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Preliminary designs for an irrigation project at lower Rombo-Tanzania

by

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CONTENTS

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APPENDIXES:

0. ABSTRACT

Rombo district lies on the south-eastern slopes of Mt. Kilimanjaro in Tanzania. The main occupation of the residents in this district is agriculture whereby coffeeand bananas are grown on the highlands while maize and a few other seasonal crops are grown on the lowlands (lower Rombo).

At the moment agriculture at lower Rombo has fallen sharply because of reliance on rainfall which has changed its pattern lately.

In this study a description of the area which is about 12.500 hectares has been given. The climate, rainfall and soil types of the area have been described together with water sources which include small streams from the mountains, underground water and Lake Chala.

Both peak-use water demands and seasonal water demands for the traditional crops grown at the area have been evaluated. This evaluation together with the description of the area have been used for preliminary designs of about 2150 hectares based on Lake Chala water for the initial stage.

Design of the water distribution system on the farms using surface irrigation has been done. Cost analysis and return on the investment have also been carried out and finally comments and recommendations are given.

All the costs have been worked out in Tanzanian currency (Tshs) in order to enable the participants (village leaders) to grasp the financial implications of the project. In this case the cost of all imported machinery is converted into Tanzanian currency.

1. INTRODUCTION

1.1 General

The importance of water for the development of man hardly needs to be emphasized. From the very beginning of human civilization, people have settled close to water sources along rivers, beside lakes or near natural springs. During these early times our ancestors recognized the importance of water for both navigation and agriculture. Indeed where people live, some water is normally available for drinking, domestic use and possibly for watering animals.

In the past, irrigation enabled civilization to establish permanent home sites in semiarid and arid lands. Today, irrigated agriculture continues to make food supplies less dependent on fluctuations in climate. Irrigation is one of the oldest known agricultural technologies, but improvements in irrigation methods and practices are still being made. The future will require even greater improvements as competition for limited water supplies continues to increase.

The oldest civilizations developed along the Nile, Tigris, Euphrate, Indus and Yellow Rivers and in Latin America. Cultivation along the Nile began about 6000 B.C. Practices to keep canals free of sediment were in effect in Mesopotamia in 4000 B.C. Shallow wells and flooding from the Indus River were used about 2500 B.C. (Fukuda, 1976).

1.2 Irrigation in Tanzania

A continuous history of irrigation in Tanzania is not available, but evidence indicates that around the 17th century some tribes esp. in Kilimanjaro built furrows (canals) to divert river water into their farms during dry periods.

In the subsequent years modern irrigation development in Tanzania began with introduction of cash crops such as sugar cane which need a lot of water for their growth and which grow best on areas which have relatively low rainfall.

More recently the government has made it a policy to use irrigation method as a move towards modern farmning. This can be seen in the government declarations of "KILIMO CHA KUFA NA KUPONA" and "KILIMO CHA UMWAGILIAJI".

1.3 Irrigation in Rombo

In Rombo and most of Kilimanjaro region the early families settled on the highlands at altitudes ranging from 1500 M.a.s.l. and more. At these altitudes the temperatures are mild and the climate is favourable for coffee and bananas. Due to the shading effects of these crops, no other crops can be grown alongside.

Maize and beans which are the common food crops are thus grown on the lowlands at altitudes around 1000 M.a.s.l. The climate here is not as mild as on the highlands and rainfall period is shorter and unreliable. To overcome this problem, the people of Rombo have developed some mini-irrigation schemes to suppliment water requirement during peak-demands. An example of these schemes is Ikuini village where there is a water reservoir about 100 m x 50 m x 2.5 m which stores water for irrigation by gravity. The problem with this scheme is that the inflow into the reservoir comes from a seasonal stream (river) which dries up during the dry period and hence no more irrigation.

1.4 Aim of the project

The aim of the project is to design an improved irrigation scheme which will eventually alleviate the irrigation problems of this area. This shall be done in the following manner:

a. Analysis of water sources and water demand.
b. Layout for an irrigation system.
c. Estimation of costs for the proposed irrigation system.

2. DESCRIPTION OF THE AREA

2.1 General

Lower Rombo area is located in Rombo district, Kilimanjaro region on the south-eastern slopes of Mt. Kilimanjaro. The area lies between $3^{0}05'$ and $3^{0}20'$ latitude south of equator and between $37^{0}37'$ and $37^{0}41'$ longitude east of Greenwich. The lowest point in the area has an altitude of about 3000 ft.a.s.l. while the highest has an altitude of 4000 ft. a.s.l.
The area is divided into wards (tarafa) which include from the southern end northwards: Mamsera, Mengwe, Keni, Mkuu, Mashati and Usseri.

The project area about 12.500 hectares is bound by the boundary between Tanzania and Kenya on the south-eastern side and the lower Rombo road on the west end. The road runs almost parallel to the Tanzania/Kenya border.

The main features of this area is that immediately above the lower Rombo road (ie. the other side of the project area) there is a dense population and extensive farming activities while the project area itself is almost without population and no proper utilization during the dry period. There is also a series of hills on the southern part of Mamsera ward which include among others Holili, Msangasanga, Mraorao and Kimanga. The rest of the project area is more or less plain except for the river valleys.

2.2 Water sources

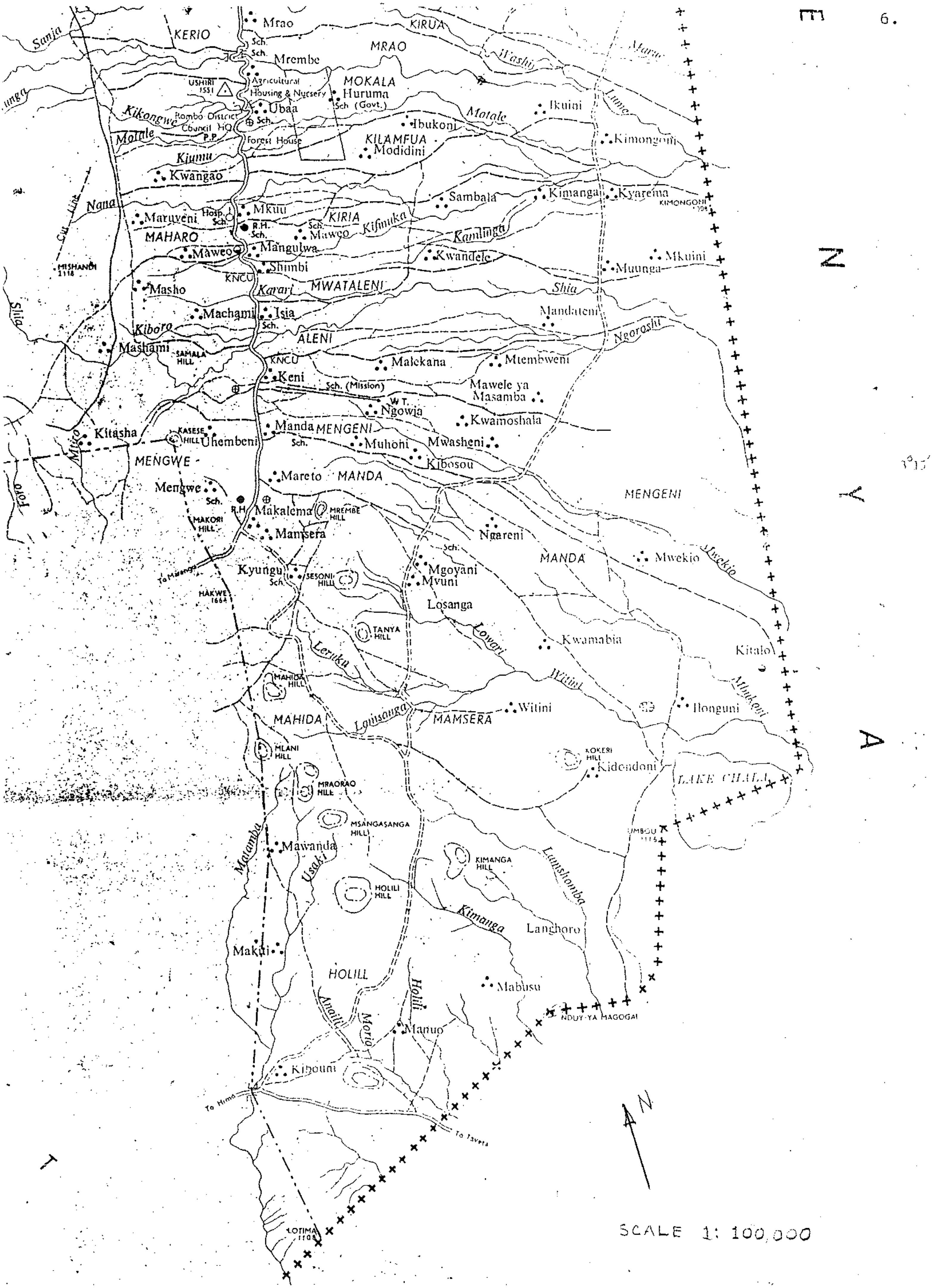
The area is drained by several streams during the rainy season but these streams dry up almost as soon as the rainy season is over. The following streams are crossed as one moves from the southern end of the project area to the north: Witini, Ngoroshi, Shia, Kamlinga, Kifinuka, Motale, Washi, Lume, Marue, Kitaha and Mlombea. It is important to mention that just across the border between Tanzania and Kenya there are several springs which can almost be traced along these rivers on the Tanzanian side. An example of these springs is Lume springs which give rise to permanent river Lumi in Kenya despite the fact that its origin in Tanzania is the seasonal river Lume.

The area has also a great potential of underground water, the most likely sites being Ikuini (south of river Lumi), Mvumi (south of Mamsera) and Sangeo which lies south of Mashati ward. Investigations on the ground water using resistivity methods have been carried out by the Kilimanjaro regional hydrologist but establishment of the quality, quantity and exact boundaries of the available water has not been done. Some boreholes have also been drilled over the project area but none of them has shown promising discharges. An example is the Chala borehole which has a discharge of 60 litres/h and water point at 160 m. below the ground surface.

The most important drainage feature of this area is Lake Chala which lies on the south-east end of the project area. Lake Chala lies exactly on the border between Tanzania and Kenya and the interterritorial boundary cuts it nearly in half - the larger portion lying in Tanzania (see drawing 1). It is a crater lake, the inner walls of which are precipitous. The lowest point of the rim is 177 ft. above the level of the lake, the highest 437 ft. (see photo 1) and the mean height is 300 ft. The volcanic outburst that caused the vent was paraxysmal and only ashes and scoria were discharged and no lava flows. The water is clear and fresh. The sides of the crater slope down under water at angles of 45 degrees, and soundings indicate that the floor is level and 275 to 300 ft. below the water-level. The reduced level of the surface of the water is 2800 ft. a.s.l. The area of the lake is 4.2 km^2 and the volume of the water it holds is approximately 3×10^8 m^3. No visible inlets or outlets are observed, but in the north west corner two small surface catchments, of about 45 hectares drain into the lake during rainy season. By using artificially injected tritium the annual subsurface inflow was estimated at 12.5×10^6 m^3 while the outflow was 8.2×10^6 m^3. The local inhabitants, however, report that the water-level remains constant - a phenomenon common in crater lakes [1].

2.3 Geology

The regional geology is well described in the Quarter Degree Sheets [2]. Considering the project area, the north-western half is covered by lava flows, some of which have been erupted from Mt. Kilimanjaro and others from subsidiary vents on the plains. Successive flows in some cases, as indicated on the western wall of lake Chala, were thin and of varying composition. The volcanoes are divided into the Rombo series, lavas of the subsidiary cones and tertiary intrusives.



MAP 1 : PROJECT AREA SHOWN IN PENCIL

(a)

(b)

PHOTO 1 : (a) LAKE CHALA FROM TOP; (b) FROM THE WATER SURFACE

2.3.1 The Rombo series

The rocks of Rombo series occupy the ground between lake Chala, the Kenyan border and the area just above the lower Rombo road extending on the north-east direction along the border. They form a gently sloping plateau which gradually increases in height towards the north-east, at the same time becoming more dissected. The series has the following succession:

- Kijabe-type basalts and olivine soda-trachytes.
- Melanocratic basalts with olivine and angite phenocrysts, interdigitated with subordinate flows of porphyritic picrite basalt.
- Dense basalts.

Subordinate intercalated lavas include anacite basalts, picrite basalts and olivine trachy-basalts. The felspathoidal lavas include nephelinites, olivine nephelinites, phololytic trachytes and phonolites but none of these have been found in situ.

No associated agglomerates are observed, and tuffs (crystallo-vitric) are confined to the north-eastern corner of the area. The eruptive cèntre of the Kijabe-type basalt covers a considerable area which straddles the Ungwasi River and is characterized by numerous small cones. No signs exist of the original craters and stumpy hillocks presumably represent plugs that sealed the vents at the close of vulcanicity and have proved more resistant to erosion than the rocks that once surrounded them.

2.3.2 Lavas and ashes of the subsidiary cones

The lavas extruded from volcanoes on the plains on western side of lake Chala along the Kenyan border, and consists essentially of vesicular olivine basalt. Of the craters still in existence that of Chala, which has a diameter of two and a half kilometers and a depth of several metres, is the best preserved. Across the border at Lemrika the crater is barely discernible. The cones have smoothly curved grass-covered slopes and have been built of ash, scoriaceous material and olivine basalts contaminated with lapili and ash.

