The Bura Irrigation Settlement Project,

Project Planning Report, comprises the following volumes:

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4 Sociology and Settlement
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BURA IRRIGATION SETTLEMENT PROJECT

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SUMMARY

The main soil units included in Phase I, Stage I of the Bura Project are Camborthids (C soils) and Halorthids (S soils). Experience of the latter group has been obtained at Hola, but Hola has none of the C soils which by recognised standards are the best soils of Phase I, Stage I of the Bura Project, located on the west bank of the Tana River.

The S soils have been sub-divided on the basis of depth to the saline-alkaline layer. The deeper S1 soils occur in much larger proportions than do the shallow S2 unit. The Bura and Chewele branch canals command a large proportion of Class 3 and Class 4 land. This has been done in order that experience may be obtained in the use of these marginal soils.

The soils are very variable and mapped units include small areas of other units. In addition, the mapped units are themselves heterogeneous, including soils which have indeed the general character of the mapped unit but which differ substantially from the representative profiles of the unit. For example, the type Halorthid S1 includes soils in which the saline-alkali subsoil may be at any depth between 20 and perhaps 60 centimetres. In addition, the limit of alkali is placed at an exchangeable sodium percentage (ESP) of 15, but the actual ESP found in the alkali layer may range from 15 to perhaps 35. Add to this the fact that the texture of the top soil of Halorthids varies over a very wide range.

The overall viability of the Bura Project Phase I is firmly based on the Hola experience. Even with some of the shallow soils, such as the S2, the experience at Hola is encouraging except that the yields of cotton on ultra shallow S2 soils do show marked reductions compared with both S1 and the better S2 soil. The consequence of the variability of the Bura soils will be an uneven crop performance. Particularly in the early stages of implementation, wide differences in yields are to be expected; this is so even on the Class 1 and Class 2 lands. In addition, the conscious inclusion of areas of marginal land is expected to accentuate the overall variation in yields. Acceptable performances on the marginal soils is a pre-requisite for the implementation of Phase II of the project.

There is general similarity between the Hola and Bura soils, but a few general observations apply to this comparison: thus, within the Natrargid (N soils) group the Bura N soils are, in general, inferior to those at Hola; another difference is that Halorthids (S soils) are finer textured at Hola than in the Bura project area. There is also some evidence that the depth to alkali layers is less in Bura than Hola, but the comparison was of only limited range.

The main Hola Irrigation Scheme has been irrigated for 20 years. After about 10 years of low yields the application of superior management and improved agronomic practices, of which the introduction of ridges and application of effective pest control measures appear to have been the most important, were accompanied by a rapid and dramatic increase in yields. The nature of the original Hola soil is not known, recent comparisons of the irrigated soils with unirrigated areas outside the Scheme show that in general salinity levels are lower on the irrigated soils and that the depths to the saline-alkali layers are greater than on the outside areas. Such comparisons cannot give unequivocal results, but the evidence for an improvement under irrigation is reasonably strong - particularly with respect to salinity. Progressive improvement in salinity would be expected and this factor may have played some part in the early poor yields. By analogy salinity may well be a factor determining the initial performance on the Bura project, particularly on the S soils. In respect of alkalinity, the quality of Tana River water is such that a slow improvement in the alkali levels in the soils is to be expected as borne out by the changes which seem to have occurred at Hola. Therefore both with salinity and alkali a progressive improvement in the soils at the Bura project is to be expected. If it is shown that a reduction of alkali is of importance, the progress can be accelerated by the use of gypsum.

CHAPTER 1 SOIL CHARACTERISTICS AND ASSESSMENTS

1.1 Descriptions and Areas

The Bura project is sited on a variety of mapped soil units, the areas of which are given in Tables 1.1 and 1.2. The system of suitability assessment used is primarily for irrigated cotton. It will be noticed that the Bura and Chewele branch canals command a large proportion of Class 3 and Class 4 land of the S2 and GU2 mapping units. This will allow experience to be obtained in the use of these marginal soils as a precursor of the implementation of Phase II of Stage I of the Bura Project.

The main soil types included in Bura Phase I, Stage I, are Camborthids (C soils) and Halorthids (S soils). Experience with the latter has been obtained at Hola, but Hola has none of the C soils which, by recognised standards, are likely to be the best soils in the project area. Table 1.3 gives the legend of the soil maps with brief descriptions of the soil units. The descriptions make it clear that the depth of salt and alkali-free top soils is the most important parameter in the establishment of the soil mapping units.

Table 1.1 - Soil Types by Irrigation Command (hectares)
Phase I, Stage I, Bura Project

Branch canal	Areas by soil mapping units (types)									
command	C	S1	S2	N41	N42	GU1	GU2	N2	US2	Total
Bura	–	1 128	99	4	20	112	498	51	3	1 915
Masabubu	1 366	39	6	120	2	–	–	80		1 613
Masatedi	22	71	–	83	–	–	–	2		178
Pumwani (S)	806	224	–	55	–	43	–	13		2 652
Pumwani (N)	700	387	82	152	45	104	18	23		
Chewele	–	40	405	231	68	–	20	22		786
Total	2 894	1 889	592	645	135	259	536	191	3	7 144
'Net' area*	2 691	1 755	551	600	125	241	498	178	3	6 642

*Gross areas converted to net areas using factor 0.93.

Table 1.2 - Soil Classes in the Project Area

	'ILACO' Classification			USBR Classification		
Class	Soil types	Area (ha)	%	Soil types	Area (ha)	%
1	C	2 691	41	C	2 691	41
2	S1	1 755	26	–	–	–
3	GU1, N41	841	13	S1	1 755	26
4	N2, GU2, N42, S2	1 352	20	GU1, N41, N42, GU2	1 464	22
5	US2	3	neg.	N2, S2	729	11
6	–	–	–	US2	3	neg.

It must be recognised that the soils are very variable and the intensity of examination has been too low to allow the mapping of small areas of units within larger areas of other units. In addition, the actual units mapped include a range of soils which have indeed the general characters of the mapped unit but which may differ substantially from one another and from the representative profile of the unit. The legend of the soil map illustrates this variability, and

Table 1.3 - Mapping Legend of the Detailed Soil Surveys

		Mapping unit	Mapping symbol
Typic Psammustent	:		PR
Typic Natrargid	:	> 50 cm over capped natric horizon	N1
Typic Natrargid	:	20 - 50 cm over capped natric horizon	N21
Typic Natrargid	:	< 20 cm over capped natric horizon	N22
Typic Natrargid	:	as N22 but above horizon only poorly developed	N23
Mazic Natrargid	:	with surface crust	N31
	:	subsoil exposed	N32
Vertic Natrargid	:	> 20 cm over natric horizon	N41
	:	< 20 cm over natric horizon	N42
Typic Camborthid	:		C
Typic Halorthid	:	> 20 cm over saline/alkaline subsoil	S1
	:	< 20 cm over saline/alkaline subsoil	S2
Natric Grumustert	:	> 20 cm over saline/alkaline subsoil	GU1
	:	< 20 cm over saline/alkaline subsoil	GU2
Natric Grumaquert	:	> 20 cm over saline/alkaline subsoil	GA1
	:	< 20 cm over saline/alkaline subsoil	GA2
Vertic Hapludent	:		U

indeed recognises some aspects of it. For example, the typic Halorthid (S) type includes soils with the non-saline non-alkali layer less than 10 cm and others with a depth exceeding 60 cm. A division has been made at a top soil depth of 20 cm, but substantially different depths may occur within the two resulting categories. In addition, the limit of alkali has been taken throughout at ESP 15, but the actual ESP found in the saline-alkali layer below the top soil may range from 15 to perhaps 35; similarly the saline-alkali layer may range in salinity from 4 to 30 mmhos/cm. It is therefore apparent that an S1 soil may include very different soils in respect of depth of top soil and salinity and alkali status of the lower soil. Added to this is the fact that the texture of both the top soil and the subsoil may vary widely. Specifically the texture diagrams of the Acres/ILACO report show that the top soil of the S unit may vary from sand to clay texture. Similar textural ranges are illustrated for other soils.

The ILACO Feasibility Study Report (1975) includes a map of the soils of an area north of Laga Hiraman. The map gives the alkali and salinity range of three layers of soil at each site. These have been analysed for a large S1 unit in the south east of the map. Considering only the 10-20 cm layer, the following combinations of alkali and salinity occur:-

ESP	0 - 15			15 - 30			+30		
EC_e (mmhos/cm)	0 - 4	4 - 8	>8	0 - 4	4 - 8	>8	0 - 4	4 - 8	>8
No. of Sites	30	2	0	11	0	2	2	0	0

Thus 30 sites are non-saline non-alkali in the 10-20 cm layer of this mapped S1 unit. Formally all the sites of an S1 unit should be non-saline non-alkali. Fifteen sites have ESP greater than 15 in the 10-20 cm layer. There is little doubt that variations of this magnitude will be reflected in crop performance; with cotton the effect may not be dramatic, but with maize, cowpea and groundnuts the effect may be severe. Apart from the variations with respect to salinity depth and alkali conditions there will also be some variation in texture.

The map of the area north of Laga Hiraman has also a large area mapped as GU2. In this case the mapped unit includes sites which have a higher suitability rating than the typical GU2 type. Thus for the 10-20 cm layer 42 per cent of the sites were non-saline and non-alkali and are therefore superior to the mapping unit in which they are included. The heterogeneity of the soils would be made clearer with more detailed survey, but the maps would become more complex. In isolated instances this might allow the exclusion of some discrete areas of marginal soils, but it would in general merely document the variability of the soils. It has to be recognised and accepted that it is not possible to design an irrigation supply system related exactly to soil distribution patterns. The problems which will arise on the Bura Project because of soil variability may require variations of agronomic techniques, or even financial adjustments between farms on lands of contrasting quality.

The salinity constraint is expected to lessen with continued irrigation as is alkalinity at a slower rate; the grounds for this expectation are given in Chapter 2. The consequence is that the early crops are expected to show a large degree of variability and that the variability is expected to decrease as the scheme ages. There may be, of course, consequences arising from textural variation which would have management implications such as, for example, furrow instability and the failure of water to reach the end of the furrows, and the need for a shortened watering interval on coarse textured soils. In respect to the two latter difficulties, counteraction is possible.

CHAPTER 2 SOIL PRODUCTIVITY AND IMPROVEMENT

2.1 Crop Yields Related to Soil Types

The viability of Bura is firmly based on the experience at Hola, the S1 soils which constitute 26 per cent of the Bura Project have been well tested at Hola, and the C soils although not represented at Hola are expected to be equally productive. Even with marginal soil such as S2, the Hola experience is encouraging, except that yields of cotton on an ultra shallow area of S2 show marked reductions compared with S1 and S2 (normal). Table 2.1 gives the averages of three years' yields on a number of soil units at Hola.

Table 2.1 - Average Cotton Yields on Main Soil Types at Hola

Soil Unit	Cotton Yield (kg/ha) Range	Average
GU/GU2	2 200 - 3 500	2 876
N41	2 200 - 3 400	2 587
A2	1 700 - 3 500	2 688
S1	1 700 - 3 200	2 575
S2	3 000 - 3 900	3 320
S2 ultra shallow	2 400 - 2 900	2 557

The poorer performance of the ultra shallow S2 soil has been confirmed as significant by other Hola comparisons. The proportions of the four suitability classes included in the Bura Project are shown in Table 2.2.

Table 2.2 - Soil Types and Classes in the Bura Project, Phase I, Stage I

Soil Unit	(Net ha)			
	Class 1	Class 2	Class 3	Class 4
C	2 690			
S1		1 755		
GU1			240	
N41			600	
S2				550
GU2				500
N42				125
N2				190
	2 690	1 755	840	1 350
Percentage	41	26	13	20

If the project average yield is equated to the yield on Class 2 land, the ratios of yields from the other three classes can be derived taking into account the proportions of the project area on each class of land. These ratios are given in Table 2.3.

Table 2.3 - Ratios of Yields by Land Classes

Crop	Class 1	Class 2	Class 3	Class 4
Cotton	1.15	1.00	0.85	0.75
Groundnuts	1.19	1.00	0.68	0.61
Maize	1.12	1.00	0.85	0.75
Cowpeas	1.18	1.00	0.85	0.63

2.2 Comparison with Hola Soils and Implications for Improvement

A few general observations have been made which bear directly on the comparison of Hola and Bura soils. For example, in N soils the depth of the surface light textured layer increases from north to south while the strength of the hard cap which crosses the B horizon decreases in that direction. Another recorded difference between the soils of Hola and Bura is that typic Halorthids (S soils) are finer textured at Hola than at Bura. GU and N4 soils, which are similar, were the subject of a limited comparison as between the depth to the salt and alkali-free top soils at Hola and Bura.

Hola - problemless layer range 15-26 cm (5 profiles)
Bura - problemless layer range 15-19 cm (4 profiles)
Bura - problemless layer range 6-10 cm (8 profiles)

Within the Bura Project there is a decrease from south to north in the proportion of the C soils and an increase in that of the S1 soils which though satisfactory are inferior to the C soils. This is excluding the canal area which has only a small proportion of C and S1 soils. North of the project area, Phase I, there is again only a small proportion of C and S1 soils found.

