"INVESTIGATION INTO PROBLEMS EMANATING FROM ROAD DRAINAGE WITH SUGGESTED METHODOLOGY FOR PREVENTION IN MURANGA AND BARINGO DISTRICTS, KENYA"

ANDREW NYAYIEMI ANYONA (BSc. Agric. 1979, NAIROBI)

A project report submitted to the University of Nairobi in partial fulfilment of the requirements for the Postgraduate Diploma in Soil and Water Conservation

1981/82

Department of Agricultural Engineering,
Faculty of Agriculture

DECLARATION

This project report is my original work and has not been presented for a postgraduate diploma in any University.

--------------------------- Date 28/6/1983

Anyona, A. N.

This project report has been submitted for examination with our approval as University Supervisors.

--------------------------- Date 29/6/1983

Prof. C. M. Jacob, B.A.
(Madras). B.Sc. Engin.
(Patna), M.S., Ph.D.
(Iowa State)

--------------------------- Date ------------

Mr. D. B. Thomas, B.A.,
Dip. Agric. (Canteb.),
M.Sc. Agric. Eng. (Reading)

DEDICATED TO

MY FAMILY, MY PARENTS AND

ALL MY FRIENDS

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SUMMARY

The report describes an investigation into the problems of soil erosion which are associated with road design, construction and drainage. Although there are many advantages to be gained from a high density road network, there are frequently adverse effects due, first, to increased runoff, secondly, the interception of runoff from higher ground by road drains which disrupt the natural drainage pattern and thirdly, the discharge of concentrated runoff through pipe cross culverts.

For the purpose of the investigation, a detailed study was carried out at two sites where serious problems had arisen. The first site was in Kandara Division of Muranga District, which is characterised by a high rainfall and steep slopes which are densely settled. Here, the erosion problem was associated with a class E road. The second site was in Eldama-Ravine Division of Baringo District which is characterised by a less humid climate and sparser population. The erosion problem was associated with a class C road.

The objectives of the study were to document the erosion problem which had occurred, to establish the causes and to make recommendations for control and future prevention methods.

The work undertaken included a ground survey with a telescopic level to determine the volume of soil eroded, measurement of catchment area and estimation of runoff. Observations on the design and

construction of the present water disposal systems were made and oral interviews with government officers and farmers were carried out.

The main finding is that most erosion problems arise either from failure to design and construct road drains on engineering principles or from failure to provide proper outlets to carry water from culverts to the main water courses.

The damage being caused to farm land and the risk to valuable property caused by soil erosion is enormous. High level cooperation between the relevant agencies is required for the present control and future prevention of gully erosion associated with roads.

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to my supervisors: Prof. C. M. Jacob and Mr. D. B. Thomas for their guidance and positive criticism on the project proposal and preparation of this report.

The author also wishes to thank Mr. G. Mochiemo, Miss Taphrine E. A. Odipo and Mr W. N. Wamicha all of the National Agricultural Laboratories for their background information on soils.

I also wish to express my sincere gratitude to the Ministry of Agriculture, my sponsor and all her field staff who helped me to collect the data presented in this report. In particular, I thank Mr. S.K. Ndaba of Kandara Division, Mr. J. O. Were of South Baringo Division, Mr. J. K. A. Omundi of the Pyrethrum Board of Kenya, attached to Baringo District.

Many thanks go to Mr. R. N. Karimi, Mr.G. Ndungu and Mr Gasiorowski of the Ministry of Transport and Communications, for their information on road construction and views on the subject matter of this report.

Finally, I am sincerely indebted to my wife, Mrs. E. Anyona, for her encouragement during the study period, and to Mrs. E. A. Onim, who typed this report.

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LIST OF SYMBOLS

L	-	Length
mm	-	Millimeter
M	-	Meter
km	-	Kilometer
mm^2	-	Square millimeter
M^2	-	Square meter
ha	-	Hectare
V	-	Velocity m/s
Q	-	Discharge m^3/s
S	-	Second (time)
a	-	Area
A	-	International trunk road
B	-	National trunk road
C	-	Primary road
D	-	Secondary road
E	-	Minor road
B.M.	-	Bench mark
B.S.	-	Back sight
I.S.	-	Intermediate sight
F.S.	-	Fore sight
H.I.	-	Height of surveying instrument
R.L.	-	Reduced Level
T.P.	-	Turning point
K	-	Runoff coefficient
I	-	Intensity of rainfall in mm per hour

1.0. INTRODUCTION

While soil erosion has been an ancient activity which has been taking place naturally (geologic erosion) without being checked by man, soil and water conservation, is a relatively recent science on a global basis. The consciousness of the whole world regarding large scale soil erosion caused by deforestation, overgrazing and other causes has recently been markedly heightened by the increasing activity and commitment of the human race on the war against the menace. The approximate limits of the area of destructive rains are latitudes 40° North and 40° South (Hudson 1976). These are the areas associated with heavy storms, thus limiting soil erosion as a serious problem to tropical and sub-tropical countries, the majority of which are developing nations. These have erosive climatic conditions, rugged terrain and intensive land use (Dunne and Ogweny 1976).

1.0.1. High rate of human and livestock population growth (Anon 1975, 1976), and high absolute population density have increased competition on the same land for cash crops, food, fodder and fuel. This has resulted in poor land use management and the problems are heightened by demands from different sectors for expanding development and industrial activities on similar types of land.

1.0.2. A nation with a rapidly increasing human population like Kenya, requires an equally rapidly increasing economic development to be able to supply her people with the basic human needs. To achieve a sectorally balanced economic development, the Kenya government has had to employ the intergrated development approach techniques. This is an approach that requires full participation of almost all government ministries and departments, in a project in any one area. Apart from isolated cases like areas within urban centres, where the density of road network is high, the nation's road construction authority has always been charged with the highest responsibility of creating accessibility to rural areas. More areas are being opened up for human settlement and farming activities to reduce population density on the more developed parts. The foregoing explains the need for an ever increasing density of road network.

1.0.3. The construction of roads in certain areas has caused acute and in many cases chronic soil erosion. This experience has been shared by other developing countries, where roads are a major source of soil erosion (F.A.O. Soils Bulletin 33). The surface erosion from road cut banks triggers rills, gullies or slides and also blocks ditches along roads. These blocked ditches divert run-off causing erosion on road surfaces and lower fill banks (Sheng 1978). The main causes of accelerated erosion following road construction, which has been mainly observed in forested areas (Megahan 1977) are:

- Removal of protective cover
- Destruction or impairment of natural soil structure and fertility
- Increased slope gradients created by construction of cut and fill slopes
- Decreased infiltration rates on parts of the road itself
- Interception of subsurface flow by the road cut slope
- Decreased shear strength, increased shear stress or both, on cut and fill slopes
- Concentration of generated and intercepted water.

1.0.4. The chief purpose of this paper is to find out the main causes of road-related erosion in Kenya, look at the possibility of preventing the same during design and construction. Control measures which may be adopted for problem situations are also suggested. It considers the possibility of high level agency co-operation in reducing the menace of road-related erosion.

1.1. Objectives

The objectives of this study are:

i) To produce a document on information about the increasing problems associated with road drains

ii) To attempt and establish the causes of the problems emanating from road drains

iii) To create awareness on the magnitude of the destructive nature of improperly designed road drains

iv) To make recommendations for controlling roadside gullies where they have occured

v) To find out the role of individuals and local authorities in road maintenance to see where responsibility lies

vi) To suggest methods of preventing the problems associated with road drains.

2.0. MATERIALS AND METHOD

The following method was adopted in order to meet the objectives listed in the previous section.

a) A survey was carried out in two problem areas, one in Kandara, Muranga District and the other in Eldama Ravine, Baringo District. The survey involved measurement of catchment area, estimation of peak discharge, survey of erosion feature and calculation of the volume of soil lost.

b) Oral interviews with the farmers, government officials, especially Ministry of Transport and Communications personnel were carried out.

c) General observations on other problem areas were also made.

The materials used in the study of this project are:

i) Quickset level

ii) Quickset stand

iii) Surveying staff

iv) Steel measuring tape

v) Dot planimeter

vi) Topographical maps of the respective study areas with scale of 1:50,000

2.0.1. The catchment size for the areas under study was estimated with the help of the dot planimeter using the topographical maps. First, walking through the catchment was done to locate the boundaries of the catchment or water divide. These boundaries were then transferred to the topographical map. The number of planimeter dots within the catchment were counted. Planimeter dots are separated from one another by 5 mm. On a scale of 1:50,000:

1 unit on map	=	50,000 units on the ground
5 mm on map	=	(5 x 50,000) mm on the ground
$(5x5)mm^2$ on map	=	$(250,000 \times 250,000)mm^2$ on the ground
25 mm^2 on map	=	62500 m^2 on the ground
	=	6.25 ha. on the ground ....(i)

Therefore one planimeter dot represents 6.25 ha. on the ground.

2.0.2. The amount of discharge (Qm^3/s) was estimated using the Rational Formula:

$$Q = \frac{KIa}{360} \quad \text{.................... (ii)}$$

where	Q	=	Design peak discharge m^3/s
	K	=	Runoff coefficient. It is a function of infiltration rate, surface cover, surface retention and intensity of rainfall. The value of K is usually considered dealing with a saturated top soil at beginning of rainfall. It is the fraction of rain that becomes runoff.

I = Rainfall intensity for the design recurrence interval and for a duration equal to the time of concentration in mm. per hour.

a = Catchment area in ha.

Source: Erosion on agricultural lands. Vostberg, K. S. 1979. (Symbols K, I, and a adopted by author).

The appropriate rainfall intensity (I) in mm. per hour to the area was estimated using appropriate Rainfall Intensity-Duration-Frequency curves for Muranga Water Supply Reservoir and Nakuru Airfield (See Figures 16.0 | 17.0). To enable use of these curves, the gathering time (T_c) was calculated using Bransby-Williams formula shown below:

$$T_c = \frac{L}{1.5\,D}\sqrt[5]{\frac{M^2}{F}} \qquad \text{.......... (iii)}$$

where: T_c = Time required in hours for water to flow from the most remote point of the catchment area, to the outlet, once the soil has become saturated and minor depressions are filled. If rainfall duration is equal to this time of gathering, it is assumed peak flow is maximum.

L = Longest distance from outlet in km.

D = Diameter of a circle equal in area to the catchment size in km.

M = Actual catchment size in km^2

F = Average fall of main watercourse in m per m

Appropriate runoff coefficients (K) were obtained using Table 5.0.

2.0.3. The level of the peak discharge in the road drains (culverts) was estimated from oral interview and deposited debris. The cross-sectional area of flow was computed and this in turn was used to establish the water velocities (m/s) obtained at the drains, using the continuity formula:

$$Q = Va \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (iv)$$

where: Q = discharge (m^3/s)

V = velocity (m/s)

a = cross-sectional area (m^2)

These velocities were then compared with the recommended maximum flow velocities at the discharge channels, depending on the floor lining of the channels. The difference between the calculated and the recommended velocities, was considered to be causing the problem of gullying.

2.0.4. Profile levelling of the erosional features was done and the volume of soil lost, in cases where earth had been detatched and transported away established. A number of cross sections were taken along the gully and average cross-sectional area obtained by arithmetical mean. The product of the average cross-sectional area (m^2) and the length (m) gave the volume of soil lost (m^3). Any cultural features destroyed or threatened to be destroyed by the runoff were also documented.

2.0.5. Oral interviews with the farmers, Government officials, especially Ministry of Transport and Communications personnel, were carried out, in addition to field observations.

3.0. BACKGROUND INFORMATION TO STUDY AREA

3.1. Location

The project area in Muranga lies at 36°59' East and 0°54' South, 3 km. from Kandara township after crossing Thika River along class E road. On way to Kianjiru School. It is situated within Kihumbuini Location.

In Baringo District, it lies at 35°51' East and 0°0', 40 km. from Nakuru town along the Nakuru-Eldama-Ravine Class C road. It is situated within Lembus Location.

3.2. Geology

Tertiary basic igneous rocks with quartz-feldspur gneisses underly the soils in Kandara.

In Eldama-Ravine, tertiary or older basic igneous rocks with undifferentiated basement system lie beneath the soils.

3.3. Hydrology

The Kandara area is drained by the Thika and Gathwariga rivers while Eldama-Ravine is drained mainly by the Esageri river and a number of ephemeral streams.

3.4. Climate

Kandara area receives bimodal rainfall with long rains falling between March-May and short rains during October-December. Exception lies with the tea zone whose long rains' period is followed by

"Gathano" rains from July-December. An average of 1500 mm of rain are in receipt annually, which is considered adequate for most crops (See Table 3.0).

A monomodal rainfall is received in Eldama-Ravine with most of the rain falling in March-May. The average annual rainfall received is 720 mm. This amount is considered inadequate for intensive rainfed farming (See Table 4.0).

3.5. Soils

Kandara has generally well drained, deep, dusky red to dark reddish brown, friable clay, with inclusions of well drained, moderately deep, dark red to dark reddish brown friable clay over rock.

Eldama Ravine has well drained, shallow to moderately deep, dark reddish brown to dark red, friable clay loam to clay. In places it has a humic top soil or gravelly over soft rock. These soils are little weathered and structure has significant amount of weatherable primary minerals.

3.6. Vegetation

Original vegetation is non-existent in Kandara, as the land has been put under intensive farming. Individual farmers have undertaken to plant trees and fruit trees for timber and fuel, apart from growing coffee, maize, beans and vegetables.

Some original vegetation of acacia species can be seen scattered in Eldama-Ravine. Even though, the original grasses and shrubs have all been removed to allow growth of crops and regeneration of grass for livestock.

3.7. Topography

In Kandara, the area around the project site is heavily dissected with a number of ridges separated by valleys forming many steep slopes and crest lines. The general gradient, measured from topographical map, is above 20% (a drop of 20 m in every descent of 100 m). The altitude is 1620 m with the hills rising to 1700 m above sea level.

In Eldama Ravine, the small catchment for the study, has an average gradient of about 7% and the rest of the area to the north has a general gradient of 3%. The average slope for the area is 5%.

3.8. Ecological potential

The project site at Kandara falls within the transitional tea-coffee zone which has a good potential for most crops. The land is nutritionally exhausted due to intensive farming. The average farm size is 0.4 - 0.8 ha.

The area in Eldama-Ravine is semi-humid and economical farming is only possible during the wet months. Maize, beans, finger millet, and sorghum are the common crops. More valuable crop production is possible with irrigation.

4.0. LITERATURE REVIEW

Geological soil erosion has been going on for centuries and its impact has not been big enough to be reflected on national or regional economies. Man's widespread interference with the natural environment has caused accelerated soil erosion whose big impact on the economies, is causing much concern. It has led to the destruction of productive areas causing a decline and a fall in civilisation in Mesopotamia, China, Lebanon (Beasley 1973), just to mention a few.

4.1. Beasley (1973) notes that the problems associated with water erosion are enormous. The major ones being:

1) Loss of soil which leads to reduction in production potential and nutritive value of crops.
2) Sedimentation which is in itself a major source of pollution.
3) Loss of water resulting from reduced infiltration rates and water holding capacity.
4) Pollution resulting from the chemicals, fertilisers, etc. in the sediment.
5) Poor public health due to inferior food in terms of nutrition and direct intake of pollutants.
6) Loss of human values. This results from reduced family income hence a low standard of living, causing the affected people to depend on society.

4.2. Warburton (1966) had an experimental roadside erosion control demonstration in the Shire of Cudgegong. He observed that roadside erosion in its various forms presents a serious problem in the construction and the maintenance of roads and highways. When it occurs as gullies alongside and encroaching on pavements or endangering culverts and road drainage it becomes an eyesore and a serious hazard to the travelling motorists. The same views are expressed by Good and Nebauer (1976) in their studies on erosion control integrated with highway landscape in New South Wales. They noted that highway construction is capable of rapidly disturbing the natural environment, especially if planning is not adequate.