2.3.3 Tertiary intrusives

Between Lume and Marue rivers float blocks of crinanite, a variety of olivine - analcite dolerite containing orthoclase, is observed.

2.4 Climate

The climate of Tanzania in general is of equatorial type influenced by a zone of low pressure surrounding the "waist line" of the earth where winds are generally light and variable. There are two "monsoons" prevailing in the area in the course of a year. The average amount of rainfall per year is moderate but not equally distributed.

The nearest metrological station to the project area is in Taveta which is about 5 km away. The 12-year mean precipitation at Taveta (Njoro Kubwa) is 575 mm. The annual values are given in Table 1. For 1968, values are also given for Taveta (W.D.D. Station) and Lake Chala where a station was installed [1].

TABLE 1

Precipitation, evaporation and relative humidity in the Lake Chala region.

Precipitation (m)	1964	1965	1966	1967	1968	mean (1964-68)
TAVETA (NJORO KUBWA)	0.455	0.463	0.557	0.842	1.276	0.713
TAVETA (W.D.D. STATION)					1.319	
LAKE CHALA					1.058	

Mean monthly evaporation and relative humidity at Taveta.

Eva.	J	F	M	A	M	J	J	A	S	O	N	D	annual mean
	0.229	0.193	0.161	0.119	0.102	0.098	0.098	0.112	0.134	0.155	0.144	0.188	1.733
R.Hu.	J	F	M	A	M	J	J	A	S	O	N	D	
	0.74	0.74	0.85	0.80	0.80	0.73	0.67	0.64	0.57	0.54	0.67	0.64	

The lower reading for Lake Chala is possibly due to an observational error or poor exposure of the raingauge, which is situated on the rim of the lake [1]. Thus the values for Taveta are taken as representative of precipitation falling on Lake Chala and the project area. Rainfall data for 1981 - 1985 at a station established within the project area at Kilimanjaro Sec. School is also shown on Table 2.

Data from an evaporation pan installed at Lake Chala indicated that the Lake Chala pan readings differ from the pan data obtained from Taveta by a factor of 0.9. Estimates of the open water evaporation from the lake (Table 1) were therefore obtained from the Taveta pan data using a pan factor of 0.8 and then adjusted by a factor of 0.9 to reflect the difference observed between the pans installed at the lake and Taveta. The estimates are in agreement with those obtained for this area by Woodhead [3].

Monthly mean values of relative humidity were available at Taveta and are also given in Table 1 [1].

TABLE 2

KILIMANJARO SEC. SCHOOL STATION 93.37128
(Rainfall mm)

Station 93.37128	J	F	M	A	M	J	J	A	S	O	N	D
1981	124.8	5.5	280.4	181.7	293.6	5.9	1.2	5.5	6.0	113.3	120.3	209.7
1982	18.3	90.2	140.7	160.1	11.3	10.6	19.3	2.1	22.0	140.2	270.1	98.7
1983	25.0	104.0	54.0	135.1	34.9	0.0	0.0	16.0	27.3	11.2	80.9	174.6
1984	17.0	10.0	146.3	190.3	10.7	11.5	53.5	0.0	22.2	155.6	326.2	126.3
1985	0.0	164.7	161.4	113.4	45.2	0.0	0.0	0.0	0.0	124.4	245.4	65.3

2.5 Soils

In Rombo up to now very little systematic and comprehensive soil mapping is done. All investigations on soils were merely reconnaissance soil surveys giving broad general ideas on the prevailing conditions and on the possible potential for development. Often the soils of Rombo are only mentioned in connection and as part of the national soils. Below is an extraction from the book "An Edaphological and Pedological Investigation of Soils in Tanzania", W Møberg, 1973.

The soils of the area are strongly influenced by the parent material which is lava flows and volcanic ash. The dominant soil unit of the area is consisting of brown to dark brown coloured soils having about 20 % clay and equal proportions of silt and sand. This soil type is generally called "loam". The depth of the soil is between 3 - 6 ft. and the available moisture ranges from 1.5 - 2.0 inch/ft. of soil depth. The permeability is moderate and it ranges from 0.3 - 0.9 inch/hour.

The content of organic matter in the soils is moderate and it depends mainly on the erosion caused by rainfall. The PH value of the soil varies from 6.0 - 7.0. It has been established that with proper manure, fertilizer application, and rotation practices the fertility of the soil can be built up to high productivity [1).

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3. WATER REQUIREMENT

3.1 General

The main objective of irrigation is to provide plants with sufficient water to prevent stress that may cause reduced yield or poor quality of harvest (Haise and Hagan 1967, Taylor, 1965). The required timing and amount of applied water is governed by the prevailing climatic conditions, crop and stage of growth, soil moisture holding capacity, and the extent of root development as determined by type of crop, stage of growth and soil.

Need for irrigation can be determined in several ways that do not require knowledge of evapotranspiration (ET) rates. One way is to observe crop indicators such as change of colour or leaf angle, but this information may appear too late to avoid reduction in crop yield or quality. This method has been used successfully with some crops like beans (Haise and Hagan, 1967).

3.2 Evapotranspiration (ET) Method

This is a method of estimating crop water requirements expressed as equivalent depth of water over the horizontal projection of the crop growing area. This information when combined with soil water holding characteristics, has the advantage of not only being useful in determining when to irrigate, but also enables specifying how much water to apply. ET information is also needed in determining the volume of water required to satisfy short-term and seasonal water requirements for fields, farms and irrigation projects, and in designing water storage and distribution systems.

3.3 Definitions

3.3.1 Evapotranspiration: (ET)

The combined process by which water is transferred from earth's surface to the atmosphere. ET includes evaporation of liquid or solid water from soil and plant surfaces plus transpiration of liquid water through plant tissues expressed as latent heat transfer per unit area or its equivalent depth of water per unit area.

3.3.2 Potential Evapotranspiration

The rate at which water, if available, would be removed from the soil and plant surface expressed as the latent heat transfer per unit area or its equivalent depth of water per unit area.

3.3.3 Crop ET

$ET = Dc.E_{tp}$

where Dc is referred to as a crop coefficient incorporating the effects of crop growth stage, crop density, and other cultural factors affecting ET.

3.3.4 Effective Precipitation

Effective rainfall or precipitation (Pe) according to Distane (1974) is "that which is useful or usable in any phase of crop production".

3.3.5 Irrigation Water Requirement

The irrigation water requirement (R) was defined by Doorenbos and Pruitt (1977) as "the depth of water needed to meet the water loss through ET of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under given growing enviroment".

$$R = E_t - P_e + (\text{other beneficial uses}).$$

The units for R usually are volume per unit area or depth.

3.4 Factors Contributing to Water Requirement

ET is the principal factor in determining irrigation water requirements, but losses in storage, conveyance and applying water, the inability to apply water uniformly, and the need for soil leaching are additional factors. The planning and operation of irrigation systems must take all these factors into consideration in determining water requirements.

3.5 Estimation of Reference Crop ET

3.5.1 Penman Method:

The Penman equation modified for estimating alfalfa based reference ET in $Cal/cm^2.d$ is:

$$E_{tr} = \frac{\Delta}{\Delta + \gamma}(Rn+G) + \frac{\gamma}{\Delta + \gamma} 15.36\ W_f(e_a - e_d)$$

E_{tr} = reference crop ET in $Cal/cm^2.d$

Δ = slope of the vapour pressure-temperature curve in $mb/{}^oC$ ($= 2.00(0.00738T + 0.8072)^7 - 0.00116$)

T = mean daily temp. (^oC)

$\gamma = \frac{0.386P}{L}$ $L = 595 - 0.51\ T(^oC)$

$P = 1013 - 0.1055\ E$ (E = altitude in m)

$W_f = Q_w + b_w U_z$ (Q_w & b_w Table values in Table 1 App. 2).

(U_z = daily wind travel (km/d) at Z m above ground).

R_n = net radiation in $Cal/cm^2.d$

G = soil heat flux to the surface in $Cal/cm^2.d$

Wf = wind function (dimensionless)

$(e_a - e_d)$ = mean daily vapour pressure deficit in mb.

15.36 = Constant of proportionality in $Cal/cm^2.d.mb$.

Place: Rombo, July

Elevation	1200 m
Max. air temperature	27^{0} C
Min. air temperature	16^{0} C
Average air temperature	21.5^{0} C
Average dew pt. temperature	10^{0} C
Vind velocity	36 km/day
Estimated $\frac{\text{daytime wind}}{\text{night time wind}}$	4.0

$$E_{tr} = \frac{\Delta}{\Delta + \gamma} (Rn + G) + \frac{\gamma}{\Delta + \gamma} 15.36\, w_f\, (e_a - e_d)$$

$$\Delta = 2.00\,(0.00738 \cdot 21.5 + 0.8072)^7 - 0.00116$$
$$= 1.567 \text{ mb}/\ {}^{0}\text{C}$$

$$P = 1013 - 0.1055 \cdot 1200 = 886.4 \text{ mb}$$

$$L = 595 - 0.51 \cdot 21.5 = 584 \text{ Cal/g.}$$

$$\gamma = \frac{0.386 \cdot 886.4}{584} = 0.586 \text{ mb}/\ {}^{0}\text{C}$$

$$\frac{\Delta}{\Delta + \gamma} = \frac{1.567}{1.567 + 0.586} = 0.728$$

$$\frac{\gamma}{\Delta + \gamma} = 1.000 - 0.728 = 0.272$$

$$U_2 = U_z \left(\frac{2}{Z}\right)^{0.2} = 36 \left(\frac{2}{3.66}\right)^{0.2} = 31.9 \text{ km/d.}$$

$$W_f = 0.75 + 0.0115 \cdot 31.9 = 1.117$$

$$e_d = 33.8639 \left[(0.00738 \cdot 16 + 0.8072)^8 - 0.000019\,|1.8 \cdot 16 + 48| + 0.001316\right]$$
$$= 18.2 \text{ mb.}$$

$$e_a = \frac{1}{2}(35.6 + 18.2) = 26.9 \text{ mb.}$$

$$Rbo = (0.39 - 0.042\sqrt{18.2})\ 11.71 \cdot \frac{(273 + 21.5)^4}{10^8}$$

$$= 186 \text{ ly.}$$

Alternative:

$$E = -0.02 + 0.261 \ \text{EXP}\left[\frac{-7.77}{10^4}(21.5)^2\right]$$

0.162

$$Rbo = \frac{0.162 \cdot 11.71}{10^8}\ (273 + 21.5)^4$$

$$= 143 \text{ ly.}$$

$$Rb = (1.2 \cdot 0.9 - 0.2)\ 186 = 164 \text{ ly.}$$

$$Rn = (1 - 0.23)\ 687 - 164 = 365 \text{ ly.}$$

Set G = 0

$$E_{tr} = 0.728\ (365 + 0) + 0.272 \cdot 15.36 \cdot (1.117) \cdot (26.9 - 18.2)$$

$$= 306.3$$

$$\doteq \frac{306.3}{584} \cdot 10 = 5.25 \text{ mm/day.}$$

3.5.2 Blaney - Criddle Method

The FAO variation of the Blaney-Criddle method is:

$$E_{to} = a_4 + b_4 f$$

$$f = P(0.46T + 8)$$

E_{to} = reference crop evapotranspiration in mm/day.

T = average monthly air temperatures , ^{o}C

P = percentage of daytime hours of a day campared to the entire year.

a_4 & b_4 represent the intercept and slope of a straight line relationship between E_{to} and $f \cdot E_{to}$. Fig. 1 App. 2.

Place: <u>Rombo</u>

Lat : $5^{o}S$

Alt : 1200 m

Time: July

T max.: $27^{o}C$

T min.: $16^{o}C$

P : 0.27

f $= 0.27(0.46 \cdot 21.5 + 8) = 4.83$

$RH_{min} = 65$

n/N = 50 %

U_2 daytime: medium (2 - 5 m/s)

E_{To} (Fig.3.1) = 5 mm/day

$E_{tr} = 1.15\ E_{to}$ (for light to moderate winds in arid climates).

$E_{tr} = 1.15 \cdot 5.0 = 5.75$ mm/day.

Peak-use demands for the other months are lower than 5.75 mm/d because the temperatures are slightly lower than the July temperature.

By using this method and Kc values for the different crops, their E_{ts} were evaluated and shown on Table 3.0.

CROP	PEAK-USE DEMAND mm/DAY	SEASONAL CONSUMPTIVE USE (mm)
MAIZE	5.75	754
BEANS	4.83	475
GROUNDNUTS	5.33	625
SUNFLOWER	5.08	750
GRAPES	5.33	675
SORGHUM	4.57	475
POTATOES	5.59	490

TABLE 3.0 PEAK-USE AND SEASONAL WATER DEMANDS

3.6 Determination of effective rainfall

Average rainfall: 5-year recording at Kilimanjaro sec. school (1981 - 1985)

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
RAINFALL (mm)	37.0	74.9	156.6	156.1	79.2	5.6	5.1	4.7	15.6	108.9	208.6	134.9

TABLE 3.1 AVERAGE RAINFALL (5-YEAR PERIOD)

The mean monthly consumptive use for maize:

Peak-use demand is 5.75 mm/day

Length of growing period is 180 days

Monthly consumptive use = 30 · 5.75 = 172.5 mm.

The monthly effective rainfall is estimated using table .2 in the appendix 2.Table 3.2 shows the monthly effective rainfall through use of tables 3.1 and A2.

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
EFFECTIVE RAINFALL (mm)	30.5	60.2	116.2	116.0	63.2	0	0	0	12.3	84.8	143.8	102.3

TABLE 3.2 MONTHLY EFFECTIVE RAINFALL

Irrigation water requirement, R = Et - Pe.
Considering maize crop, table 3.3 shows the irrigation water requirement to supplement rainfall.

