are satisfactory for use as rootstocks but nurserymen must be adequately trained in order to be able to graft and topwork macadamia on a large scale. Training of nurserymen to the rather specific techniques required in grafting macadamias successfully is absolutely necessary. Without adequately trained nurserymen who have some actual experience in grafting macadamia, any large scale attempt to graft or topwork seedling trees will probably fail.

8. Areas such as Kisii and Kitale districts have an annual rainfall of 1,500m/m or more, well distributed over most of the year, and a relatively short dry season. They are considered more suitable for growing macadamia nuts than those with less rain or a longer dry season. Areas such as Thaika and Machakos with a bimodal rainfall pattern may also be suitable for macadamia nut growing but for best results would probably require some supplemental irrigation during the driest period of the year.

9. Areas too high or too cool for successful coffee growing as well as those with mean monthly maximum temperatures above 90°F 1/, for more than two months of the year, are questionable and probably would be marginal sites for macadamia growing.

10. Of current interest and immediate importance to growers, cooperatives, Ministry of Agriculture officials and others concerned is the marketing and utilization of the current crop of nuts to the best possible advantage. There are largely M. tetraphylla nuts from many small seedling orchards planted in highland areas. In spite of their low production per tree, relatively low oil content of kernels and variability in shape, size and shell thickness of nuts, it is estimated that approximately 60 percent of the Kernels produced could be utilized as dessert nuts provided they are handled correctly. This involves several critical operations from harvesting through packing for retail and includes the following steps:

a) Nuts should be harvested weekly or at least within two weeks after they mature and fall from the trees. They should be husked within 24 hours after harvesting and air dried in shade for 10 days to two weeks before marketing.

b) Nuts should be handled rapidly enough so that they can be cracked, processed and packed not more than three to four months after harvesting. Speed in handling and marketing in-shell nuts by the farmer is necessary to avoid spoilage and/or ransidity which renders the nuts unfit for processing and human consumption. A small proportion of mouldy, rancid or spoiled nuts will make an entire stock of nuts unfit for processing. The entire lot is then fit only for use as animal food.

1/ 90°F = 32.2°C

c) Nuts received by processor or cooperative should be dried at not more than 115°F, 1/, for about 72 hours or until they contain approximately 1 1/2 percent moisture by weight.

d) The dried nuts should be cracked, roasted and vacuum sealed before they again take up additional moisture from the atmosphere.

e) Conventional macadamia nut cracking machinery and methods developed for M. integrifolia nuts will probably need considerable modification and adapting for cracking M. tetraphylla nuts, which differ considerably in size shape, shell thickness and shell consistency from those of M. integrifolia.

f) Kernels obtained should be graded to a minimum of approximately 67.5 percent oil by the floutation method, using a 1.025 specific gravity solution of sodium chloride.

g) Grade 1 kernels having a minimum oil content of about 67.5 percent should be redried, cooked in oil or dry roasted at appropriate temperatures, coated with an adhesive, salted with finely ground popcorn salt and finally vacuum sealed in attractive containers for retail marketing. As an alternative packing and marketing procedure, well dried, uncooked, grade 1 kernels with a minimum oil content of 70 percent can be marketed or successfully stored under refrigeration for at least six months depending on the storage temperature and quality of nuts involved.

11. In connection with immediate and pressing problems involved in the processing, storage and utilization of present production of M. tetraphylla nuts, an effort should be made to secure the services of the best qualified consultants available.

12. Existing seedling plantings may be looked upon as a stopgap, providing a good source of information and practical experience on cultural problems. They should not, however, be considered as improved orchards since their potential is low compared to improved clonal orchards of M. integrifolia, the preferred commercial type for production of processed nuts. It is estimated that the maximum potential production of nuts per area from seedling M. tetraphylla orchards is less than 25 percent of that expected from clonal M. integrifolia orchards of comparable age and condition. The percent kernel recovery from seedling M. tetraphylla nuts was about 29 percent by weight (Appendix I). It is estimated that about 65 percent of these kernels contained at least 67.5 percent oil and could be processed into a satisfactory dessert nut pack (Appendix I). M. integrifolia nuts of commercial varieties would be

1/ 115°F = 46°c

expected to give about 40 percent kernel recovery, about 90 percent of which contain 72 percent or more of oil. Even if a lower oil content of 67.5 instead of 72 percent is accepted in grading M. tetraphylla nuts, one acre 1/ of grafted M. integrifolias would produce a yield of usable kernels equal to that from approximately 7.3ac. of tetrapohylla seedlings of similar conditions and age. Assuming a yield per acre for mature grafted M. integrifolia trees of 4,000 pounds 2/ of in-shell nuts valued at 1.80 Sh 3/, per pound, the computed value of grade 1 kernels would be 7,200 Sh per acre. This can be compared with a computed value of 906 Sh per acre for usable grade 1 & 2 kernels from comparable M. tetraphylla seedling trees under similar conditions. Figured on a percentage basis, an acre of M. tetraphylla seedlings in full production could only be expected to produce about 15 percent or less gross income per acre as an acre of good grafted M. integrifolia trees of similar age under comparable growing conditions. Even when the comparatively low oil content of 67.5 percent is accepted for seedling M. tetraphylla kernels, the comparative advantage of planting grafted M. integrifolia trees is obvious. The implication is clear that seedling M. tetraphyllas, because of their low yields, extreme variability and comparatively low kernel quality, are not suitable for establishing commercial orchards. They should, therefore, not be planted except for home use as a fresh nut or as rootstocks for improved varieties of M. integrifolia, the preferred commercial type.

13. The relative potential return per acre from alternative crops should be considered objectively in comparison with that obtainable from macadamia nuts. This is particularly pertinent since the type of Macadamia tetraphylla seedling widely planted and now coming into production probably has a lower potential gross income per acre than some of the possible alternative crops such as pyrethrum, passion fruit, corn, avocados and coffee.

1/ 1 ac = 0.4047 ha
2/ 1 lb = 0.45369 kg
3/ 1 US$ = 7.14 Kenya Shillings

PHYSICAL CONDITIONS OF THE PROJECT SITE

1. Topography and Geology

The proposed Project site is situated at the southern end of Murang'a District, Central Province. Central Province is a mountainous area bordered by Mount Kenya on the northeast and the Aberdare Range (Nyandarua Mountains) on the west. The latter extends 70km from north to south, with an altitude range of 3,000-4,000m above sea level. Mount Oldoinyo Lesatima is situated at the northern end of the said range while Mount Elephant is located at the southern end, northwest of the Project site. It is from this mountain that the Thika River, which flows close to the Project site, originates.

The lower slope of the Aberdare Range, surrounded by the towns of Nyeri, Murang'a, Thika, Kiambu and Limuru, is a volcanic field of the Aberdares, having an altitude of 1,500-2,100m. This area presents an undulating belt with an average length of 40km, dissected by numerous parallel river valleys which include the Thika, Maragua, Mathioya and Gura rivers. The Project area is located at the lowest edge of the volcanic field where the average land slope is about 1/150.

As shown in the topographic map, the area is undulating with a maximum elevation difference of 10m. An existing non-paved road, 4m in width, passes through the said areas. Presently, the higher areas are used as experimental farms for macadamia nuts, avocados, grapes and vegatables, while the lower areas, which become swampy during the wet season, remain unutilized except to provide a windbreak forest for the existing macadamia farm.

To take advantage of the natural topography in the layout of Project facilities, the main building will preferably be located at a higher elevation along the existing road in the east of the area, while the proposed experimental farm will partially utilize existing farmland. At present, drainage canals for the experimental farm do not exist and accordingly, drainage water is conveyed to the lower swampy area utilizing the natural slopes.

Lavas of Tertiary age are exposed at the Project site and a volcanic association which is related to volcanicity in the region of the Aberdare Mountains is also present. The Trachytic Tuff Series, which includes agglomerates and claystones are exposed in the Thika riverbed. Commonly these tuffs overlie basalt agglomerates of the Simbara Series. The geological formation of the area is provided below.