4.3. In the past, apart from a low density of road network in any one area, roads were built to suit the capabilities of the vehicle using them and provide for the needs of the road users, limited by the machinery available. This resulted in roads which followed land forms that least interfered with the natural environment. Good and Nebauer (1976) have observed that today, vehicle capability has increased, road user demands are greater and construction machinery has a higher capability. The result is much wider and straighter road pavements which conform less closely to original landform. In obtaining such design, the ratio of disturbed land to pavement width has increased. Reduction of road gradients demands extensive areas of cut and fill batters.

4.4. In the Road Design Manual Part I (Anon. 1979), the Ministry of Transport and Communications has classified roads into A, B, C, D and E. The non-classified roads belong to another category of "other roads". All the classified roads have a road reserve, which either remains as desirable or is reduced, depending on economic, financial or environmental reasons. The functions of such road reserves are:

1) To accommodate future road connections or changes in alignment, road width or junction layout for existing roads.

2) To enhance the safety, operation and appearance of the roads (See Table 1.0)

Functional class	Road reserve width (m)	
	Desirable	Reduced
A	60	40
B	60	40
C	40	40
D	25	25
E	20	20

Table 1.0. Road reserves applicable to the different road classes.

4.5. Hudson (1976) while carrying out some studies on increases in flood run-off, he found out that major roads, increased the catchment area. Major road construction changes the natural drainage patterns and the natural catchments. Several water courses belonging to several catchments may be closed, divert runoff along a road drain and add it to one water course, passing the increased flow through a culvert. This is more often done by construction firms, in an attempt to reduce expenses on having to install many cross culverts. (See Fig. 1). All natural watercourses are at the state of metastable equilibrium (Hudson 1976). This means that the size, roughness, gradient and shape of channel are suitable for the flow volume it has to carry. A change in flow volume, is an external force that will force the channel to return to its equilibrium by widening, deepening, increase in gradient of the floor, thus resulting into gully erosion.

4.6. Bennett (1939) in his studies on soil conservation found out that concentrated runoff from roads discharged over farmland caused huge gullies. Such gullies often cut back and destroyed the roads themselves. Under such situations he suggested that the farmer and the highway maintenance agency may develop a joint outlet water course that serves the purpose of disposing off runoff from both terraces and the highway. In Kandara Division, one of the project areas, this had not been done and a huge gully has been confined along the berm and road reserve.

4.7. Leslie (1962), while carrying out a survey of agriculture and land use in Machakos District, observed that the highest order roads appeared to be responsible for a disproportionate amount of gullying. This means that the wider and more compacted a road surface is,

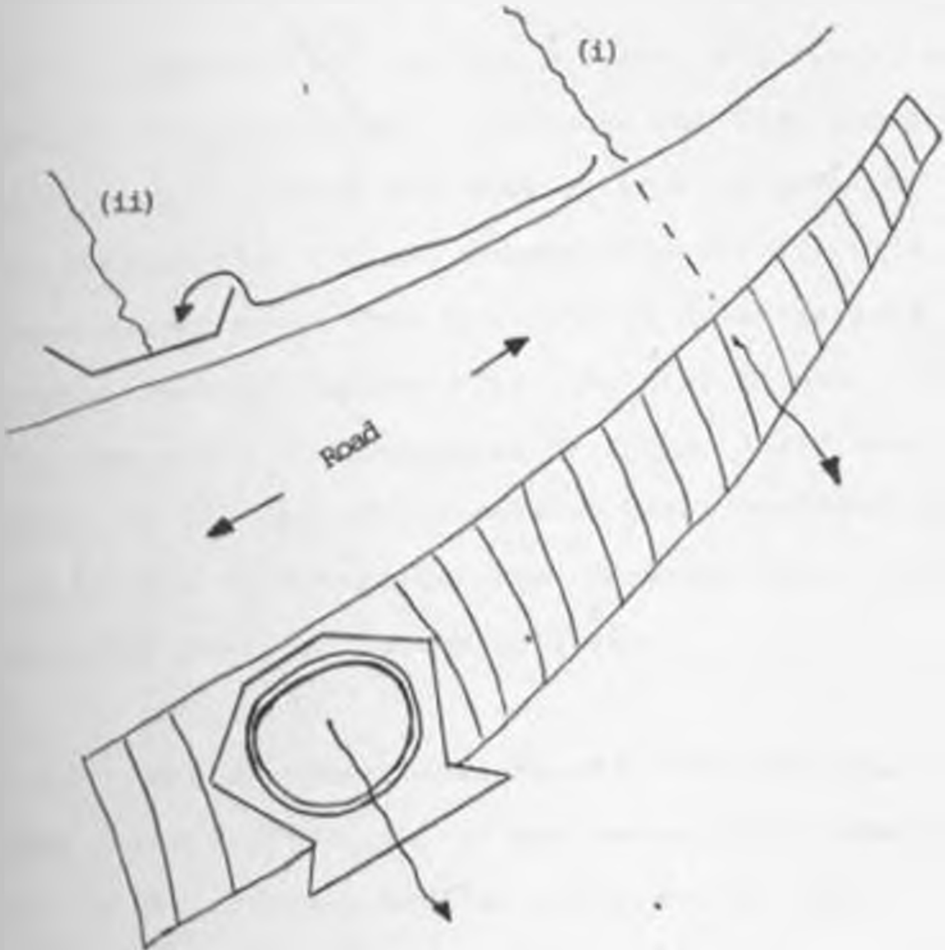


Fig. 1.0. Illustration of increased catchment area. In (i) a natural watercourse has been closed and runoff diverted to the pipe cross culvert at (ii).

the more its presence will increase the local runoff. Increased runoff increases the discharge in a drainage channel making it more capable of eroding the channel into a gully.

4.8. Ayres (1936) carried out some studies on soil erosion and its control. He found out that among the factors which affect the rate of erosion were the highway embankments, railway embankments and culverts. These divert water from the natural drainage into often poorly installed culverts at unnatural points. Almost the same views are expressed by Damba (1981) when he found out that partly, excessive concentrations of runoff from uncontrolled road drainage into badly designed waterways caused gullies.

4.9. While concentrated runoff from the roads has been found destructive, it can be put into some economical use in the arid and semi-arid regions of Kenya. Trials carried out by Baringo Semi-Arid Area Project (1981) confirm that water harvesting techniques could be beneficial in terms of crop production, even in a season with above average rainfall. Runoff from the road is collected in channels and led onto contour ridges where it is impounded. Sorghum crop yields more than doubled when planted on these ridges. This technique works best on farms adjacent to the road.

4.10. Constantinesco (1976), while carrying out studies on soil conservation for developing countries, concluded that the best and economical policy is to prevent gully formation since cost of reclaiming large gullies may exceed the returns thereof. Mechanical protection works (Hudson 1976) when properly designed to control gully erosion must be supplemented with good agronomic and cultural practices especially if catchment is farmland. When the source of concentrated runoff is farmland and th- road itself (most common), then caution must be taken to convey the flow safely into the stream. Foster (1985) recommended grassed waterways designed with a return period of ten years and if permanent material is used, a return period of fifty years is used in design. However, Thomas (1982) is of the opinion that grassed waterways require a lot of land if they have to discharge reasonable runoff, thus becoming uneconomical in densely settled areas. The same view has been expressed by Greenland and Lal (1975). The reasons they give are that

1) Grassed waterways require more land that could be used to produce valuable crops.
2) They slow down farm operations thus increasing their cost.
3) Cost of maintaining them is high.

With the reasons given above, underground outlets are becoming popular even though expensive initially. These are conduits made of clay, steel, plastic, concrete, aluminium, iron or any other material substantial enough to withstand weight of earth above it.

All sources seem to agree that road construction increases catchment area for runoff and concentrates the same runoff through cross culverts. While the material of the culverts and their size may have been constructed according to the civil engineering requirements, there seems to have been little attention given to the waterways discharging such runoff beyond the road reserve. This is the case most commonly observed on the Kenyan roads.

5.0. RESULTS OF THE INVESTIGATION

5.1. Kandara

5.1.1. Area of watershed

The watershed (catchment) area was made up of two different land surfaces, both of which contributed to the runoff into the road drains. One was the road pavement itself and the other, the land surface beyond the shoulders of the road. Though the former surface was very small compared to the latter surface, its contribution towards runoff was thought to be significant. (See fig. 2.0(a) & (b)).

The watershed area was divided into I and II (See Fig. 2.0(a)). Area I was taken to be responsible for the initiation and development of the gully while area I and II were both responsible for the enlargement of the same gully. Their discharge points were a pipe cross-culvert and end of gully respectively.

Area I

This area was represented by two (2) planimeter dots and each dot represents 6.25 ha on the ground.

$$2 \times 6.25 = 12.5 \text{ ha}$$

$$= 0.125 \text{ km}^2 \text{ (refer to equation (1))}$$

Area I and II

Number of planimeter dots = 6

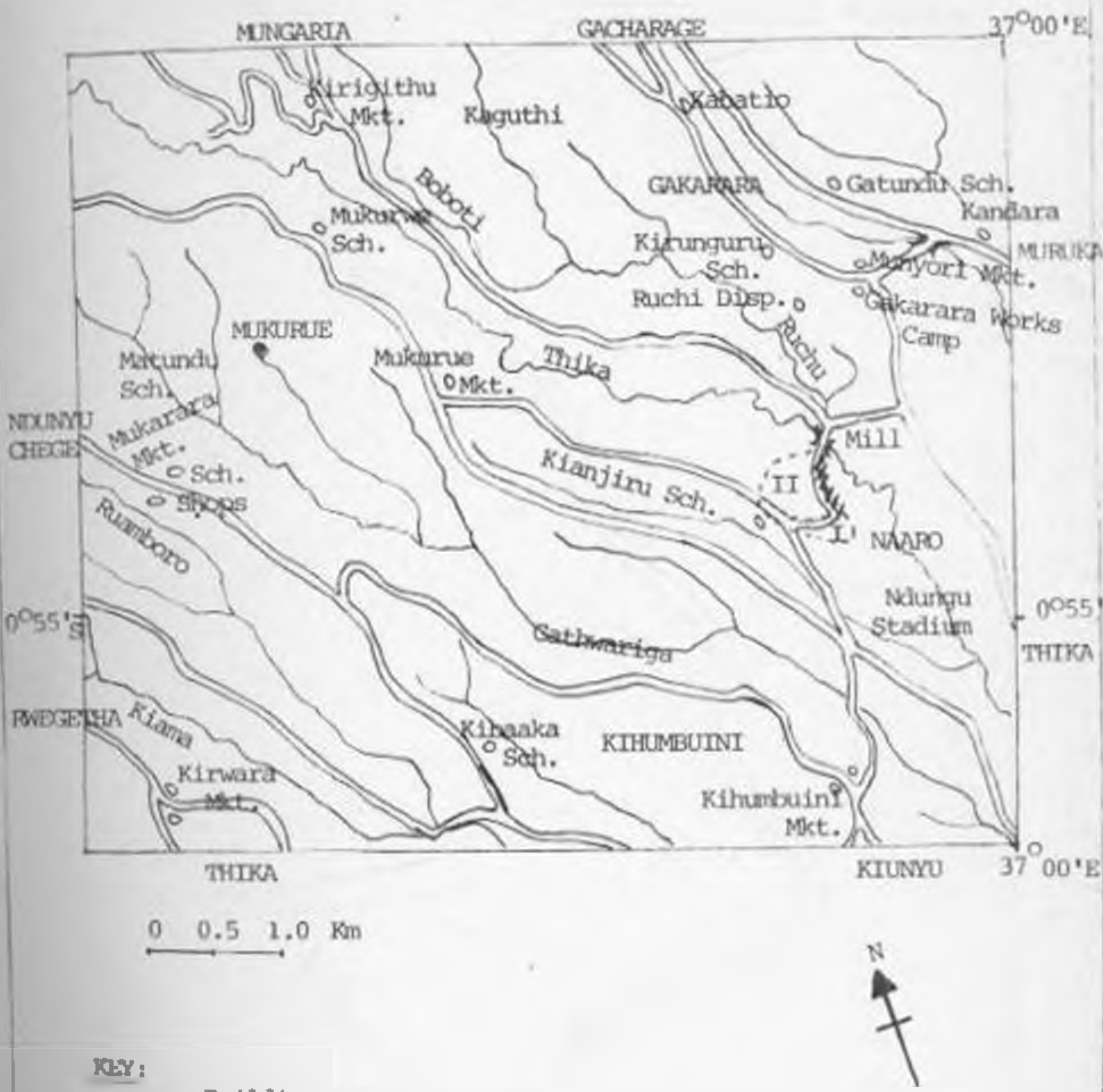
Number of ha. on ground = 6 x 6.25

= 37.5 ha

= 0.375 km^2

Fig. 2.0.(a). Map of Kandara showing the project site, road network, centres and drainage system.

Scale: 1:50,000.



KEY:

Buildings

Road network and bridge

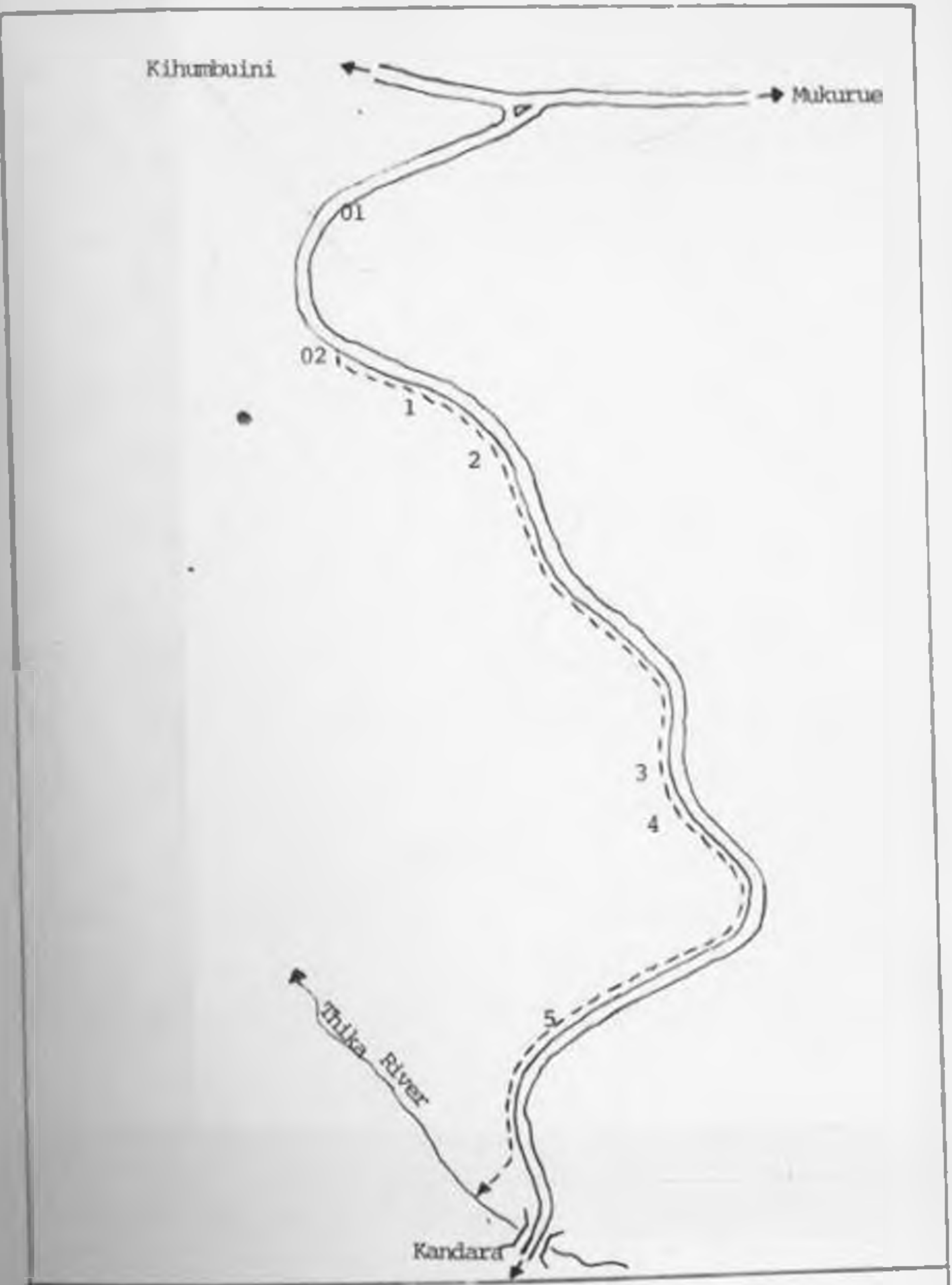
Rivers and streams

Project site

Catchment area

Source: Survey of Kenya Mangu Sheet 134/4

Fig. 2.0.(b). Sketch map of the project site at Kandara, showing position of cross culverts, wooden bridges and gully



KEY

01 = Cross culvert in Fig. 11.0.
02 = Cross culvert in Fig. 12.0.
4 = Wooden bridge in Fig. 13.0.
1,2,3,5, = Other wooden bridges
- - = Kihumbuini gully

Fig. 3.0. Long profile survey of Kihumbuini Gully, Kandara

Scale: Vertical - 1 cm = 5.0 m.
Horizontal - 1 cm = 20.0 m.