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
IRRIGATION REQUIREMENT	141.5	112.3	56.3	56.5	109.3	172.5	172.5	172.5	160.2	87.7	28.7	70.2

TABLE 3.3 IRRIGATION REQUIREMENT

3.7 Size of land to be Irrigated

Total area under consideration is about 12.500 hectares (see 1.1). It has been established that there are three possible sources of water for irrigation ie. Lake Chala, the streams from the mountains and the underground water sources (see 1.2).

One way of carring out the project is to divide the area under consideration according to the water sources. In this case the area is considered divided into three portions. The size of each portion will depend on the capacity of the water source over the area to supply water.

Of the three water sources, Lake Chala is the one which has most information relevant for design. For this reason the project is limited to irrigating areas around the Lake using its water. The amount of land which can be irrigated in this way will be established in the next section after determining the frequency of irrigation as well as depth of water required for each irrigation.

4. DESIGN OF IRRIGATION SYSTEM

4.1 General

Three major considerations influence the time of irrigation and how much water should be applied, namely, a) water needs of the crop, b) availability of water with which to irrigate, and c) capacity of the root-zone soil to store water. Water needs of a crop are of paramount importance in determining the time of irrigation during the crop-growing season on irrigation projects which obtain their water supplies from storage reservoirs or from other dependable sources of water [4].

Growing crops use water continuously, but the rate of use varies with the kind of crop grown, age of the crop, temperature and atmospheric conditions - all variable factors. At each irrigation a volume of water sufficient to supply the needs of the crop for a period varying from a few days to several weeks is stored in the unsaturated soil in the form of available water.

4.1.1 Frequency of irrigation

During the active growing period of the crop, the most important factor governing frequency of irrigation is the need to keep adequate moisture in the soil for the crop. Two approches can be made based upon the need for water by the root-zone soil. Both depend upon the capacity of the soil within the root-zone to store water and the amount of water to be depleted. The available water per unit depth of soil multiplied by the depth to which moisture will be depleted will give the total water-holding capacity. However, maximum production can be obtained on most crops if not more than 50 per cent of the available moisture is removed during the vegetative, flowering and wet-fruit stages of growth. Frequency of irrigation can be determined by dividing the amount of moisture to be depleted from the soil by the consumptive use per day. [4]

4.1.2 Depth of water to be applied during irrigation

Determining how much water to apply can be calculated either by using the consumptive-use rate or the amount of soil moisture to be depleted from the soil. When the consumptive-use rate is to be used, it is necessary to know how many days since the field was last irrigated and the efficiency of the irrigation which is influenced by management, by method of irrigation, and by leaching requirements.

Starting with consumptive use - evaporation ratio, the depth to be applied can be determined using the monograph of Fig. 4.1. When the amount of water available per foot of soil is known, the monograph of Fig. 4.2 can be used to calculate the depth to be applied considering depth of the root zone, percentage of moisture to be depleted, and efficiency of irrigation. Converting the depth to be applied into stream size or the hours required to apply the necessary water can be accomplished by using the nomograph as shown in Fig. 4.2[4)].

4.2 Design for Rombo

Imperial units are used here in order to enable use of tables.

Place: Rombo

Crops: maize, beans, sunflower, potatoes, grapes, groundnuts, sorghum.

Consumptive use: max. 5.75 mm/day, 0.23 in./day.

Soil:

Type: Loam

Depth of root zone = 3 - 6 ft.

Available water at field capacity = 1.8 in./foot of soil

Percentage of total water to be depleted = 50

Efficiency of irrigation = 60 %.

4.2.1 Frequency of irrigation

$$\text{No. of days between irrigations} = \frac{\text{Amount of water to be depleted}}{\text{Consumptive use}}$$

Consideration is made for the extreme conditions of no precipitation because the rainfall pattern is unpredictable and sometimes it does not rain at all for several months (see tables 2 and 3.2).

Total available water at field capacity = $5 \cdot 1.8 = 9$ in.
Amount of water which can be depleted = 50 %
= 9 in. · 0.5 = 4.5 in.

No. of days between irrigations for maize crop is:

$$\frac{4.5\text{ in.}}{0.23} \simeq 19 \text{ days}$$

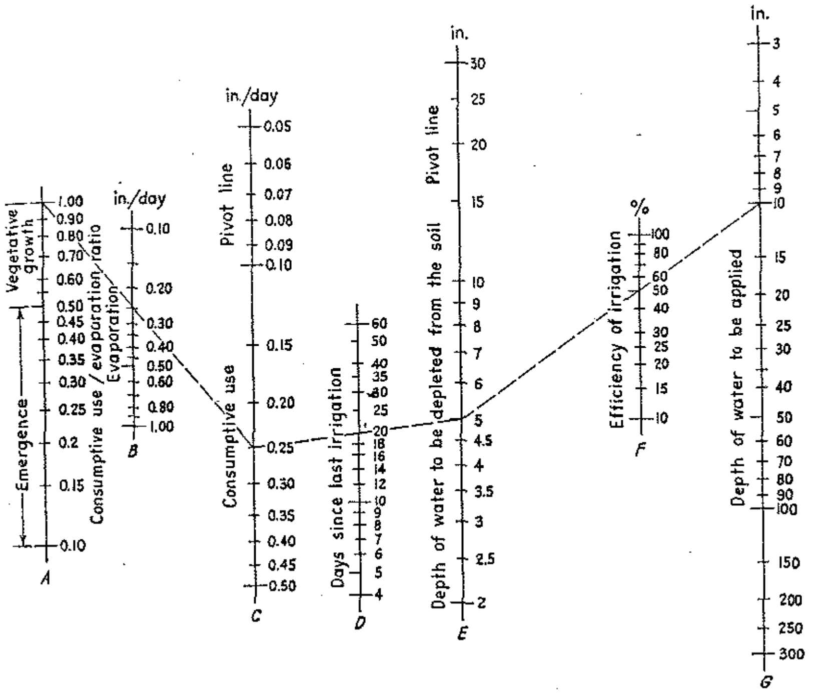
The growing period of maize is between 5 - 6 months.
The crop needs water for 150 days of its growing period.

$$\text{Number of irrigations necessary} = \frac{150}{19} \simeq 8$$

Table 4.1 shows the summary of the length of the growing seasons of the various crops to be irrigated and the number of irrigations necessary.

CROP	LENGTH OF THE GROWING SEASON (DAYS)	CONSUMPTIVE USE (IN/DAY)	NUMBER OF IRRIGATIONS
Maize	150	0.23	8
Beans	110	0.19	5
Groundnuts	105	0.21	5
Sunflower	-	0.21	-
Potatoes	145	0.22	7
Sorghum	135	0.18	5
Grapes	-	0.20	-

TABLE 4.1 NUMBER OF IRRIGATIONS/SEASON



4.1 Calculating depth of water to be applied per irrigation, starting with age of growth of the crop. (Directions for use are same as for Fig. 4.2.

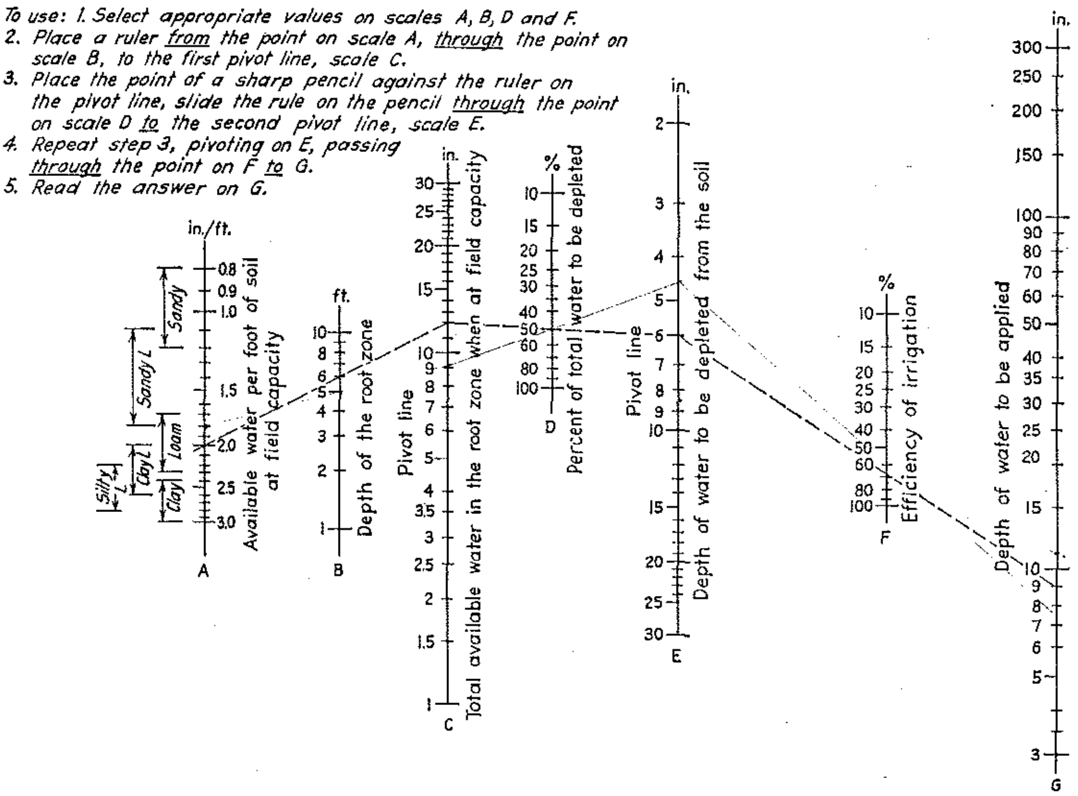


Fig. 4.2 Calculating depth of water to be applied per irrigation.

4.2.2 Depth of water to be applied per irrigation

Using nomograph pf Fig. 4.2, the depth of water to be applied per irrigation is 7 · 5 in.

Number of hours required to reach the capacity of 7 · 5 in. is

$$\frac{\text{depth}}{\text{rate}} = \frac{7 \cdot 5}{0.5\text{in/hour}} = 15 \text{ hours.}$$

With irrigation of 12 hours/day, one irrigation circle is about 2 days.

4.3 Size of land to be irrigated using lake Chala

The average inflow into lake Chala is 12,5 · 10^6 m^3 per year. 1) The average outflow is 8.2 · 10^6 m^3 per year. 1) The difference is evaporation loss. It is anticipated that if water is pumped from the Lake, the net outflow can be reduced. In this case 4.3 · 10^6 m^3 of Lake water which is as high as evaporation loss are considered to be available for irrigation thus reducing the average outflow to about 4.1 · 10^6 m^3 per year.

Of all the crops intended for the area, maize has the highest peak-demand ie. 5 · 75 mm/day and it needs water in 150 days of its life period.

Assuming extreme case of unreliable rainfall, available water is:

$$\frac{4.3 \cdot 10^6 \text{ m}^3}{150 \text{ days}} = 28667 \text{ m}^3/\text{day.}$$

The water will be pumped for 20 hours/day:

$$\frac{28667}{20} = 1433 \text{ m}^3/\text{hour.}$$

The size of land which can be irrigated using this water with an irrigation efficiency of 60 % is:

$$A \cdot 10^4 \cdot 0.001 = 1433 \cdot 0.6$$

$$A = 86 \text{ ha-mm per hour.}$$

The irrigation work is carried out in 12 hours/day (daylight time)

$86 \cdot 12 = 1032$ ha-mm per day.

From the daily peak demand of 5.75 mm, the actual area :

$$\frac{1032}{5.75} = 180 \text{ hectares/day.}$$

For maize with irrigation frequency of 8 and irrigation interval of 19 days a total of 1800 hectares can be irrigated.
However, considering the mean annual precipitation which is about 575 mm, the peak demand is reduced to about $4 \cdot 8$ mm/day and the total area which can be irrigated is thus about 2150 hectares.

4.4 Water supply arrangement

From the Lake, water will be pumped to a primary reservoir which is located at 1500 m from the Lake. The altitude of the reservoir is 3150 ft.a.s.l. The height from the water surface in the Lake which is at 2800 ft.a.s.l to the reservoir is 350 ft or $0.3048 \cdot 350 = 107$ m.

Pumping from the Lake to the reservoir will be done using a steel pipe with a diameter of 24" or 0.608 m.

Friction losses in the pipeline are:

$$h_L = \frac{f.L.V^2}{d.2g}$$

V = Average velocity = $Q/A = \frac{0.39 \cdot 4}{\pi \cdot 0.608^2} = 1.37$ m/s.

d = diameter of the pipe = 0.608 m.

L = Length of the pipeline = 107 + 1500 = 1607 m.

f = Coefficient of friction loss = 0.012 (from moody diagrams).

$$h_L = \frac{0.012 \cdot 1607 \cdot 1.37^2}{2 \cdot 0.608 \cdot 9.81} = 3.03 \text{ m.}$$

Total pumping head = 107 + 3 = 110 m.

4.5 Pump selection

The pump required has the following characteristics:

Discharge, Q = 1433.3 m^3/h or 0.398 m^3/sec.

Total head, H = 110 m.

FLYGT can supply a centrifugal pump with the following characteristics:

Max. discharge = 400 l/sec.

Max. head = 60 metres.

The cost of such a pump is about 850,000 SEK (ex-factory).