The main Hola Irrigation Scheme has been irrigated for 20 years, over the first half of this period the cotton yields were low. There then followed the introduction of superior management and improved agronomic practices, of which the introduction of high ridging seems to have been the most important. These changes and others such as improved insect control and water supplies were accompanied by a rapid and dramatic increase in yields. The nature of the original Hola soils is not known, though examinations of areas excluded from the original layout have been made. The unirrigated areas in general show higher salinity levels and shallower depths to the saline alkali layers than in the irrigated areas. Such comparisons must have an element of dubiety, but it has to be accepted that the evidence of improvement in the alkali and salt status has occurred over the lifetime of the scheme. One would expect that the reduction in salinity levels would have been taking place progressively and that salinity would have played some part in the early poor yields, and by analogy that initial salinity will be a factor in the early performances on the Bura Project, particularly on the S soils. On the Camborthids there should be no such problem.

The changes under irrigation in the soils of the Hola Irrigation Scheme must be in part due to the addition of suspended matter in the irrigation water. Making allowance for the sediment removed in the sand trap and in the night storage reservoirs, the Bura Project area will receive an addition of about 3 mm of soil per year. Hola has received less water than is projected for Bura, but its desilting structures are probably less efficient and so it would be reasonable to suppose that the older parts of Hola have had an average addition of 6 cm of canal deposits. Such material would be non-saline and non-alkali.

2.3 Management Implications of Soil Features

The requirements of high ridges (40 cm) has influenced the choice of 20 cm depth of non-saline non-alkali top soil in the suitability classification. In the shallow soils such as S2, the formation of the ridges will involve mixing of alkali subsoil with the top soil. It is to be expected that when this mixing finally gives a ridge with ESP greater than 15 the stability of the ridge will be adversely affected. A higher figure than 15 has been put forward, but the conventional figure of 15 should not be rejected without direct evidence. There are few figures available at this time on the likely ridge ESP to be expected. Figures from the ILACO Memorandum of October 1976 are given in Table 2.4 below.

Table 2.4 - Exchangeable Sodium Percentages (ESP) of Unirrigated Halorthids Type Soils

Depth (cm)	Site Numbers 21	22	23	25	26	27	28	29	210
0-10	5	5	6	12	4	4	3	3	7
10-20	8	16	7	21	22	6	4	4	20
20-30	17	28	13	33	38	9	12	11	30
30-40	19	37	17	33	51	20	24	22	36
40-50	21	52	21	44	56	22	29	24	48
50-60	36	53	24	52	48	23	41	31	51

With these profiles complete mixing of the 0-20 cm layer would in only one case result in a ridge ESP greater than 15 and there would be two marginal values. In contrast there would be five cases with entirely satisfactory values. The table illustrates the variability present within a group of profiles in the same or similar unit. It was observed in late February 1977 that there were examples of badly slumped ridges on the Hola Irrigation Scheme when the ridges could only have been watered once or twice. If this aspect of alkali is important it would stress the need to take actual levels of alkali into account in evaluating shallow soils.

This question of high ridges and their stability is involved where shallow soils are made shallower by levelling operations; inevitably levelling a soil with even 20 cm of top soil will produce some patches with high ESP ridges, conversely some areas will be improved in this respect. The ESP of the Bura soils in general increases down the profile, and this is illustrated by the figures in Table 2.4 which emphasise the need to avoid interfering with the deeper layers during levelling. To some extent the requirement of levelling will necessarily require disturbance of the lower very alkali soil layers, and this is among the reasons for the low suitability ratings of the shallow soils.

The quality of Tana River water is excellent. The salt content is very low and consequently the leaching requirement to maintain the soil salinity levels satisfactorily for even sensitive crops is very small; the EC_w of water is 0.30 mmhos/cm. For a very sensitive crop the EC_d of the drainage water should be around 8 mmhos/cm so that the leaching requirement to maintain this figure is about 0.04, a very low figure which should be readily attainable with even very slowly permeable soils. With such soils general in the Bura Project, the leaching requirement is not likely to be greatly exceeded and the major part of the field losses would be expected to arise as surface flows.

The chemical composition of the water (0.72 milliequivalents per litre (me/l) Ca, 0.40 me/l Mg and 0.75 me/l Na) gives a sodium absorption ratio of 0.4. This is unusually low and treatment of the soils with large quantities of such water would give them an ESP of around 1, again a very low figure and far removed from the values existing in subsoils. Even allowing considerable concentration of the applied water as it passes downward through the soil, the effective SAR remains low and the equilibrium ESP similarly low. The composition of the water is such that conventional reasoning would conclude that its application would slowly lead to reduced ESP values in the soil over considerable depths. The possibility of the bicarbonate content of the water increasing the SAR by precipitating calcium has been tested by the use of the Langelier Index procedure, and this again shows no important change is to be expected.

Though the arguments are strong that the river water will cause a general improvement in the alkali status of the Bura soils, it is to be accepted that this process will be slow. The process of de-alkalisation principally involves the replacement of exchangeable sodium in the soil by calcium from the water. One metre depth of Tana River water has enough calcium to replace 0.1 me per cent of sodium in a 50 cm layer of soil, and therefore a 10 metre application of river water replaces 1.0 me per cent of sodium. In fact the replacement is a reversible process and does not go to completion, so it is reasonable to assume that a 12 metre application is required to effect such a replacement.

If 50 cm of a soil has 5.0 me per cent of exchangeable sodium and a cation exchange capacity of 40, reaction with 12 m of water will reduce the exchangeable sodium to 4 me per cent and the ESP from 12.5 to 10. The designed depth of application for cotton is 2.5 m per year, so the calculated change in ESP theoretically requires 5 years. The reductions of ESP at Hola depend upon comparisons of irrigated soil within and soil just outside the irrigated areas; they have therefore no precise basis, but the changes displayed in the October 1976 Memorandum are consistent with the rates calculated above.

The Hola demonstrations of salinity reductions show a much clearer picture than do those of ESP reductions. This is to be expected and will be repeated on the Bura soils. When the actual salinity levels of the Bura soils become available, it may be possible to identify saline areas which would merit deliberate application of leaching water in advance of cropping.

The process of de-alkalisation can be accelerated by the use of gypsum, increasing the calcium concentration of the soil water. Although the process of replacing exchangeable sodium by calcium will proceed, it does not follow that the difficult structures of the B horizon will be improved at the same rate and most penetration difficulties may persist. The exchange process is, however, expected to have a more rapid effect on ridge stability.

TanaRiver water has an unusually high potassium content, and the designed water application to cotton (2.5 m) will contain 50 mg of potassium or 70 mg of K_2O per hectare. Such a quantity should meet crop requirements and indicate that applications of potassium should not be required. The decision that phosphorus applications will not be required is not completely supported by the available analyses. The Feasibility Report gives phosphorus contents of a number of representative soils; for the top soils the values range from 12 ppm to 100 ppm. Such a range, and the occurrence of low figures indicates that it would be wise to continue experiments with phosphoric fertilizers. (Note: a P content of 12 ppm in the upper 30 cm of soil is equivalent to only about 20 mg of P per hectare.)

CHAPTER 3 MONITORING OF SOILS

3.1 Monitoring Objectives and Requirements

It is of paramount importance that the long term performance of the land irrigated in Phase I should be monitored. The important changes to be expected in the soils are progressive reductions in salinity and alkali. It has been shown that the mapped units include impurities (that is areas of other soil units) and a range of profiles within the mapped unit. It is likely that the range of profiles accepted within any unit will include variations in depth to saline and/or alkali conditions and in texture. Variations of both kinds will influence the movement of salts down the profile and the rate of change in alkali levels. To provide a before irrigation base some detailed soil survey is needed, which will require analytical support. Each holding will have associated with it an annual seed cotton production; the changes in this will be easily monitored. It is clearly impractical and unnecessary to attempt to monitor soil change in every holding. It is proposed that an overall two per cent of holdings should have a pre-irrigation sampling; the sampled holdings would be chosen by a stratified random selection. The above overall project sampling procedure would be modified by the selection of sufficient holdings located on marginal soils to provide sufficient observations for valid statistical analysis of the results. This sampling would be repeated at two year intervals; a provisional sampling intensity would be three sites per holding, the sampling depths and the laboratory measurements should be discussed with the Soil Survey of Kenya before land preparation starts.

Because it is planned to have a Field Assistant assigned to between 80 and 110 farms (4-5 irrigation units), a two per cent sample means that each will have two farms selected for monitoring of soil changes. It is obviously sensible that these farms should be the subject of more detailed routine recording of farming practices, including especially records of watering difficulties such as, for example, persistent failure to get adequate water to the ends of the long furrows. In the same way, it will be impossible to do insect inspections after spraying on all farms, but this particular task should be done on the monitored sample farms.

3.2 Sampling Procedures and Analyses

The total number of monitored farms on the project will be about 120, so the task of sampling should not be insupportable, and with 3 sites per farm and 5 samples per site, a total of 1 800 samples would require processing.

The four units of the Research Farm will be the subject of a special pre-irrigation sampling. Within the units a more intensive monitoring system for soil changes will be instituted on six plots (the same as farm holdings on the project area). These will be studied intensively in the early stages of irrigation - in the long term their value may be limited by the experimental treatments imposed on the plots. In the early stages there will be a number of plots not in experimental use, but being cropped on the project rotation.

The special sampling of the Research Farm units is intended to provide large reference samples. They will be taken from pits and sampled at fixed depths and also by horizons, and will be described in detail with special attention to structure.

3.3 Selection of Research Programme Areas

The research programme areas have been chosen (see Agricultural Planning Annexe) to represent the important soil units in the project area - S, C, N41, GU2 and S2 - and include small areas of other units. These units will be in use under the Bura, Chewele and Pumwani canal commands. It will be necessary to monitor their behaviour along the same lines as the farms. The important element of their behaviour will be the yields of cotton, observation and scoring of crop growth for both cotton and other crops, and the water distribution obtained in the furrows. If water distribution difficulties become apparent, solutions will have to be tested in the field, perhaps by shortening furrows or by increased rates of application or changed irrigation frequencies. Special experiments such as, for example, gypsum applications will have to be done on farmers' fields with the agreement of the farmers. To ensure that behaviour is observed and recorded in these problem areas, the standard monitor farms will be supplemented so that each area is covered by a monitored farm. To inject a rather higher level of observational skill in this area, the research programme staff could be involved.

CHAPTER 4 SOIL STUDIES ON THE EAST BANK

4.1 Reconnaissance Survey Results

It has always been envisaged that the ultimate development of the Lower Tana River Basin would include development of the left (east) bank (Stage II) opposite the Stage I Bura Project area. The diversion structure at Nanigi is designed to allow irrigation of the right bank lands though the supply route and levels have still to be determined.

A reconnaissance soil study (1) has recently been carried out by Sambroek, Mbuvi and Leyder of the Kenya Soil Survey, and subsequent studies by Van der Pouw and Ngari have refined this investigation. These studies showed that the pedological processes and parent material on the east bank are similar to those on the west bank areas of the Bura Project and the Hola Irrigation Scheme. Closely related soils have developed, but the pattern of soils is in contrast in that the units mapped on the east bank are in large topographically ordered discrete areas, whereas the west bank has a complex heterogeneous soil pattern.

The preliminary evaluation mapped two principal soil types occurring in large blocks as suitable for large scale irrigation:-

Moderately suitable : Unit Splr - 69 000 ha
Marginally suitable : Unit Spl(r) - 70 000 ha

The descriptions of the two soils are:-

Splr: Imperfectly drained, very dark, greyish brown, sandy to clay, moderately to strongly calcareous throughout or from shallow depth, non-saline and non-alkali to 60 cm or more, and with no clear hardpan layer. Classified as Camborthid.

Spl(r): Imperfectly drained, dark greyish brown, moderately calcareous, non-saline, non-alkali, sandy clay to about 15 cm, over dark grey strongly calcareous, moderately to strongly saline and moderately to strongly alkali clay, mostly without clear hardpan character. Classified as natric Halorthid.

In Bura Project nomenclature Splr is a C soil, and Spl(r) is an S2 soil.

The investigation covered a total of 375 000 hectares, most of which was regarded as unsuitable for irrigation. This category is mainly composed of Malragid, the M soils of the Bura Project, though there is evidence from Hola that some units within the Malragids are productive under irrigation, and certainly the Bura Project area includes considerable areas of M soil.

In an addendum to the main Site Evaluation Report, Van der Pouw and Ngari investigated the variability of the Splr soils. They showed in general that the distribution of salt down the profile was regularly lower in the centre of the blocks, away from the more saline fringing units Splv and Spid and Spl(d). Recognising that the Splr unit is variable in a predictable way, so far as salts are concerned, they divided the unit into categories in the following way:-

(a)	Non-saline, non-alkali to 100 cm	33 000 ha
(b)	Non-saline, non-alkali to 60 cm	22 000 ha
(c)	Non-saline, non-alkali to 40 cm	13 000 ha
(d)	Soils which should be classified as Spl(d), classified as natric Halorthid Malragid - unsuitable	11 000 ha

The suitability classes for (a), (b) and (c) are given as Classes 1-2, 2 and 3, respectively, and with this refinement we agree.

4.2 Relationship to Bura West Area

A considerable area (2 700 ha) of undifferentiate C soils are to be irrigated in the Bura Project; the monitoring programme outlined elsewhere may provide information on the relative merits of the different C soil categories outlined above. Indeed, it seems desirable that the monitoring programme should be designed, or modified, to provide this information.

