0.127		0	Pumping Stop 13h 30min
		08	12608	8	10.000	6.000	1616.4	3.208	0.127		0	
		50	12650	50	4.970	0.970	254.0	2.405	0.127		0	
	31	20	12680	80	4.430	0.430	158.9	2.201	0.127		0	
	32	00	12720	120	4.290	0.290	106.0	2.025	0.127		0	
	33	00	12780	180	4.190	0.190	71.0	1.851	0.127		0	
		30	12810	210	4.155	0.155	61.0	1.785	0.127		0	
	34	00	12840	240	4.135	0.135	53.5	1.728	0.127		0	
		30	12870	270	4.125	0.125	47.7	1.678	0.127		0	
	35	00	12900	300	4.095	0.095	43.0	1.633	0.127		0	
	36	00	12960	360	4.090	0.090	36.0	1.556	0.127		0	
	36	30	12990	390	4.070	0.070	33.3	1.523	0.127		0	
	37	00	13020	420	4.065	0.065	31.0	1.491	0.127		0	
		30	13050	450	4.065	0.065	29.0	1.462	0.127		0	
	38	00	13080	480	4.060	0.060	27.25	1.435	0.127		0	
	39	00	13140	540	4.050	0.050	24.3	1.386	0.127		0	
	40	00	13200	600	4.045	0.045	22.0	1.342	0.127		0	
	41	00	13260	660	4.040	0.040	20.1	1.303	0.127		0	
	42	00	13320	720	4.040	0.040	18.5	1.267	0.127		0	
	43	00	13380	780	4.030	0.030	17.2	1.234	0.127		0	
	44	00	13440	840	4.030	0.030	16.0	1.204	0.127		0	
	45	00	13500	900	4.025	0.025	15.0	1.176	0.127		0	
	46	00	13560	960	4.020	0.020	14.1	1.150	0.127		0	
	47	00	13620	1020	4.013	0.013	13.4	1.126	0.127		0	
	48	00	13680	1080	4.010	0.010	12.7	1.103	0.127		0	
	49	00	13740	1140	4.005	0.005	12.1	1.081	0.127		0	
	50	00	13800	1200	4.000	0	11.5	1.061	0.127		0	

Annex 7 Pumping Test Curve



Annex 8		Data of Pumping Test (B. H-№2)		
Recovery Time		Depth of Water Table from Ground Surface (m)	Drawdown s (m)	Remarks
min.	sec.			
0		5.49	0	Q = 0.0273 m^3/sec.
10'	600	9.15	3.660	
15'	900	12.2	6.710	
300'	18,000	14.945	9.455	
320'	19,200	15.25	9.760	

Annex 9		Data of Pumping Test (B. H-№3)		
Recovery Time		Depth of Water Table from Ground Surface (m)	Drawdown s (m)	Remarks
min.	sec.			
0		2.135	0	Q=0.0218 m^3/sec
	30"	15.25	13.115	
1'50"	110"	24.4	22.265	
12'50"	770"	25.315	23.180	
1°	3600"	25.315	23.180	