<u>Tertiary</u>

- Lava
- Trachytic tuffs with thin basalt flows
- Welded tuffs
- Upper Thika building stone
- Lake beds
- Coarse agglomerates
- Lower Thika building stone
- Basalts and agglomerates
- Kapiti Phonolite

<u>Precambrian</u>

- Basement System

The sequence from trachytic tuff to lower Thika building stone is about 30m thick.

2. Soil

The soil of the Project area is classified into reddish laterite derived from pyroclastic flow of Tuffs. Although partial outcroppings of country rock occur in several areas along the Thika River, the depth of the soil layer ranges from 0-120cm. Due to topography, soil in the upland area on the left bank of the Thika is well-drained whereas soil in the bottomlands further left of the same becomes waterlogged during the wet season. From the comparatively poor drainage in the latter area it may be assumed that the effects of water logging persist into the early part of the dry season and consequently the area is generally considered unsuitable for agriculture.

The Project area can be broadly divided into 3 blocks with due consideration of soil types, land classes and topography as shown in Fig. 1 and briefly presented below;

Block 1: a narrow strip of alluvial soil along the river terrace on the left bank of the Thika

Block 2: upland area adjoining the above terrace

Block 3: poorly drained bottomland behind the upland area

Block 1: In this section the fluvisols are distributed, along the Thika River, which is relatively deep with good drainage. However, the area is also subject to frequent flooding during the wet season and consequently suffers from severe erosion.

Block 2: This section which borders the Thika can be further subdivided into 2 main topographical areas; Block 2-1 the steeply inclined (3-25^{o}) area directly adjoining the river and river terrace, and Block 2-2 the gently sloping area further east. The soil of these 2 areas is broadly classified into 2 types, humic acrisols (U5) and dystric nitosols (U1, U2) respectively. In the steeper area, the country rock is frequently exposed and areas of thinly distributed topsoil are widespread due to erosion caused by heavy rains during the wet season.

Soil on the more gently inclined slope (Block 2-2), on the other hand, is much deeper with good drainage and is considered ideally suited for cultivation.

Block 3: This section mainly consists of humic cambisols and humic gleysols, and becomes waterlogged during the wet season. Due to the poor drainage capacity of the same, the possibility of using the area for cultivation is low.

Detailed soil properties for each area are as shown in Table-1. Alluvial and upland area soils are dark red to dark brown in color while those in the bottomlands range from dark grey to dark greyish brown. Soil pH tests revealed no great variation in the acidity of soil according to area, and overall, soils were slightly acid.

Judging from various factors such as soil depth, soil properties, and soil conditions, discussed above, soil in the upland areas, ie. dystric nitosols classfied as U1 and U2, are most suitable for cultivation.

3. Meteorology

(1) General

The seasons of Kenya are governed by the sun's movement. The sun is approximately directly overhead at the end of March, and again at the end of September, and a rainy season occurs a month after each of these respective periods in April/May and October/November. When the sun is over the Tropic of Cancer in July, the southeast trade winds are predominant and accordingly, widespread stratiform clouds frequently form on the eastern mountain slopes, while in January when the sun is over the Tropic of Capricorn, the wind is northeasterly resulting in almost cloudless conditions and high temperatures.

Although Nairobi, the capital of Kenya, is situated quite close to the Equator, its altitude of about 1,700 meters results in an equable as opposed to a tropical climate, with temperatures neither uncomfortably high during the daytime nor uncomfortably low at night. The Project area adjoining Thika Town to the north with an altitude of 1,500m, is under similar climatic conditions.

The main features of the climate are the definite wet and dry seasons, and the absence of any large seasonal changes in temperature. The year can be subdivided into 4 seasons as follows:

- Mid-December to Mid-March : Dry season; warm and sunny
- Mid-March to May : Main rainy season
- June to Mid-October : Dry season; cool, rather cloudy (especially July - August)
- Mid-October to Mid-December: Secondary rainy season

Meteorological observations were made at the objective horticultural research station from 1962 by the Kenyan Meterological Department. Based on these records, meteorological characteristics of the Project site are as described below and presented in Fig. 2.

(2) Temperature

Although the average temperature over a 24 hour period varies only from about 18°C during July and August to 21°C in March, the daily temperature range is quite large, averaging about 10°C from April to July and 14°C in January and February. The monthly average maximum and minimum temperatures, and the average monthly temperature ranging over a 10 year period (1974-83) are tabulated below:

Unit: °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Mean Maximum	26.6	27.7	27.7	25.5	24.7	23.8	22.6	23.5	25.9	26.7	25.1	25.0	27.7
Mean Minimum	12.5	13.4	14.4	15.7	15.2	13.3	12.8	12.5	13.1	14.3	14.9	14.1	12.5
Mean Range	14.1	14.3	13.3	9.8	9.5	10.5	9.8	11.0	12.8	12.4	10.2	10.9	-

The maximum and minimum temperatures recorded during the past 22 years at the Project site are 33.3°C in February and 5.6°C in January and August respectively.

During the months from June to August, when the southeast monsoon prevails in the coastal regions, a cloud cap frequently forms over the uplands of Kenya immediately east of the Great Rift Valley, sometimes persisting for several days. When this phenomenon occurs, daytime temperatures remain low, the maximum temperature falling to 18°C, while temperatures at night and early morning have been recorded as low as 8°C. Low temperatures also occur at night during January and February when the sky is clear.

(3) Relative Humidity

Being some 400km from the sea, the Project site does not experience the rather high humid heat which is so characterisic of tropical coastal towns, although there is a very marked daily range of relative humidity. The monthly mean relative humidity recorded at 9:00 a.m. and at 3:00 p.m. for the past 10 years (1974-83) is tabulated as follows:

Unit: %

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
9:00a.m.	73	76	79	85	83	81	85	84	79	75	81	80	80
3:00p.m.	45	43	43	56	60	56	58	55	45	43	51	53	51
Mean	59	60	61	71	72	69	72	70	62	59	66	67	66

In the early morning the air is frequently at or very close to the saturation point, while in the afternoons the relative humidity is usually about 50% and may fall as low as 10% on clear sunny days in February and March.

(4) Sunshine

Although early mornings at the Project site are often cloudy, the sun usually breaks through by mid-morning. Throughout the year there is an average of 6.5 hours of bright sunshine per day, 30% more of which occurs in the afternoon than in the morning. The monthly mean daily sunshine observed for the past 10 years (1974-83) is shown below.

Unit: hrs.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Daily Sunshine	9.1	9.1	7.7	6.5	5.9	4.9	3.5	3.8	5.5	7.2	6.9	8.0	6.5

There is considerably more sunshine during the 6 month period when the sun is in the southern hemisphere (Dec - May) than when it is in the north. Days with no sunshine occur only occasionally and even in the cloudiest month, July, there is an average of 3.5 hours of sunshine per day.

(5) Winds

The wind is predominantly easterly throughout the year, generally between northeast and east from October to April, and between east and southeast from May to September. The strongest winds occur during the dry season prior to the "main rainy season" when speeds of 20-25m/hr are not uncommon from mid-morning to early afternoon. At other times of the year wind speeds are usually 10-15m/hr while at night time the wind is usually light.

The monthly mean daily wind run for the past 10 years (1974-83) is tabulated below.

Unit: km/day

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Daily Wind Run	160	165	158	125	106	96	95	116	136	148	141	153	133

(6) Evaporation

Evaporation at the Project site was observed by the A-pan method. Monthly pan-evaporation varies from a high of 183mm in March to a low of 84mm in July with almost the same curve as daily sunshine, while annual pan-evaporation amounts to 1,601mm. The mean monthly pan-evaporation for the past 10 years (1974-83) is tabulated below.

Unit: mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Epan	167	171	183	127	113	96	84	102	132	158	129	139	1,601

(7) Rainfall

The average annual rainfall at the Project site is about 950mm, but the actual amount in any one year varies from less than 700mm to more than 1,200mm. As already mentioned, there are two rainy seasons, from mid-March to the end of May ("Long Rains"), and from mid-October to mid-December ("Short Rains").

Average monthly rainfall based on records for the last 10 years (1974-83) is as follows:

Unit: mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Monthly Rainfall	30	40	128	219	110	30	21	12	18	90	188	62	948

During the rainy season, afternoon showers and thunderstorms often occur, but a large amount of rain falls after dark, sometimes persisting until early morning. Light rain or drizzle and very low cloud is quite frequent shortly after dawn, but does not commonly last beyond 10 a.m. Rain does not fall every day during the rainy season, though there are sometimes spells with four or more consecutive rainy days. The average number of days of rain in each month is shown in the table below.