In assessing the value of C soil, it must be borne in mind that these soils are in fact untried. Accepted knowledge is that the Camborthids are the best soils available in Bura west and Bura east, but their superiority has yet to be established by the evidence of crop yields.

Reference:

(1) Preliminary Evaluation of the Soil Conditions on the East Bank of the Lower Tana (Bura East Area), Soil Survey of Kenya, Site Evaluation Report No.21, 1975.

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SUMMARY

Water Availability

The Tana River is Kenya's largest and most important river, with an average annual flow, measured at Garissa, of 5 000 million cubic metres. The Kenya Government realise the value of this resource and a number of projects are in hand to develop the river for hydro-power, water supply and irrigation. At the moment investment in a river regulating reservoir in the upper catchment - the 'Upper Reservoir Scheme' - is being considered, with a live storage of 1 560 million cubic metres. River regulation at the moment is achieved using the reservoir at Kamburu which has a storage of 123 million cubic metres, less than 3 per cent of the total average annual flow.

Discharges, measured at Garissa since 1934, fluctuate throughout the year with two low flow seasons, February to March, and September to October. The higher flood flows occur from April to June and November to December. The minimum river flows to be maintained downstream of the project offtake are not clearly defined. Government policy is to guarantee "natural" flows in the river. This has been interpreted by the Tana River Development Authority (TRDA) to be a monthly flow of 80 million cubic metres, except for March which is 68 million cubic metres.

Analysis of the flow records indicates that there is an adequate flow in the Tana River with flow regulation, by Kamburu reservoir alone, to supply the needs to Phase I, Stage I, of the Bura Project (the west bank) and enough to supply Phase II, Stage I (the west bank) in addition, if the rather low values adopted by the TRDA for the minimum downstream river flows are accepted. However, irrigation development of the east bank of the Tana River, Stage II of the Bura Project, will depend, primarily, upon the development of the Upper Reservoir Scheme. In their appraisal report for this Scheme, the TRDA estimate that the maximum Lower Tana irrigated agricultural development would be 49 500 hectares. This would indicate a maximum development on the east bank of approximately 42 200 hectares. However, development of agriculture in the Lower Tana Basin is only one of the possible development options arising from the Upper Reservoir Scheme. Some decisions will have to be made as to the relative priorities of the three principal partially conflicting options of hydro-power generation and of development of irrigated agriculture in the Upper and Lower Tana Basins. Only when this decision is made can the magnitude of possible development on the east bank of the river be estimated.

Water Demand

The average open water evaporation for the Bura area has been re-calculated using additional climatic data and the Penman method, to yield an average value of 6.4 mm a day. Crop water requirements were calculated using crop factors very similar to those estimated by ILACO. A first irrigation application of 150 mm has been allowed for the irrigation demand calculations instead of a pre-cultivation application because of the problems of mechanically cultivating wet land. An end of season soil moisture depletion of 50 mm has been assumed.

Various values of effective rainfall were calculated for different conditions, namely:

(a) for calculating available supply from the Tana River and the monthly critical design flows for the irrigation system, an effective rainfall of zero;

(b) for calculating the irrigation demands using a 1 in 5 dry year design, an effective rainfall of 336 mm.

The field application efficiency of 87.5 per cent assumed in previous reports was considered to be high and a figure of 70 per cent was adopted. When combined with a conveyance efficiency of 70 per cent this gave an overall efficiency of 50 per cent, which was used in calculating the net irrigation demand.

To the crop irrigation requirements allowances were added to allow for the irrigation supply to tenants' gardens, domestic and industrial water supply, the wildlife drinking pools and all losses, to enable the estimated intake requirements for Stage I, Phase I, of the Bura Project to be calculated for the 1 in 5 dry design year. These are given below:

Estimated Intake Requirement - Stage I, Phase I, Bura Project
(cumecs, 24 hours per day)

Month	JAN	FEB	MAR	APR	MAY	JUN
Flow	0.8	4.7	6.9	4.2	7.1	7.8
Month	JUL	AUG	SEP	OCT	NOV	DEC
Flow	5.7	2.4	3.4	4.0	3.1	2.1

The peak intake requirement is estimated to occur in a 10 day period in May and amount to 9.6 cubic metres per second for 24 hours per day.

Drain Design

The drain design was based upon a five year return period storm. It was assumed that it would take 24 hours to drain such a flood from the irrigated land. The calculations indicate that in such a case the run-off rate will be 1.2 litres per second per hectare for 30 hectares. This run-off rate will reduce for the larger drained areas and various reduction factors are recommended.

Flood Flows

The annual maximum daily flows recorded at Garissa were reviewed, fitted to a Gunbel distribution and used to estimate the flood flows expected to occur at certain return periods. The results obtained were very close to the ILACO estimates.

The laga flows for various return periods were estimated by employing the US Soil Conservation Service method to calculate run-off from estimate catchment rainfall. The results indicate appreciably higher run-off rates than those previously used.

Sediment Transport

A review of the sediment transport data available for the rivers of Kenya was made by Dunne in 1974. His results indicate that the rate of sediment transport in the Tana River has been seriously over-estimated, because data collected after 1961 has been ignored. For the range of flows mostly likely to be considered, Dunne's relationship between discharge and sediment transport yields about one half the sediment flow rate previously assumed.

River Water Quality

The chemical analysis of samples of the Tana River water shows that it is of excellent quality for irrigation.

CHAPTER 1 INTRODUCTION

The review nature of this annexe of the Project Planning Report, prepared in a short period of time, has relied heavily on the three main existing studies of future irrigation in the Lower Tana River Basin, namely:

(a) Survey of the Irrigation Potential of the Lower Tana River Basin - 1967 - F.A.O./Acres International/ILACO

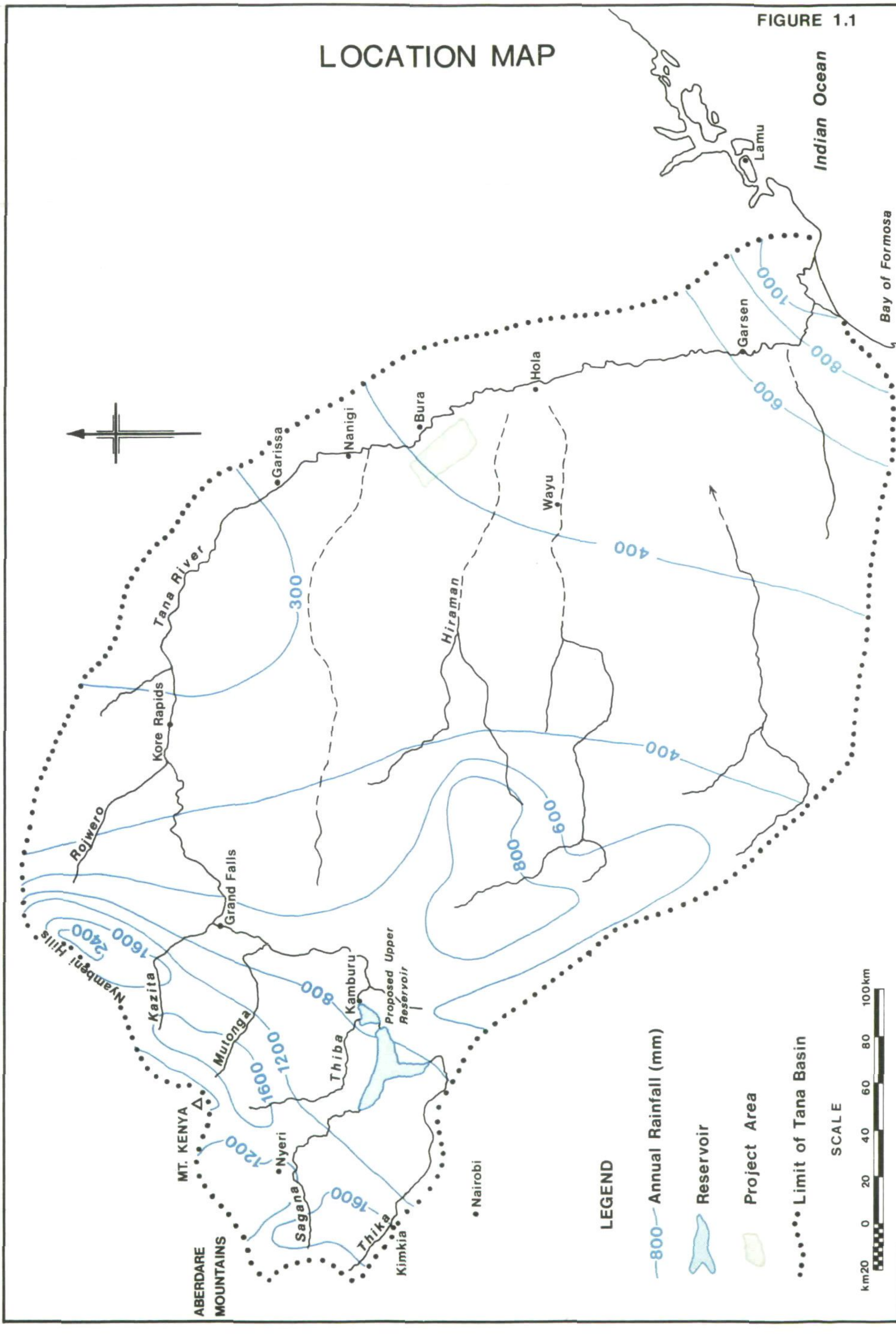
(b) Bura Irrigation Scheme - Feasibility Study - July 1975 - ILACO

(c) Upper Reservoir Scheme (Appraisal Report) - September 1976 Tana River Development Authority

The present Consultants have had the advantage of studying the Tana River Development Authority Appraisal Report of the Upper Reservoir Scheme. For this study flows in the River Tana were processed for several stations and 24 years of records were used as input for a simulation study. Various options of water development, in five year planning horizons, were estimated up to the year 2000. With and without Upper Reservoir cases were also investigated for comparison purposes. The results of this recent study, therefore, provide the necessary background to the probable overall basin development of the water resources of the Tana River. The proposed Bura Project and possible further extensions to irrigation in the Lower Tana River Basin can therefore be viewed in the context of storage potential and competition from other sources of demand.

FIGURE 1.1

LOCATION MAP



CHAPTER 2 RIVER BASIN DESCRIPTION

2.1 Physiography and Drainage

The climate and hydrology of the Tana River Basin have been adequately described in various publications and in several reports (1, 2, 3) dealing with the future water development of the region. A brief summary is included here to provide the basic background to the hydrological and climatological analysis contained in this annexe.

The Tana River Basin with its catchment area of some 95 000 square kilometres covers 16 per cent of the total land surface of Kenya; it is Kenya's largest and most important river. The variation in climate within the basin derives mainly from differences in altitude and influences of the major airstreams. Previous studies have divided the basin into three physiographical regions:-

(i) An upper catchment - above Kamburu with altitudes in excess of 1 000 metres (catchment area of 9 000 square kilometres)

(ii) A middle catchment - between Kamburu and Kore Falls, with altitudes ranging from 200 - 1 000 metres (catchment area of 15 500 square kilometres)

(iii) A lower catchment - (catchment area of 70 000 square kilometres)

The river rises on the eastern slopes of the Aberdare Mountains just north of Nairobi with mountain peaks reaching elevations of 4 000 metres. The most southern area is drained by a tributary, the Thika, which joins the Sagana, the main source of the Tana River, 80 kilometres north-east of Nairobi. Twenty kilometres downstream, the third major tributary, the Thiba, joins the river just above the reservoir at Kamburu. The catchment area of these three tributaries, the latter draining the south eastern flanks of Mount Kenya (5 199 m) constitute the upper catchment (Figure 1.1).

Below Kamburu the right bank tributaries are seasonal but the left bank tributaries Mutonga and Kazita with sources on Mount Kenya are perennial. At Grand Falls, just upstream of the Kazita confluence, the general course of the river deviates from its northerly bearing and thereafter flows in a predominantly easterly direction for the remainder of the middle catchment.

Within the middle catchment the river descends from a level of 1 000 metres at Kamburu through a series of falls formed from gneiss outcrops of basement complex rock.

Further tributaries with their sources on the eastern side of the Ngambeni Hills enter the Tana from the north. The last perennial stream to join the Tana River is the Rojwero. Beyond the Kore rapids, the eastern limit of basement outcrops at an elevation of 245 metres, the river enters the lower catchment characterised by a flat alluvial plain.

The Tana River gradually turns southwards in the region of Garissa before meandering through the Ngangerabeli Plain for a distance of some 200 kilometres.

Below Garissa, the river experiences water losses, with the only supplementary surface water inflow arising from usually dry wadis, locally called "lagas". Although these lagas have large catchment areas their contribution to the flow of the Tana River can generally be neglected.

The river finally discharges into the Bay of Formosa in the Indian Ocean, over 1 000 kilometres from its source in the Kenyan Highlands.

Precambrian metamorphic rocks underlie the Tana catchment. The Kenya Highlands, however, including Mount Kenya, the Aberdare Range and the Nyambeni Hills, have been formed as the result of volcanic activity. The high porosity of the volcanic rocks results in a relatively high base flow being maintained in the River Tana throughout the two dry seasons.

The basement complex outcrops in the middle catchment and bands of durable gneiss create the series of rapids and falls which characterise this region. It is these falls which create the valuable natural hydro-power potential which this length of the river possesses.

East of the Kore rapids carboniferous and recent sediment form a vast featureless plain which has potential for large scale irrigation development.