For this kind of pump to be suitable for the project 2 Nos. will be required and will be connected in series so that discharge from the first pump is piped into the inlet side of the second pump.
In this way the total head will be 2 · 60 = 120 m., which is greater than the required 110 m.

The total cost of the pumps is about 1,75 m.SEK (1 SEK = 5 · 7 Tshs).

UPONOR can supply 24" PVC pipes at a cost of about 545 SEK per meter but the max. pressure which they can withstand is not yet clear.

The effects of water-hammer pressures shall be counteracted by use of automatic relief valve.

4.5.1 Power requirement

Pump head = 110 m.

Pump efficiency = 75 %.

The pump works 20 hours/day.

$$P = \frac{1}{\eta} Q\rho gh \quad (w)$$

$$= \frac{0.398 \cdot 9.81 \cdot 110 \cdot 10^3}{0.75 \cdot 10^3} = 572.6 \text{ Kw.}$$

Energy = Power x time.

$$E = 572.6 \cdot 20$$

$$= 11453 \text{ Kwh/day.}$$

4.6 Service reservoir

A service reservoir is included in the project in order to make it possible to carry out surface irrigation under gravity and also to avoid interruptions which would be caused by holidays, week-ends and break-downs if the distribution system is done directly from the Lake.

The reservoir shall be constructed of earth fill with an appropriate sealing method in order to make it economical.

a) Capacity:

The capacity of the reservoir is the amount of water which is enough for 1 day irrigation ie. 28667 m^3.

Due to evaporation, seepage and sediment, the efficiency of the storage is 80 %.

$$\text{Actual reservoir volume} = \frac{28667}{0.8} = 35834 \text{ m}^3.$$

For economic earthwork a triangular reservoir will be constructed with the long base placed parallel to the contour along the highest edge of the site. A water depth of 2.5 - 3.0 m will be used for ease of operation and safety..

The plan of the reservoir is shown on Fig. 4.6.1 and other details in Fig. 4.6.2 and Fig. 4.6.3

b) Height of reservoir

The required height is the distance from the foundation to the water surface in the reservoir when spill way is discharging at design capacity plus a freeboard allowance for wind set up, waves and earthquake motions [5].

$$H = 3 \cdot 0 \text{ m} + \text{freeboard } (0.5 \text{ m})$$
$$= 3 \cdot 5 \text{ m}.$$

c) Top width

The top width of the reservoir should be sufficient to keep the phreatic line, or upper surface of seepage, within the reservoir when it is full. Top width should also be sufficient to withstand earthquake shock and wave motion. In this case it is 2 m which is the minimun distance that a scraper can form.

d) Excavation method

The embankment to be built above the ground should be constructed entirely of the soil burrowed from the lower part of the reservoir, dug into the ground. The reservcir has been located at a point where there is a balance between cut and fill within the reservoir. In case of a little discrepancy more fill material can be stripped from the adjacent land. Calculations of earthwork is done in the subsequent sections. A straight scraper shall be used to do the job on hire terms assisted by the villagers.

e) Sealing the reservoir

The method adopted for sealing the reservoir is compaction at optimum moisture content. One disadvantage of this method is the fact that soil burrowed from the lower half of the reservoir is not always suitable for compaction. However, after applying the required amount of moisture to it the sealing job can be carried out.

The fill for the embankment shall be spread in very thin horizontal layers of up to a maximum of 5 cm. The work shall be organized in such a way that embankment rises uniformly so that the scraper can travel as much as possible over the fill - the same number of trips over each layer.

A sheepfoot roller can be made of an empty oildrum filled with concrete and studded with screws and pipe sections to give further compaction[6], (as it was done with the existing reservoir at Ikuini).

To safeguard against seepage along the natural field level through voids developed due to disintegration of organic matter, the topsoil layer shall be stripped from the reservoir site especially from the embankment foundation, and deposited along the outer edge of the embankment.

The inside slopes of the reservoir shall be 1:3, whereas the outside shall be 1:2. To protect the sides against wave impact, erosion and drying, a gravel blanket of at least 10 cm thick shall be placed on the inside slopes of the reservoir. A dead storage of 200 cm shall be at the bottom to prevent drying out of the compacted soil. Reservoir drawings are shown in Fig. 4.6.1 - 4.6.3.

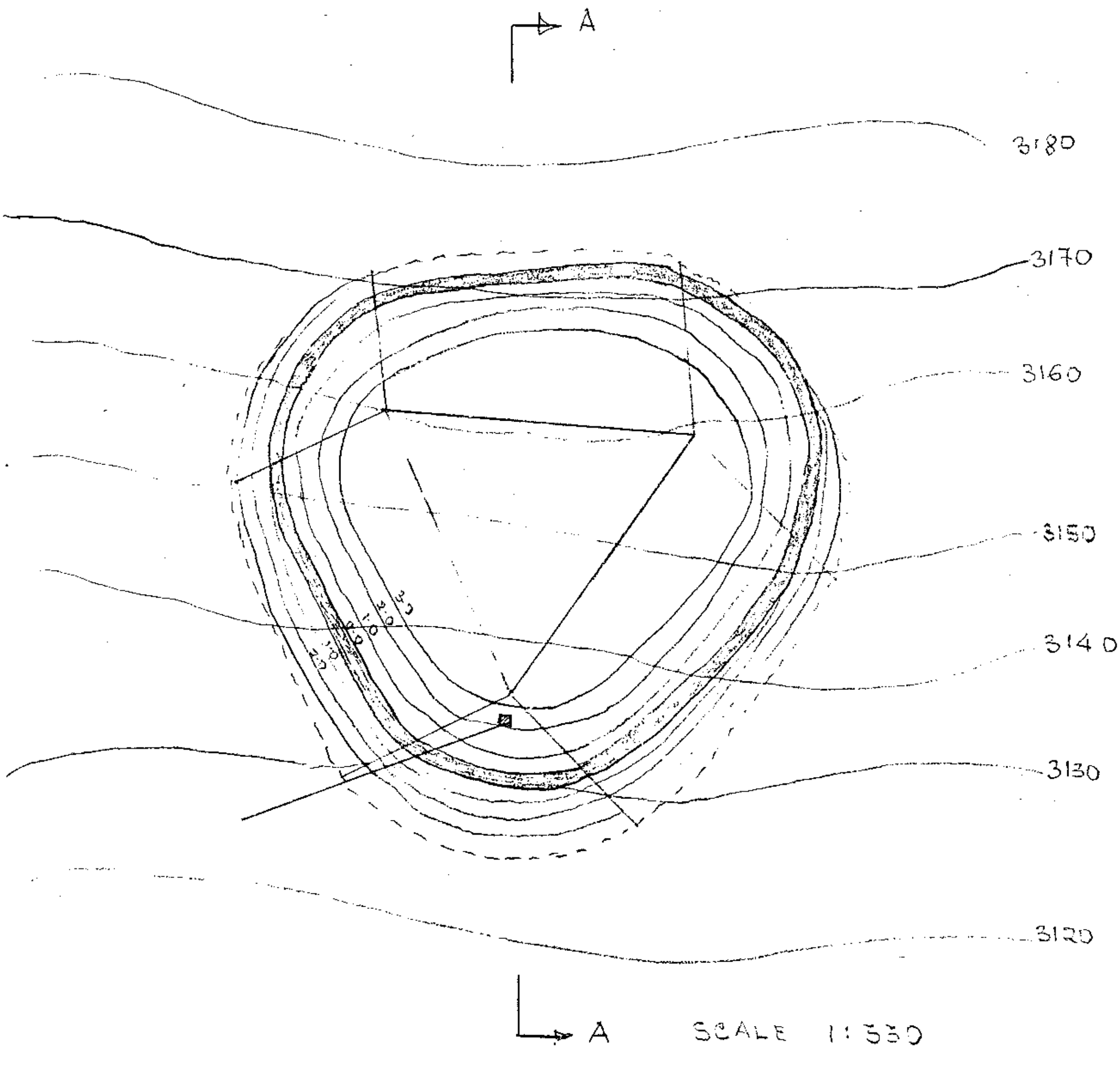
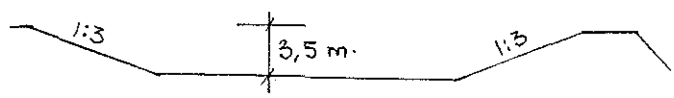


FIG 4·6·1 EATHWORK PLAN FOR THE CONSTRUCTION OF A SERVICE RESERVOIR

4.6.1 Calculation of earthworks

Section A - A Fig. 4.6.1



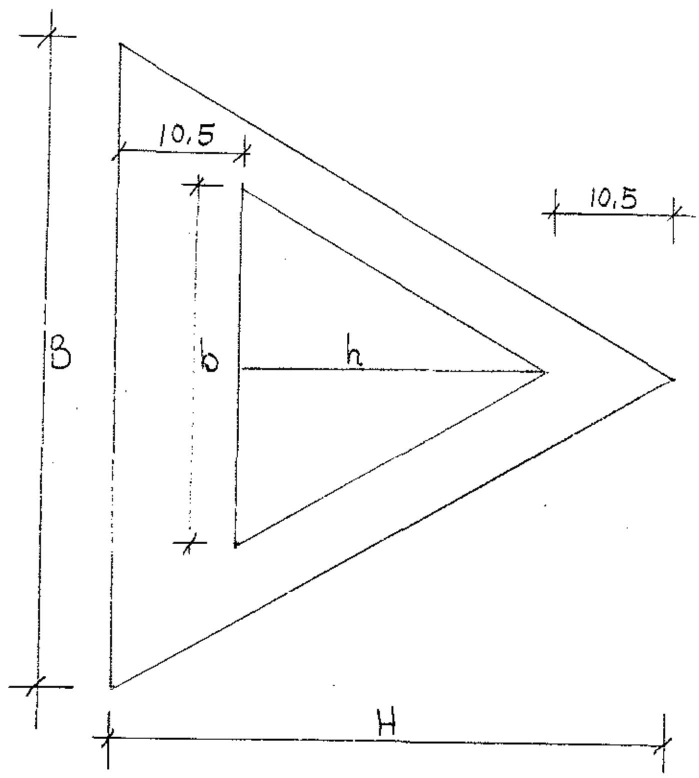


FIG. 4.6.2

Area of the top triangle (outer), $A = \frac{1}{2}\ BH$

But $H = B\mathrm{Sin}60$

$$A = \frac{1}{2}\ B^2\mathrm{Sin}60 = 0.433B^2$$

Area of the bottom triangle (inner), $a = \frac{1}{2}bh$

But $h = H - 21 = 0.866B - 21, \quad b = (0.866b21)/0.866$

$$a = \frac{1}{2}\ \frac{(0.866B - 21)^2}{0.866} = 0.577(0.866B - 21)^2$$

The height between the bottom area and the top area is 3.5 m.

$$\text{Volume} = \frac{h}{3}\,(A + \sqrt{A \cdot a} + a)$$

The volume of water to be contained in the reservoir = 35834 m^3.

$$\frac{3.5}{3}\,(0.433B^2 + \sqrt{0.433B^2 \cdot 0.577(0.866B - 21)^2} + 0.577(0.866B - 21)^2) = 35834$$

$$0.433B^2 + 0.5B(0.866B - 21) + 0.577(0.75B^2 - 36.372 + 441) = 30714.9$$

$$0.433B^2 + 0.433B^2 - 10.5B + 0.433B^2 - 20.987B + 254.5 = 30714.9$$

$$1.299B^2 - 31.487 = 30460.4$$

$$B^2 - 24.24B = 23449$$

$$B = 12.12 \pm \sqrt{12.12^2 + 23449}$$

$$B = 166 \text{ m.}$$

$$A = 0.433 \cdot 166^2 = 11932 \text{ m}^2$$

$$a = 0.577(0.866 \cdot 166 - 21)^2 = 8694 \text{ m}^2$$

Check:

$$V = \frac{3 \cdot 5}{3}\,(11932 + \sqrt{11932 \cdot 8694} + 8694)$$

$$= 35946 \text{ m}^3 \approx 35834 \qquad \text{OK}$$

By trial and error it can be shown that the volume of cut approximately equals the volume of fill if the inner triangle (in plan) is laid out with the mid-point of its height at contour 3150 ft. a.s.l.