Unit: Days

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainy Days	5	4	9	17	11	4	4	4	2	5	15	7	87

4. Thika River

The Thika River which flows alongside the Project site was surveyed and studied as a water source for irrigation of the proposed experimental farm and domestic use. The results of the study are presented below.

(1) River Condition

The Project site is situated in the Thika River basin. The Thika River originates from Mount Elephant (alt. 3,500m) and flows some 70km southeastward through a deeply incised valley to join its principal tributary, the Chania River, near Thika Town. Thika Falls is formed at the confluence of the two rivers and about 200m upstream from the falls there is a gaging station, "4CB4", under the jurisdiction of the Ministry of Water Development.

From there the Thika River flows generally eastward through relatively flat plateau land, though still in a well formed valley. Some 40km east of Thika Town on the right bank is a gravity intake to the Yatta Furrow. This contour canal presently takes a flow of just over one m^3/sec for irrigation and water supply.

A few kilometers downstream of the Yatta Furrow diversion, the Thika turns northward towards the Tana River. The Masinga Dam, presently under construction on the Tana, will create a reservoir extending about 20km up the Thika Valley at highest water level so that in future the Thika will flow directly into the reservoir.

The catchment area of the Thika River at gaging station "4CB4" is 324km^2, and is composed of a long and slender basin with an average width of 6km. The river gathers numerous tributaries which mainly flow southeastward, parallel to the Thika River. As most of the streams and rivers originate from the Aberdare Range and flow along the volcanic field, the Thika River is perennial. Relatively high precipitation, over 1,500mm annually, occurs in the elevated regions flanking the Aberdare Range and is retained as groundwater in volcanic rocks, while surface runoff is stabilized by forest vegetation, especially in areas above altitude 2,300m.

The proposed Project site is situated on the left bank of the Thika, 3.7km upstream from gaging station "4CB4". The site's catchment area is 292km^2. At the site, the river forms a V-shaped valley with a bottom width of 20m, and bank slopes of about 10°. The depth of the valley is 45m. The slope on the left bank is presently used for small-scale farming of corn, vegetables, etc., though the land is owned by the government. The riverbed is composed of rock, trachytic tuff, and outcroppings of rocks are evident on the left bank.

(2) Average Discharge

There are 3 gaging stations along the Thika River upstream from the confluence of the Chania River; namely, "4CB4", "4CB5" and "4CB7". As stated earlier, "4CB4" is situated just upstream of the confluence, while "4CB5" and "4CB7" are situated in the elevated regions with catchment areas of about 40km^2 or less. Consequently, the Team concentrated on the records of "4CB4".

Daily discharge has been observed at "4CB4" station by measurement of water surface level at Cipoletti weir by staff gage and automatic recorder since 1945. The observed mean average and minimum daily discharge for each month of the period from 1974-83 is tabulated below.

DAILY DISCHARGE AT "4CB4" (C.A.=324km^2)

Unit: m^3/sec

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
average	3.2	2.7	2.9	11.6	17.4	8.8	6.4	3.7	2.4	3.1	7.2	6.1	6.2
minimum	2.4	1.9	1.4	3.9	8.5	6.0	4.2	2.7	1.9	1.7	3.4	3.9	3.5

The lowest mean minimum discharge is 1.4m^3/sec in March, and the second lowest is 1.7m^3/sec. The estimated 1.4m^3/sec corresponds to 0.43m^3/s/100km^2, though actual flow for each month fluctuates considerable year by year. In contrast, the mean minimum discharge for May and December is comparatively high at 8.5 and 3.9m^3/sec respectively, representing a one month delay of the peak rainfall for the 2 annual wet seasons.

As stated earlier, the catchment area of the Thika River at the proposed Project site is 292km^2. Discharge at the Project site is estimated on the basis of the catchment area and the annual average rainfall ratio therein is as shown below.

ESTIMATED DAILY DISCHARGE AT PROJECT SITE (C.A.=292km^2)

Unit: m^3/sec

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
average	3.0	2.5	2.7	10.8	16.2	8.2	6.0	3.4	2.2	2.9	6.7	5.7	5.8
minimum	2.2	1.8	1.3	3.6	7.9	5.6	3.9	2.5	1.8	1.6	3.2	3.6	3.3

(3) Present Water Utilization

The Thika-Chania Basin is well developed, especially the Chania River Basin which supplies 80% of the water to the capital, Nairobi. Major demands within the catchment area of the Thika River upstream of Thika Falls are for irrigation and crop processing. Irrigation water is mainly used for coffee, while horticultural crops are grown alongside the same, typically occupying 4% of coffee estates.

Within the Thika River Basin upstream of "4CB4", including numerous tributaries, there are 167 registered water rights as of February 1984. The Ministry of Water Development is responsible for granting the said water rights and applications for water permits must be submitted to the same Ministry in advance of development. Out of these registered water rights, only in several cases is water consumption consistently large in scale with a peak use of more than 10ℓ/sec. According to the Chania-Thika Water Resources Study prepared by Kenyan consultants for the Ministry of Water Development, in the critical dry periods of the year with the present level of development and mode of use, the resources of the catchment area are barely sufficient to meet all the demands.

As discussed in CHAPTER V the proposed peak demand for irrigation of the experimental farm and domestic use is 20ℓ/sec. Accordingly water from the above source would be sufficient to meet the requirement. An application for a water permit should be submitted to the Ministry of Water Development in the detail design stage.

(4) Water Quality

As discussed previously, the Thika River is well developed as a water source for irrigating, crop processing, and domestic, industrial and public uses. Coffee, pineapple and horticultural crops are irrigated from the Thika River and thus it may be assumed that water quality is sufficient for irrigating the experimental farm. According to the Team's survey during February 1983, the average pH of the river water was 7.7.

Hearings conducted in the vicinity revealed that the river transports a large amount of wash load during high discharge periods which could negatively affect the mechanism inside the pump. Accordingly a silting pond would be constructed to avoid this potential problem. Furthermore a purifier system would make it possible for river water to be used as domestic water.

5. Groundwater

(1) Existing Boreholes Around the Site

Numerous boreholes for groundwater have been sunk around the Project site particularly in volcanic rock on large scale coffee and pineapple farms, etc. In general, boreholes sited on volcanic areas, i.e. agglomerates or tuffs, appear to be more successfull than those sited on Basement System rock. Volcanic rocks rest on an old bevelled land surface around the Project site, and it is probable that the weathered gneiss of that surface provides an aquifier. Based on a geological report prepared by the Ministry of Natural Resources, there are a series of buried ridges and valleys on the sub-volcanic floor in this part of the area, and it is usually found that when a borehole passes through the volcanic rock into a buried valley, the yield of water is greater than that for a borehole sunk into a ridge.

Fig. 3 shows locations of existing boreholes around the Project site, while Table-2 tabulates records of these boreholes. As these records show, all boreholes in the area are sited on volcanic rocks and lava. Rest water levels of boreholes in the area indicate a westward rise of the watertable in volcanic rock.

(2) Electric Resistivity Survey

The Team conducted an electric resistivity survey at six points in the Project site. The survey points are illustrated in Fig. 4. A Yokokawa Type 3244 resistivity survey device was utilized to identify the geological strata of the site. The presumed geological profile on the basis of the survey is presented in Fig. 5.

As shown in the geological profile, a shallow well is conceivable at the Project site, and the depth of an aquifier is assumed to be around 50m. The electric resistivity underground was surveyed to the depth of 100m. Four geological strata are assumed to exist from ground level as follows:

- wearing course of 0-1.0m stratum
- lava of 1.0-20.0m
- clay mixed rock of 20.0 to 35.0-60.0
- clay and lava

The second and third stratum may be aquifers, while the fourth stratum is comparatively impervious.

As the ideal borehole site would be where there is a deep buried valley of impervious rock, out of the six points surveyed, No. 6 seemed the most suitable site. Further electric resistivity surveys at about 5 points around No. 6 site and test boring and pumping at a proposed point is deemed necessary to confirm the available yield, in case of utilization of groundwater for domestic water supply and for laboratory use.