2.2 Climate

As with all tropical climates the heat engine driving the major airstreams obtains its energy from the vast supply of equatorial solar radiation. This is greatest in the region of the equatorial pressure trough and follows the path of the zenith of the sun (4). In East Africa the primary airstreams are the south-east monsoons from the Indian Ocean and the north-east trade winds from the Arabian Sea and the Indian Ocean. During the northern winter, the north-east trades dominate the area. The air mass is dry and stable, and in January the area has low rainfall.

In April and May the northern movement of the sun changes the circular pattern. The heating of the Sahara promotes the migration of the south-east trades and as the inter-tropical convergence zone (ITCZ) passes north across East Africa, the "long rains" of April and May prelude the winter drought.

During the early northern summer the south-east trades from the Indian Ocean penetrate inland giving heavy localised rainfall along the coastal region. As summer progresses and autumn falls the rainfall continues to decrease, until with the southern migration of the sun, the south-east trades are replaced by winds from the north-east. During this period, October-December, the "little rains" occur on the inland areas.

The altitude of the Kenya Highlands is the most important single physical parameter in modifying the general rainfall pattern over the Tana River Basin (see Figure 1.1). With the Equator bisecting Kenya, seasonal variations in climate are not large.

Table 2.1 summarises the main variations in climate at three stations spread throughout the Basin.

Table 2.1 - Comparison Between Selected Climatic Parameters Recorded at Nairobi, Garissa and Lamu

Element	Nairobi Altitude - 1 661 m		Garissa Altitude - 122 m		Lamu Altitude - 9 m	
	Mean annual	Extreme monthly means	Mean annual	Extreme monthly means	Mean annual	Extreme monthly means
Temperature (°C)	18	16-19	29	27-31	27	26-31
Humidity (%)	67	59-75	60	57-64	79	77-83
Rainfall (mm)	830	14-181	282	2-65	881	2-360
Sunshine (h/day)	–	–	8.7	8.1-9.2	–	–

Source: Meteorological Office (UK), 1967, (5) The range of mean monthly temperatures at individual locations varies by less than 5°C throughout the Tana River Basin. However, significant differences result from variations in altitude. The mean annual temperature is only 18°C in Nairobi compared with 29°C at Garissa. The slightly lower temperatures on the coast reflect the modifying influence of the sea as do the higher humidities.

The mean annual rainfall amounts over the Basin are given in Figure 1.1. The highest falls of over 2 400 mm occur over the Nyambeni Hills with slightly lower amounts on the slopes of Mount Kenya and the Aberdare Range. A trough of low rainfall occurs between the high region in the upper catchment and the coast which is influenced by the south east monsoons in the early summer months. In this trough the annual rainfall drops below 300 mm. In fact, as can be seen from the figures in Table 2.2, the rainfall decreases to a low of 282 mm at Garissa before climbing to 480 mm at Hola adjacent to the Bura Irrigation Scheme area and finally reaching 881 mm at the coast.

Table 2.2 - Mean Monthly Rainfall Recorded at Selected Stations for the Period, 1931-60

Latitude and Longitude	Station	Altitude (m)	Mean Monthly Rainfall (mm) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Rainfall (mm)
1°17′ S 36°50′ E	Nairobi*	1 661	44	53	110	181	130	43	14	16	24	45	99	71	830
0°26′ S 36°57′ E	Nyeri*	1 829	49	46	62	167	165	27	32	39	32	81	104	82	886
0°29′ S 39°38′ E	Garissa*	128	10	6	26	55	17	5	2	5	4	22	65	65	282
1°30′ S 40°02′ E	Hola†	90	21	17	39	83	39	31	19	16	34	39	82	49	480
2°16′ S 40°54′ E	Lamu*	9	6	2	17	121	360	144	69	42	26	41	24	29	881

* East African Meteorological Department, 1966 (6)

† (i) Extracted from Climatic Survey Sheets (East African Meteorological Department)

(ii) Period of records 1959 - 1976

The two rainfall seasons March-May, the "long rains" and November-December, the "little rains" are illustrated in Table 2.2 for all the stations except Lamu which has no late rainfall. Monthly rainfall for Hola within the area of the proposed Bura Irrigation Scheme is given in Table 2.3.

Table 2.3 - Monthly Rainfall Recorded at Hola (1959-76)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual (mm)
	Monthly Rainfall (mm)												
1959	11	17	22	96	51	30	31	16	2	4	77	29	386
1960	3	14	87	62	40	21	15	5	0	101	50	50	448
1961	74	46	6	58	2	4	59	18	299	88	218	66	938
1962	85	17	55	65	14	8	19	2	8	24	98	35	430
1963	17	11	53	40	23	12	10	7	28	8	113	145	467
1964	30	41	19	88	42	46	7	15	2	7	35	126	458
1965	38	2	21	16	29	23	18	35	47	68	116	10	422
1966	19	10	62	113	65	33	2	7	12	37	55	7	422
1967	29	3	1	298?	48	57	23	54	50	187	82*	0	832?
1968	0	4	54	137	90	79	48	3	17	10	147	86	676
1969	8	47	90	63	16	30	3	61	2	23	150	17	508
1970	15	0	63	68	23	12	9	8	21	4	21	30	275
1971	0	5	4	82	41	117	15	3	22	7	56	30	695
1972	19	8	2	92	96	0	17	25	23	23	83	70	457
1973	8	48	37	88	18	27	3	14	12	56	105	7	424
1974	11	3	60	13	38	5	15	2	17	0	49	31	447
1975	6	2	45	40	65	51	48	3	8	40	8	39	355
1976	0	34	21	67	6	3	5	4	47	20	43	112	362
Mean	21	17	39	83	39	31	19	16	34	39	82	49	480

Source: Published 10-day climatic data by East African Meteorological Department.

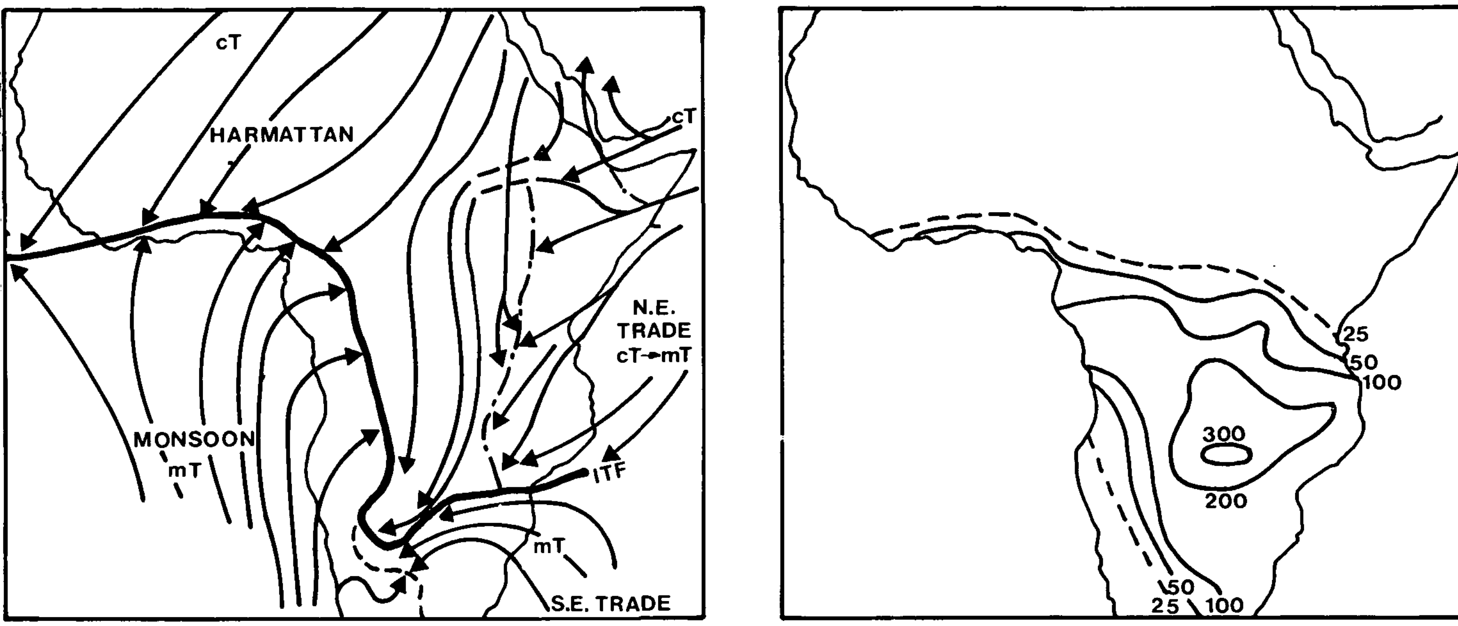
The mean monthly Penman open water evaporation rates calculated by Woodhead (14) for Garissa and Hola (Galole) are reproduced in Table 2.4.

Table 2.4 - Penman Open Water Evaporation

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual (mm)
	Penman E_o (mm per month)												
Hola (1956-66)	198	202	221	191	191	168	169	182	191	198	190	192	2 293
Garissa (1941-66)	201	191	216	203	207	183	188	199	206	219	182	179	2 374

Within the Tana River Basin evaporation varies almost linearly with altitude (1). Annual evaporation at the Kimakia Research Station falls to 1 370 mm as the altitude rises to 2 400 metres. Nairobi and Nyeri have mean annual Penman open water evaporation rates (E_o) of 1 820 mm and 1 750 mm respectively.

REGIONAL CIRCULATION PATTERNS AND MONTHLY RAINFALL



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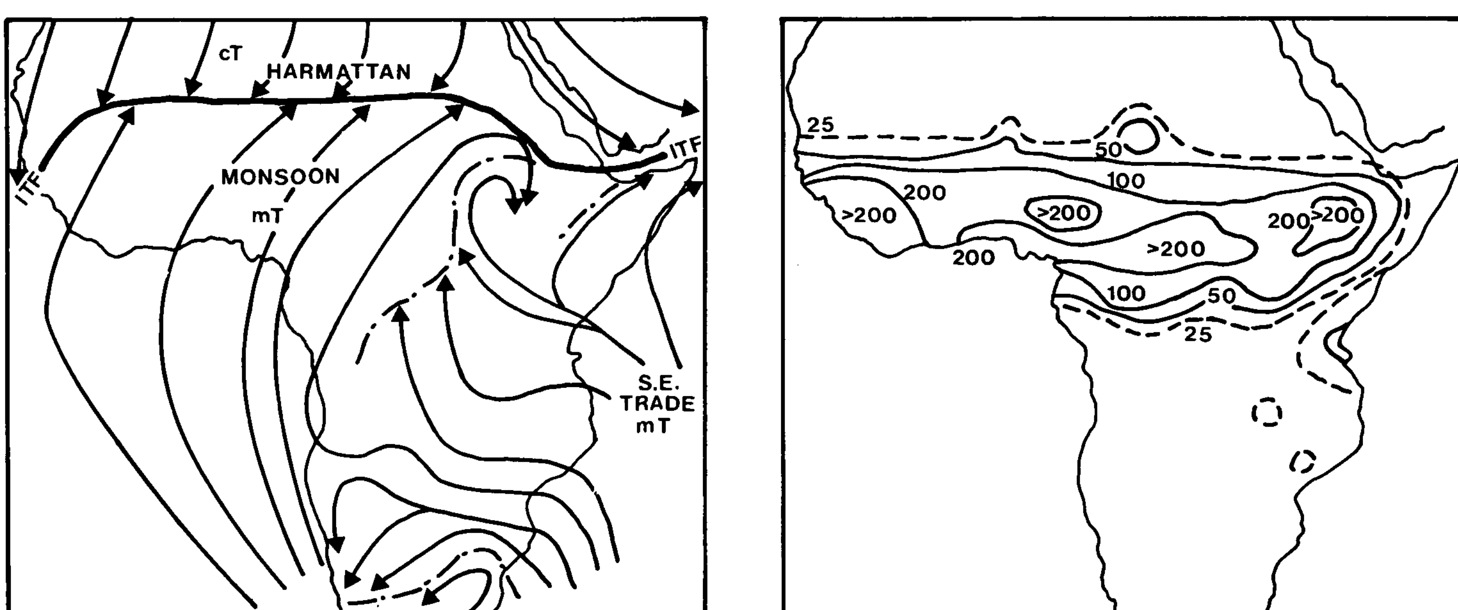

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NOTES

(1) Monthly rainfall in millimetres

(2) mT Maritime tropical

cT Continental tropical

ITF Inter-tropical front

(After Brooks & Mirrlees)

CHAPTER 3 HYDROMETRIC RECORDS

3.1 Existing Network

A comprehensive description of the existing hydrometric network in the Tana River Basin is contained in the FAO/Acres/ILACO Report (1).

The earliest stations were established in the 1920's and since this time the numbers have continuously increased until records from over one hundred water level recording stations are now available. Many of these stations, however, have short incomplete records; others have not been discharge rated or are affected by an unstable bed, producing variable stage-discharge relationships.

For the purposes of this study, which is basically a review of existing reports, only those stations which have records which are fundamental to the analyses have been investigated. Details of these stations are given in Table 3.1 and their locations shown in Figure 1.1.