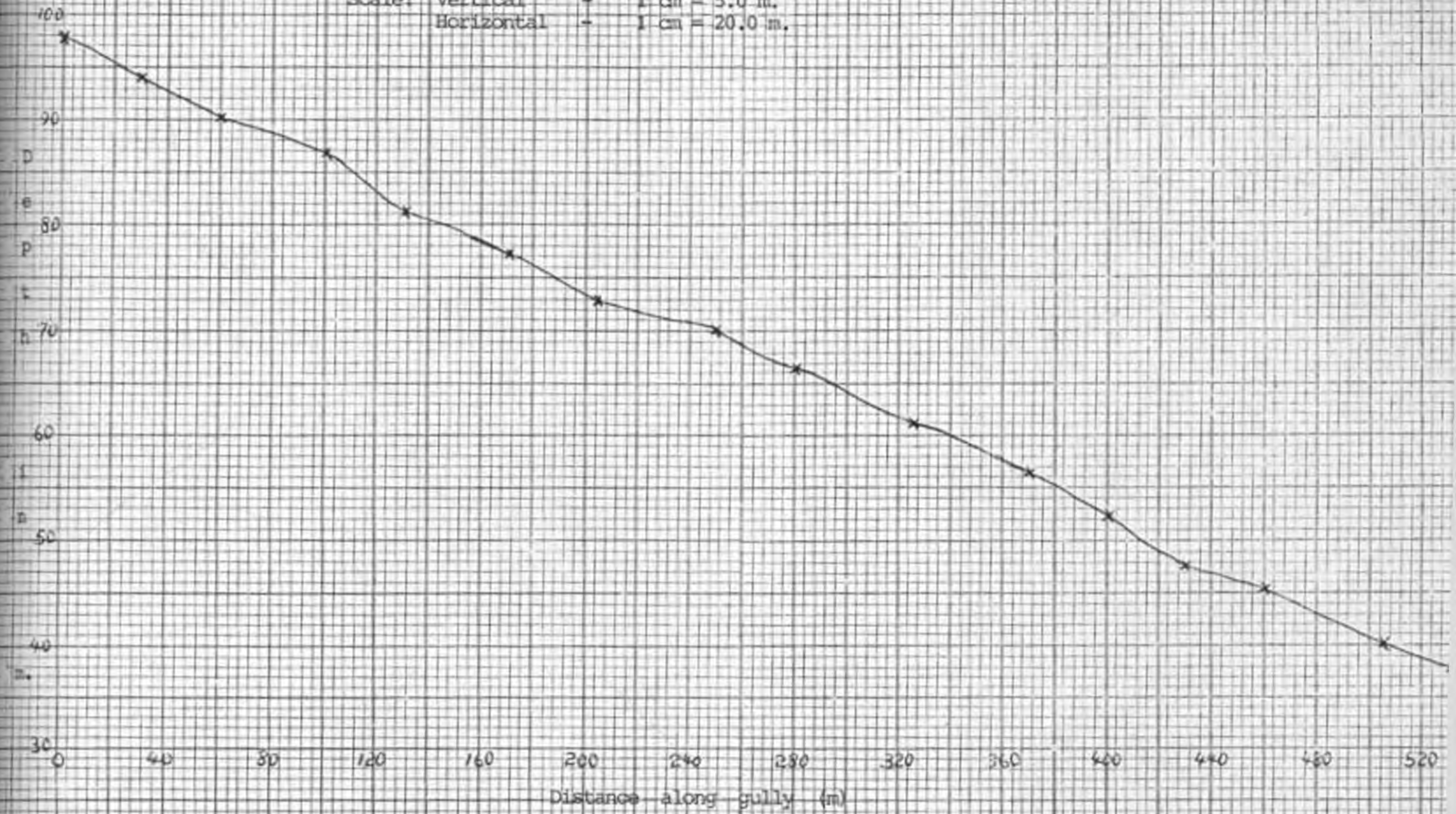


Fig. 4.0. Cross profiles of Kihumbuini Gully, Kandara

Scale: Vertical - 1 cm = 0.5 m.
Horizontal - 1 cm = 1.0 m.

NB. (1) Numbers on the right hand of each graph shows the distance in meters along the gully. (2) Number against each graph letter is the cross sectional area on the ground.

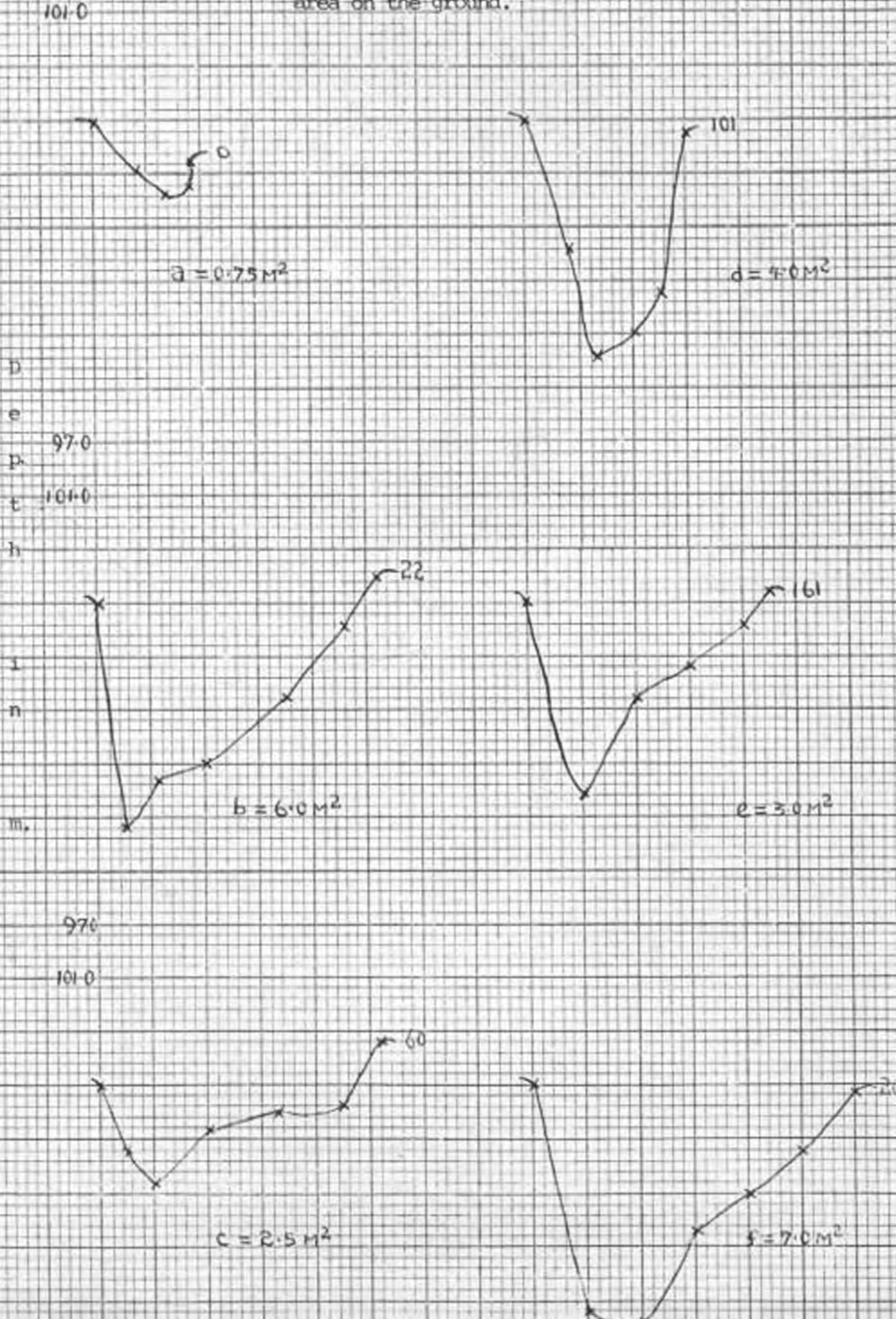
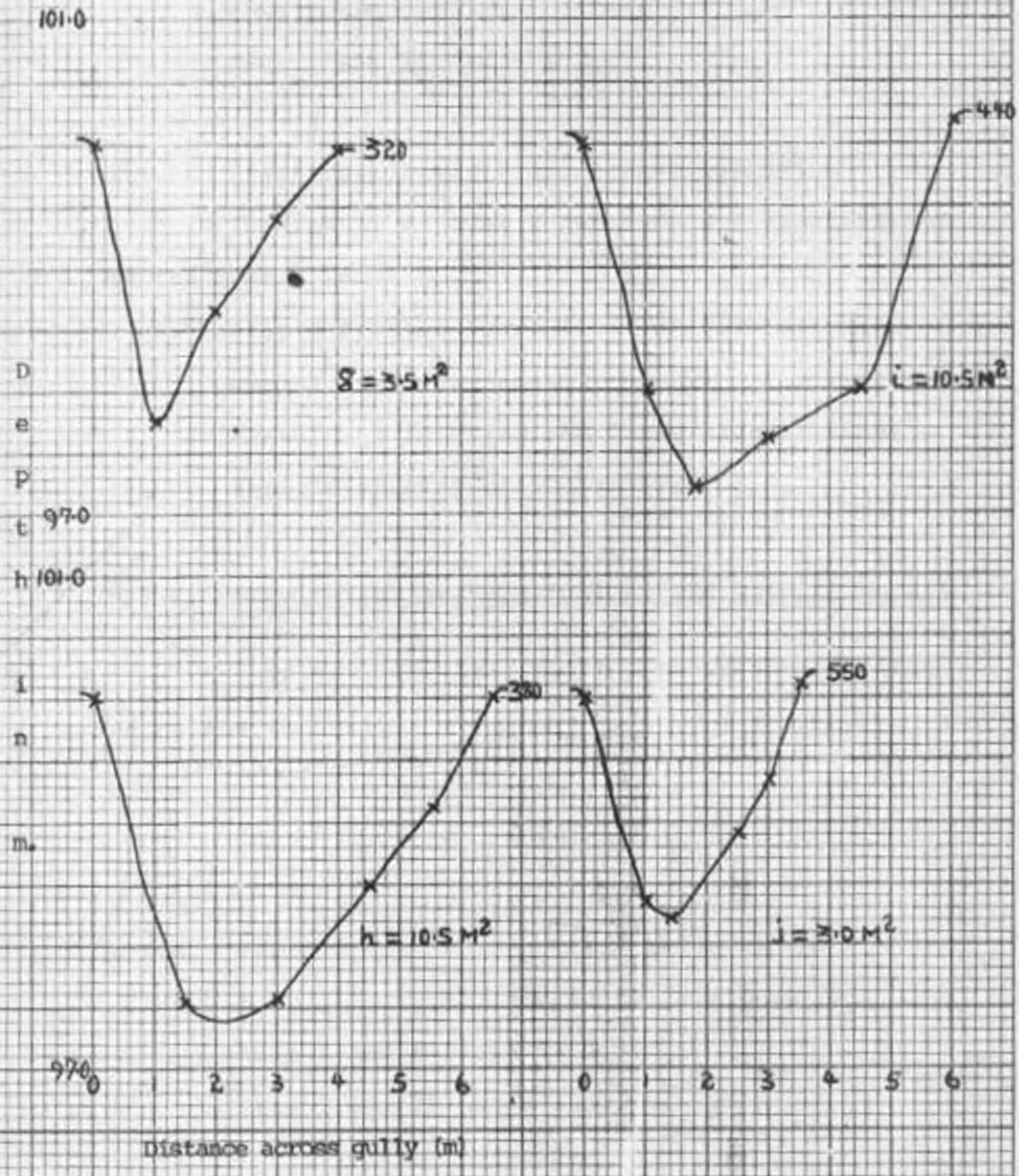


Fig. 4.0. continued



5.1.2. Longest path of flow for runoff (km)

This was determined for each catchment by walking, following the channels made by surface runoff.

Area had 0.75 km

Area I and II had 1.20 km

5.1.3. Discharge level of each cross-culvert

The result of oral interviews and observation of the debris were:

Area I cross culvert flows at full capacity during peak discharge.

Area I and II gully and flows at half (0.5) capacity during peak discharge.

5.1.4. Gradient or average fall of the path of runoff (m/m)

This was computed from the topographical maps using the formula:

$$\frac{V.I.}{H.D.} = \text{slope (m/m)}$$

where V.I. = vertical interval (m)

H.D. = horizontal distance (m)

Area I had a slope of 0.05

Area I and II had a slope of 0.08

5.1.5. Time of concentration T_c (hours)

T_c is computed using the formula in equation (iii) (see 2.0.2).

$$T_c = \frac{L}{1.5\,D}\sqrt[5]{\frac{m^2}{F}}$$

Area I: L = 0.75 km

D = 0.4 km (from the empirical formula for area of a circle $= \pi r^2$)

m = 0.125 km^2

F = 0.05

$$T_c = \frac{0.75}{(1.5)0.4} \sqrt[5]{\frac{(0.125)^2}{0.05}}$$

= 0.89 hours

From the Intensity-Duration-Frequency curve for Muranga, using a 50-yr return period (preferable for permanent structures), the appropriate intensity (I) is 85 mm/hr. The same formula was applied for area I and II.

T_c = 1.30 hours

Intensity (I) = 58 mm/hr

In this situation a return period of 10 years was used because the gully floor was not a permanent structure.

5.1.6. Estimate of discharge and velocity at outlet of road drains

The peak runoff from each catchment area was estimated using the rational formula (see equation (ii)).

$$Q_{(m^3/s)} = \frac{KIa}{360}$$

Area I

Assumptions: It was estimated that 85% of rainfall on the road pavement becomes runoff and that the pavement contributes 20% of the total runoff. Farmland contributes 80% of total runoff and 40% of the rainfall becomes runoff.

$$K = \left\{\frac{20}{100} \times 0.85\right\} + \left\{\frac{80}{100} \times 0.4\right\}$$

$$= 0.48 \text{ (the runoff coeffient)}$$

$$I = 85 \text{ mm/hr}$$

$$a = 12.5 \text{ ha}$$

$$Q = \frac{0.48 \times 85 \times 12.5}{360}$$

$$= 1.45 \text{ m}^3/\text{s}$$

Using continuity equation (see equation (iv)):

$$Q = Va$$

$$V_{(m/s)} = \frac{Q}{a}$$ but $a = \pi r^2 = \frac{(3.14)(0.9m)^2}{4}$, since diameter of culvert is 0.9 m.

$$= \frac{1.45}{0.636}$$

$$= 2.28 \text{ m/s}$$

The same formular were used to estimate the peak discharge and velocity for Area I and II. The assumptions made in this situation were: the road cut slopes, pavement and berm contributed 25% of total runoff and 85% of the rainfall became runoff. Farmland contributed 75% of total runoff and 40% became runoff. The weighted runoff coefficient was 0.51.

$$Q_{(m^3/s)} = 2.96$$

$$V_{(m/s)} = 1.97$$ but $a = 1.5 \text{ m}^2$ since gully outlet cross-sectional area is 3.0 m^2 and level of flow at peak discharge is half (0.5).