(3) Application and Admission Procedure

The Water Application Board under the Ministry of Water Development is responsible for granting permission to drill well-boreholes. Not less than one month prior to actual commencement, notice of intention must be submitted to the said Ministry which files well-borehole records.

Table-1

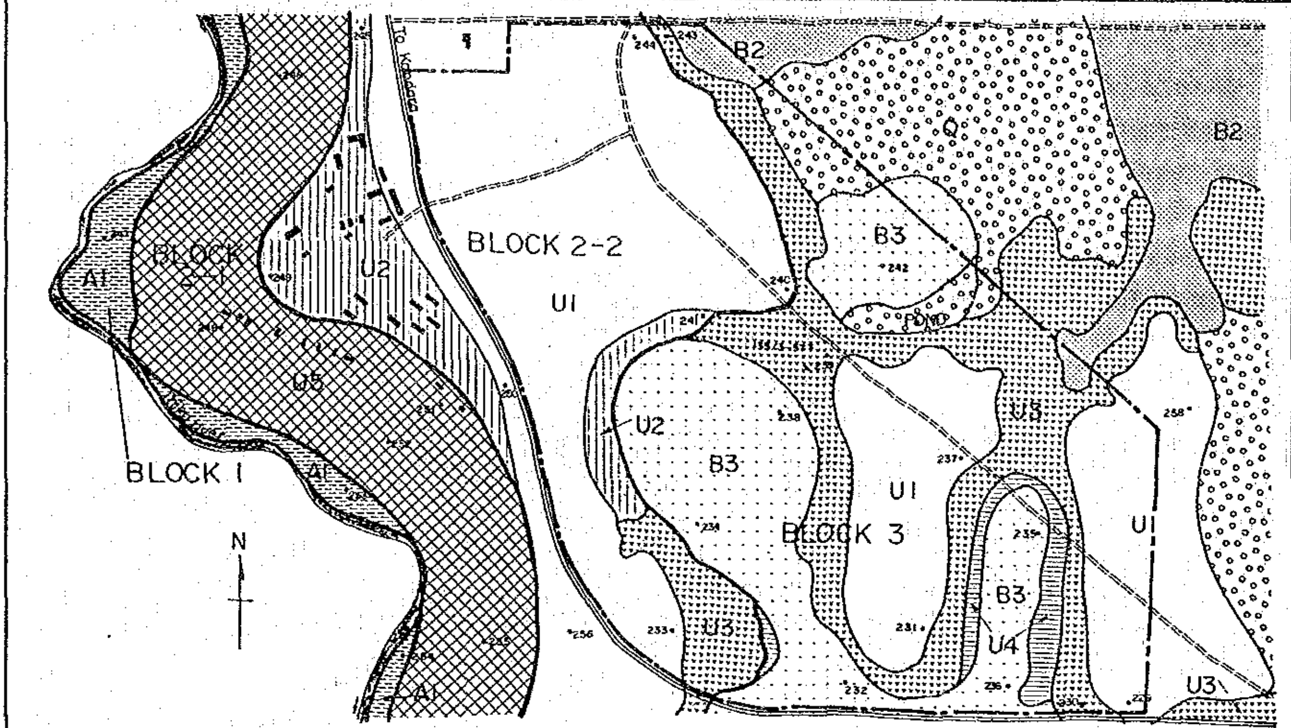
PROPERTIES OF SOIL

Soil	Texture of topsoil	Colour	pH	CEC	B.S. (me/ 100g)	Fertility (%)	FAO Classification
U1	Moderate, Medium to subungular blocky	Dark Reddish brown to dark red	5.2-6.0	23.8	50	Highly suitable	Distric NITOSOLS
U2	"	"	5.0-6.6	24.6	50	Moderately suitable	"
U3	Very fine crumbs	"	6.0-6.2	19.6-23.2	50	Variable	Humic ACRISOLS
U4	Gravelly clay to soil	Dark reddish brown to dark red	-	-	-	Permanently not suitable	LITHOSOLS
U5	"	Dark reddish brown to dark red	6.1-6.6	11.8 22.0	50	"	Humic ACRISOLS
A1	Silty clay to clay soil	Dark reddish brown to reddish brown	-	-	-	Currently not suitable	Eutric FLUVISOLS
B2	Fine clay soil	Dark grey to dark greyish brown	5.2	29.6-36.6	44-78	Currently not suitable	Fumic GREYSOLS
B3	Moderate, very fine soil	"	5.2	29.6-33.6	44-78		

Table-2

RECORDS OF EXISTING BOREHOLES

BOREHOLE NUMBER	TOTAL DEPTH (m)	WATER STRUCK (m)	REST LEVEL (m)	TESTED YIELD (m^3/h)	FORMATION	DATE COMPLETE
C727	60.9	27.4/39.6	-	6.8	VOLCANIC	8-9-48
C1254	193.6	91.4	25.9	3.4	VOLCANIC	22-12-50
C1326	153.0	-	-	1.9	TERT. VOLCANIC	9-5-52
C1421	132.9	115.8	28.7	13.6	TERT. VOLCANIC	11-5-51
C1457	81.7	36.3/71.6	32.3	2.1	VOLCANIC	21-5-51
C1458	111.3	18.3/120.4	7.9	5.0	VOLCANIC	28-6-51
C1547	179.5	36.6/ 131/153.9	41.2	3.2	TERT. VOLCANIC	11-8-51
C1587	124.0	35.0/ 74.7/117.3	41.2	9.0	TERT. VOLCANIC	17-11-51
C1601	243.8	18.3/134.1 170.1	14.0	3.7	TERT. VOLCANIC	23-11-51
C1616	161.5	18.3/60.4/ 110.6	32.9	6.8	TERT. VOLCANIC	18-12-51
C1660	152.4	24.4/ 48.8/149.4	40.8	9.0	TERT. VOLCANIC	6-2-52
C2002	161.5	48.8/ 85.3/152.4	61.9	13.0	LAVA	15-8-53
C2072	140.2	53.9/139.3	43.3	14.0	LAVA	16-12-53
C2418	103.6	99.9	35.4	8.0	VOLCANIC	12-7-55
C4048	161.6	51.2	17.1	5.5		24-8-74



LEGEND

U UPLANDS (slopes 1–18%)

UP Soils developed on pyroclastic rocks (trachytic tuffs)

U 1 well drained, very deep to extremely deep, dark red to dark reddish brown, friable clay (dystric NITOSOLS)

U 2 well drained, deep to very deep, dark red to dark reddish brown, friable clay; in places shallow to moderately deep over petroplinthite (murram) (dystric NITOSOLS; with ferralic CAMBISOLS, petroferric phase)

U 3 well drained to moderately well drained, shallow to moderately deep, dark red to dark reddish brown, friable, sandy clay to clay, over rock or petroplinthite (murram) (humic ACRISOLS, lithic or petroferric phase)

U 4 well drained to moderately well drained, very shallow to shallow dark reddish brown to dark brown, rocky and bouldery, gravelly clay to clay; in places over petroplinthite (murram) (LITHOSOLS)

U 5 complex of well drained, very shallow to deep, dark red to dark reddish brown, friable, rocky, gravelly clay to clay (humic ACRISOLS, partly lithic phase, with LITHOSOLS)

A RIVER TERRACE (slopes 0–2%)

AA Soils developed on alluvial deposits

A 1 moderately well drained to imperfectly drained, very deep, stratified, reddish brown to dark reddish brown, friable, silty clay to clay (eutric FLUVISOLS)

A 2 very poorly drained, deep to very deep, dark grey to very dark grey, mottled, friable to firm, clay; in places over pisoferric material (murram) (humic GLEYSOLS)
(not found in this area)

B BOTTOMLANDS (slopes 0–2%)

BP Soils developed on pyroclastic rocks (trachytic tuffs)

B 1 moderately well drained to imperfectly drained, deep, dark reddish brown to dark yellowish brown, friable clay, over pisoferric material (murram)
(not found in this area)