Table 3.1 - Selected Hydrometric Stations Located in the River Tana Basin

Reference No.	Name	River	Catchment Area (km^2)	Date Installed	Type of Station
4DD1	Thiba	Thiba	1 890	1947	S g & D
4ED3	Kamburu	Tana	9 500	1948	R & D
4F13	Grand Falls	Tana	17 000	1948	R & D
4G1	Garissa	Tana	33 000	1934	R & D
4G	Nanigi	Tana	37 500	1973	S g & D
4G2	Garsen	Tana	87 500	1932	R & D
	Total Catchment	Tana	95 000		

Note: R = Recorder
D = Discharge measurements
Sg = Staff gauge

The hydrometric stations are maintained by the Ministry of Water Development and records are kept in the Ministry's Offices in Nairobi. Access was obtained to original files of all the gauging stations of interest to the Bura Project and relevant data, such as minimum and maximum water levels, flows and discharge measurements, were extracted. However, because of the limited nature of the study, no attempt was made to review the existing stage-discharge relationships although certain anomalies were apparent.

The Garissa records show that the stage-discharge curve for this station has been changed on a number of occasions since it was installed in 1933. A large amount of information is available including surveys of river cross-section, changing of gauge datums, etc. especially for the older records. This is presently under review as part of a national water resources and water development study being undertaken by consultants attached to the Ministry of Water Development under Swedish bi-lateral aid. Monthly flow records have been published in a number of reports: Tana River Development Authority (1976), ILACO (1975) and the FAO/Acres/ILACO (1967). In preparing the latest records for the Upper Reservoir Scheme, the Tana River Development Authority, recalculated the flows at Kamburu, Garissa and Thiba. Although these flows have not been checked, they have been accepted for the purpose of this report as the most accurate available.

A detailed review is being undertaken of basic data and in particular stage-discharge relationships for gauging stations on the Tana River. The results of this study should be available within the next six to twelve months. Although errors could exist in the published flow records they would not influence the proposed west bank Bura Irrigation Project; the proposed abstractions are small relative to historic low flows recorded in the Tana River. However, for future development of the east bank a detailed re-appraisal of flows in the Tana River will be required.

3.2 Unregulated River Flows - Without Upper Reservoir

The Tana River is at present for all purposes unregulated. The only reservoir with a significant live storage is at Kamburu with a capacity of 123 million cubic metres (Mm^3) which is equivalent to less than four per cent of the annual run-off. However, if the reservoir is so operated as to try and maintain a base flow (ILACO 1975 Report specifies 42.5 m^3/s = (112 Mm^3)), then some regulation of low flows is possible.

A comparison is given in Table 3.2 of published annual discharges at Kamburu.

Table 3.2 - Comparison between Published Mean Annual Flow (Mm^3) at Kamburu and Garissa

Year	Kamburu		Garissa	Year	Kamburu	Garissa
	TRDA (1976) (2) (5)	FAO (1967) (3) (9)	TRDA (1976) (2) (5)		TRDA (1976) (2) (5)	TRDA (1976) (2) (5)
48/49	2 132	1 670	3 621	63/64	5 417	9 293
49	1 243	725	2 158	64	4 439	6 995
50	2 062	2 205	4 569	65	2 969	4 028
51	4 735	4 275	10 340	66	3 779	5 585
52	2 100	1 664	3 372	67	5 583	9 184
53	1 757	1 315	3 402	68	6 407	11 908
54	3 048	2 541	5 058	69	2 293	3 444
55	2 027	1 536	3 556	70	3 194	4 488
56	3 088	2 642	5 428	71	2 807	4 162
57	3 568	3 140	5 884	72	–	5 621
58	3 617	3 156	5 313	73	–	2 988
59	2 331	1 874	3 383	74	–	4 319
60	2 032	1 602	3 721	75	–	2 891 (1)
61	7 429	6 706	11 895	76/77	–	2 491 (1)
62/63	3 479	–	5 281			

Notes:
(1) Information extracted from M.W.D. files
(2) Water Year, April - March
(3) Calendar Year, January - December
(4) 1 $Mm^3 \equiv 0.032\ m^3/s$ per year
(5) Flows adjusted to allow for upstream abstraction
(6) Figures based on recorded data
(7) TRDA – Tana River Development Authority
(8) FAO – Food and Agricultural Organisation of the U.N.
(9) Flows reduced on average by 440 Mm^3 to allow for future development upstream in upper basin

The annual flows published in the TRDA Report (1976) and the FAO/Acres/ILACO Report (1967) are not strictly comparable as the TRDA values allow for past abstractions upstream of Kamburu whilst the FAO/Acres/ILACO figures include deductions for future abstractions. According to the TRDA Report (1976) present day abstractions amount to some 240 Mm^3 (7.7

m^3) per annum. The abstraction rate should be represented as a gradual build-up: for example the Mwea Irrigation Scheme abstractions have increased from zero in 1956 to 68 Mm^3 (2.2 m^3/s) in 1971. The main reason for the average difference between the two sets of data (440 Mm^3/year) is that the FAO data represent net values after deducting estimated future upper catchment requirements of 472 Mm^3/year (15.1 m^3/s). There is therefore a fairly close agreement between the Kamburu discharge estimates published by FAO and TRDA and it would appear the TRDA have accepted the FAO figures for the period 1948-1961.

The catchment areas of the Tana River at Kamburu and Garissa are 2 500 square kilometres (km^2) and 33 000 km^2 respectively. The inflow from the intervening catchment some 23 500 km^2 only increases the mean annual flow by some 68 per cent from 3 315 Mm^3 (106 m^3/s) to 5 560 Mm^3 (178 m^3/s).

The principal recessions of the Tana River occur between January and March and July to September with maximum flow occurring in April/May and November/December following the bi-modal rainfall distribution in the highland region.

For irrigation abstractions March is the most critical month. Table 3.3 contains the published data for March flows between the years 1948 and 1972. The lowest mean March flow in the River Tana occurred at Garissa in 1971 with a total discharge of 76 Mm^3(28m^3/s). However, it is sigificant that the lowest consecutive three year sequence spanned the current period 1974-76 inclusive.

The Kamburu Reservoir was completed in 1974. The March flow data in Table 3.3 have therefore been divided into recorded flows and regulated flows assuming the Kamburu Reservoir had been operational for the whole period of the records. A comparison of recorded flows for the period 1948 to 1961 again demonstrates that TRDA estimated mean March flows are some 31 per cent higher than the FAO figures, 84 Mm^3 (31 m^3/s) as opposed to 64 Mm^3 (24 m^3/s). This difference, as with the annual flows reflects the allowance inbuilt into the FAO for future upper catchment abstractions.

A comparison between flows at Garissa and Kamburu for the period 1948 to 1972 shows that the mean March flow increases from 128 Mm^3 (48 m^3/s) to 229 Mm^3 (85 m^3/s) through tributary flow below Kamburu.

ILACO (1975) estimated Kamburu flows after regulation produced by the recently constructed Kamburu reservoir by assuming a minimum threshold release of 42.5 m^3/s (114 Mm^3). However, it is clear from the record of monthly flows at Kamburu (see Appendices Table A.1.) that with only a live storage of 123 Mm^3 the reservoir could not sustain a minimum release of 42.5 m^3/s in at least 25 per cent of the years. It is recommended therefore, that the TRDA outflows should be used as these have been based on a reservoir operational study. The results show that the minimum March flow from the Kamburu reservoir is increased from 49 Mm^3 (18 m^3/s) to 100 Mm^3 (37 m^3/s) in 1971; a similar increase would be expected for the Garissa flow giving a minimum March flow of 122 Mm^3 (47 m^3/s).

From a review of the existing flow records currently available it is recommended that the published Tana River Development Authority records should be used. Recorded monthly run-off, adjusted only for increased abstraction in recent years, is included in Appendix A, Tables A1, A2, A3 and A4 for the Thiba tributary and the Tana River at Kamburu, Garissa and Nanigi.

The effect of the Kamburu reservoir is also shown in Tables B1 and B2 which contain regulated low flows at Nanigi for planning horizons 1980 and 1985. All the figures have been adjusted to allow for estimated increases in upper catchment abstractions and minor regulation by the Kamburu reservoir.

As a preliminary check on the consistency of the TRDA data, Tables A1, A2 and A3, cumulative curves were prepared to compare the flow records. The results are shown in Figure 3.1. It can be seen that the Kamburu - Garissa flows are extremely consistent for the period 1954 to 1971, but

Table 3.3 - Comparison between Published March Flows (Mm^3) at Kamburu and Garissa

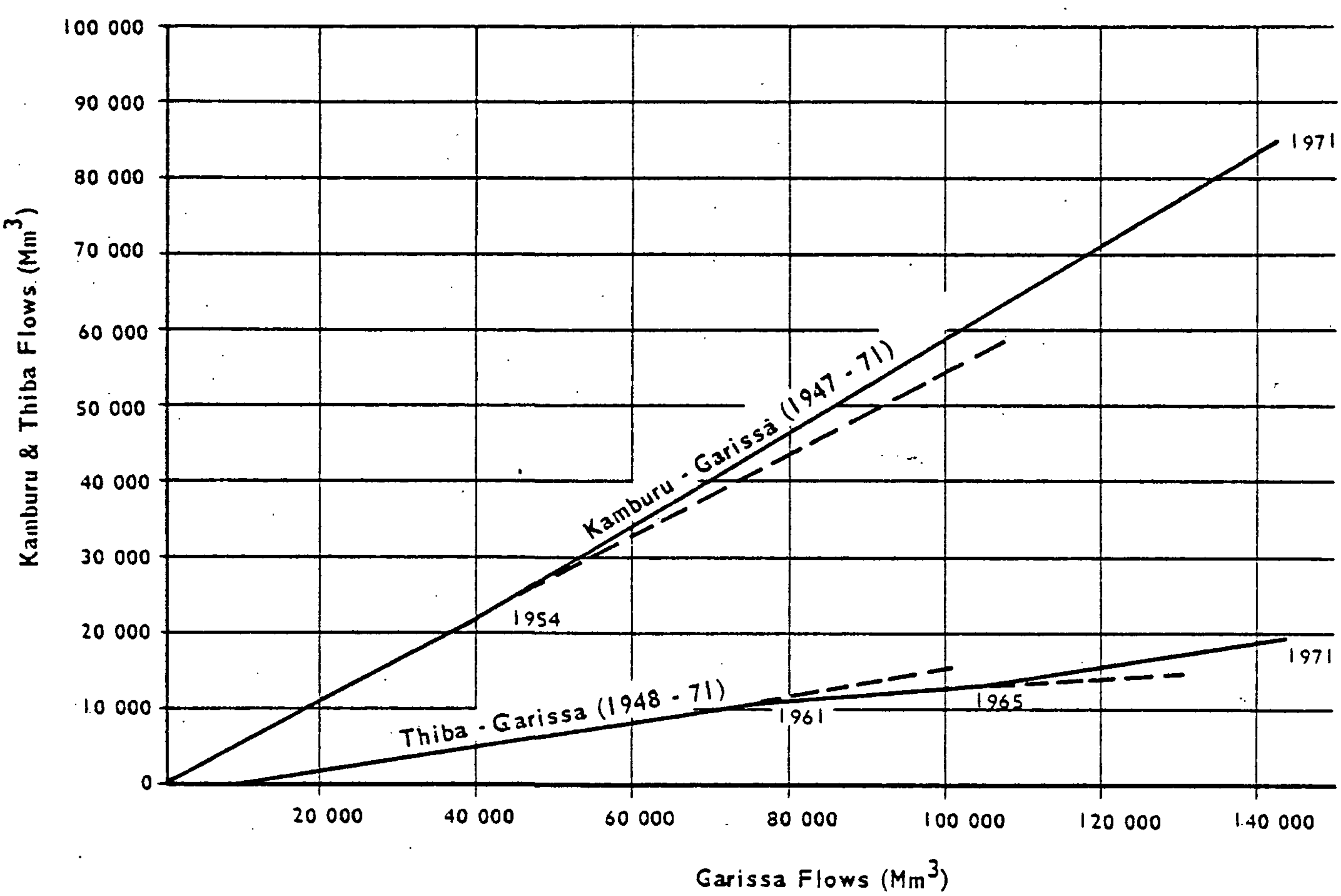
Year	Kamburu recorded TRDA[4] (1976)	Kamburu recorded FAO[5] (1967)	Garissa recorded TRDA[4] (1976)	Kamburu Reservoir Outflow TRDA[3] (1976)	Kamburu Reservoir Outflow ILACO[7] (1975)	Year	Kamburu recorded TRDA[4] (1976)	Garissa recorded TRDA[4] (1976)	Kamburu Reservoir Outflow TRDA[3] (1976)	Kamburu Reservoir Outflow ILAC[illegible] (197[illegible]
1948	66	42	–	–	112	63/4	161	233	208	15[illegible]
1949	53	30	57	104	112	1964	192	394	213	19[illegible]
1950	99	76	209	89	112	1965	115	151	162	11[illegible]
1951	82	105	108	116	112	1966	194	285	212	19[illegible]
1952	95	70	186	143	112	1967	80	142	129	11[illegible]
1953	58	36	103	103	112	1968	479	961	412	47[illegible]
1954	53	32	116	104	112	1969	280	548	265	27[illegible]
1955	69	46	128	110	112	1970	150	143	197	14[illegible]
1956	115	86	210	170	113	1971	49	76	100	11[illegible]
1957	89	64	168	137	153	1972	100	133	147	11[illegible]
1958	155	133	267	202	153	1973	–[2]	156[2]	–	–
1959	84	59	148	132	112	1974	–	95[2]	–	–
1960	103	79	276	151	112	1975	–	99[2]	–	–
1961	60	38	113	108	112	1976	–	105	–	–
1962	217	–	364	206	214					

Notes:

1. 1 Mm^3 per month = 0.375 m^3/s per month
2. Information extracted from MWD files - not adjusted for upstream abstractions
3. Values estimated upper catchment abstractions in the year 1980 (3)
4. Flows adjusted to allow for upstream abstractions (3)
5. Recorded flows less an estimated potential abstraction in the upper catchment of 472 Mm^3 (1)
6. There appears to be an error in the March 1951 values for Kamburu
7. Reference (2)

prior to this period the flows at Garissa were significantly higher relative to those recorded at Kamburu. The Thiba flows also appear to be too low relative to Garissa flows during the period 1961 to 1965. It would therefore be advisable to analyse the records and basic data in some detail prior to the development of major irrigation schemes on the East Bank. However, the water requirements for the proposed Bura Project are small in comparison with the available supply and therefore any errors or inconsistencies in the available flow estimates have no consequence in assessing the viability of the project.