5.1.7. Volume of soil lost (m^3)

The volume was estimated by computing the product of the arithmetic mean of the area of the cross-sections surveyed along the gully and the length of the long profile survey carried out on the same gully

1 cm^2 on the graph	=	$0.5m^2$ on the ground (see Fig. 4.0)
Total cross sectional area	=	50.75 m^2
Arithmetic mean	=	50.75 ÷ 10
	=	5 m^2
Length of gully surveyed	=	585 m
Volume of soil lost	=	(585 x 5) m^3
	=	2825 m^3

5.2. Eldama-Ravine

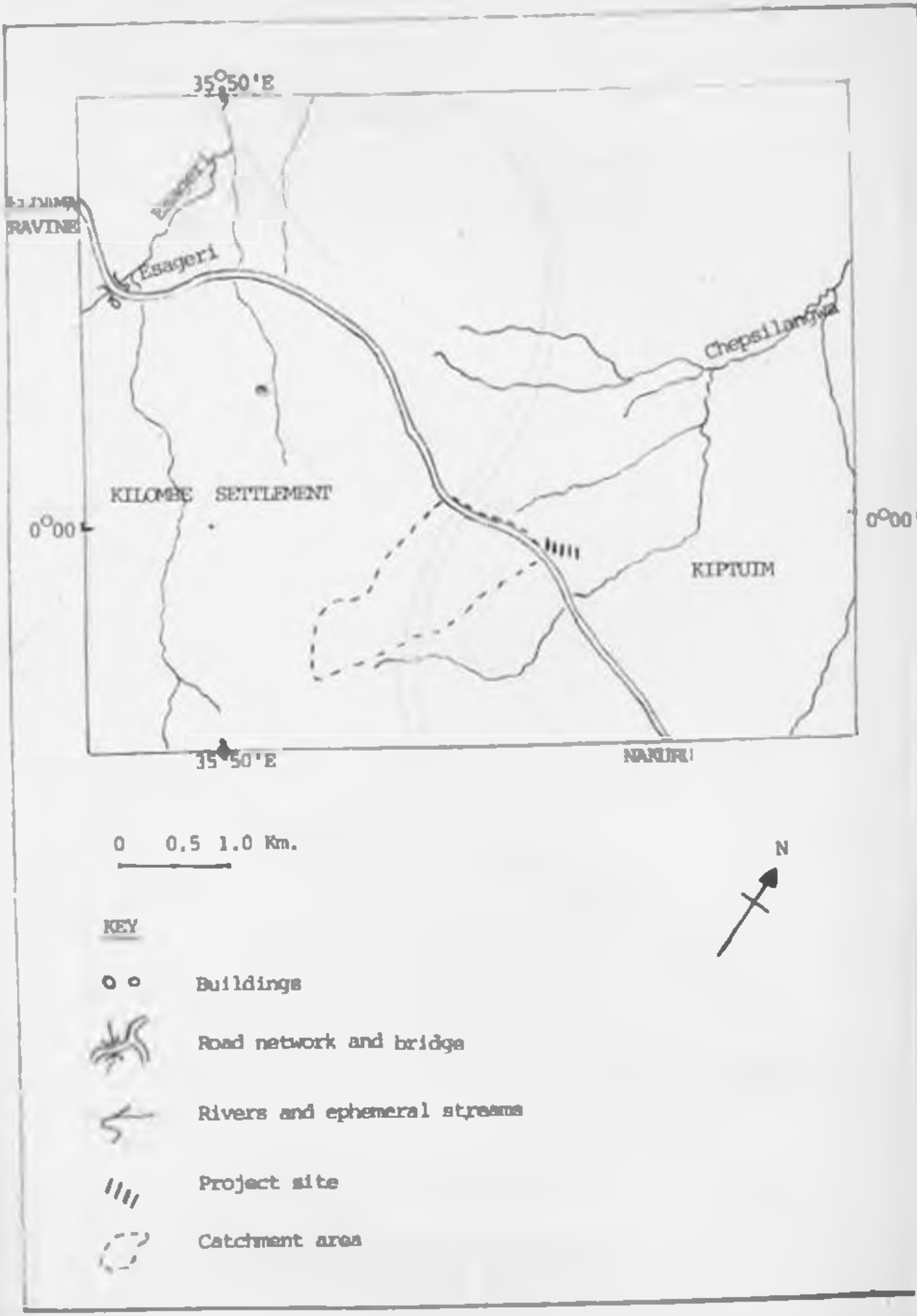
5.2.1. Area of watershed

Runoff from the catchment was drained by two cross culverts. Considering the shape of the catchment, it was assumed that 40% of the runoff was drained by the first double pipe concrete cross culvert and 60% by the second corrugated galvanised iron cross culvert (See Fig. 5.0.(b) and Fig. 6.0.(a).(b)).

Number of planimeter dots	=	18
Number of ha. on ground	=	18 x 6.25
	=	112.5 ha
	=	1.125 km^2

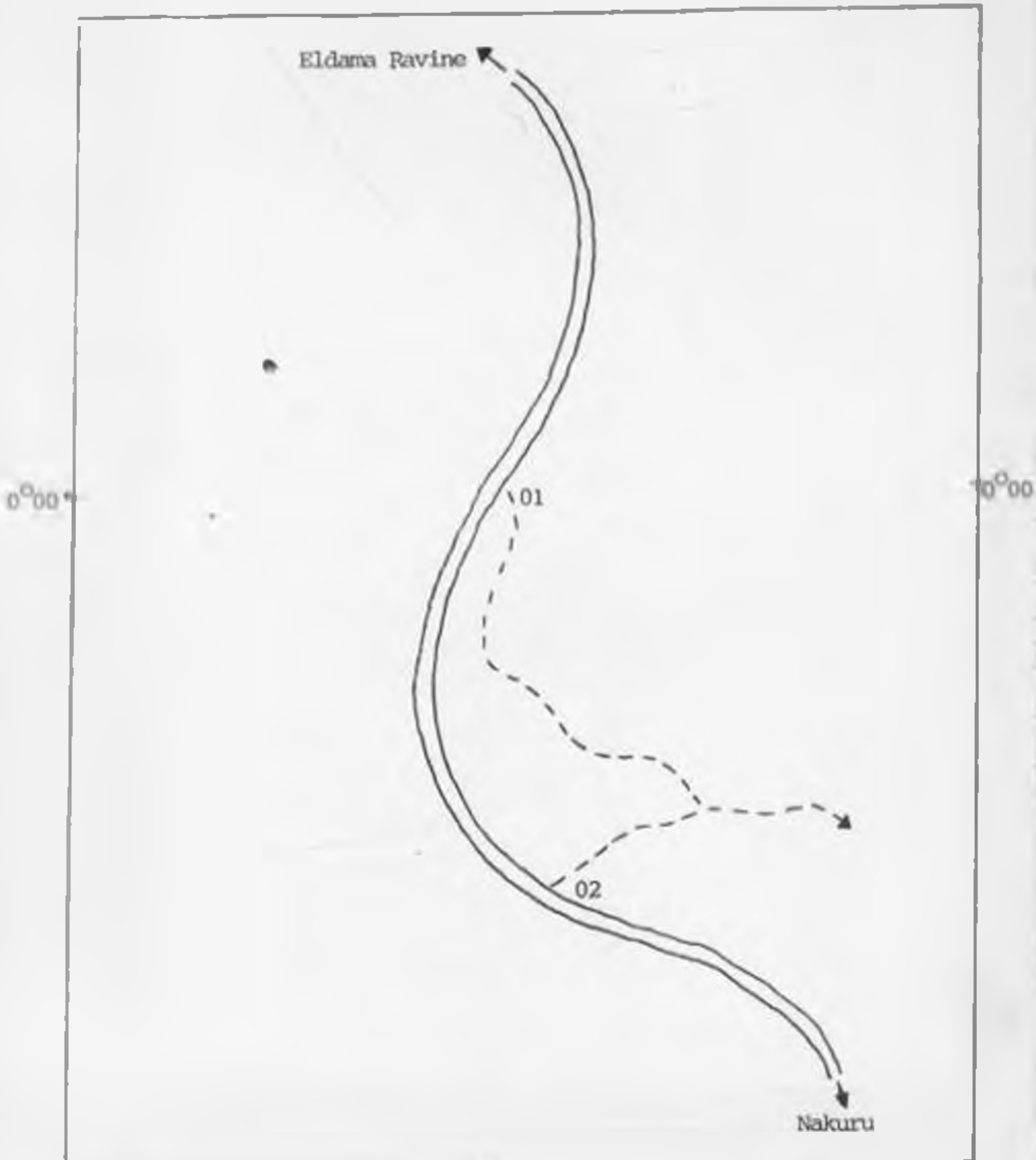
Fig. 5.0(a). Map of Eldama Ravine showing the project site, road networs, centres and drainage system.

Scale: 1:50,000.



Source: Survey of Kenya, Emining Sheet 104/4
Rongai Sheet 118/2

Fig. 5.0.(b). Sketch map of project site at Eldama Ravine showing position of cross culverts and beginning of Lembus Gully.

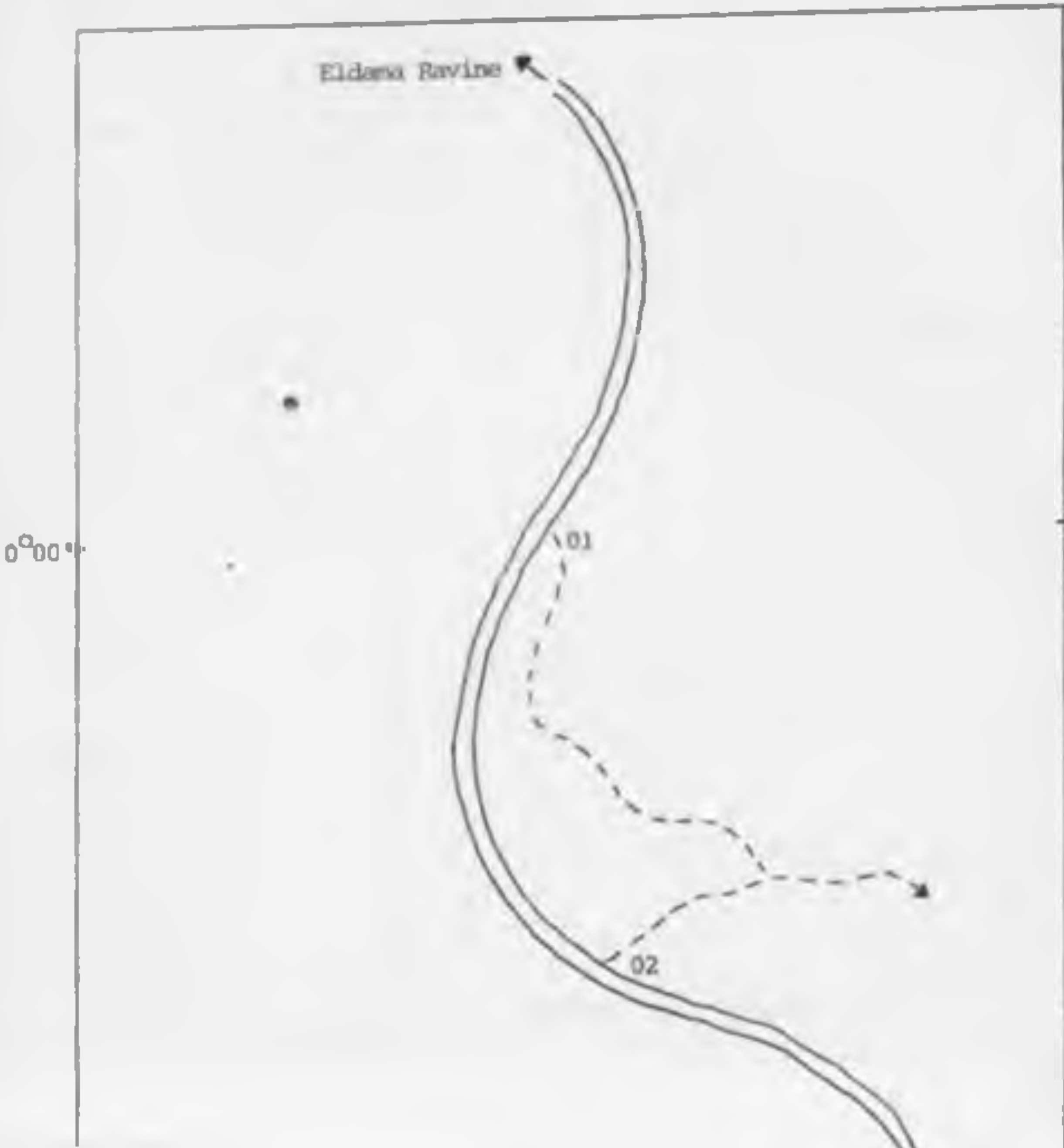


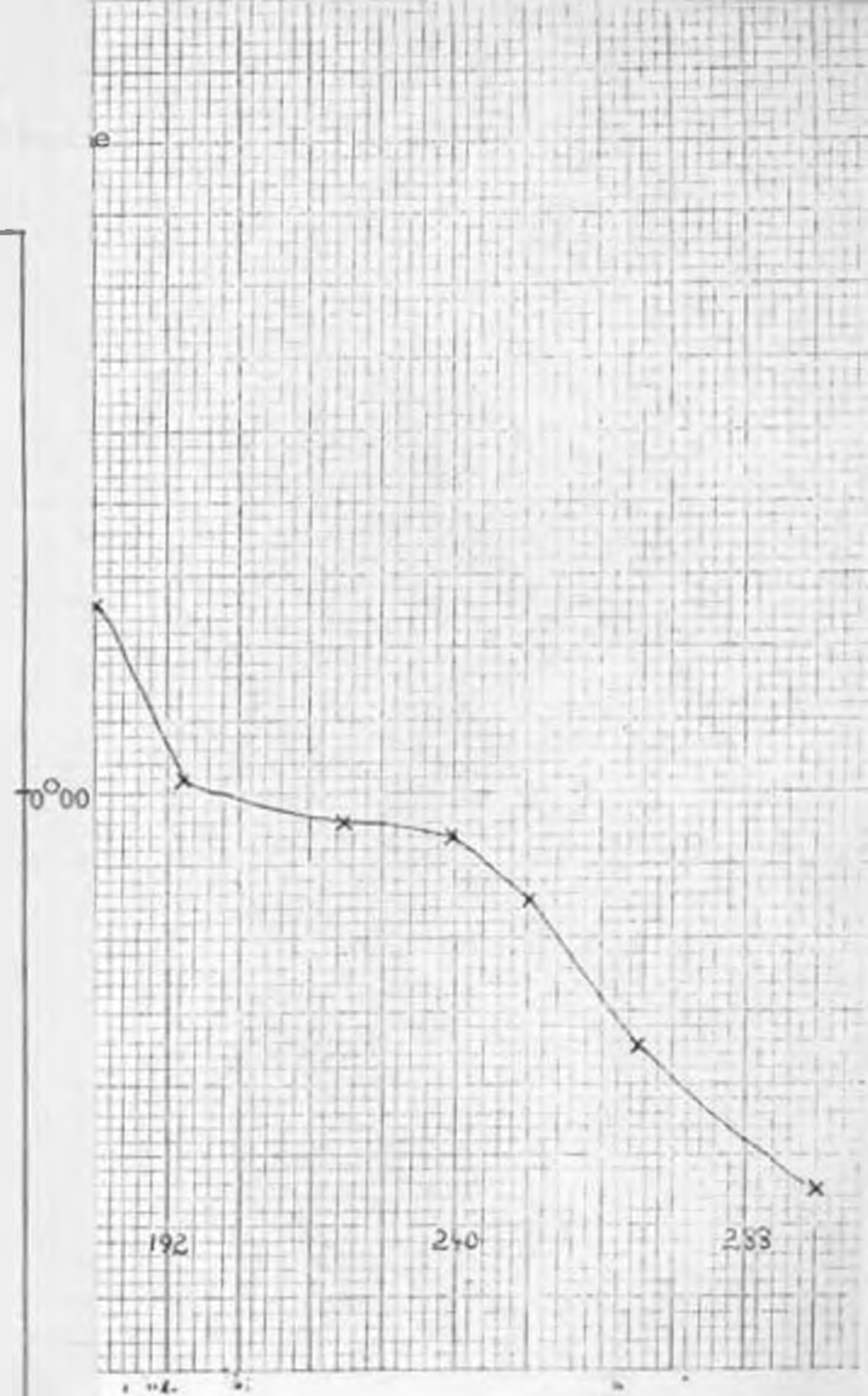
KEY

01 = Double concrete cross culvert in Fig. 8.0.(a).