B 2 imperfectly drained to very poorly drained, shallow, dark reddish brown to dark brown, clay, over petroplinthite or pisoferric material (murram) (humic CAMBISOLS, petroferric or pisoferric phase)

B 3 very poorly drained, deep to very deep, dark grey to dark greyish brown, mottled, firm clay, over petroplinthite (murram) (humic GLEYSOLS, partly petroferric phase)

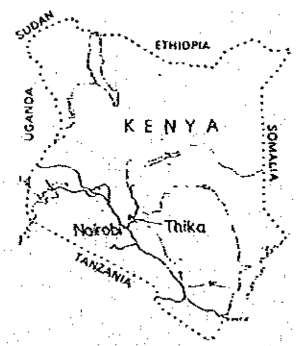
Q Quarry

Q Broken ground with murram excavation pits, in places ponded

FIG. 1 DETAILED SOIL MAP OF THE PROJET SITE

KEY

- soil mapping symbol
- UPr2m..... depth class symbol
- C........ slope class symbol
- soil boundary
- 135/3–47 sampled profile pit, with reference number
- .82 augerhole observation, with reference number
- 1sq cm 0.25 hectares
- tarmac road
- motorable track
- river
- dam and stream
- buildings
- fence (boundary of survey area)
- Boundary of the project area