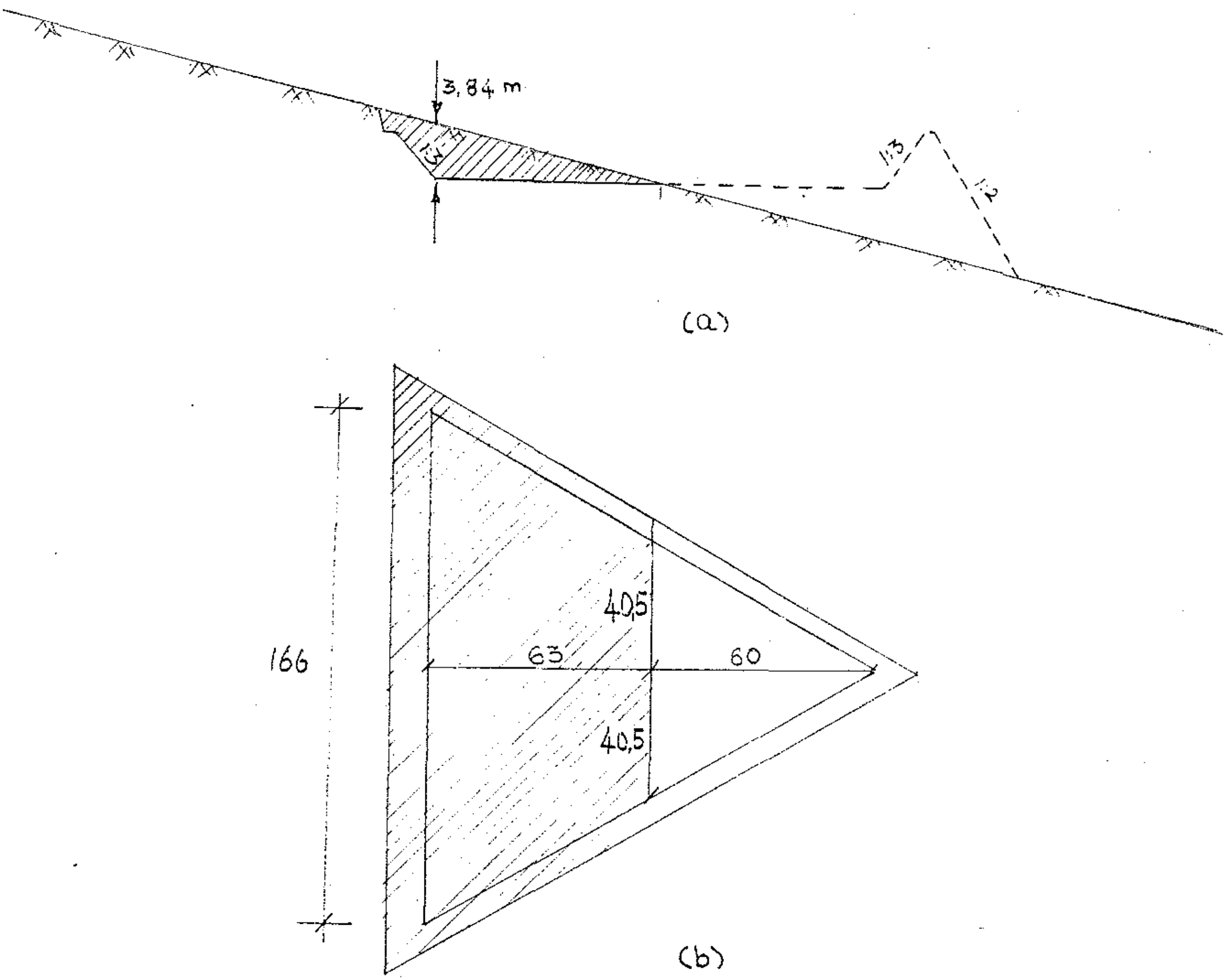


FIG. 4.6.3

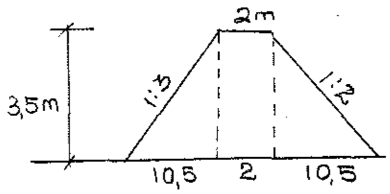
Cut:

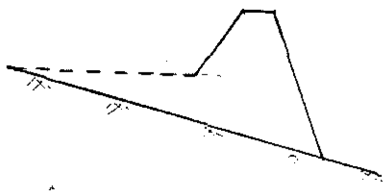
Section area = $\frac{63 \cdot 3.84}{2}$ = 121 m^2

Volume = $\frac{121}{2}$ (166 + 81) = 14.940 m^3

+ $\frac{2.42}{2}$ (166 + 152) = $\frac{385'' \, m^3}{15.325 \, m^3}$

FILL:





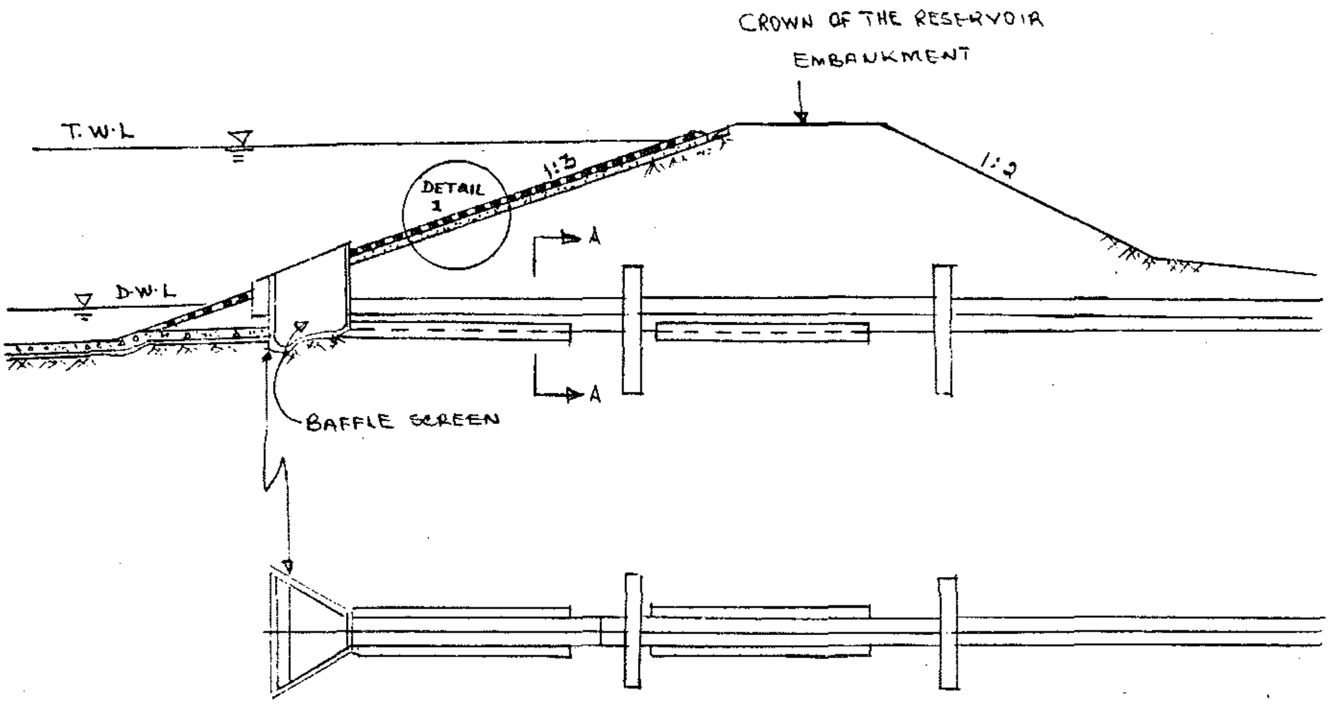
X-sectional area = 37.6 m^2

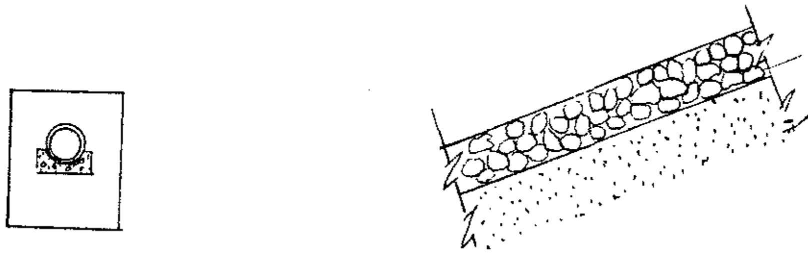
Length $\simeq$ 145 m

$$
\begin{aligned}
\text{Volume} &= 145 \cdot 37.6 = && 5452\ m^3 \\
&+ \frac{4.88}{2} \cdot 80 \cdot 40.5 = && 7906\ m^3 \\
&+ \frac{4.88}{2} \cdot 10.5 \cdot 85 = && \underline{2178\ m^3} \\
& && 15536\ m^3
\end{aligned}
$$

The difference between fill material required and cut material is 15536 - 15325 = 211 m^3, ie. additional 211 m^3 of fill material is required. This material can be stripped from the adjacent land not far from the reservoir in order to minimize/avoid transport costs. However, the material must be tested for suitability before use.

TWL – TOP WATER LEVEL
DWL – DEAD WATER LEVEL





SECTION A–A

DETAIL 1

4.7 Main Canal

4.7.1 General

The main canal will convey water from the service reservoir to the points of application. The main requirements of the canal are that it must have an economic cross-section from the construction point of view, it must be convenient to operate and remain operational with a minimum of maintenance and it must moreover be watertight.

4.7.2 Design considerations [7)]

a) Canal layout from the functional point of view is that it shall be placed along the head of the irrigation fields. Starting from the reservoir outlet it shall run along the highest line and command as large an area as feasible. The canal shall almost follow the contour, s = 0.01 with the larger part of its cross-section dug into the natural ground along the major part of its run. Some parts, however, may have to be dug in completely while others have to be built on an earthfill in order to straighten the canal alignment. See appendix A1.

b) The hydraulically most efficient cross-section considering fixed values of section area, slope and roughness coefficient is a half circle. But considering the working conditions and farm implement available at the project area (Rombo) a trapezoidal channel is opted for. For maximum efficiency in this case the hydraulic radius is 0.5 d. (d = depth of water).

c) For prevention of growth of aquatic plants and moss the depth of water in the canal shall not be less than 0.6 m and the least velosity shall be 0.75 m/sec.

d) To prevent weed and grass growth in the canal the least velocity of flow shall be put at least 0.6 to 0.8 m/sec. This velocity shall keep the balance by tearing out young shoots and prevent seeds from settling.

e) In order to prevent erosion along the canal perimeter for the soil type on the project area (loam) a velocity can be maintained between 0.85 - 1.5 m/sec.

f) To prevent silt deposits in the canal, the velocity mentioned in e) can be enough so long as it is not less than the critical velocity $V_g = cd^m$ in which d is the depth of flow, and c and m are constants which vary according to the grain size of the silt and the location where these are or have been established. [7]

4.7.3 Selected channel shape

Discharge, $Q = 2388 \cdot 8\ m^3/hour$
$= 0.66\ m^3/sec.$

Mannings roughness coefficient = 0.025 (Chow, 1959)
(for earth canal with no vegetation).

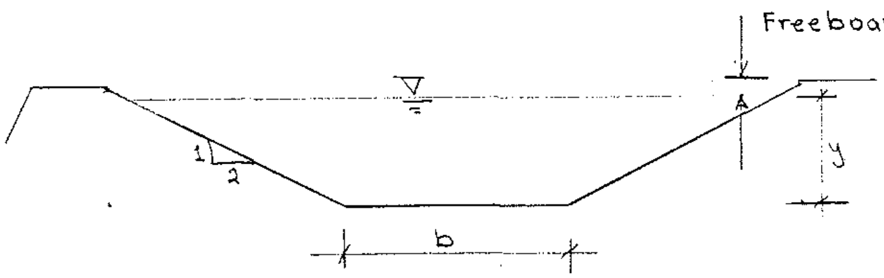


FIG. 4.7 PROPOSED CROSS-SECTION

Standard bottom width is 0.5 m (for available equipment).

$$Q = AV \tag{4.7.1}$$

Q = discharge, $m^3/sec.$
A = cross-sectional area, m^2
V = velocity, m/sec.

$$V = C\ R^{\ 2/3} S^{1/2} \qquad (4.7.2)$$

$C = \frac{1}{n}$ (n = Mannings No.)

R = the hydraulic radius

S = the energy gradient

From Fig. 4.7 with b = 0.5 m:

y is assumed by trial and error; in this case = 0.38.

$$A = (0.5 + 2 \cdot 0.38)0.38 = 0.48 \text{ m}^2$$

$$P = 0.5 + 0.38 \cdot 2\sqrt{5} = 2.19$$

$$R = \frac{A}{P} = 0.22$$

$$V = \frac{1}{0.025} \cdot 0.22^{2/3}\ 0.01^{1/2} = 1.44 \text{ m/s (equation } 4 \cdot 7 \cdot 2)$$

$$Q = 1.44 \cdot 0.48 = 0.69 \text{ m}^3/\text{s}$$

The actual value of y = 0.375 m.

The velocity calculated is suitable for both non-corrosion of the canal bank and prevention of silt deposition.

4.8 Subdivision of the project area

The area is sub-divided according to topography and physical features into 12 sections. It is considered that for each section, one irrigation cycle which takes 2 days is enough. It is also considered possible to alternate cropping pattern within these sections. This means that some of the sections can be used for maize crop, others for beans etc. Crop rotations in the different sections in different seasons is encouraged, while leaving some sections fallow after some years of cropping is also suggested. [8)]

The whole area lies below the altitude of 3150 ft.a.s.l. The main canal follows the contour of 3150 ft.a.s.l. The different sub-sections are shown in App. A1 and are briefly described below.

Section I

This section lies on the extreme north-east part of the area under consideration. To the south of the section lies Mwekio stream while the border between Kenya and Tanzania is on the east. The section slopes into two directions, towards the stream to the south and towards the border. The max. slope is 3 %.

Section II

This section lies between Mwekio stream which is on the north-east and Kenyan border to the south-east. Section III lies on the southern end of this section. The section slopes towards the south-east direction and the max. slope is approx. 3.2 %.

Section III

This section lies between section II to the north-east and Mbukoni stream to the south west. The section slopes towards south-west into the stream and towards south-east. The max. slope is approx. 2.8 %. The section is rather long about 3 km and is about 700 m wide.

Section IV

Lies between Mbukoni to the east and section V to the west.
It slopes towards the stream as well as towards south-east. The length of the section is about 300 km and width is about 650 m.

Section V

Lies between section IV to the north-east and Witini stream to the south. The section slopes generally to the south-east towards Lake Chala with a max. slope of about 36 % and min. of 1.5 %. The section is 2 km long and about 0.95 km wide.