02 = Single corrugated galvanized iron cross culvert in Fig. 8.0.(b).

Fig. 5.0.(b). Sketch map of project site at Eldama Ravine showing position of cross culverts and beginning of Lembus Gully.





Scale: Vertical - 1 cm = 0.5 m.
Horizontal - 1 cm = 1.0 m.

NB: (1) Numbers on the right hand side of each graph shows the distance in meters along gully. (2) Number against each graph letter is the cross sectional area on the ground.

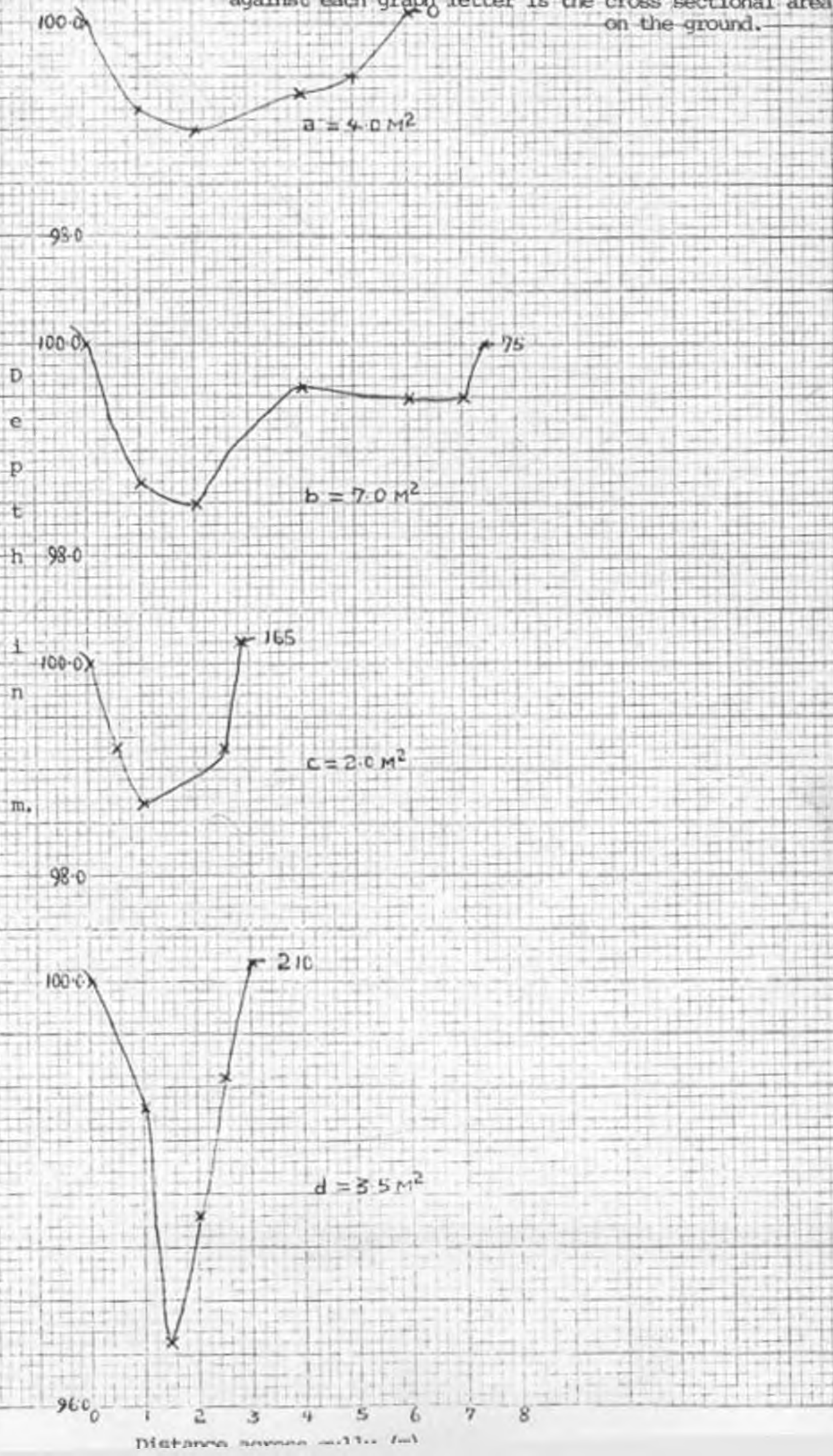
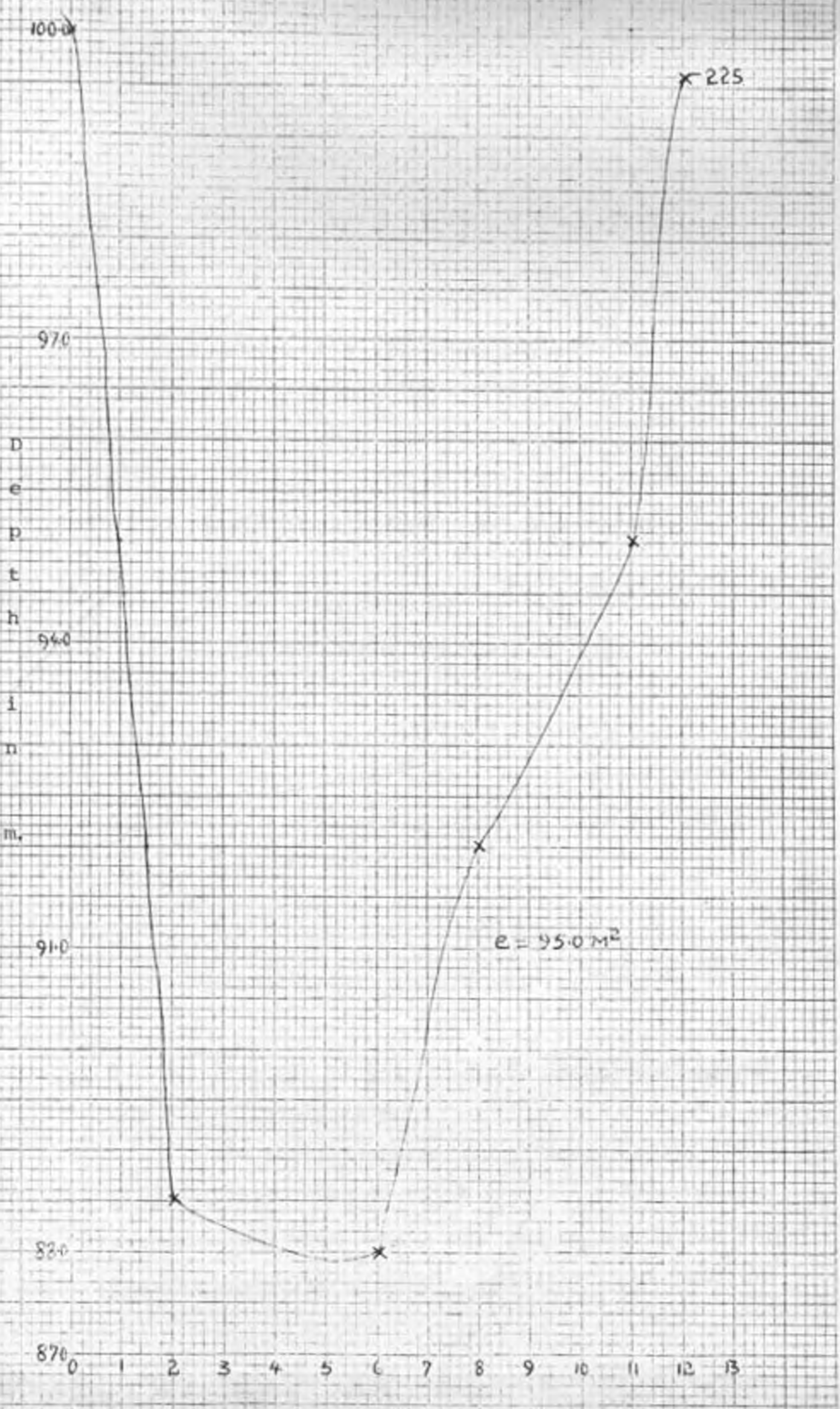


Fig. 7.0. continued



5.2.2. Longest path of flow for runoff (km)

Determined as in 5.1.2.

Total catchment had 2.10 km

5.2.3. Discharge level of each cross culvert

Determined as in 5.1.3.

The double pipe concrete cross culvert and the corrugated galvanised iron cross culvert. flow at three quarters (75%) capacity during peak discharge.

5.2.4. Gradient or average fall of the path of runoff (m/m)

Computed as in 5.1.4..

Total catchment had a slope of 0.10.

5.2.5. Time of concentration T_c (hours)

Computed as in 5.1.5. A return period of 50 years was preferred because the cross culverts were considered to be permanent structures.

T_c = 1.80 hours

Intensity (I) = 40 mm/hr., from fig. 17.0

5.2.6. Estimate of discharge and velocity at outlet of road drains

The peak discharge was estimated using the rational formula as in 5.1.6.

Assumptions: 100% of the rainfall on the termac pavement becomes runoff and that the road contributes 10% of the total runoff. The remaining catchment contributes 80% of the total runoff and 50% of the rainfall becomes runoff.

The weighted runoff coefficient (k) = $\left\{\frac{10}{100} \times 1.0\right\}$ +

$\left\{\frac{90}{100} \times 0.5\right\}$

= 0.55

$Q_{(m^3/s)}$ = $\frac{0.55 \times 40 \times 112.5}{360}$

= 6.875 m^3/s, (a) 40% of total discharge flows through the double pipe concrete cross culvert (refer to 5.2.1.). The discharge at this culvert: = (6.875 x 0.4) m^3/s

= 2.75 m^3/s

The cross-sectional area of the double culverts discharging at 75% capacity is given by:

a = πr^2 (2) (0.75)

= 3.14 $(0.45)^2$.2.(0.75)

= 0.954 m^2

Applying the continuity equation (refer to equation (iv)):

$V_{(m/s)}$ = $\frac{Q}{a}$

= $\frac{2.75}{0.954}$

= 2.88 m/s, (b) corrugated galvanised iron cross culvert:

$Q_{(m^3/s)}$ = 6.875 - 2.75

= 4.125 m^3/s

Cross-sectional area of this culvert, discharging at 75% capacity (refer to 5.2.3.) is given by:

$$a = \pi r^2 (0.75)$$

$$= 3.14 (0.55)^2 (0.75)$$

$$= 0.712 \text{ m}^2$$

Using the continuity equation:

$$V_{(m/s)} = \frac{Q}{a}$$

$$= \frac{4.125}{0.712}$$

$$= 5.79 \text{ m/s}$$

5.2.7. Volume of soil lost (m^3)

The procedure followed to calculate the volume of soil lost is the same as in 5.1.7. (refer fig. 7.0.).

Total cross-sectional area	= 111.5 m^2
Arithmetic mean	= (111.5 ÷ 5) m^2
	= 22 m^2
Length of gully surveyed	= 300 m
Volume of soil lost	= (300 x 22) m^3
	= 6600 m^3

Table 2.0. Summary of results

Site	Watershed Area (ha)	Concentration Time (T_c) hrs	Peak Discharge m^3/s	Culvert Floor material	Culvert Outlet structure	Water Velocities attained (m/s)	Soil Lost (m^3)
[illegible]	12.5	0.99	1.45	concrete	none	2.28	2625
I and II	37.5	1.30	2.98	gully and	N.A.	1.97	
Eldama-Ravine	112.5	1.90	Culvert I 2.75	concrete	gabion matress	2.88	6600
			Culvert II 4.13	galvanised iron	energy dissipator	6.88	

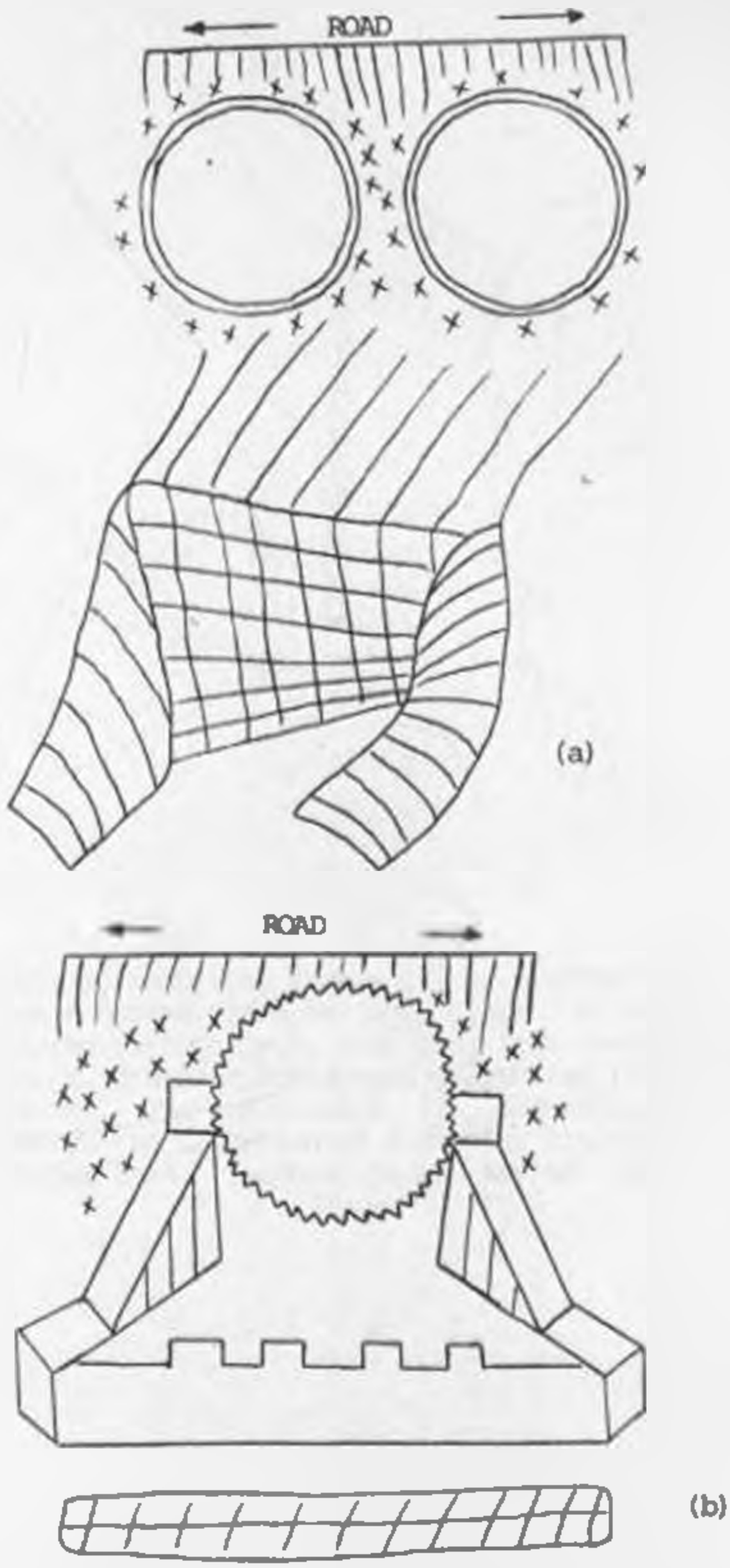


Fig. 8.0.(a). 0.9 m. double pipe concrete cross culvert, with gabion at the outlet.