■ Location of surveyed area

SCALE 1:5,000

0 50 100 200 300 400 500m

FIG. 2 METEOROLOGY OF THE PROJECT SITE 1974 - 83

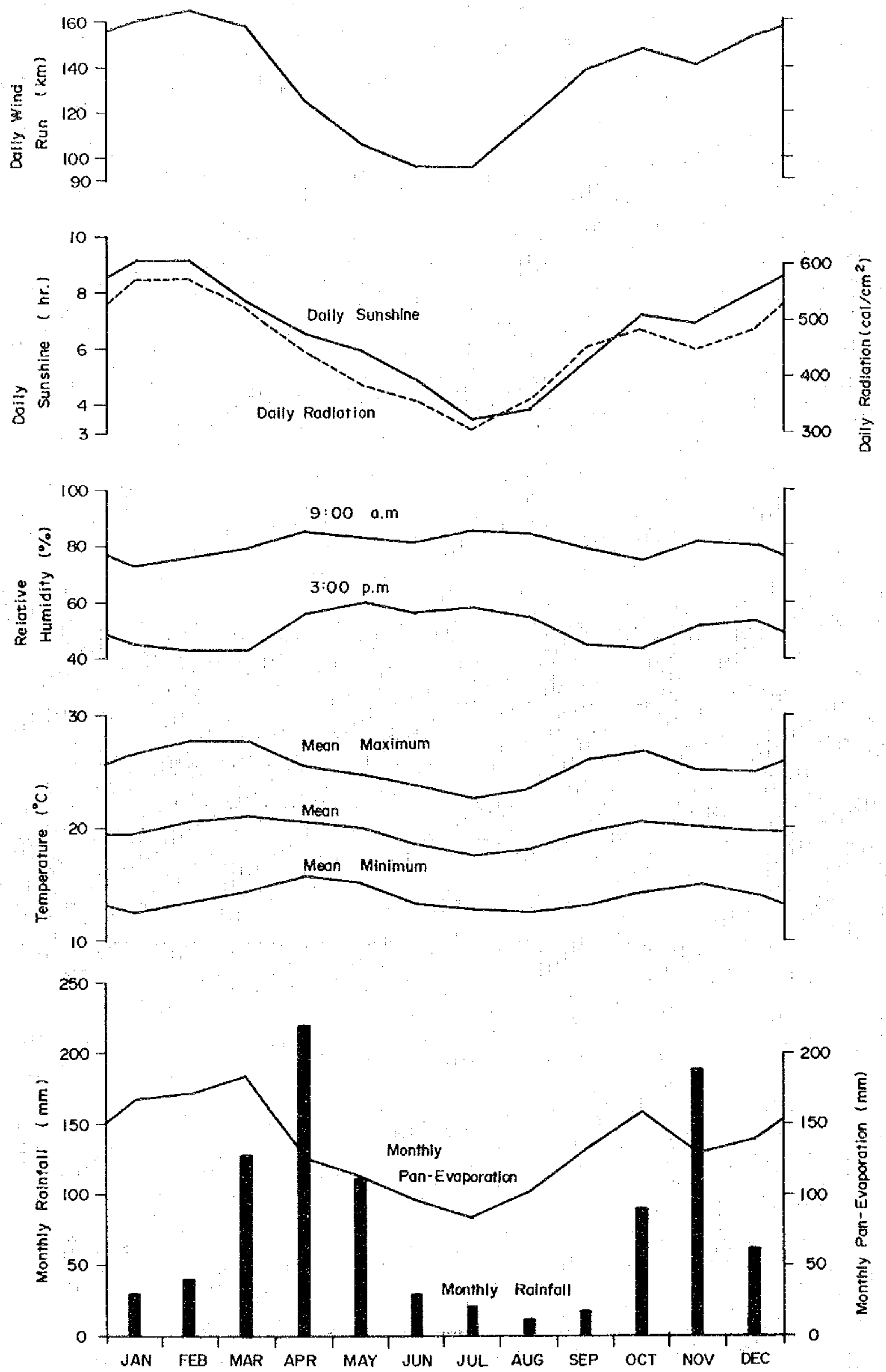


FIG. 3

LOCATION OF EXISTING BOREHOLES AROUND THE PROJECT SITE

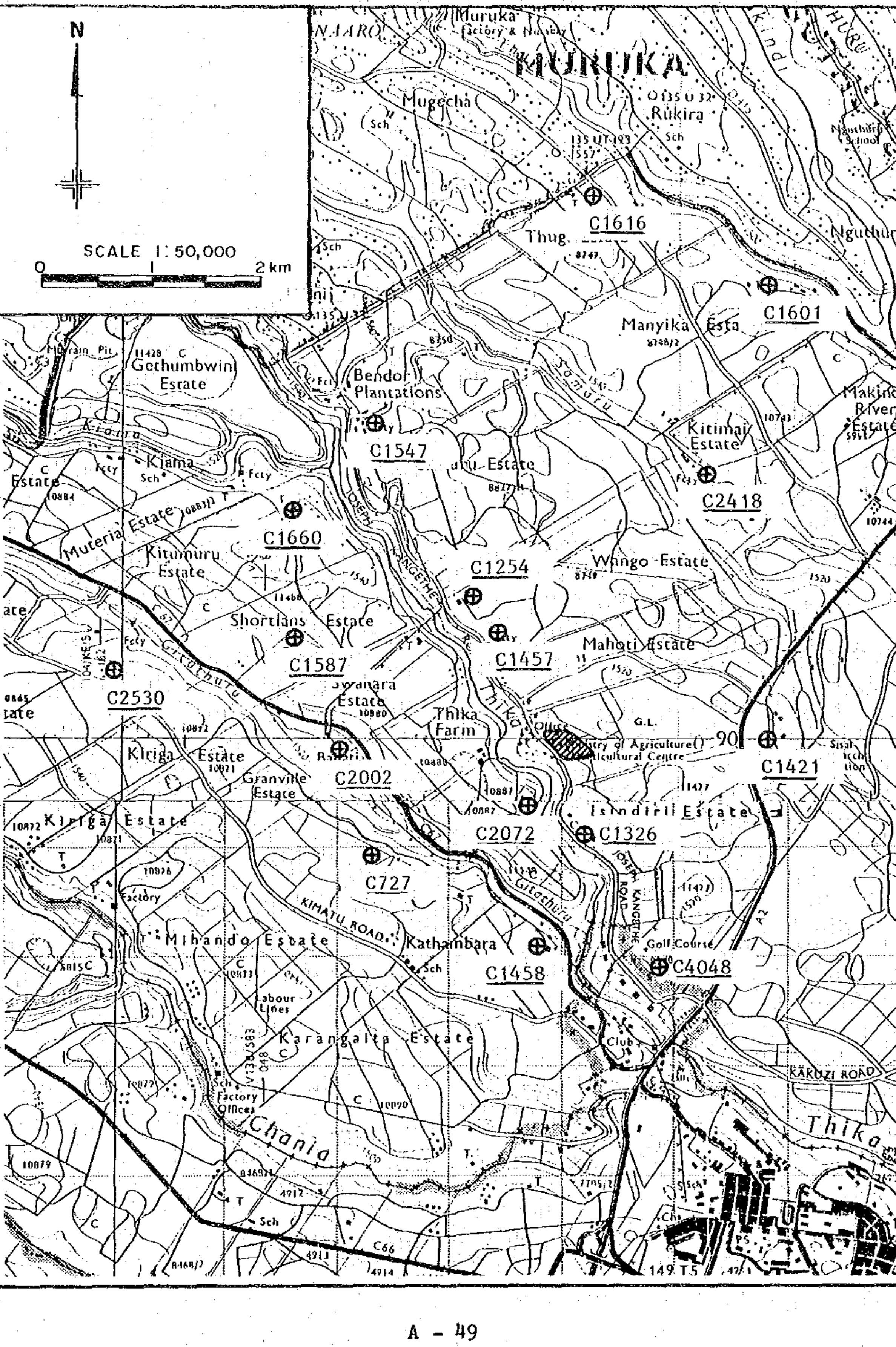


FIG. 4 LOCATION OF ELECTRIC RESISTIVITY SURVEY POINT

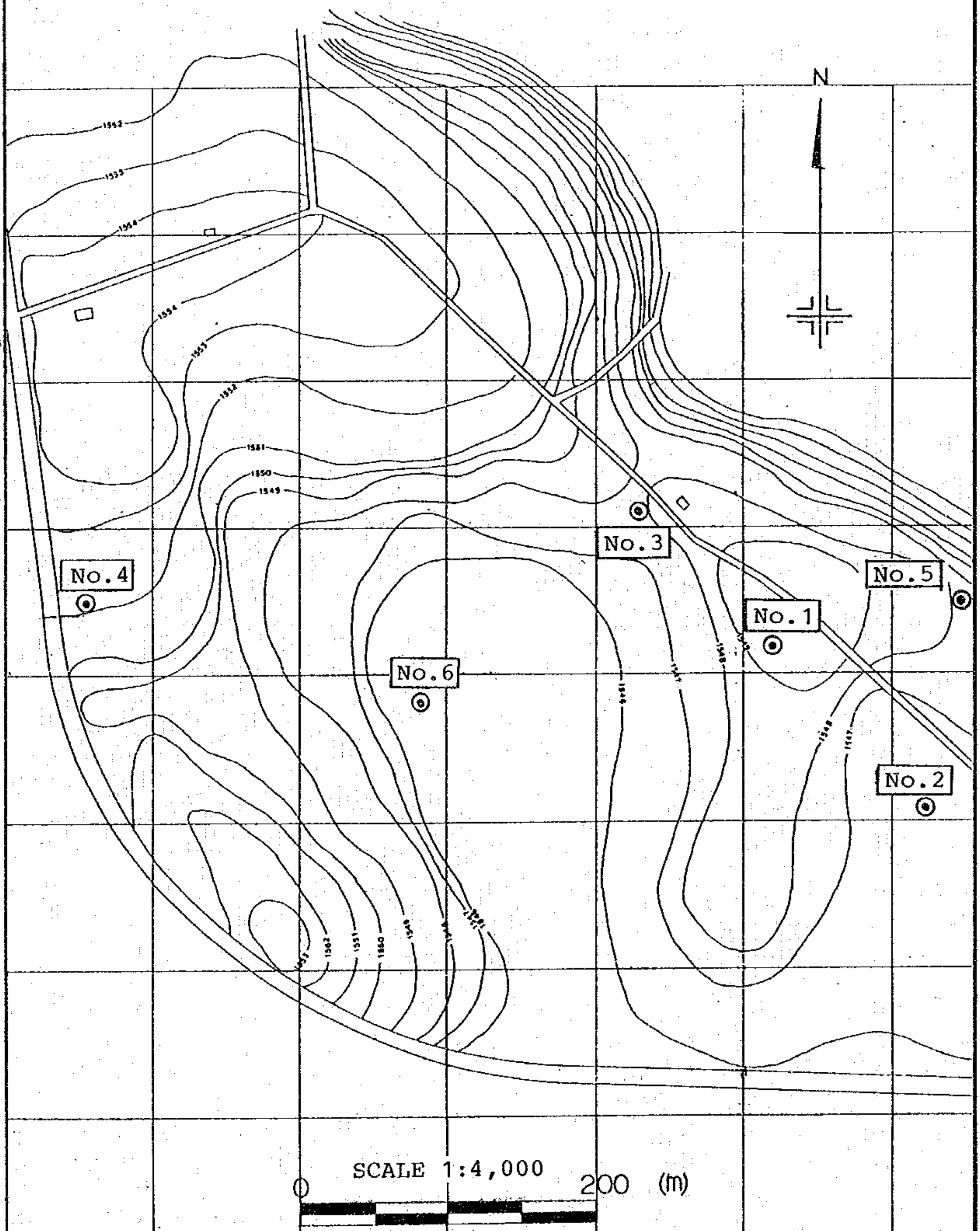
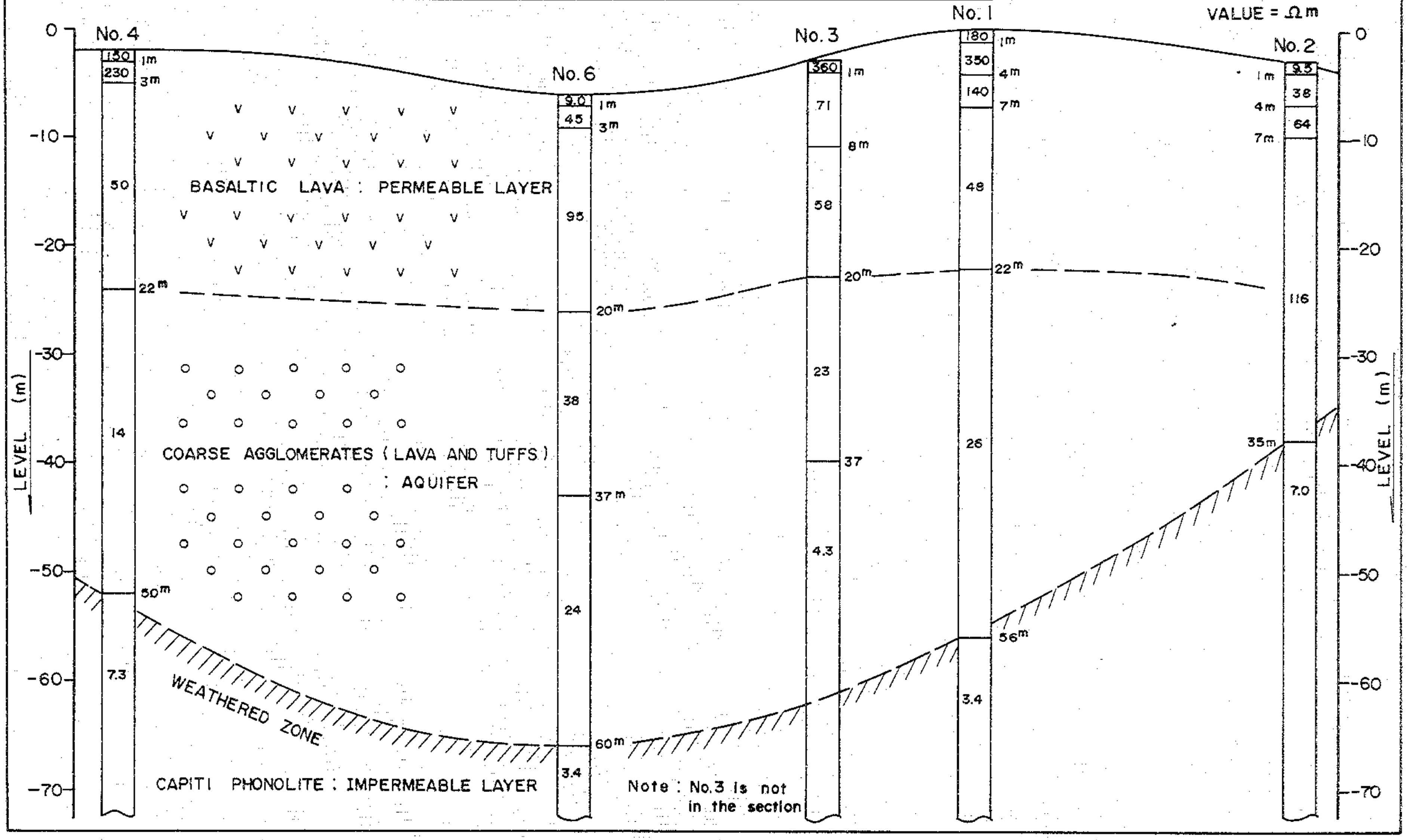


FIG. 5

PRESUMED GEOLOGICAL PROFILE



CALCULATION OF WATER REQUIREMENT

In consideration of evapotranspiration, crop coefficient, irrigation efficiency in the area, and supply for domestic water, the peak volume of water required has been determined at 20ℓ/sec. Procedures for determination of the water requirement are given in the following sections.