Section VI

Lies between section VII and Witini stream. The section slopes slightly to the south-east with a max. slope of about 1.9 %. To the south-east of the section is Lake Chala towards which the section generally slope. The length of the section is approx. 1.5 km and width is approx. 1 km.

Section VII

This section is generally level and lies between the permanent path to the south and section VI to the north-east. The section has a length of about 1.5 km and a width of about 1.2 km. The irrigation method suitable for this section is level furrow system. To the far south-east end of the section is a hill with altitude 3663 ft. a.s.l. which separates the section from Lake Chala.

Section VIII

This section lies between section VII which lies to the north-east and Lamshamba stream which lies to the south. This section is rather irregular and long. To the south-east it gives room to section X which lies along the border between Tanzania and Kenya. The max. slope of the section is approx. 4.5 % and the section slopes both towards the stream and to south-east.

Section IX

This section lies between the two tributaries of Lamshamba stream. The section is about 1.5 km long and 0.85 km wide. Max. slope is about 4 % to the south-east of the section. The section slopes towards the stream also.

Section X

This section lies exactly on the border between Kenya and Tanzania and can not be irrigated directly from the main canal. Max. slope is

4 % to the south. Subsections XI and XII are similar to IX.

4.9 Water distribution system on the land

The irrigation water will be distributed on the farms using furrow system. These are small evenly, shallow channels which are dug down or across the slope of the field to be irrigated. Water is turned in at the high end and conveyed in the small channels to the vicinity of plants growing in, or on beds between the channels. Water is applied until the desired application and lateral penetration is obtained.[9)]

Advantages of this method is that many different kinds of crops can be grown in sequence without major changes in design, layout, or operating procedures. The initial capital investment is relatively low on lands not requiring extensive land forming as the furrows are constructed by common farm implements. Water does not contact plant stems and scalding is thus avoided.[10)]

4.9.1 Design equations[11)]

In furrows, intake is in both vertical and horizontal directions. The wetted perimeter is increased by an emperical constant to account for horizontal intake caused by soil moisture gradients.

$$P = 0.265 \quad (Q \cdot n/S^{0.5})^{0.425} + 0.227 \qquad --- 1$$

P = adjusted wetted perimeter (m)

Q = inflow rate (L/S)

S = the slope or hydraulic gradient (m/m)

n = Manning roughness coefficient

The time for water to advance to successive points along the furrow is:

$$Tt = \frac{x}{f} e^{\beta} \qquad --- \quad 2$$

Tt = the advance time (min.)

x = distance (m) from upper end of the furrow to point x (max. distance is L (the furrow length)

Q = inflow rate (L/S)

S = furrow slope (m/m)

f, g are advance coefficients varying with furrow intake family.

$$\beta = \frac{gx}{Qs^{1/2}}$$

Furrow opportunity time ie. the time water is available for infiltration at any point is equal to the inflow time less the time required to advance plus the time water remains after inflow ends.

$$To = Ti - Tt + Tr \quad - - - \quad 3$$

To = the opportunity time at point x.

Ti = inflow time - a constant for a specific irrigation.

Tt = advance time - increases at successive points downstream.

Tr = recession time - assumed zero for open end furrows.

The average opportunity time is from o - x m.

$$T(o - x) = Ti - \frac{0.0929}{fx\,\frac{0 \cdot 305\beta^2}{x}}(\beta - 1)(e^{\beta} + 1) \quad - - - \quad 4$$

T(o - x) = average opportunity time (min.) over length x.

The gross water application is:

$$Fg = \frac{60QTi}{WL} \quad - - - \quad 5$$

Fg = gross application in mm.

W = furrow spacing in m.

Cummulative intake is expressed as an equivalent depth over furrow spacing and unit length by the equation.

$$F = (aT^{b} + c)\,P/W \quad - - - \quad 6$$

F = equivalent intake depth in mm.

T = time in minutes.

a, b = intake family coefficients (Table 3 App. 2).

The opportunity time required is:

$$Fn = \left[(Fn\,\frac{W}{P} - c)\,/a\right]^{1/b} \quad - - - 7$$

The outflow from the furrow can be estimated as the difference between the gross application, Fg and the average intake F(0-L).

$Ro = Fg - F(0\text{-}L)$

Ro = outflow depth in mm.

Deep percolation is the average equivalent depth of water which infiltrates the soil in excess of the design application depth.

$DP = F(0\text{-}L) - Fn$ --- 9

DP = deep percolation in mm.

4.9.2 Design for a typical sub-section

Irrigation network for subsection VI (see App. A1) is designed using the method described in section 4.9.1 and the actual parameters for Rombo.

For the soil type which is loam and surface irrigation system, the appropriate intake family is 0.3. The average length of the furrows is 750 m (Fig. 4.9.1). For the first irrigation, however, the length of the water run is kept at 250 m and increased gradually in subsequent irrigations.

The slope of the furrows between 1.9 - 2.1 %. Furrow spacing is 0.75 m. With this spacing many differnt crops can be grown on the space between two furrows. For example, two rows of maize can be grown on the space between two furrows.

Roughness coefficient for the furrows is kept at 0.04 (Manning's roughness coefficient) [7].

Design application depth is 75 mm.

Inflow rate is:

Number of furrows $\simeq \frac{1000}{0.75} \simeq 1330$

Total flow in the canal = 0.66 m^3/sec.

Flow in each furrow is $\frac{0.66}{1330}$ m^3/sec. $\simeq$ 0.5 l/s.

Water from the canal is conveyed into the furrows by use of siphon tubes.

Layout of the furrows is shown on Fig. 4.9.1 and Fig. 4.9.2.

Parameters for intake family 0 · 3 (~~T~~able 3 App. 2).

$a = 0.925$

$b = 0.720$

$c = 7.0$

$f = 7.61$

$g = 1.904 \cdot 10^{-4}$

Advance time is:

$$\beta = \frac{(1.904 \cdot 10^{-4})250}{0.5\ (0.019)^{0.5}} = 0.69$$

$$Tt = \frac{250}{7.61}\ e^{0.69} = 65.5 \text{ min.} \qquad \text{(equation 2)}$$

Adjusted wetted perimeter

$$P = 0.265\ (0.5 \cdot 0.04/\sqrt{0.019})^{0.425} + 0.227 = 0.34 \text{ m} \quad \text{(equation 1).}$$

Net opportunity time

$$Tn = \left\{\left[\left(75 \cdot \frac{0.75}{0.34}\right) - 7.0\right]/0.925\right\}^{1/0.720} = 1266 \text{ min.}$$

Design inflow time

$$T = 1266 + 65.5 = 1331 \text{ min.} \quad \text{(22 hours).}$$

Gross application

$$Fg = \frac{60 \cdot 0.5 \cdot 1331}{0.75 \cdot 250} = 213 \text{ mm.} \qquad \text{(equation 5)}$$

Average opportunity time

$$T(0\text{-}L) = 1331 - \frac{0.0929}{7.61 \cdot 250\left[\frac{0.305 \cdot 0.69}{250}\right]^2}\ (0.69 - 1)(e^{0.69} + 1)$$

$$= 1331 + 68.9 = 1400 \text{ min.} \qquad \text{(equation 4).}$$

Average intake:

$$F(0\text{-}L) = (0.925 \cdot 1400^{0.72} + 7.0)\,\frac{0.34}{0.75} = 81 \text{ mm.} \qquad \text{(equation 6).}$$

Outflow:

$$RO = 213 - 81 = 132 \text{ mm.} \qquad \text{(equation 8).}$$

Deep percolation:

$$DP = 81 - 75 = 6 \text{ mm.}$$

The outflow is collected by the cross ditch and directed to the drainage water collection point. From here it shall be used on the adjacent plot.[11)]

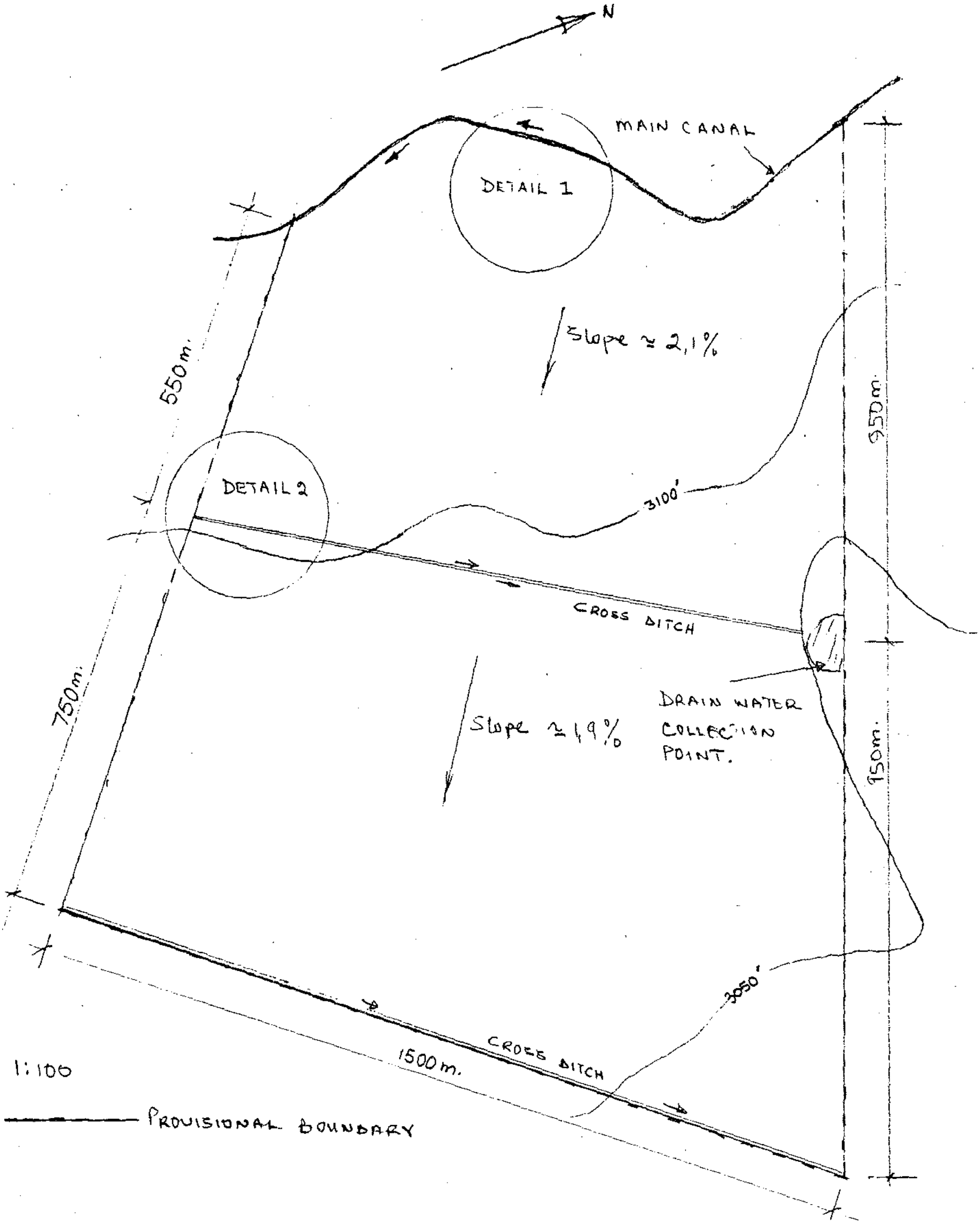


FIG 4.9.1 IRRIGATION SUB-SECTION VI

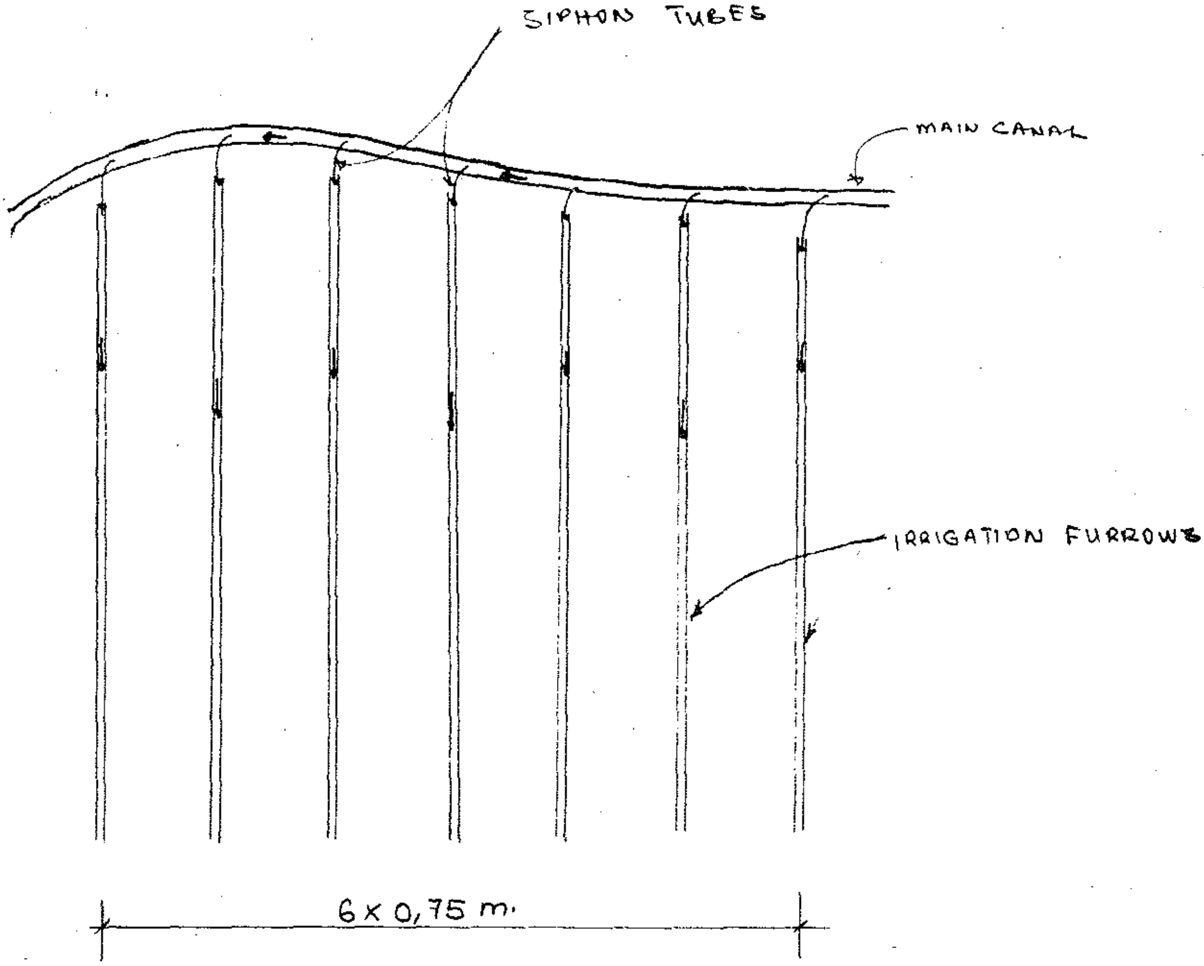


FIG.4.9.2(a) DETAIL 1 (1:50)