(b). 1.01 m. single corrugated galvanized iron cross culvert with energy dissipating device and gabion at outlet.

Both contribute to gully formation further down (see Fig. 9.0.).

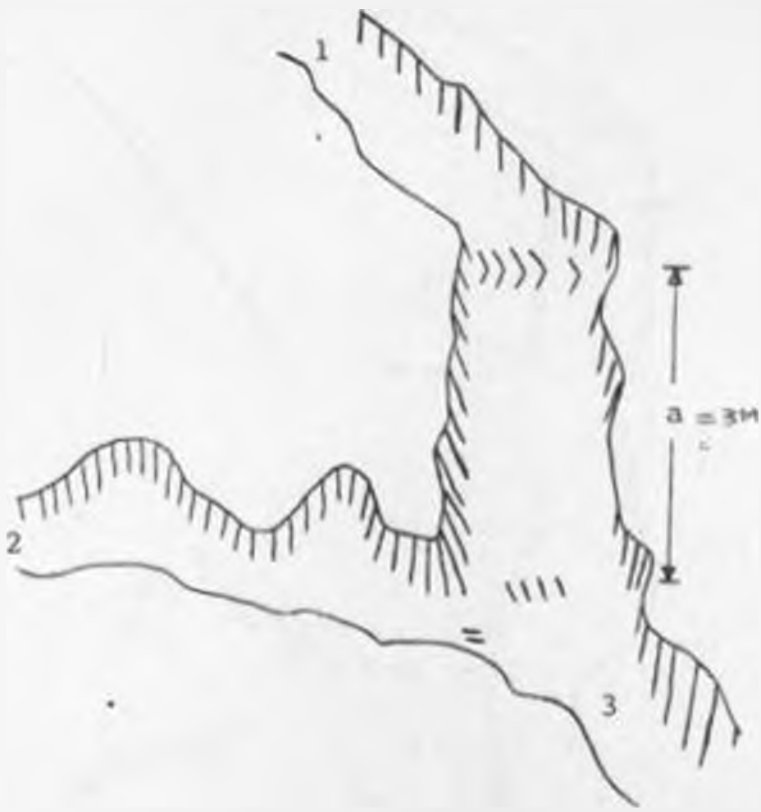


Fig. 9.0. Gully 1, resulting from a 0.9 m. diameter double pipe concrete cross culvert, drops 3 m. before joining with gully 2, resulting from a single pipe 1.01 m. diameter corrugated galvanized iron cross culvert. The two gullies, (3), contribute towards the formation of a complex digitate gully farther down. (Lembus, Eldama Ravine) (See Fig. 10.0).

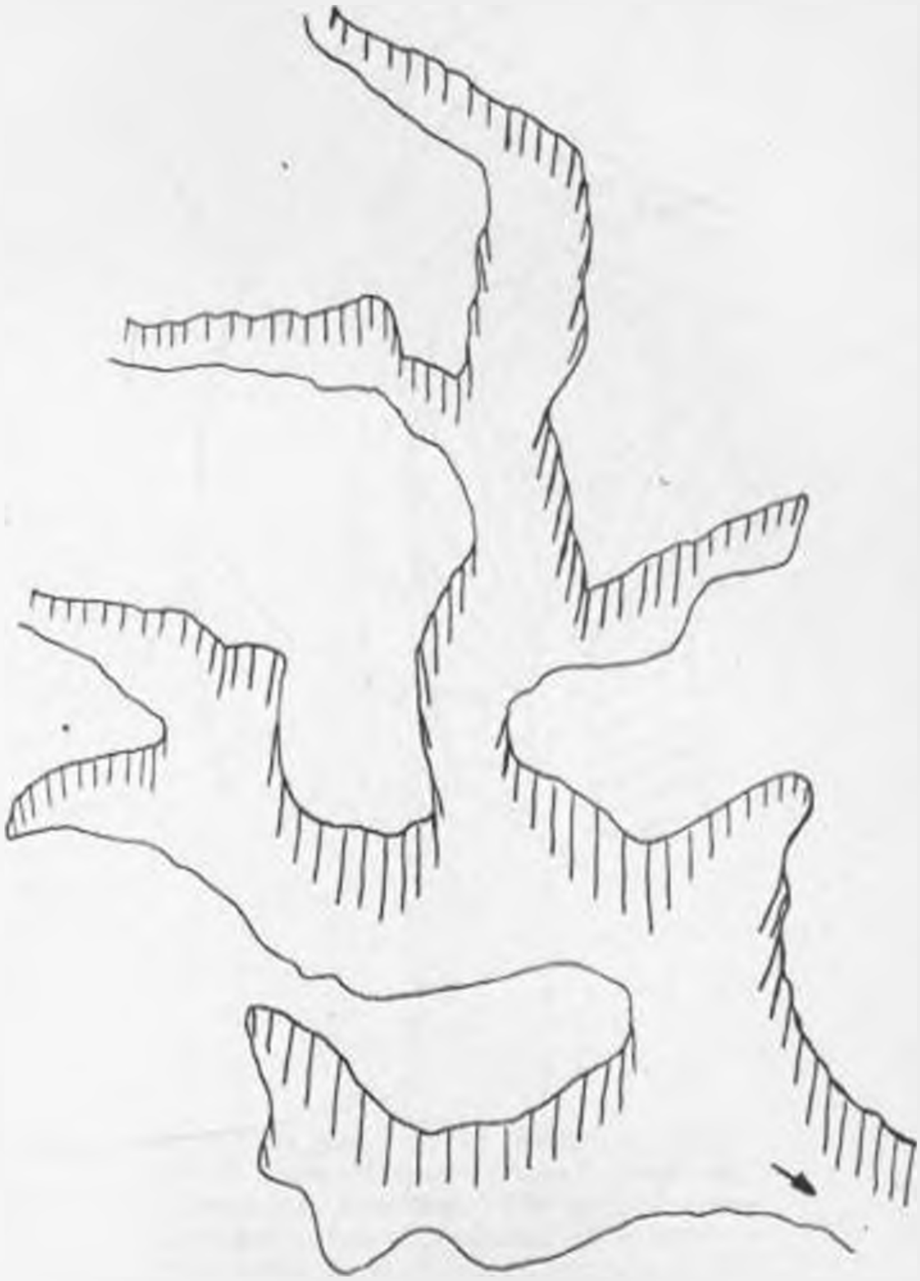


Fig. 10.0. Digitate gully at Lembus, Eldama-Ravine.

It is 12 m. wide and 10 m. deep. The gully forms a boundary between two adjacent farms. However, the farms themselves are being "eaten" by the gully. Reclamation costs may be too high.

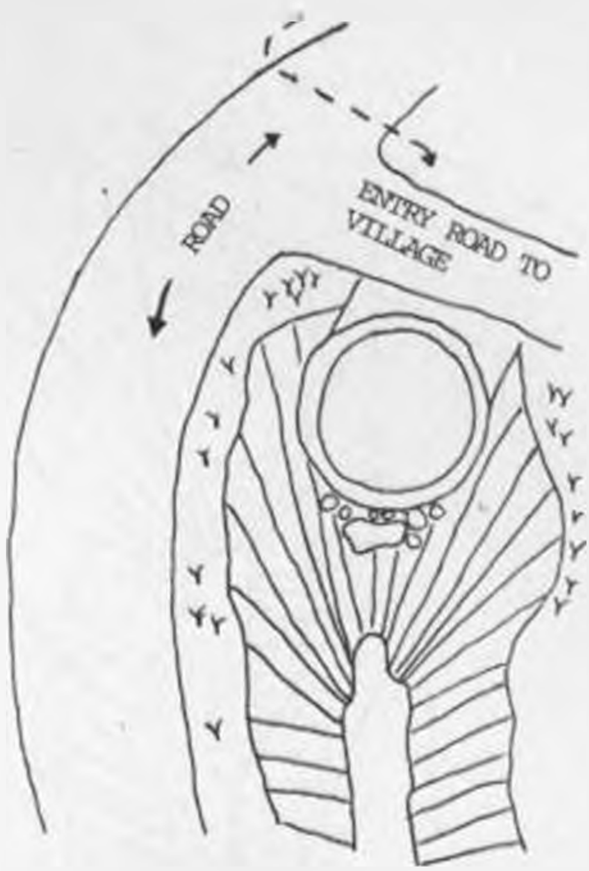


Fig. 11.0. An active young gully resulting from 0.9 m. pipe concrete cross culvert at Kihumbuini, Kandara. The dotted arrow line indicates a position of a non-functional pipe cross culvert that is meant to collect flow along the left side of the road into this cross culvert that provides entry road to a village. The gully which is threatening the village buildings is 2.0 m. deep, 2.4 m. top width and 0.6 m. bottom width.

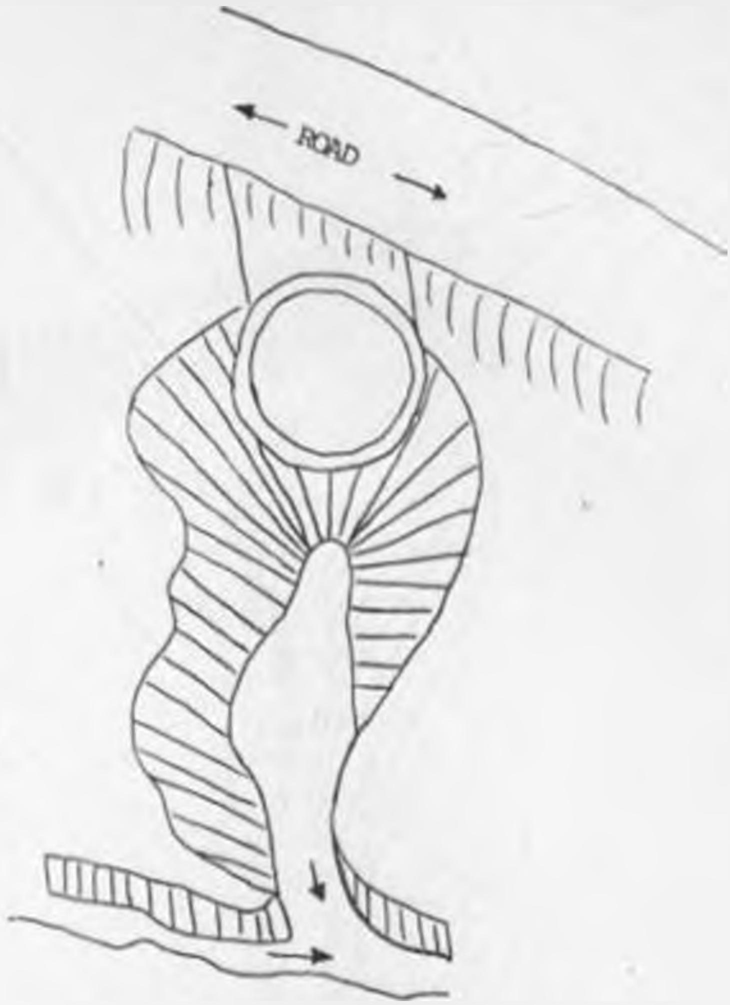


Fig. 12.0. The pipe cross culvert where the more than half kilometer long gully at Kihumbuini, Kandara, starts. The gully is confined to the road reserve even though the adjacent farms' crops are in danger of being washed away.

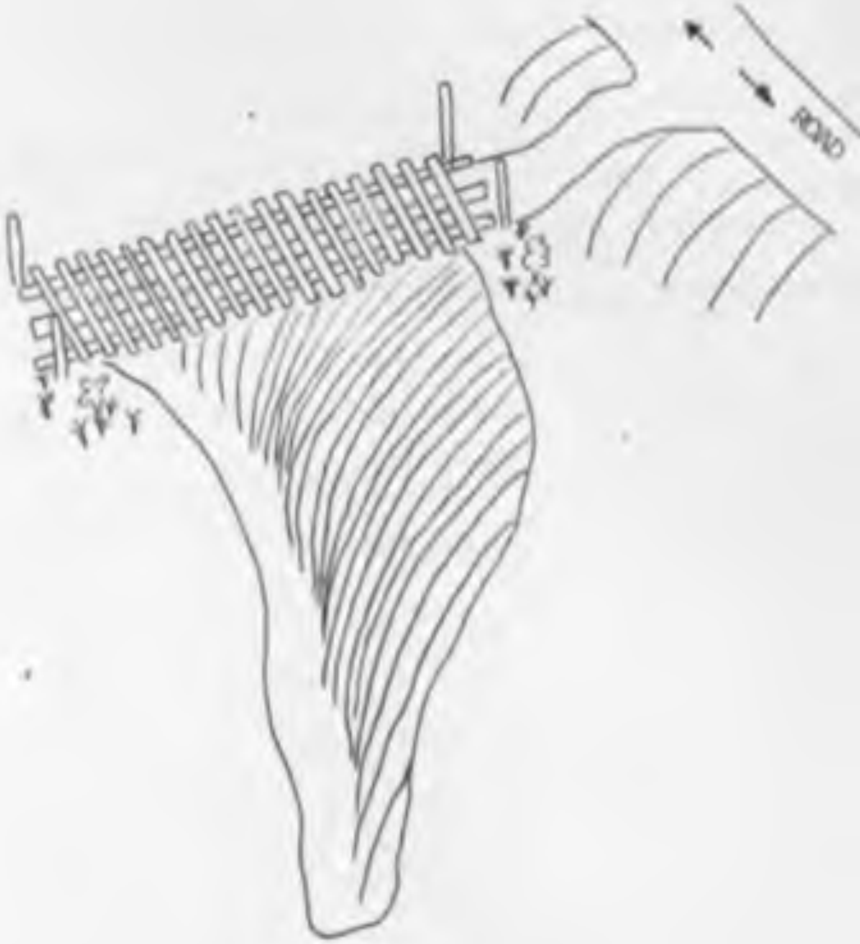


Fig. 13.0. One among the five bridges (made of wood) which have been constructed by the villagers, to enable them connect the road. It is no longer easy to walk across the gully.

8.0. DISCUSSION

8.0.1. The artificial causes of gullying in the two problem situations investigated may be summarised as:

8.1.1. Kandara

i) Poor installation of pipe cross culverts. The culverts did not have energy dissipators at the outlet.

ii) Concentration of runoff from the catchment into the pipe cross culverts.

iii) Lack of scour checks and or drop structures along the roadside drainage channel.

iv) Properly designed and constructed waterway to discharge runoff into the natural drainage system was lacking.

v) Lack of mitre drains

vi) Cooperation among the road construction agency, local leaders and farmers in order to arrive at a lasting solution regarding the disposal of the runoff was lacking.

8.1.2. Eldama-Ravine

i) Concentration of runoff from the catchment into the pipe cross culverts.

ii) Lack of properly designed and constructed waterway to discharge runoff into the natural drainage system.

iii) There were no scour checks along the runoff disposal channel.

6.0.2. The design of the pipe cross culverts is based on peak runoff computed using a five (5) minute rainfall storm and two (2) year return period (Anon. 1978). This results in undersize culverts. Since these are permanent structures, a return period of more than two years (ten years, preferably fifty years) should be used to obtain an appropriate size of culvert to discharge the peak volume of runoff. The Transport Road Research Laboratory (TRRL) method uses only approximate peak discharge of small catchments (less 15 m^2) thus leaving out large catchments of natural drainage systems.