(1) Irrigation Plan

Procedures for determination of the irrigation water requirement is discussed below.

1) Reference crop evapotranspiration: ETo

Average monthly reference crop evapotranspiration (ETo) occuring in the Project area over a 10-year period (1974-83) was obtained from data collected by the meteorological station at the NHRS and calculated by the Modified Penman Method as presented below.

CROP EVAPOTRANSPIRATION

Unit: mm/day

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
ETo	5.5	5.7	5.1	3.7	3.2	2.9	2.6	3.0	4.1	4.8	4.1	4.4	49.1

Note: Mean = 4.1

As shown in the table below, the evapotranspiration data indicated above can be broadly divided into 4 periods.

FOUR PERIODS OF ETo

Period	Months	Period Total ETo (mm/day)	Average ETo (mm/day)	Comparison (1st period = 1.00)
1st	Jan - Mar	16.3	5.43	1.00
2nd	Apr - Jun	9.8	3.27	0.60
3rd	Jul - Sept	9.7	3.23	0.60
4th	Oct - Dec	13.3	4.43	0.82

Accordingly, for the present Project the 1st period from January to March will be adopted as the calculation standard of irrigation water supply.

2) Crop evapotranspiration: ET crop

Crop evapotranspiration (ET crop) is defined as follows:

$ETcrop = Kc \cdot ETo$

In the above formula, Kc indicates the crop coefficient which varies according to cultivated crop and growing stage. As no experimental results with regard to the crop coefficient were available in the Project area, experimental results from FAO were adopted (Table 1).

Accordingly, adopting average crop coefficient Kc = 1.10, the crop evapotranspiration during the critical period is thus calculated at Et crop = 6.0mm/day. Furthermore, consumptive use of crops during the critical period is therefore determined at 6.0mm/day.

3) Irrigation water requirement

For calculation of irrigation water requirement, the loss of irrigation water has been considered on the basis of the following factors:

Total Irrigation Efficiency	0.62 (0.65x0.95=0.6175≑0.62)
- Field efficiency	0.65
- Operation efficiency	0.95

Under these assumptions, the total irrigation efficiency was calculated at 0.62, and accordingly, the peak daily irrigation requirement has thus been calculated at 10.0mm.

$$6.0mm \times 1/0.62 = 9.68 \fallingdotseq 10.0mm$$

Average daily effective rainfall during the dry season when the peak irrigation water requirement occurs is 0.6mm/day, although yearly fluctuation is very high. Accordingly for calculation of irrigation water requirement effective rainfall is neglected. On the basis of the daily irrigation requirement of 10.0mm the irrigation water requirement for each area has been estimated (Table 2).

(2) Domestic Water Plan

The working population in the Project area is estimated at 100 persons including 66 staff members and subordinates, a maximum of 20 trainees, and 14 temporary workers. According to the water supply plan in Thika Town, where the neighbouring NHRS is located, water consumption per person per day is 160ℓ. Based on this information, 160ℓ will be adopted for the Project. Therefore, the water requirement for 100 persons will be 16,000ℓ/day.

On the other hand, water requirement in the buildings for laboratories and miscellaneous water consumption including the transplanting and grafting workshop is estimated at 13,000ℓ/day.

Thus, total unit water (29,000 or $29m^3$/day) requirement for domestic water with 7 hours supply is calculated as follows:

$$29,000\ell \div (7hr \times 3,600sec) \times 1.4 = 1.61\ell/sec \doteqdot 1.6\ell/sec$$

The peak water requirement will be an increase of 40% in relation to the average water requirement.

(3) Total Water Requirement

The summary of water requirement is shown below.

WATER REQUIREMENT

Section	m^3/day	Water Requirement (ℓ/s)
Domestic Water for buildings	29.0	1.6
Nursery Facilities	35.0	1.8
Scion Garden	60.0	2.8
Proposed Experimental Farm	229.0	10.6
Existing Macadamia Farm	62.4	3.2
Total	415.4	20.0

TABLE 1 CROP COEFFICIENT

Crop	Relative Humidity (%) / Wind Velocity (m/sec)	over 70 0-5	over 70 5-8	less than 20 0-5	less than 20 5-8	Adopted Value
	Crop Stage					
Peanut	3	0.95	1.00	1.05	1.10	1.05
	4	0.55	0.55	0.60	0.60	
Potato	3	1.05	1.10	1.15	1.20	1.15
	4	0.70	0.70	0.75	0.75	
Beans	3	1.00	1.05	1.10	1.15	1.10
	4	0.50	0.50	0.55	0.55	
Tomato	3	1.05	1.10	1.20	1.25	1.20
	4	0.60	0.60	0.65	0.65	
Cucumber	3	0.90	0.90	0.95	1.00	0.95
	4	0.70	0.70	0.75	0.80	
Onion	3	0.95	0.95	1.05	1.10	1.05
	4	0.75	0.75	0.80	0.85	
Radish	3	1.05	1.10	1.15	1.20	1.15
	4	0.90	0.95	1.00	1.00	
Pasture	3	1.05		1.15		1.15
Average	4					1.10

Note: Crop Stage 3: mid-season stage
4: last-season stage

Source: Crop Water Requirements, FAO Irrigation and Drainage Paper 24, revised 1977

TABLE 2 IRRIGATION WATER REQUIREMENT

Item / Section	Field (block)	Area (ha)	No. of Trees	Irrigation Area (m^2)	Unit Volume (mm)	Daily Irr. Requirement (m^3)	Water Supply Volume (ℓ/s)	Remarks
1. Existing Macadamia Farm								
	a.	0.65	133	1,200	10	12.0	1.2	
	b.	0.60	123	1,100	"	11.0	1.2	
	c.	0.60	123	1,100	"	11.0	1.1	
	d.	0.55	112	1,000	"	10.0	1.1	
	e.	0.50	102	920	"	9.2	0.9	
	f.	0.50	102	920	"	9.2	0.9	
Sub-total		3.40	695	6,240	10	62.4	3.2	a + c + e = 3.2 b + d + f = 3.2
2. Scion Garden								
	A	0.30	150	3,000	10	30.0	1.4	
	B	0.30	150	3,000	"	30.0	1.4	
Sub-total		0.60	300	6,000	10	60.0	2.8	
3. Experimental Farm								(Inter-crops)
	F1	0.30	47	2,200	10	22.0	3.6	Beans
	F2	0.32	50	2,350	"	23.5	3.6	Tomato
	F3	0.43	67	3,180	"	31.8	3.6	Cumcumber
	F4	0.25	39	1,880	"	18.8	3.4	Cabbage
	F5	0.35	55	2.590	"	25.9	3.4	Radish/Carrot
	F6	0.40	63	2,950	"	29.5	3.4	Potato
	F7	0.40	63	2,950	"	29.5	3.6	Onion
	F8	0.30	47	2,400	"	24.0	3.6	Peanuts
	F9	0.30	47	2,400	"	24.0	3.6	Grass
Sub-total		3.05	478	22,900	10	229.0	10.6	
4. Nursery								
Seedbed		0.02	-	200	10	2.0	0.1	
Stockyard		0.045	-	450	"	4.5	0.2	
Greenhouse		0.02	-	200	"	2.0	0.1	
Shadehouse		0.185	-	1,850	"	18.5	1.0	
Others		0.08	-	800	"	8.0	0.4	
Sub-total		0.35	-	3,500	10	35.0	1.8	
Total		7.40	1,473	38,640		386.4	18.4	

BASIC DESIGN OF WATER SUPPLY FACILITIES

1. River Intake Facilities

The river banks on both sides of the intake point have a slope of 1/4 (16°). The topsoil layer of this sloped area is relatively thin with an approximate depth of 20cm, and in some places exposed lava outcrops may be seen. The bedrock of the area is composed of tuff. A very narrow strip of level land ranging in width from 3-10m extends along both banks. The same are underlain by bedrock at a depth of only 2-3m below ground surface. Boulders with diameters from 1.0-1.5m are scattered in the river.