Figure 3.1 - Comparative Curves of Cumulative Annual Flows Recorded at Thiba, Kamburu and Garissa



The Garissa gauging station is closest to the proposed abstration intake at Nanigi, some losses occur downstream and the following section has been included to assess the reliability of previous estimates.

3.3 Water Losses between Garissa and Nanigi

The Lower Tana River, in all but the wettest periods, loses water between Garissa and the sea. The water that is lost through evaporation, seepage and percolation is not replaced by run-off from the predominantly arid lower catchment. Previously attempts have been made to try and estimate the probable flow at a point downstream of Garissa, from the measured Garissa flow by establishing a numerical relationship between the Garissa flow and the downstream losses. ILACO (1975) by comparing monthly flow records of the Garissa and Hola gauging stations obtained the expression:

$$F_H = F_G \times 0.96 - 12.1 \ (m^3/s)$$

where F_H is the flow at Hola
and F_G is the flow at Garissa.

The data used to establish this relationship gave a correlation coefficient of 0.98, a remarkably high value. The losses to Nanigi were assumed to be one third of those estimated for the reach to Hola.

The Tana River Development Authority also required a method for calculating losses between Garissa and Nanigi for inclusion in a simulation programme for studying future development in the Tana River Basin. The relationship adopted was:

$$F_N = F_G \times 0.978 - 3.9 \ (m^3/s)$$

where F_N is the flow at Nanigi.

These two methods are reasonably compatible as can be seen from Figure 3.3. As additional information in the form of measured flows and water levels at Nanigi is now available in the Ministry of Water Development, a revised approach was attempted.

Several different methods were tried. These involved a review of actual recorded flow measurements at Garissa, Nanigi and Garsen to compare recorded flows taken on the same day or reasonably close together. This approach proved to be inconclusive due to the lack of data and the apparently wide fluctuation in flow from day to day.

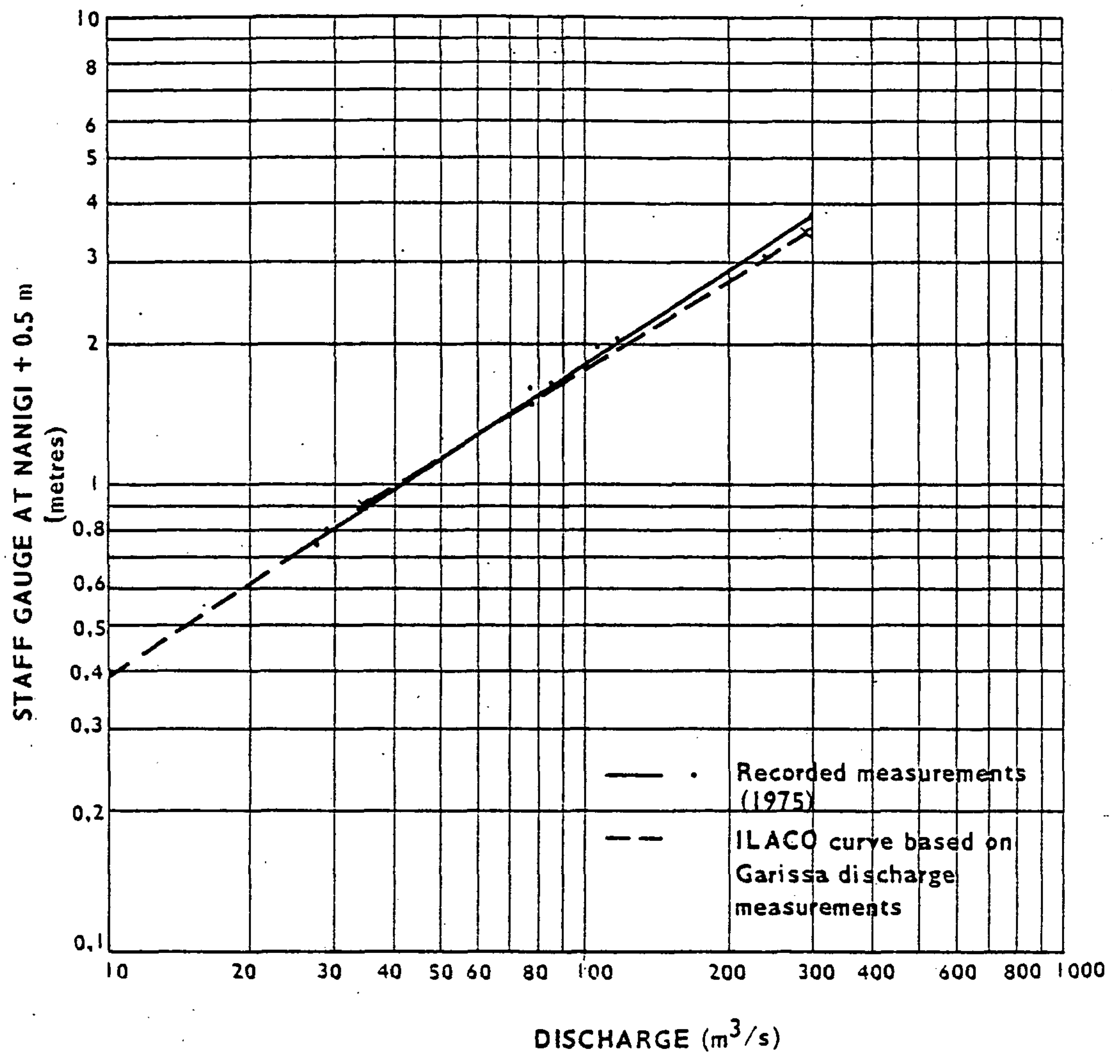
With the recorded flow measurements at Nanigi a provisional stage-discharge curve was prepared (see Figure 3.2) this curve compares closely to one prepared by ILACO for Nanigi, but based on recorded flow measurement at Garissa. The readings of the Nanigi gauge when compared with Garissa values appeared somewhat erratic and when calculated daily flows at the two stations were compared similar wide deviations were encountered between the two sets of flow data. To eliminate the day to day variations monthly flows were used. These are shown in Table 3.4.

Table 3.4 – Monthly Flows at Garissa and Nanigi (Mm^3)

Year	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1974	Garissa	128	–	95	–	–	–	–	–	245	268	555	252
	Nanigi	141	–	90	–	–	–	–	–	272	222	451	256
1975	Garissa	180	116	94	399	412	293	271	225	174	197	–	200
	Nanigi	162	103	55	468	453	182	178	165	180	109	–	149
1976	Garissa	140	119	–	–	319	296	224	169	79	108	285	–
	Nanigi	158	107	–	–	264	251	197	163	60	68	272	–

Fitting a simple regression relationship to these data results in the relationship $F_N = F_G \times 0.94 - 4.0 \ (m^3/s)$.

Figure 3.2 - Provisional Stage-Discharge Curve - River Tana at Nanigi



The data, and various alternative relationships, are shown in graphical form in Figure 3.3.

An attempt was also made to calculate the quantity of water transpired by the riverine forests, as it had been suggested that this is the principal cause of water loss. This analysis produced a constant loss of 120 l/s/km, or 7.5 m^3/s between Garissa and Nanigi.

It can be seen from Figure 3.3 that each relationship fits the widely scattered data quite well, and, as a result, it was decided to use the TRDA regression equation to prepare estimates of flow at Nanigi to be consistent with the flow records used in other parts of the report, which we obtained from the TRDA simulation model.

Figure 3.4 presents a frequency curve for estimated river mean monthly flows at Nanigi in March for two conditions: firstly, the natural unregulated flow and, secondly, allowing for the effect of regulation by the low capacity reservoir constructed at Kamburu in 1974. The regulated flow curve also includes for estimated abstractions in the Upper Tana Basin in the year 1980 and reservoir releases are made to be consistent with supplying irrigation water to an area in the Lower Tana Basin of 14 500 hectares.

Table 3.5 – Mean Monthly March Flows at Nanigi for Selected Return Periods with Kamburu Reservoir and 1980 Abstractions

Mean March Flows at Nanigi (m^3/s)

1 in 2 years	1 in 5 years	1 in 10 years	1 in 25 years	1 in 50 years
72	54	48	44	42

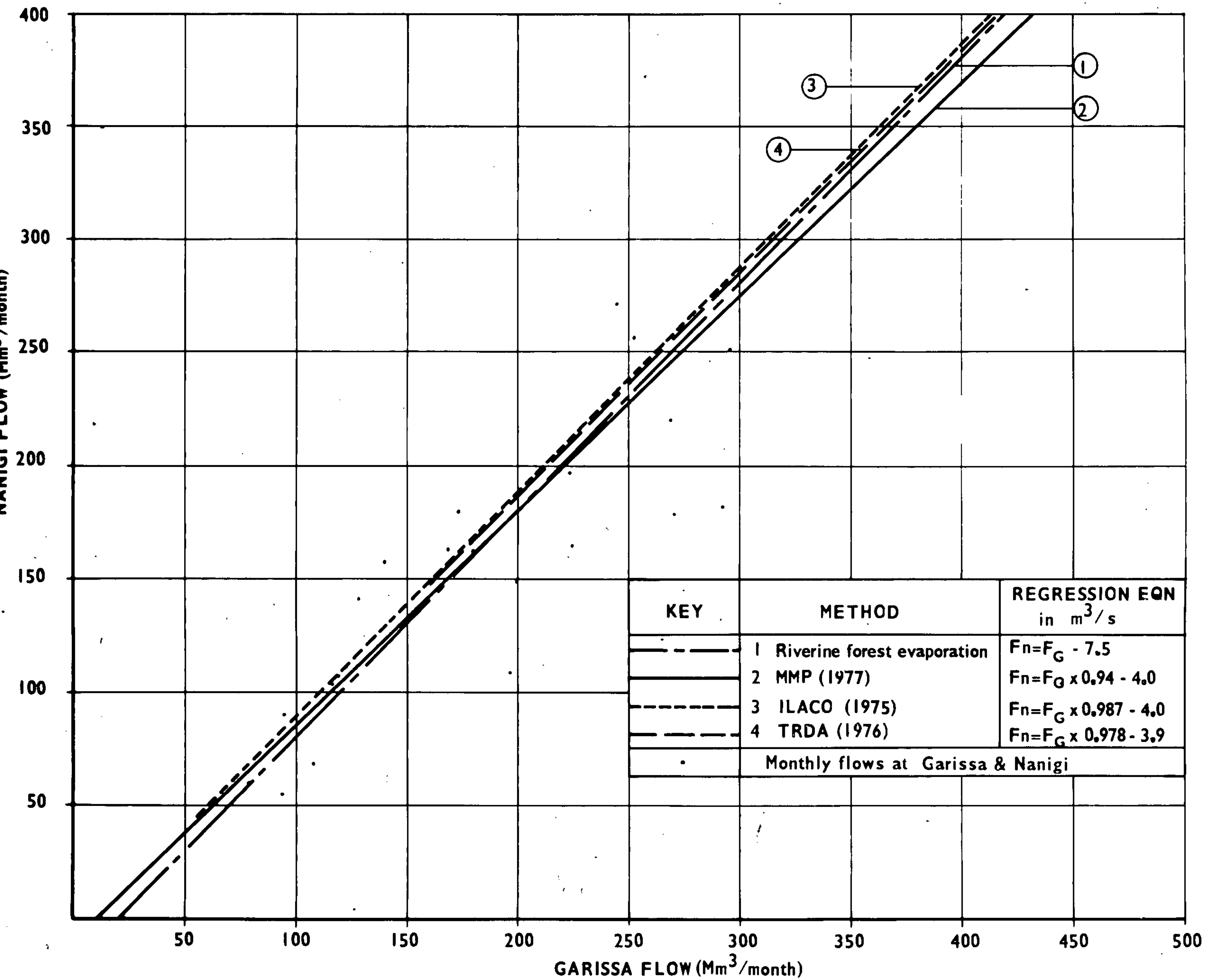
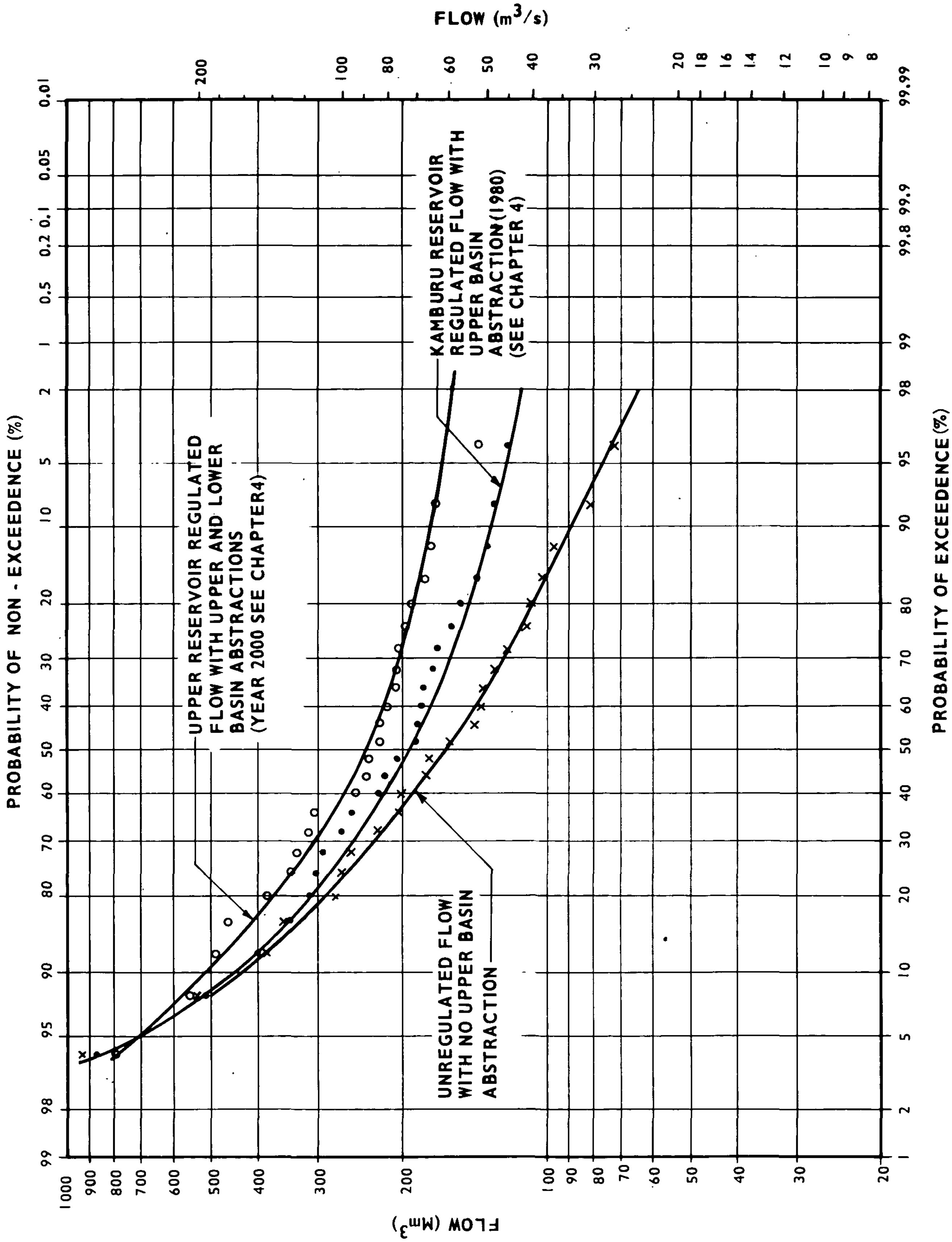