6.0.3. The concentration of runoff into the pipe cross culverts increases the mass and velocity hence the capacity and competency of the flowing water. The velocities attained at the discharge mouth of the culverts (Table 2.0.) both in Kandara and Eldama Ravine, are safe only for the floor lining material of these culverts. The velocities are more than the safe maximum velocities, recommended for the bare soil discharge channels beyond the road reserve area (Table 6.0.). Unless adequate prevention methods are employed during design and construction of roads, these velocities are capable of causing scouring in the disposal channels.

6.0.4. Observations made elsewhere in Kenya have shown that often runoff is carried in road side ditches, for long distances due to lack of suitable natural drainage channel into which to discharge it. Scour check and gabion dams, which are used to prevent scouring, in such cases are inadequately planned. The crest of the mid-spillway of each successful check dam does not correspond to the lowest point of the preceeding check dam. This leaves some erodible bed which will not be filled by sediment deposition. Scour check dams should be closely spaced, adequate spillway provided in the middle and an erosion resistant apron on down-slope side.

6.0.5. In some densely populated areas like Kandara, the value of land is so high that farmers are not willing to have artificial waterways constructed through their small farms. The Kihumbuini gully is confined to the road reserve though the gully is widening and threatening boundary fences and farms. This resulted from the farmers blocking the mitre drains and returning the water to flow along the road reserve. If drainage problem would have been thought about earlier, properly designed disposal channels would have been included in the road construction, would have involved the farmer and a soil conservation engineer.

6.0.6. The number of causes of gullying in the two problem situations are not the same. The gully in Kandara is associated with class E road and runs along the road while the one in Eldama Ravine is associated with class C road, with tarmac pavement and runs perpendicular to the road. In both situations there was a clear failure to design and construct a proper water disposal channel for the concentrated flow, into the natural drainage system.

7.0. RECOMMENDATIONS

7.1. Control

7.1.1. The side slopes of the gully if too steep (greater than 60°) should be battered and gentle slopes, which can be mulched and grass seeded obtained. The gentle slope encourages volunteer species, then perennial grasses like Kikuyu grass (*Pennisetum clandestinum*) can be planted. This is followed by an appropriate series of scour check dams in the side ditches. Depending on the severity of the erosion, and the class of the road, the dams can be temporary or permanent, so long as they can hold back sediment.

7.1.2. Wherever possible, the gully should be lined with properly placed riprap. This will prevent the floor from scouring and should continue into the natural stream.

7.1.3. In some cases, it may be necessary to line the gully floor with hard core to prevent further gully floor erosion. It is more expensive but will definitely control the gully floor erosion.

7.1.4. Under special circumstances, where cost is not prohibitive and on major roads, construction of an underground conduit should be done. In this case, special energy dissipating devices should be built at the outlet to accommodate the high water pressures developed. This is expensive but may form a small percentage of the cost of constructing high class roads.

Such drainage device should be included in the tender document.

7.2. Prevention

Gully prevention in the design and construction of roads is the best and most economical policy since the cost of reclaiming large gullies, once formed, may exceed the returns.

7.2.1. Where possible, all roads should be designed to follow crest lines of the natural terrain. This will reduce the flow in the side drains since there will be no higher land draining into them.

7.2.2. All cut slopes, should be provided with a diversion ditch (cutoff drain) to divert flow into suitable culvert thus, avoiding the steep erodible slopes (See Fig. 15.0.).

7.2.3. The fill slopes should inevitably be seeded or planted with suitable grasses.

7.2.4. Drop inlets and head spillways on the upper end of cross culverts should be provided. This will prevent gully formation on side ditches and adjacent agricultural land. Drop outlet structures should be provided at lower end of discharge to lower the flow to a stable gradient.

7.2.5. The number of mitre drains should be increased so that the volume being discharged by a single mitre drain is reduced . The momentum of such water flow will not be capable of detatching and transporting soil particules.

7.2.6. Where it is absolutely necessary that catchment area must be increased by concentrating surface runoff into one cross culvert, water spreading channels should be provided at the lower end of the culvert. These will share the discharge through the culvert. The momentum and erosive velocities which are destructive will be reduced. The system may be applicable to places where economics of land allow (See Fig. 14). The spacing of the channels will play a major role in achieving the non-erosive momentum and water velocities.

7.2.7. The "Public Roads and Roads of Access Act" should be amended to give responsibility in whole or part to the local road construction authority over poorly designed water disposal channels. This will enable the authority to be keen on water discharge channels before such water reaches a natural stream or river. More often, disposal channels from road drains do not follow the original natural water courses.

7.2.8. In semi humid areas like Eldama-Ravine, surface water runoff may be stored in properly designed surface dams. Such water can be useful for livestock consumption and even some limited irrigation for kitchen gardening, after the rains have stopped.

7.2.9. There is absolute need to design road drains based on anticipated velocities. Everything possible

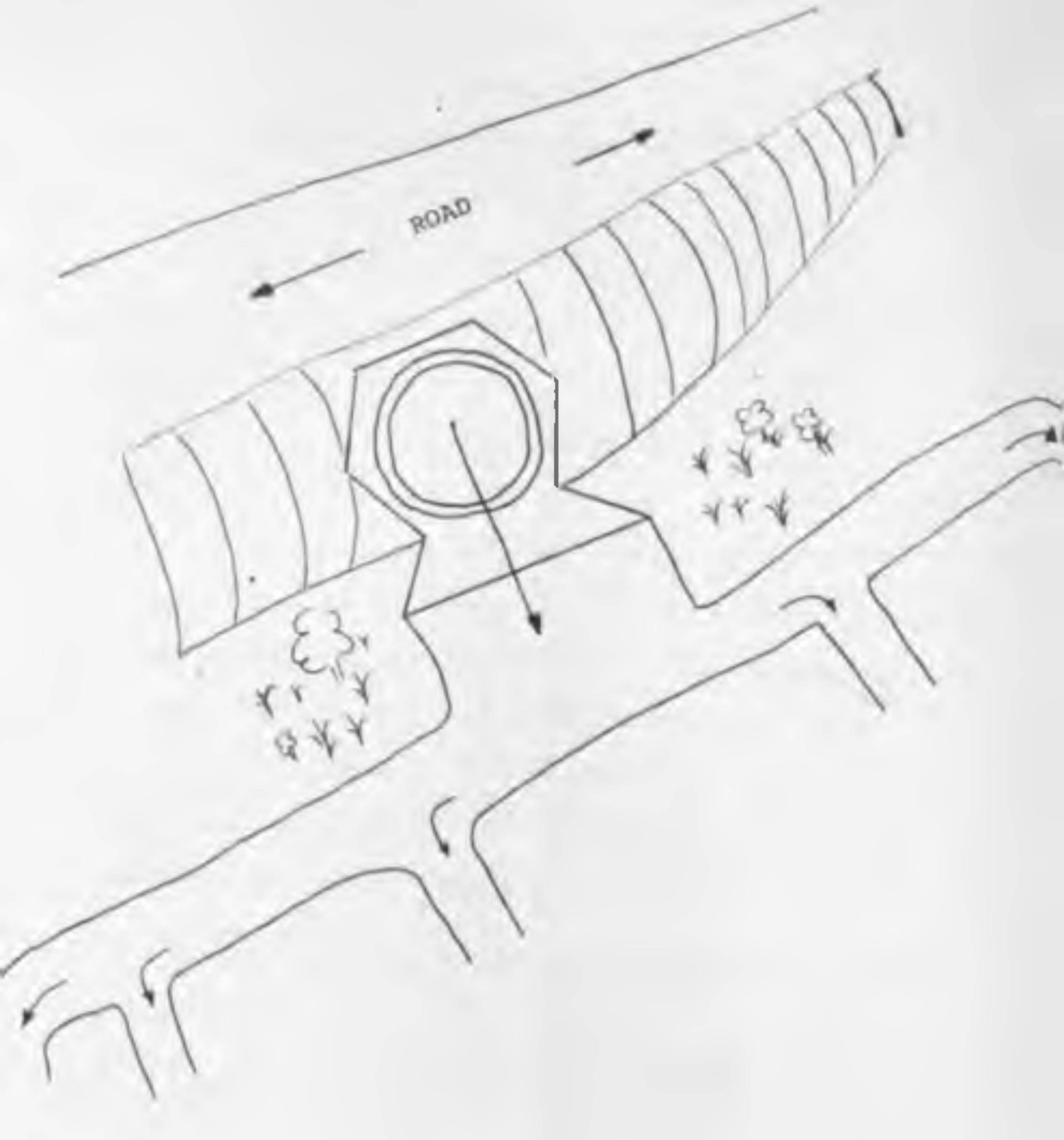


Fig. 14.0. Spreading channels

should be done to reduce concentration of runoff, design road drains which will not scour either by means of drop structures or hard core lining if grass alone is not adequate. Any good design must satisfy the continuity (equation (iv)) and Manning's (equation (v)) equations:

$$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (v)$$

where: R = hydraulic radius m

S = bedslope of channel m/m

n = roughness coeffient

7.2.10. Erosion problems should be reflected in the planning and design of a road so that necessary measures to conserve the soil is stipulated in the drawings and instructions in the tender documentation. The consultants charged with the tender documentation should seek advice of a soil conservation engineer, who must be equipped with knowledge of agriculture.

7.2.11. A high level of cooperation is essential during planning and designing of a road if erosion problems resulting from road drains are to be reduced. The local administration, Ministry of Transport and Communications, Ministry of Agriculture, Ministry of Water Development, Ministry of Livestock Development, Agricultural Engineering Department of the University of Nairobi, Ministry of Environment and Natural Resources and the farmers have a big role to play in reducing the problems.

8.0. CONCLUSION

8.0.1. Adequate water drainage from the road pavement is an integral part of an engineering design of a good road. Water being drained from the road pavement causes some soil erosion at the outlets of the road drains. Every effort should be made to control the amount of erosion.

8.0.2. Further work could be carried out to give the specifications and ascertain the cost of implementing some of the control and prevention methods suggested in specified problem areas.

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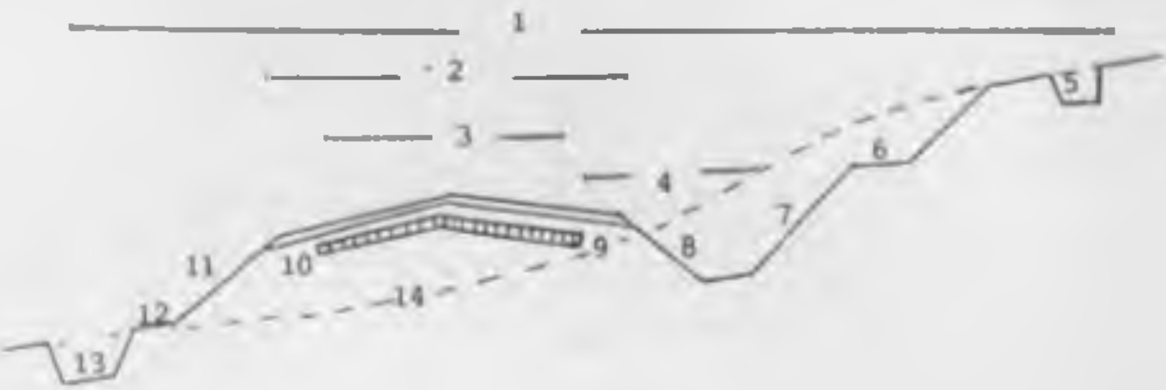

Fig. 15.0. Cross section of a road

KEY

1 Construction width
2 Road width
3 Carriageway
4 Verge
5 Cut-off ditch
6 Berm
7 Back slope or slope of cutting
8 Side ditch
9 Shoulder
10 Shoulder
11 Side slope or slope of embankment
12 Berm
13 Side ditch
14 Original ground surface

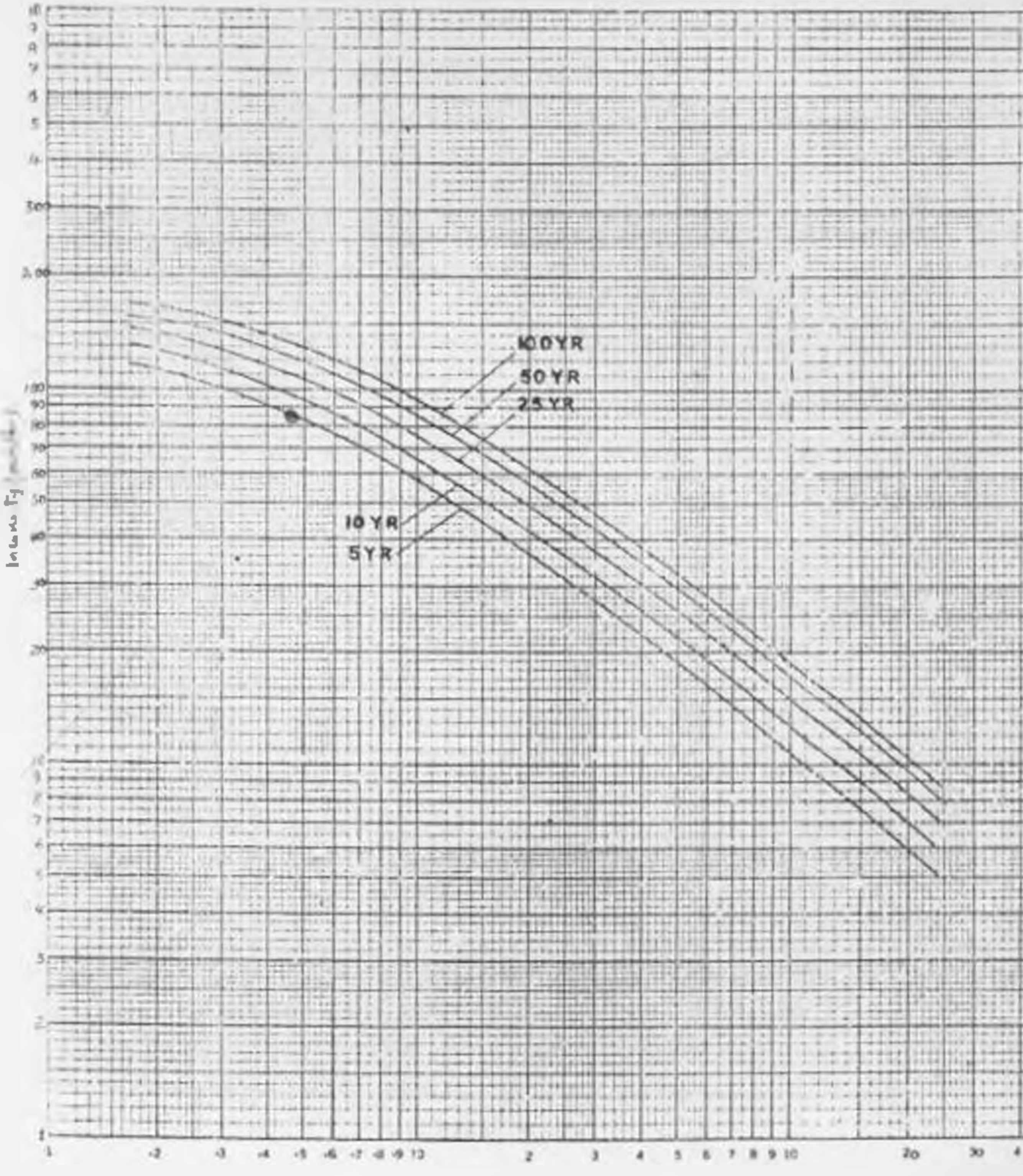

Fig. 16. Rainfall Intensity - Duration - Frequency Relationships for Muranga Water Supply Reservoir.