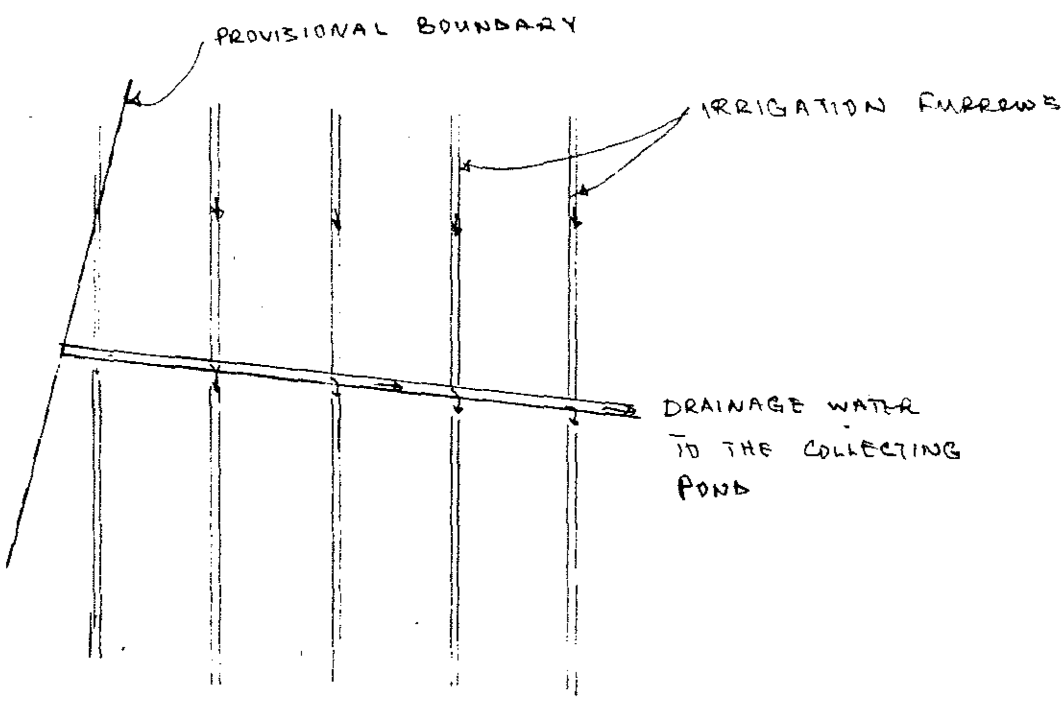


FIG. 4.9.2 (b) DETAIL 2 (1:50)

5. DETERMINATION OF COSTS AND RETURN ON THE INVESTMENT

Determination of the expected cost and return on the proposed irrigation system is evaluated using the following procedures:[12)]

a) Compiling information needed.
b) Determining the initial cost.
c) Determining the annual depreciation cost.
d) Determining the annual operating cost.
e) Determining the return on investment.

5.1 Compiling information needed

a)

CROPS TO BE IRRIGATED	EXPECTED INCREASE IN YIELD/HECTARE	VALUE OF CROP PER UNIT(TSHS)	PEAK-USE DEMAND RATE (mm/DAY)	SEASONAL CONSUMPTIVE USE (mm)
MAIZE	800-1000 KG	12.20	5.75	754
BEANS	400- 700 "	13.20	4.83	475
GROUNDNUTS	200- 400 "	50	5.33	625
SUNFLOWER	200- 500 "	30	5.08	750
GRAPES			5.33	675
SORGHUM		20.31	4.57	475
POTATOES	1000-1500 "	15	5.59	490

TABLE 5.1 PARAMETERS FOR THE CROPS TO BE IRRIGATED

b) Soil type - Loam
Particle size (0.1 - 0.25 mm)
Root zone depth (1.2 - 2 m)
Water-intake rate is 0.5 in/hour (12.7 mm/h).

c) Number of hours to operate the system per day is 12.

d) Minimum number of days required for each irrigation is 2.

e) Number of irrigations per season (see Table 4.1).

f) Number of hours operation per year is 1800 (consider irrigation for maize which takes about 150 days).

g) Type of irrigation system: Gravity system.

h) Number of hectares to be irrigated is 2150.

i) Pumping rate needed: 0.39 m^3/sec.

j) Source of water: Lake.

k) Total height water has to be lifted = 106.7 m.

l) Total operating head is 110 m.

m) Size of power unit need is 573 Kw.

n) Type of power unit: Electricity.

o) Interest rate is 7.5 - 10 % = 9 %.

p) Hours labour per hectare per irrigation is 2.4.

5.2 Determining the initial cost

Information on the initial cost helps to determine the total cost of owning and operating the system.

ITEM	EST. YEARS OF LIFE	INITIAL COST TSHS · 1000
RESERVOIR	20 +	200
PUMP (s) (CENTRIFUGAL)*	12	10000
CABLE CONNECTORS *	25	10
CABLES (COPPER) *	25	125
ELECTRIC POLES	25	200
TRANSFORMER	15	350
ELECTRIC SWITCHES	20	15
PUMP HOUSE	25	250
CIVIL WORKS/FURROWS	20	150
WATER PIPE *	15	5000

*to be imported

TABLE 5.2 INITIAL COSTS

5.3 Determining the annual depreciation cost

The annual depreciation cost is determined from the initial cost of the system, interest, taxes and insurance, fixed charges, loss of income from land taken out of production for water development and life expectancy of the system.[13)]

To find the annual depreciation cost for the system Table 4 in Appendix 2 is used to give the values in column 4 in Table 5.3.

ITEM	EST. YEARS OF LIFE	INITIAL COST (TSHS · 1000)	COST FACTOR	ANNUAL COST (TSHS · 1000)
RESERVOIR	20	200	0.0950	19
PUMPS	12	10000	0.1283	1283
POWER CONVEYANCE *	25	350	0.0850	29.75
TRANSFORMER	15	350	0.1117	39.095
PUMP HOUSE	25	250	0.0850	21.250
WATER PIPES	15	5000	0.1117	558.5
CIVIL WORKS	20	150	0.0950	14.25

* Power conveyance = cable connectors + cables + electric poles + switches.

TABLE 5.3 DEPRECIATION COSTS

5.4 Determining the annual operating costs

Annual operating cost is determined from the annual expenses in operating the system. They include power (Kwh), repair and maintenance of equipment, reservoir and field maintenance, additional seed, fertilizer, pesticides and harvesting cost for the increase in yield as well as labour.[14)]

ANNUAL OPERATING COST:

1. Electricity: Power required = 573 Kw.
   Number of hours of operation = 3000 hrs.
   Cost per unit = 0.95 Tshs.
   KVA cost = 7200 Tshs/month.
   Total cost = 1633050 + 7200 · 5 = 1669050 Tshs.

2. Repair and maintenance:
   (Power unit) - Power available = 573 Kw.
   Number of hours of operation = 3000 hrs.
   Cost per unit = 0.07 Tshs.
   Total cost = 120330 Tshs.

3. Repair and maintenance:
   (Irrigation equipment)
   Initial cost of the equipment = 15 m Tshs.
   Repair cost = 0.005 · 15 m = 75000 Tshs.

4. Reservoir and field maintenance:
   Initial cost of the equipment = 350KTshs.
   Repair cost = 0.005 · 350 000 = 1750 Tshs.

5. Additional Seed, Fertilizer, Chemicals and Harvesting cost:
   (Estimates) Number of hectares irrigated = 1800 ha.
   Cost per hectare = 4000 Tshs.
   Total cost = 4000 · 2150 = 86 00000 Tshs.

6. Labour: Hours per hectare per irrigation 2.4 hrs.
   Number of irrigations = 8.
   Cost per hour = 50 Tshs.
   Total cost = 2150 · 2.4 · 8 · 50 = 2064000 Tshs.

5.5 Determination of the return on the investment

The primary purpose for estimating the total annual cost of the system is to have a figure with which to compare the value of the expected increase in production from using the system.

At the initial stage, maize crop is considered to be grown on all the irrigated land.

Value per hectare of expected increase from irrigation:

Yield per hectare = 900 kg.
Unit price of maize = 12.20 Tshs/kg.
Total expected income = 900 · 12.20 = 10980 Tshs/hectare.

Total annual cost per hectare of irrigation:

$$= \frac{\text{Total annual costs}}{\text{No. of irrigated hectares}}$$

Total annual depreciation costs	=	1964845
Taxes and insurance (1 %)	=	19648
Total annual operating costs	=	12530130

$$\text{Total annual costs} = \frac{14514623}{2150} = 6750 \text{ Tshs/hectare.}$$

Expected additional profit per hectare from irrigating is value of the expected increase less annual operating costs per hectare:

= 10980 - 6750 = 4230 Tshs.

6. COMMENTS/RECOMMENDATIONS

In this preliminary study as much land as possible has been brought under command of irrigation using water pumped directly from Lake Chala. The refinements of the system and the development of the other water sources for further irrigation land have been left aside until enough study has been done and local agricultural experience gained from the initial stage.

The general soil type and its properties is used in the study, but as soil types differ from one place to another even over short distances, detailed soil survey should be carried out during the actual planning. The detailed survey should establish for every hectare of land, the soil texture and the inherent fertility of the topsoil, the permeability of the subsoil and the substrata, soil depth, erodibility, crusting, salinity, drainage and potential dangers due to locality.

To a great extent, the study has been based on maize crop which is the main crop of the area. However, during the actual planning the area should be sub-divided according to use for different crops and hence water requirements will vary from one sub-section to another. Also the search for new crops and their adaption to the irrigation area should never end.

Surface irrigation system has been generally proposed in this study, but a closer analysis during the actual design can reveal cheaper irrigation methods for the different sub-sections recommended above.

Due to unavailability of the proper topographical maps, the study was carried out on 1:50,000 scale maps instead of the recommended maps having a scale of 1:10,000 (with 5 ft. interval). This has, however, provided an insight into the general pattern and so it is recommended that in the actual planning and location of conveyance net-work 1:2500 scale maps (with interval of 1 - 5 ft.) should be used.

7. PROBLEMS EXPECTED FOR THE PROJECT

1. The main components of the project ie. pumps, pipes and electrical materials will be imported. As the importation process takes long time, considerable delays are expected before the project can take off.

This delay can, however, be avoided by planning the implimentation in such a way that the local components are carried out while importation issues are being processed.