NANIGI FLOW (Mm3/month)
GARISSA FLOW (Mm3/month)
400
350
300
250
200
150
100
50
50
100
150
200
250
300
350
400
450
500
KEY
METHOD
REGRESSION EQN in m3/s
1 Riverine forest evaporation
Fn=FG - 7.5
2 MMP (1977)
Fn=FG x 0.94 - 4.0
3 ILACO (1975)
Fn=FG x 0.987 - 4.0
4 TRDA (1976)
Fn=FG x 0.978 - 3.9
Monthly flows at Garissa & Nanigi
1
2
3
4

FIGURE 3.3

FIGURE 3.4

FREQUENCY CURVES FOR MARCH FLOWS IN THE TANA RIVER ABOVE NANIGI (1948 - 1971)



CHAPTER 4 FUTURE WATER DEVELOPMENT

4.1 Introduction

The Kenya Government proposes to construct a large multi-purpose reservoir on the River Tana called the Upper Reservoir Scheme. This reservoir will be the key to the development of Kenya's largest river and benefits will range from increased hydro-power production, increased irrigation supplies, and development of urban and rural water supply schemes. The reservoir, as proposed, has a capacity of 1 560 Mm^3 (46 per cent of the Tana River's mean annual flow at Kamburu). The location of the dam, immediately upstream of the Kamburu reservoir, is ideal both for control of flows through the reach of the Tana River with potential for hydro-power generation and for irrigation in the Lower Tana Basin.

The contract documents for the Upper Reservoir are under preparation and it is expected the tenders will be called for late in 1977 for commissioning the scheme in 1981. The chances appear to be very high that the Upper Reservoir Scheme will be built during the next decade. Although the scheme is likely to be built, it is advisable also to investigate the proposed Bura Project, together with other water demands which may arise later this century, assuming the present river regime. "With" and "without" Upper Reservoir storage have therefore been considered.

4.2 Tana River Simulation Model

The simulation model was developed by the Tana River Development Authority (TRDA) in conjunction with their consultants for the Upper Reservoir Scheme to assess the economic viability of that scheme. The river system assumed for simplicity in the model consists of the five tributary systems – the Thika, Sagana, Thiba, Mutonga and Kazita – flowing into the main stem of the Tana (see Figure 4.1). The contributions of each tributary system have been estimated for the period 1948-71 from the records of the three principal gauging stations: Garissa, Kamburu and Thiba.

The hydrological raw data used in the programme were abstracted from the records of Garissa, Kamburu and Thiba, for the years 1948 to 1972 (see Appendix A and Section 3.2). Attempts were made to adjust the recorded flows to allow for past abstractions from the river system for water supply and irrigation purposes, i.e. to produce a "natural" run-off figure. When the programme is operated to study the effect of development at various future planning horizons then the abstractions from the tributary systems that correspond to this date are deducted from the 24 years of flow data. In computing the increase in future abstractions, expansion has been allowed for in major and minor irrigation schemes and increased demand for public water supply in general and in Nairobi in particular.

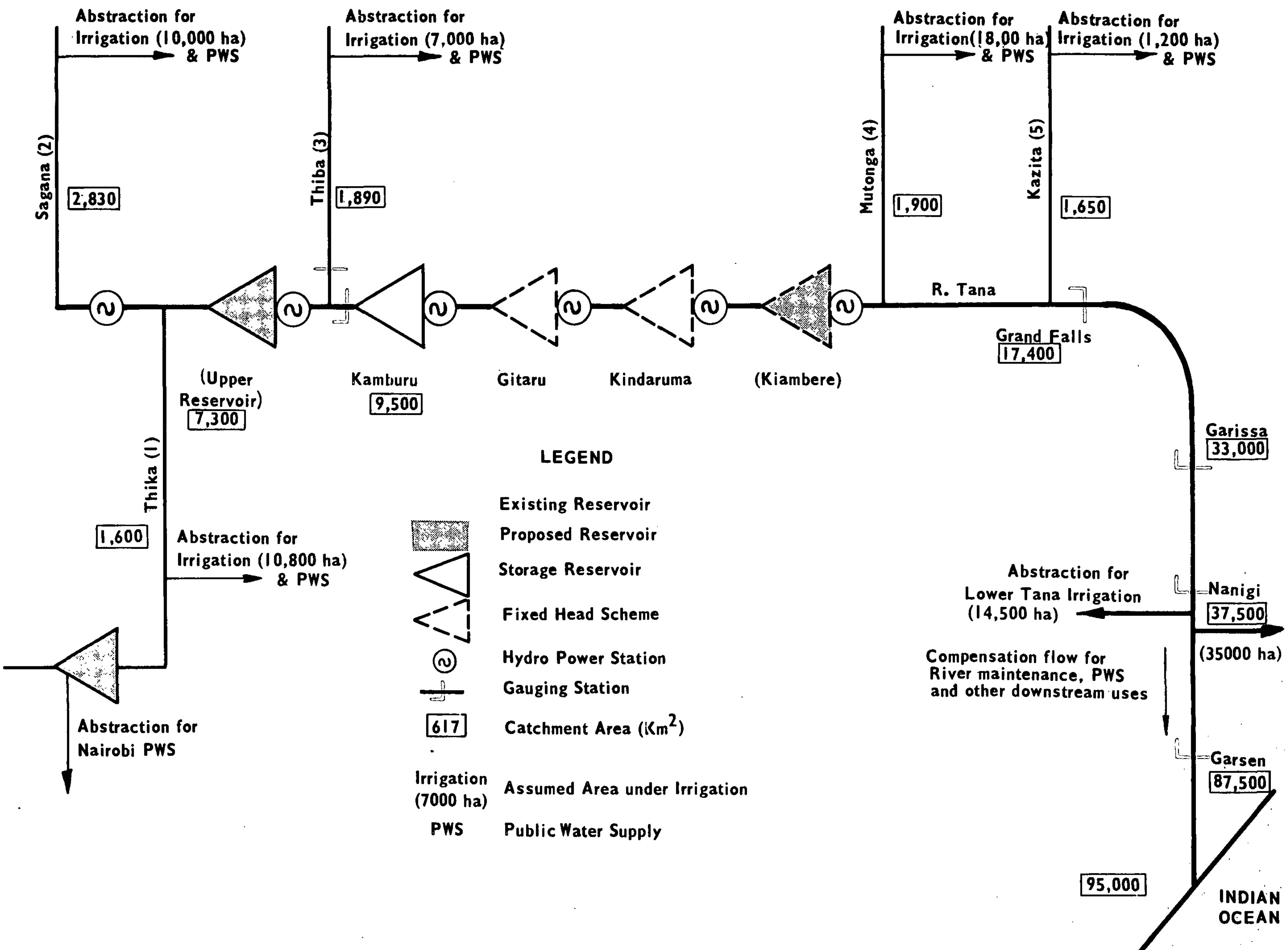
The Upper Reservoir was designed principally to perform a role of flow regulation. The proposed operation of the reservoir is quite complex and reflects the partial conflict between the hydro-power and downstream irrigation demands. For each run of the programme an area of the Lower Tana River Basin is identified for irrigation development, and the water required calculated. This water supply is then treated as a firm, invariable demand upon the river system, and so minimum releases from the regulatory reservoirs can be calculated. The operation of the reservoirs is then examined to optimise the hydro-power generation through the series of generating stations, within the constraint of the downstream irrigation demand.

Flow regulation on the Tana River is provided both by the proposed Upper Reservoir and the recently completed Kamburu reservoir. As a result, the final flow regulation of the river is performed at Kamburu, which lies upstream of the Mutonga and Kazita river systems. Allowance is made for inflow from these two systems to help to meet the Lower Tana River Basin irrigation demands. At the moment of flow regulation, it is assumed that the contribution from these two lower river systems is unknown (in fact this need not be the case) and releases are made which would satisfy lower basin irrigation if the intervening catchment contribution corresponds to a

Table 4.1 - Example of Calculations to Determine the Minimum Release from Kamburu Reservoir to Satisfy Irrigation Demand

	Required Minimum Release at Kambaru (Mm^3/month)											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Minimum permitted flow at Garissa	80	80	80	80	80	80	80	80	80	80	80	62
Less : flow gains Kamburu/ Garissa	-39	-164	-93	-57	-35	-28	-22	-86	-115	-60	-36	-30
Plus : all abstractions below Kamburu												
(i) Mutonga/Kamburu abstractions[1]	+2.7	+3.5	+7.1	+6.6	+6.3	+3.7	+3.4	+3.7	+4.3	+7.7	+5.8	+3.4
(ii) Bura abstractions[1]	+30.6	+42.3	+39.1	+26.5	+10.5	+22.6	+30.5	+29.0	+22.5	+4.5	+23.7	+33.5
Hence : required flow at Kamburu	74.3	-38.2	33.2	56.1	61.8	76.3	91.9	26.7	-8.2	32.2	73.5	68.9
Input Minimum Kamburu Releases	74.3	10.0[3]	33.2	56.1	61.8	76.3	91.9	26.7	10.0[2]	32.2	73.5	68.9

Notes:
[1] Table taken from TRDA Report (1976) (3)
[2] Example shown is for year 2000, Bura Project, and no further Upper or Lower Tana Irrigation
[3] Minimum Kamburu release set at 10 Mm^3/month