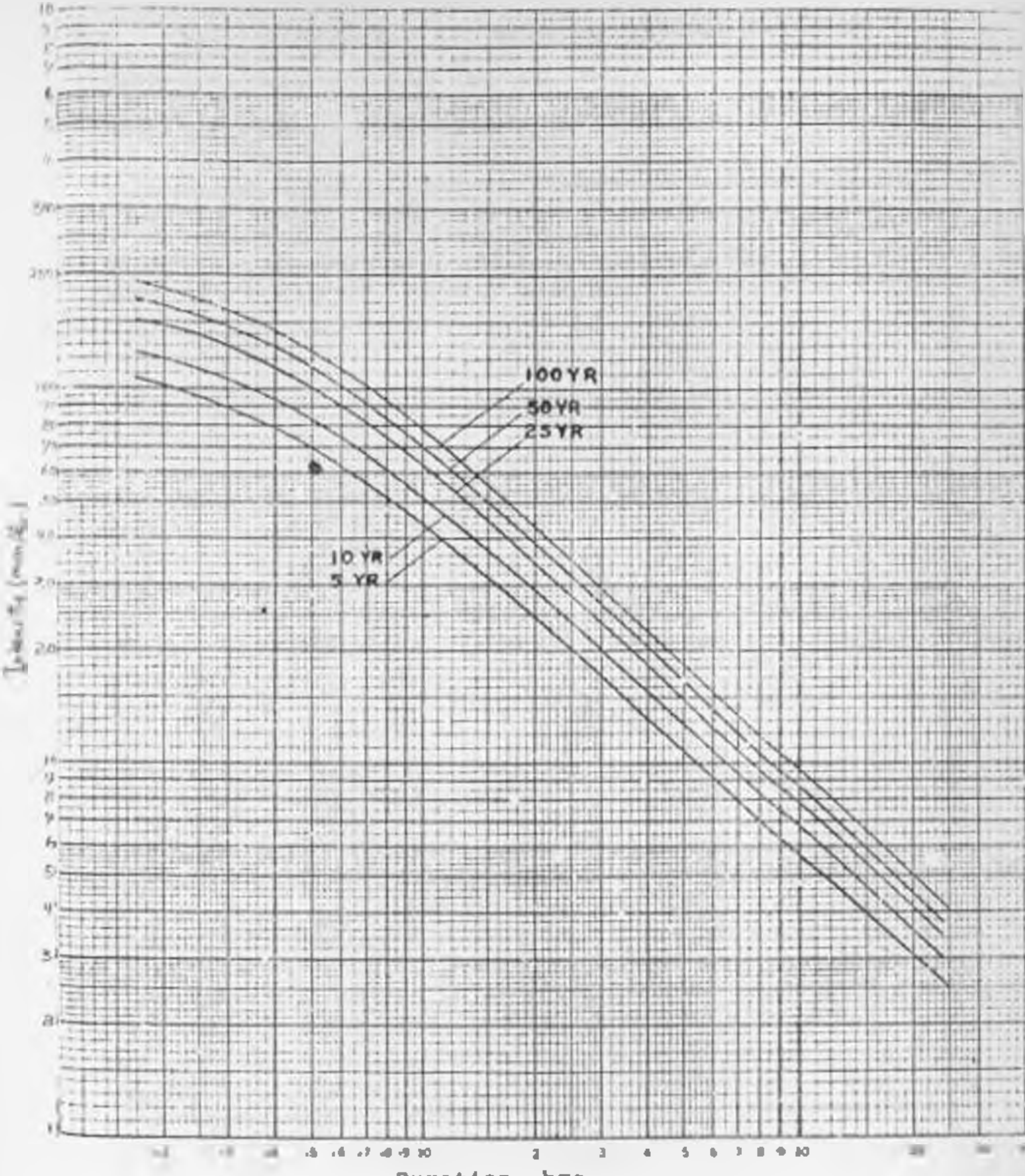

Fig. 17. Rainfall Intensity - Duration - Frequency Relationships for Nakuru Airfield.

3.0. Annual Rainfall data for Kandara Division

Table 3.1. Kariara Station 1980 and 1981

Table 3.2. Ruchu Station 1980 and 1981 (below)

Year	1980		1981	
Month	Quantity (mm)	Days	Quantity (mm)	Days
J	150.05	8	40.64	3
F	10.00	2	25.80	5
M	98.50	6	251.10	16
A	171.50	11	426.50	22
M	382.50	22	383.50	26
J	75.00	5	33.80	7
J	10.00	3	29.40	10
A	65.00	9	38.10	10
S	50.80	1	13.10	1
O	81.25	7	137.70	12
N	530.86	10	74.90	14
D	144.78	8	129.70	8
Total	1781.14	112	1584.24	138
. J	111.25	11	15.24	1
F	11.25	1	18.51	2
M	81.25	5	285.43	15
A	104.14	8	232.40	18
M	222.25	15	382.80	20
J	41.25	4	49.53	5
J	25.40	4	62.23	12
A	86.00	11	53.24	8
S	28.70	2	21.59	4
O	138.59	8	207.01	11
N	207.31	20	138.43	13
D	44.45	6	137.16	8
Total	1094.84	96	1581.57	115

Source: Divisional Extension Office, Kandara

4.0. Annual Rainfall data for Eldama-Ravine Division

Table 4.1. Kabimoi Station 1980 and 1981

Table 4.2. Esageri Station 1980 and 1981 (below)

Year	1980		1981	
Month	Quantity (mm)	Days	Quantity (mm)	Days
J	24.50	5	0.00	-
F	0.00	-	30.00	1
M	40.30	4	140.00	10
A	127.80	11	132.00	12
M	173.50	16	159.70	7
J	51.40	6	55.40	4
J	0.00	-	80.00	6
A	54.20	5	61.00	6
S	24.00	2	80.00	6
O	3[illegible].00	2	52.00	4
N	90.50	3	25.00	2
D	0.00	-	35.00	1
Total	621.20	54	830.10	58
J	0.00	-	0.00	-
F	0.00	-	0.00	-
M	0.00	-	170.00	14
A	79.90	13	155.20	19
M	165.80	16	120.70	8
J	53.[illegible]0	9	62.50	4
J	0.00	-	182.80	14
A	82.00	13	85.20	11
S	70.60	6	130.80	15
O	7.10	2	67.20	9
N	0.00	-	17.70	5
D	0.00	-	29.20	8
Total	408.40	59	1001.10	105

Source: Divisional Extension Office, Eldama-Ravine

Table 5.0. Values of runoff coefficient (K) for use in rational formula

	Type of catchment	Large	Small and steep
1.	Rocky and impermeable	0.3	1.0
2.	Slightly permeable, bare	0.6	0.8
3.	Slightly permeable, partly cultivated or covered with vegetation	0.4	0.6
4.	Cultivated absorbent soil	0.3	0.4
5.	Sandy absorbent soil	0.2	0.3
6.	Heavy forest	0.1	0.2

Source: Water Development Division, 1970

Table 6.0. Maximum safe velocities in bare channels

	Type of floor material	Velocity (m/s)
1.	Very light silt sand	0.30
2.	Light loose sand	0.50
3.	Coarse sand	0.75
4.	Sandy soil	0.75
5.	Firm clay loam	1.00
6.	Stiff clay or stiff gravelly soil	1.50
7.	Coarse gravels	1.50
8.	Shale, hardpan, soft rock etc	1.80
9.	Hard cemented conglomerates	2.50
*10.	Hard rock	3.00
*11.	Masonry	3.00
*12.	Concrete	3.00

Source: Hudson, [illegible]. (1976) Soil Conservation
* Road Design Manual, M.O.T.C. (1979)

8.0. Long profile survey of land surface of Kihumbuini Gully, Kandara

Station	Distance (m)	B.S. (m)	I.S. (m)	F.S. (m)	H.I. (m)	R.L. (m)	Remarks
*	-	0.83			100.83	100.00	On B.M.
1	00		2.80			98.03	
2	15	2.30		4.80	98.33	98.03	T.P.1
3	30		3.44			94.89	
4	45	1.9[illegible]		5.70	94.53	92.63	T.P.2
5	60		4.05			90.48	
6	75	1.[illegible]		5.26	90.85	89.27	T.P.3
7	100		3.42			87.43	
8	115	1.60		5.41	87.24	85.44	T.P.4
9	130		3.75			81.69	
10	145	0.50		4.65	83.09	82.59	T.P.5
11	160		2.34			80.75	
12	175	2.91		4.75	81.25	78.34	T.P.6
13	190	2.55		4.88	78.92	76.37	T.P.7
14	205	3.14		5.12	76.94	73.80	T.P.8
15	220		4.47			72.47	
16	235		5.42			71.52	
17	250	1.68		6.37	72.25	70.57	T.P.9
18	265		3.67			68.58	
19	280	0.35		5.48	67.12	66.77	T.P.10
20	295		2.28			64.84	
21	310		3.65			63.47	
22	325	0.10		5.87	61.35	61.25	T.P.11
23	340		1.30			60.50	
24	355		2.91			58.44	
25	370		4.46			56.89	
26	385	3.78		6.40	58.73	54.95	T.P.12
27	400	2.23		6.08	54.88	52.65	T.P.13
28	415	1.89		4.54	52.23	50.34	T.P.14
29	430	2.06		4.29	50.60	47.94	T.P.15
30	445		4.35			46.25	
31	460	2.[illegible]		5.20	47.97	45.40	T.P.16
32	475		3.1[illegible]			44.56	
33	490		3.58			43.39	
34	505	2.[illegible]7		6.65	43.89	41.32	T.P.17
35	520		3.93			39.98	
36	535	1.59		5.20	40.28	38.69	T.P.18
37	550	2.[illegible]4		3.69	38.83	36.59	T.P.19
38	565		6.00			32.83	
		39.27		106.34		32.93	
Check		-10[illegible]				-100.00	
		- 67.07				- 67.07	

The arithmetic check: [illegible].S.) [illegible] Σ(F.S.) [illegible] Last R.L. - First R.L.

Table 7.1. Cross-section survey of Kihumbuini Gully, Kandara

Inst. Stn.	Staff Stn.	Distance (m)	B.S. (m)	I.S. (m)	F.S. (m)	H.I. (m)	R.L. (m)	Remarks
a	a1	0.0	0.25			100.25	100.00	B.M.
	a2	0.8		0.69			99.56	
	a3	1.4		0.93			99.32	
	a4	1.7		0.85			99.40	
	a5	1.8			0.63		99.62	
b	b1	0.0	0.48			100.48	100.00	B.M.
	b2	0.80		2.58			97.90	
	b3	1.4		2.18			98.30	
	b4	2.0		1.98			98.50	
	b5	3.0		1.33			99.15	
	b6	3.5			0.23		100.25	
c	c1	0.00	0.60			100.60	100.00	B.M.
	c2	0.5		1.15			99.45	
	c3	1.0		1.50			99.10	
	c4	2.0		1.05			99.55	
	c5	3.5		0.85			99.75	
	c6	4.5		0.80			99.80	
	c7	5.2			0.21		100.39	
d	d1	0.0	0.15			100.15	100.00	B.M.
	d2	0.8		1.35			98.80	
	d3	1.3		2.40			97.75	
	d4	2.0		2.10			98.05	
	d5	2.5		1.75			98.40	
	d6	3.0			0.20		99.95	
e	e1	0.0	0.80			100.80	100.00	B.M.
	e2	1.0		2.60			98.20	
	e3	2.0		1.70			99.10	
	e4	3.0		1.44			99.36	
	e5	4.0		0.95			99.85	
	e6	4.5			0.70		100.10	
f	f1	0.0	0.98			100.98	100.00	B.M.
	f2	1.0		3.08			97.90	
	f3	2.0		3.18			97.80	
	f4	3.0		2.33			98.65	
	f5	4.0		1.98			99.00	
	f6	5.0		1.53			99.45	
	f7	6.0			1.10		99.88	
g	g1	0.0	0.22			100.22	100.00	B.M.
	g2	1.0		2.47			97.75	
	g3	2.0		1.62			98.60	
	g4	3.0		0.82			99.40	
	g5	4.0			0.30		99.92	

Table 7.1. cont.

Inst. Stn.	Staff Stn.	Distance (m)	B.S. (m)	I.S. (m)	F.S. (m)	H.I. (m)	R.L. (m)	Remarks
h	h1	0.00	0.31			100.31	100.00	B.M.
	h2	1.5		2.61			97.70	
	h3	3.0		2.63			97.68	
	h4	4.5		1.83			98.48	
	h5	5.5		1.19			99.12	
	h6	6.5			0.27		100.04	
i	i1	0.00	0.39			100.39	100.00	B.M.
	i2	1.0		2.44			97.95	
	i3	1.8		3.19			97.20	
	i4	3.0		2.79			97.60	
	i5	4.5		2.39			98.00	
	i6	6.0			0.21		100.18	
j	j1	0.0	1.22			101.22	100.00	B.M.
	j2	1.0		2.87			98.35	
	j3	1.4		3.07			98.15	
	j4	2.5		2.32			98.90	
	j5	3.0		1.87			99.35	
	j6	3.7			1.00		100.22	

Table 8.0. Long profile survey of land surface at Lembus Gully, Eldama Ravine

Station	Distance (m)	B.S. (m)	I.S. (m)	F.S. (m)	H.I. (m)	R.L. (m)	Remarks
-	-	0.95			100.95	100.00	On B.M.
1	00		0.73			100.22	
2	15		2.24			98.71	
3	30		2.76			98.19	
4	45		3.57			97.38	
5	60	2.47		4.88	98.54	96.07	T.P.1
6	75		2.76			95.78	
7	90		3.67			94.84	
8	105		4.17			94.37	
9	120	1.96		4.40	96.10	94.14	T.P.2
10	135		2.23			93.87	
11	150		2.46			93.64	
12	165		2.87			93.23	
13	180	1.59		2.99	94.70	93.11	T.P.3
14	195		5.20			89.50	
15	210		5.69			89.01	
16	225	2.08		6.11	90.67	88.59	T.P.4
17	240		2.56			88.11	
18	255		3.89			86.78	
19	270		6.90			83.77	
20	285		8.90			81.77	
21	300			10.00		80.67	
		9.05		28.38		80.67	
Check		-28.38				-100.00	
		-19.33				- 19.33	

The arithmetic check: Σ (B.S.) - Σ (F.S.) = Last R.L. - First R.L.

Table 8.1. Cross-section survey of Lembus Gully, Eldama Ravine

Inst. Stn.	Staff Stn.	Distance (m)	B.S. (m)	I.S. (m)	F.S. (m)	H.I. (m)	R.L. (m)	Remarks
a	a1	0.0	0.24			100.24	100.00	B.M.
	a2	1.0		1.04			99.20	
	a3	2.0		1.24			99.00	
	a4	4.0		0.89			99.35	
	a5	5.0		0.74			99.50	
	a6	6.0			0.13		100.11	
b	b1	0.0	0.17			100.17	100.00	B.M.
	b2	1.0		1.43			98.74	
	b3	2.0		1.67			98.50	
	b4	4.0		1.05			99.12	
	b5	6.0		2.17			98.00	
	b6	7.0		2.17			98.00	
	b7	7.4			0.45		99.72	
c	c1	0.00	1.62			101.62	100.00	B.M.
	c2	0.5		2.42			99.20	
	c3	1.0		2.97			98.65	
	c4	2.5		2.32			99.30	
	c5	2.8			1.43		100.19	
d	d1	0.0	0.79			100.79	100.00	B.M.
	d2	1.0		1.39			99.40	
	d3	1.5		4.19			96.60	
	d4	2.0		2.99			97.80	
	d5	2.5		1.69			99.10	
	d6	3.0			0.58		100.21	
e	e1	0.0	0.81			100.81	100.00	B.M.
	e2	2.0		12.31			88.50	
	e3	6.0		12.81			88.00	
	e4	9.0		8.81			92.00	
	e5	11.0		5.81			95.00	
	e6	12.0			1.21		99.60	