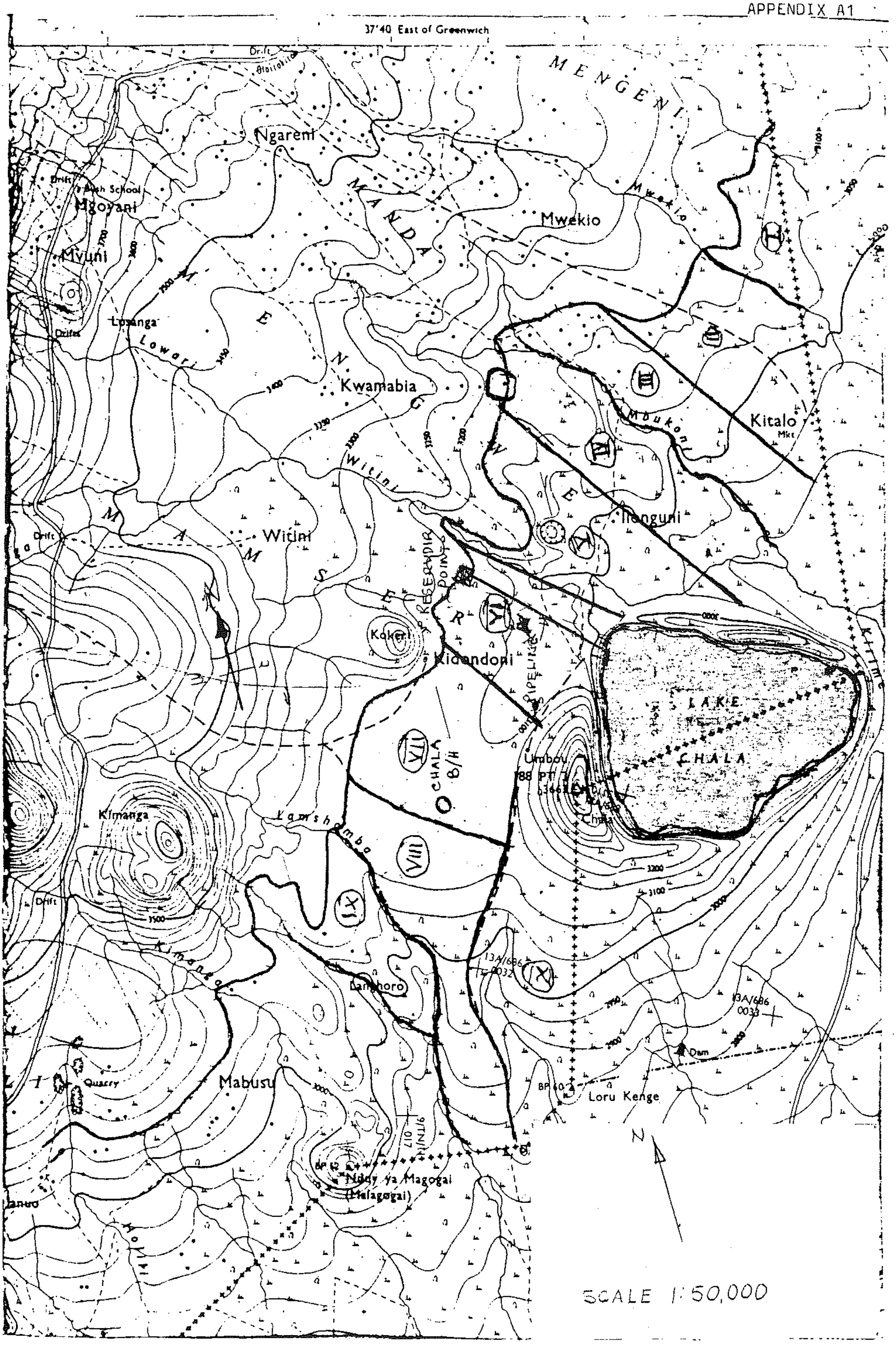
2. Repair of pumps during operation can cause difficulties as there are not capable experts in the villages who can take care of them. This problem can be avoided by training one of the villagers to take care of maintenance and minor repairs.

3. As the Lake is replenished by sub-surface streams, it is likely that if the underground water sources are developed near the Lake, they can interfere with inflow pattern.

However, this can be avoided by identifying the exact characteristics of water inflow into the Lake before developing the underground sources near the Lake.

Successful Implementation?

Chances of successful implementation of the project are high at the moment because the goverment has declared to support improved agriculture in its five year plan. Also there are several initiatives which have been done by the villagers towards this respect. An example is a water reservoir which has been constructed by the villagers to store water from the seasonal streams.


37°40 East of Greenwich
MENGENI
Ngareni
MANDA
Mgoyani
High School
Drift
Mvuni
Mwekio
Losanga
Lowari
MENGWE
Kwamabia
Kitalo
Mkt
Mbukoni
Witini
Ilonguni
MAMSERA
RESERVOIR POINTS
Kokeri
Kidondoni
PIPELINE
LAKE CHALA
Umbou
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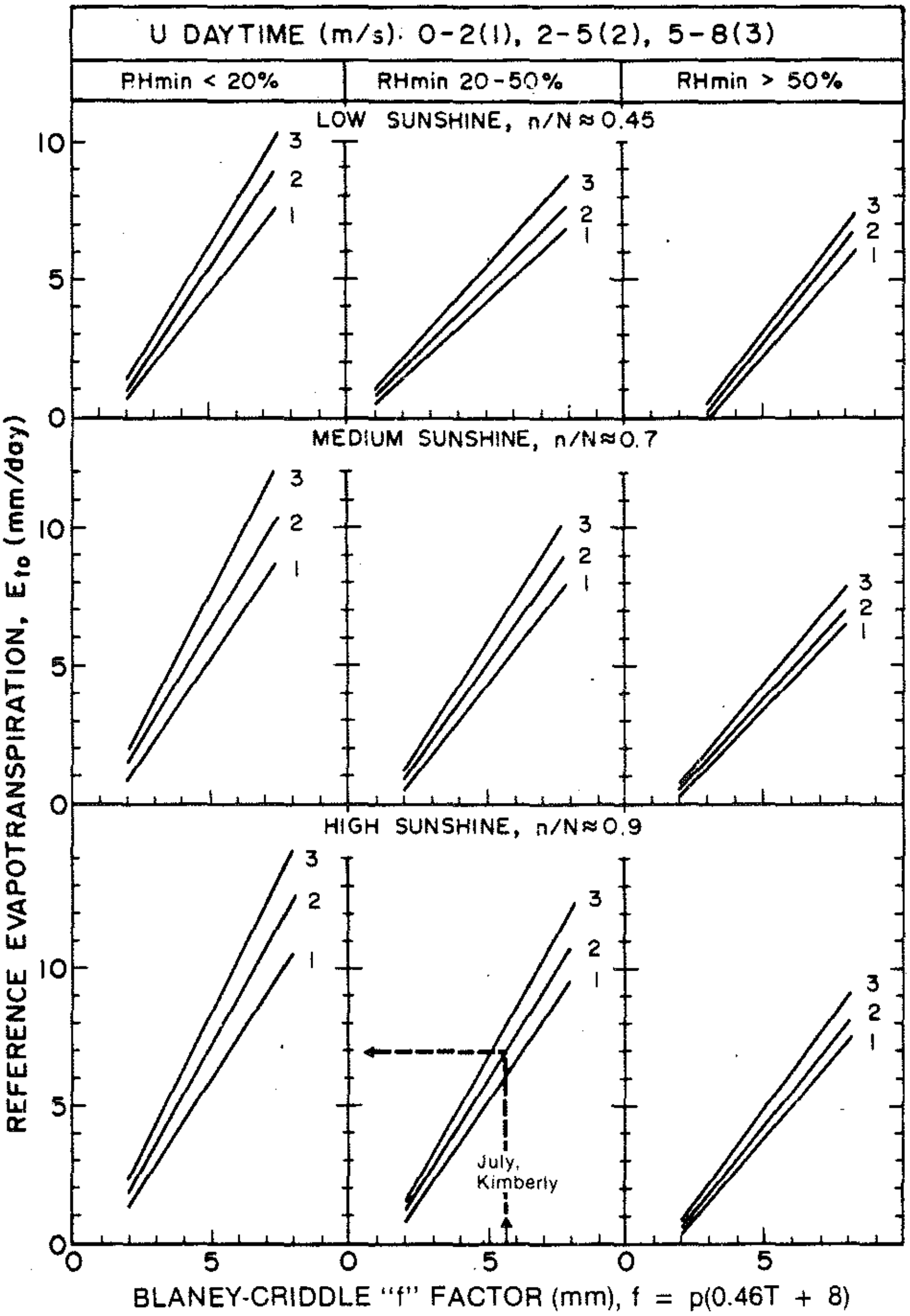

FIG. 1 Prediction of reference ET for grass (E_{to}) from Blaney-Criddle f factor for different conditions of minimum relative humidity, sunshine duration and day-time wind (from Doorenbos and Pruitt, 1977).

GRAVITY OR SURFACE SYSTEMS

TABLE 3. FURROW INTAKE FAMILY AND ADVANCE COEFFICIENTS

Intake family	a	b	c	f	g
0.05	0.5334	0.618	7.0	7.16	1.088×10^{-4}
0.10	0.6198	0.661	7.0	7.25	1.251×10^{-4}
0.15	0.7110	0.683	7.0	7.34	1.414×10^{-4}
0.20	0.7772	0.699	7.0	7.43	1.578×10^{-4}
0.25	0.8534	0.711	7.0	7.52	1.741×10^{-4}
0.30	0.9246	0.720	7.0	7.61	1.904×10^{-4}
0.35	0.9957	0.729	7.0	7.70	2.067×10^{-4}
0.40	1.064	0.736	7.0	7.79	2.230×10^{-4}
0.45	1.130	0.742	7.0	7 88	2.393×10^{-4}
0.50	1.196	0.748	7.0	7.97	2.556×10^{-4}
0.60	1.321	0.757	7.0	8.15	2.883×10^{-4}
0.70	1.443	0.766	7.0	8.33	3.209×10^{-4}
0.80	1.560	0.773	7.0	8.50	3.535×10^{-4}
0.90	1.674	0.779	7.0	8.68	3.862×10^{-4}
1.00	1.786	0.785	7.0	8.86	4.188×10^{-4}
1.50	2.284	0.799	7.0	9.76	5.819×10^{-4}
2.00	2.753	0.808	7.0	10.65	7.451×10^{-4}

Intake (see equations [13.1] and [13.40]) Advance (see equation [13.35])

$F = (aT^b + c)\,P/W$, mm $\qquad T_T = \frac{x}{f}\,e^{(gx/QS^{1/2})}$, min

T = minutes $\qquad$ Q = furrow inflow

$\frac{P}{W} = \frac{\text{Wetted perimeter}}{\text{Furrow spacing}}$ $\qquad$ S = furrow slope

x = distance

TABLE 4 ANNUAL DEPRECIATION AND INTEREST COST FACTORS*

Interest Per Cent	Cost Factors at Various Expected Years of Life						
	6	10	12	15	18	20	25
5	.1917	.1250	.1083	.0917	.0806	.0750	.0650
5½	.1942	.1275	.1108	.0942	.0831	.0775	.0675
6	.1967	.1300	.1133	.0967	.0856	.0800	.0700
6½	.1992	.1325	.1158	.0992	.0881	.0825	.0725
7	.2017	.1350	.1183	.1017	.0906	.0850	.0750
7½	.2042	.1375	.1208	.1042	.0931	.0875	.0775
8	.2067	.1400	.1233	.1067	.0956	.0900	.0800
8½	.2092	.1425	.1258	.1092	.0981	.0925	.0825
9	.2117	.1450	.1283	.1117	.1006	.0950	.0850

*Based on one-half initial cost times interest rate plus initial cost divided by the expected year of life.

TABLE 1 . SELECTED VALUES OF a_w AND b_w FOR 7)
VARIOUS WIND FUNCTIONS FOR THE PENMAN METHOD

No.	Author(s)	Reference crop	a_w	b_w	Method of calculating $(e_a - e_d)$
1	Penman (1963)	Clipped grass	1.0	0.00621	1
2	Wright and Jensen (1972)	Alfalfa	0.75	0.0115	2
3	Doorenbos and Pruitt (1977)	Grass	1.0	0.01	1
4	Wright (1981)	Alfalfa	(varies with time)		2

TABLE 2 AVERAGE MONTHLY EFFECTIVE RAINFALL AS RELATED TO MEAN MONTHLY RAINFALL AND MEAN MONTHLY CONSUMPTIVE USE (USDA, SCS)

Monthly mean rainfall mm	Mean monthly consumptive use mm													
	25	50	75	100	125	150	175	200	225	250	275	300	325	350
	Mean monthly effective rainfall mm													
12.5	7.5	8.0	8.7	9.0	9.2	10.0	10.5	11.2	11.7	12.5	12.5	12.5	12.5	12.5
25.0	15.0	16.2	17.5	18.0	18.5	19.7	20.5	22.0	24.5	25.0	25.0	25.0	25.0	25.0
37.5	22.5	24.0	26.2	27.5	28.2	29.2	30.5	33.0	36.2	37.5	37.5	37.5	37.5	37.5
50.0	25	32.2	34.5	35.7	36.7	39.0	40.5	43.7	47.0	50.0	50.0	50.0	50.0	50.0
62.5	at 41.7	39.7	42.5	44.5	46.0	48.5	50.5	53.7	57.5	62.5	62.5	62.5	62.5	62.5
75.0		46.2	49.7	52.7	55.0	57.5	60.2	63.7	67.5	73.7	75.0	75.0	75.0	75.0
87.5		50.0	56.7	60.2	63.7	66.0	69.7	73.7	77.7	84.5	87.5	87.5	87.5	87.5
100.0		at 60.7	63.7	67.7	72.0	74.2	78.7	83.0	87.7	95.0	100	100	100	100
112.5			70.5	75.0	80.2	82.5	87.2	92.7	98.0	105	111	112	112	112
125.0			75.0	81.5	87.7	90.5	95.7	102	108	115	121	125	125	125
137.5			at 122	88.7	95.2	98.7	104	111	118	126	132	137	137	137
150.0				95.2	102	106	112	120	127	136	143	150	150	150
162.5				100	109	113	120	128	135	145	153	160	162	162
175.0				at 160	115	120	127	135	143	154	164	170	175	175
187.5					121	126	134	142	151	161	170	179	185	187
200.0					125	133	140	145	158	168	178	188	196	200
225					at 197	144	151	160	171	182				
250						150	161	170	183	194				
275						at 240	171	181	194	205				
300							175	190	203	215				
325							at 287	198	213	224				
350								200	220	232				
375								at 331	225	240				
400									at 372	247				
425										250				
										at 412				
450	25	50	75	100	125	150	175	200	225	250				

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