The intake site was selected for the following reasons:

a) The intake site is situated at the minimum possible distance from the Project site. Construction costs of water distribution facilities will thus be minimized.

b) A suitable bedrock foundation extends across the entire breadth of the riverbed facilitating construction of an intake weir at minimal cost.

c) As the land from the intake point to the irrigation area is entirely owned by the government it will not be necessary to either buy or rent land. For the same reason, although maize is presently cultivated on the proposed water pipeline route which connects the intake tank to the settling pond, payment of crop compensation, etc. will be unnecessary.

d) The site selected has sufficient level area at the end of the water pipeline to allow for installation of a settling pond, pump station, distribution tank, and necessary other facilities.

e) The Kandara Road which runs along the Project area is asphalt paved and therefore will facilitate operation and management of the above mentioned facilities and other related structures.

f) The electric power line runs along the Kandara road, and thus service wire will be easily facilitated.

g) The existing access road which at present extends from the river terrace to the intake point will facilitate transport of construction materials to the river.

The intake weir will be located at elevation 1,508.5m and will be of concrete construction built on bedrock. The proposed structure and scale of the weir is:

- Height	4.00m
- Length	20.00m
- Crest width	1.00m
- Bottom width	4.00m
- Upstream slope	1:0.0
- Downstream slope	1:1.0
- Concrete volume	approx 500m^3
- Gate	2.00m x 3.00m
- Riverbed protection	Upstream 5.0
	Downstream 10.0
- Riverbed elevation	EL 1,508.50m
- Crest level	EL 1,511.50m
- Normal water level	EL 1,511.00m

2. <u>Intake Pump and Introduction Pipe</u>

As previously discussed, the intake pump will be installed in the intake tank. The intake tank will be constructed on a level area of the left bank located 20m upstream from the intake weir. The structure will be of concrete with dimensions 3.0m x 3.0m x 5.0m. An intake installed in the riverbed will convey water to the tank at the lower front face of the structure. The tank will be divided into 2 sections, the first of which contains the inflow control valve and the latter of which acts as a temporary reservoir and contains a submerged pump to pump water into the settling pond. To facilitate pump inspection and cleaning of the intake tank a manhole will be installed.

The dimensions of the proposed intake tank are:

- Dimension	3.0 x 3.0 x 6.0m deep
- River elevation	EL 1,509.00m
- Normal water level	EL 1,511.00m
- Height of intake	EL 1,508.80m
- Pond floor	EL 1,508.00m

Inside the intake tank a pump will be installed. A submerged vertical-type motor-driven pump is proposed as the intake pump in consideration of the following factors:

a) Water level fluctuation of the river is comparatively slight, at about 4.00m with a low water level of EL 1,509.00m and a high water level of EL 1,513.00m to an average level of EL 1511.00m.

b) The design intake discharge required to irrigate the Project area is as slight as 1.2m^3/min (0.02m^3/s) and the same volume is required for only 5-6 months in a year. At other times, the required intake is only 1/2 to 1/3 of the same.

c) There is only a limited area of level space along the narrow strip of the riverbank in the vicinity of the intake point.

d) The selected pump provides maximum efficiency and ease of operation under site conditions.

e) Costs of construction, pump equipment, electrical supply, etc., are minimized.

The main specifications of the proposed submerged motor pump are:

- Lowest suction surface	EL 1,509.00m
- Discharge water surface	EL 1,556.00m
- Net Head	47.00m
- Loss of head	8.0m
- Suction side	1.0m
- Discharge side	7.0m
- Total head	55.00m
- Theoretical horsepower	14.7kW
- Shaft horsepower	21kW (efficiency: 70%)
- Motor input	25kW (motor efficiency: 85%)

Water pumped up from the intake suction tank by the submerged motor pump will be conveyed to the settling pond via a 6" (15cm) diameter iron pipe. The level distance between these two points is 270m with a difference in height of 44m and an inclined distance of 274m. The average incline of the area is 10°.

The slope is composed of an extremely thin layer of topsoil (approximately 20cm) beneath which lies lava deposits. For this reason the pipeline will be laid along the ground surface. The pipe will be castiron and will be laid on a bed of concrete thrust blocks to avoid displacement. To prevent backflow of water inside the pipe in the event of pump failure, etc., a stop valve will be placed in the mouth of the pipe leading into the intake tank. At the opposite end, where water is discharged into the settling pond, the pipe will be divided into two branches, each leading to a separate settling pond.

3. **Settling Pond**

Two settling ponds, each with an effective capacity of $420m^3$, will be installed and the sedimentation period for both will be 24hrs. Dimensions of each pond will be 20m x 15m x 2m ($600m^3$), although only 1.40m of water is useable. The bottom of the pond will be inclined and a drain installed at the lower end. The latter will be connected to a drainage pipe and automatically controlled by a valve to discharge sediment from the pond.

4. **Distribution Pump**

The suction tank structure is:

- Dimension:	4.00m x 5.00m x 3.00m
- Bottom elevation	EL 1,553.0m
- Suction water surface	EL 1,554.0m

The pump for the suction tank will be installed at the top of the same while the pump controls will be located seperately in the pump shed. Pump type and dimensions are:

- Type	Single suction volute pump
- Capacity	$0.020m^3/s$ ($1.2m^3/min$)
- Actual head	19m
- Total head	20m
- Motor input	9kW

The specifications of the distribution tank are:

- Quality	Acrylic resin
- Dimension	3m x 5m x 10m ($150m^3$)
- Foundation	Steel framing, concrete foundation

5. **Distribution Pipe**

The pipe from the distribution tank will be laid along the ground surface for 60m up to the Kandara Road. The same will thereafter be embedded in the ground, crossing beneath the said road and into the area for the purpose of irrigation and domestic water. From there the said pipe will branch in two directions, one main pipe extending to the east up to the reservoir tank for domestic water and the other extending south along the existing road. Pipe used within the Project area will be polyvinyl chloride embedded type. The projected pipe lines for water supply are tabulated below:

PROJECT PIPE LINES FOR WATER SUPPLY

	Length (m)	Scale (ø) (mm)	Remarks
Main Pipe			
- North-south line	500	40-75	existing farm
- East-west line	860	75-150	scion garden, expt. farm, nursery building
Branch Pipe			
- Existing farm	600	40	diverted from north-south line
- Experimental farm	1,850	50	diverted from east-west line
- Scion garden	120	50	" "
- Nursery	430	40	" "
- Domestic water 1/	200	50	" "

1/: Domestic water for buildings

6. Domestic Water Supply Facilities

The domestic water source will be intaken from the terminal of the east-west main pipe line, and distributed to each building and facility through a water processing facility including a purifier, water tank, lift pump and elevated distribution tank.

The following buildings and facilities will be supplied with water for domestic use.

- Main building
- Nursery workshop
- Hostel

The specification of the facilities are tablated below.

DOMESTIC WATER SUPPLY FACILITIES

Facilities	Structure	Dimension	Remarks
1. Intake	Hard vinyl chloride	Q=1.6ℓ/s ø 50mm	from main pipe terminal to purifier
2. Purifier	Castiron	Capacity $50m^3$/day	projected water requirement $29m^3$/day
3. Water tank	Reinforced concrete	3m x 3m x 3m	
4. Lift pump	Centrifugal	Q=$0.096m^3$/min H=15m	
5. Distribution tank	Acrylic resin	5m x 5m x 2m ($50m^3$)	projected water requirement $29m^3$/day

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