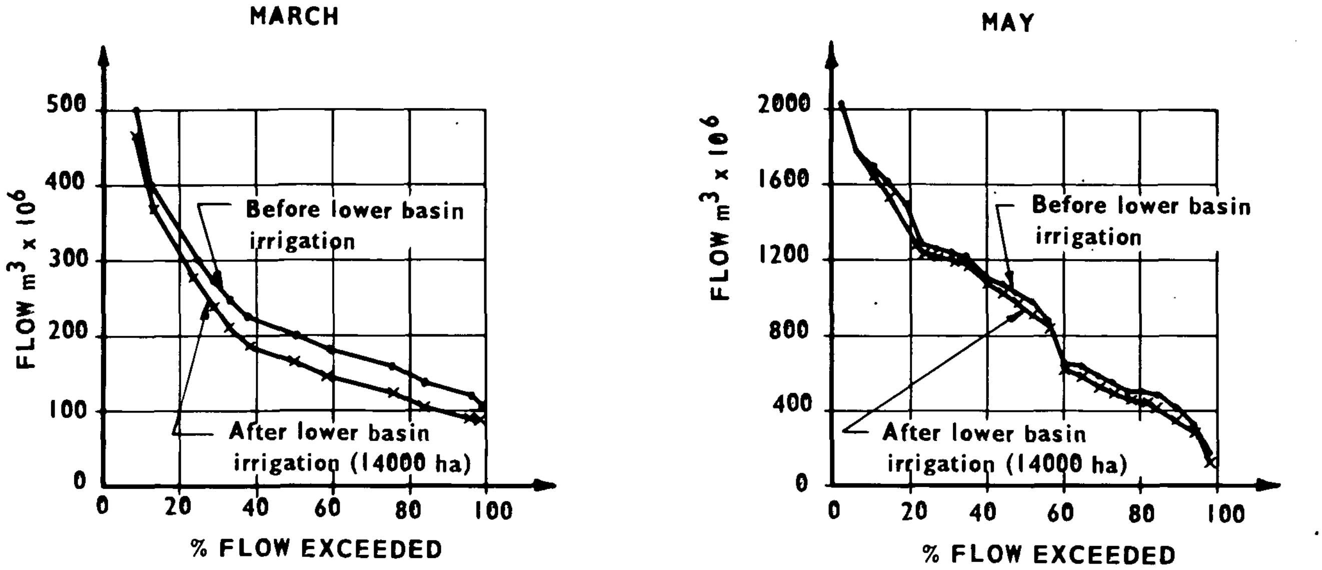
SCHEMATIC REPRESENTATION OF TANA RIVER SYSTEM

BASED ON FIGURE PREPARED BY TANA RIVER DEVELOPMENT AUTHORITY UPPER RESERVOIR SCHEME APPRAISAL REPORT (1976)

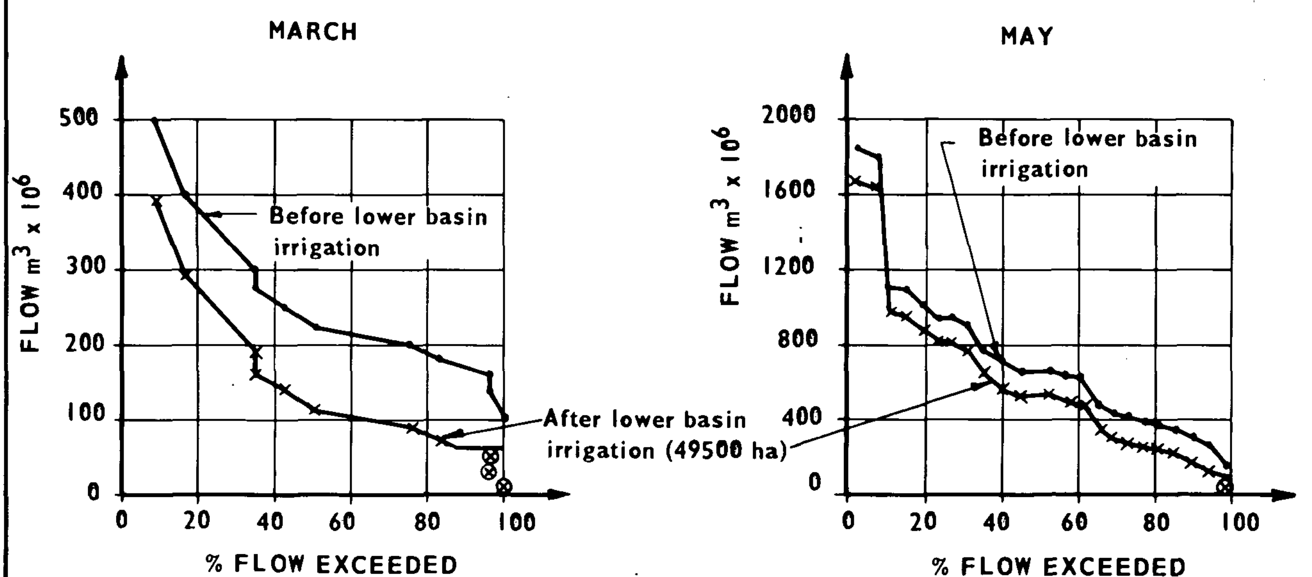
FIGURE 4.1

FIGURE 4.2

DURATION CURVES FOR RIVER TANA FLOWS AT NANIGI FOR MONTHS OF MARCH AND MAY



CASE 1 DEVELOPMENT IN YEAR 1985 - NO UPPER RESERVOIR



CASE 2 DEVELOPMENT IN YEAR 2000 - WITH UPPER RESERVOIR

NOTE
1 ALLOWANCE INCLUDED FOR INCREASED UPPER TANA BASIN ABSTRACTIONS
2 IRRIGATION REQUIREMENTS MET 4 YEARS OUT OF 5
3 ⊗ YEARS OF IRRIGATION DEFICIT
4 DATA EXTRACTED FROM TRDA SIMULATION MODEL RUNS

low run-off likely to arise once every 5 years. As a result, built into the computer programme is the assumption that, for 1 year in 5, the demand for irrigation water in the Lower Tana River Basin will not be met due to abnormally low flows in the Mutonga/Kazita river systems.

The calculation of the 'minimum irrigation release' necessary from Kamburu reservoir, for a typical situation, is shown in Table 4.1.

4.3 Development Without Upper Reservoir

Future demand estimates for water supply and irrigation from the River Tana have been published in various reports allowing for no significant additional reservoir storage in the Tana River Basin. The results are shown in Table 4.2.

The object of presenting these figures is to give an overall picture of possible future development. A large increase in water supply to Nairobi is anticipated, as is the build up of rural and urban water supply. However, this increase in public water supply is in line with Government policy for providing piped water to each individual home. This programme will inevitably necessitate some additional reservoir storage.

The most recent estimates prepared by TRDA for the future irrigation demand in the upper Tana catchment is 317 Mm^3 (10.1 m^3/s) in the year 2000. Although the FAO figure is larger, 472 Mm^3 (15.1 m^3/s), it is probable that the FAO estimate also allows for future public water supply abstractions.

The TRDA figure is based on doubling the area under irrigation in the upper catchment from 15 000 to 30 500 hectares with abstractions amounting to an average annual flow of 10.1 m^3/s.

The availability of water for irrigation in the Lower Tana River Basin depends on the selected compensation flow released downstream of the main abstraction points. TRDA adopted the criterion that dry weather flows below Nanigi should not fall below a value of 80 Mm^3 per month (30.5 m^3/s) in any one month (see Table 4.1). Only on one occasion in the 24 years (1948-1971) recorded at Garissa has the mean monthly flow fallen below this value; 72 Mm^3 in March 1971. Without regulation by the Upper Reservoir the amount of irrigable area is effectively limited by the river flow in the months of February and March. The TRDA estimate that up to 14 500 hectares, together with 15 000 hectares in the upper catchment, could be developed by the year 2000 without additional storage. This increase in irrigation is additional to the amount of water set aside for satisfying public and industrial water supply demand.

In most months the flows maintained in the Lower Tana River are well in excess of the selected value of 80 Mm^3/month and without storage the flood regime of the Tana River is little affected. The influence of abstractions for irrigation of an area of 14 500 hectares on river flows during the months of March and May is illustrated in the form of du ration curves in Case (1) of Figure 4.2. The particular example illustrated is for the year 1985 and allows for some increase in abstractions in the upper and middle catchments of the Tana River Basin.

The flows at Nanigi for the base case of normal anticipated increases in abstractions for the planning horizons 1980 and 1985 are tabulated in Appendix B, Tables B1 and B2.

It can be seen that in 1985 the effect of irrigating 14 500 hectares in the Lower Tana Basin is negligible.

4.4 Development with Upper Reservoir

As mentioned in the introductory section of this chapter, it is extremely likely that the Upper Reservoir will be built and be operational within the next 10 years. With a live storage of 1 400 Mm^3 it will provide a significant amount of regulation to the Tana River flows in the lower basin.

Table 4.2 - Comparison between Published Data of Present Supply and Future Demand - Without Upper Reservoir

Reference	Planning Horizon	Nairobi (Mm^3/year)	Water Supply Tana Basin (Mm^3/year)	Total (Mm^3/year)	Irrigation: Upper Tana Basin Area (ha)	Upper Tana Basin Demand (Mm^3)	Upper Tana Basin Demand (m^3/s)	Lower Tana Basin Area (ha)	Lower Tana Basin Demand (Mm^3)	Lower Tana Basin Demand (m^3/s)	Total Abstractions (Mm^3)	Total Abstractions (m^3/s)
TRDA (1976)	Present	38	35	73	15 500	161	5.2	900	25	0.8	259	8.3
	Year 2000	163	105	268	30 500	317	10.1	14 500	335	10.7	920	29.4
ILACO (1975)	Present	36	40	76	–	213	6.8	900	25	0.8	314	10.0
	Year 2000	125	50	175	Not considered			14 500	428	13.7	603	19.3
FAO (1967)	Present	–	–	–	–	–	–	–	–	–	–	–
	Year 2000	–	–	–	–	472	15.1	–	–	–	–	–

Although the prime consideration chosen by TRDA in preparing the basin simulation model has been to optimise the hydro-power generation, this is reasonably compatible with irrigation development in the Lower Tana Basin. The irrigation requirements estimated by TRDA for the fairly large scale developments proposed in the Upper and Lower Tana Basin are obviously very approximate, but the study does provide the opportunity for assessing possible long term developments.

The water supply requirements and supply for both "with" and "without" the Upper Reservoir are assumed to be the same. Priority, therefore, has been given to the use of water for public and industrial purposes (see Table 4.2). Table 4.3 gives a comparison between various sources of water development up to the year 2000.

Table 4.3 - Comparison between Published Data on Present Supply and Future Demand - With Upper Reservoir

		Irrigation						Total abstractions including water supply	
		Upper Tana Basin			Lower Tana Basin				
Source	Planning Horizon	Area (ha)	Demand (Mm^3/year)	Demand (m^3/s)	Area (ha)	Demand (Mm^3/year)	Demand (m^3/s)	(Mm^3/year)	(m^3/s)
TRDA (1976)	Present	15 500	161	5.2	900	25	0.8	259	8.3
	Year 2000	30 500	317	70.1	49 500	1 223	39.1	1 715	54.9
ILACO (1975)	Present	–	213	6.8	900	25	0.8	314	10.0
	Year 2000	Not considered			14 500*	428	13.7	603	19.3
FAO (1967)	Present	–	–	–	–	–	–	–	–
	Year 2000	–	472	15.1	101 000	2 500	80	2 972	95.1
					121 500	3 000	95	3 472	110.0

* Original Stage I area of the Bura Project, i.e. 14 500 ha only considered.

Figure 4.2, Case (2) shows the effect of project water supply and upper and lower basin irrigation development by the year 2000 on Tana River flows. The reservoir releases are planned to satisfy irrigation demand in the Lower Tana River Basin (49 500 hectares) 4 years out of 5. As can be seen from the curve for March flows, in the 24 years of records a deficit has occurred on three occasions. Superimposed on the irrigation demand are the hydro-power releases, downstream abstractions and the unregulated flows in wet years. The duration curves for the "with" and "without" Upper Reservoir situations are not startlingly different for the March flows because the smaller Kamburu reservoir is quite effective in making a satisfactory threshold flow in low flow years (see Figure 3.4). In spite of this a flow in excess of 200 Mm^3 (75 m^3/s) is maintained for 75 per cent of the time compared with 50 per cent for the pre-reservoir situation. Abstractions in the Upper Basin are also much heavier in the year 2000 compared with 1985. A different situation arises in the month of May when the regulatory effect of the reservoir is more apparent. For example, without the Upper Reservoir 58 per cent of the mean May flows exceed 800 Mm^3 (298 m^3/s); with the reservoir this percentage is reduced to 30.

Nanigi flows based on reservoir releases in the year 2000 for meeting the estimated irrigation requirement (see Table 4.3) are included in Appendix B, Table B.3.

4.5 Summary

The results of the simulation model of the River Tana indicate that there is still a considerable scope for development of the existing water resources even without using the large storage potential available.

One option investigated by the TRDA found that existing resources are available to develop:

(i) An additional 13 600 hectares under irrigation in the lower basin - 156 Mm^3/year.

(ii) An additional 15 000 hectares under irrigation in the upper basin - 310 Mm^3/year.

(iii) An additional 195 Mm^3/year for water supply.

A minimum compensation flow below Nanigi of 62 Mm^3/month (20 m^3/s) was allowed in March and 80 Mm^3/month (26 m^3/s) in other months.

If the Upper Reservoir is constructed then even with priority assigned to the generation of hydro-power, there would be a greatly increased potential for development of irrigation especially within the Lower Tana River Basin.

One option which TRDA investigated with the help of the simulation model allowed for the development of:

(i) An additional area under irrigation of 48 600 hectares in the lower basin.

(ii) An additional area under irrigation of 15 000 hectares in the upper basin.

(iii) An additional 195 Mm^3/year (6 m^3/s) for water supply.

It is quite clear therefore that the immediate development of an irrigation area of 6 700 hectares will present little conflict with existing water users on the Tana River nor indeed with any future development that is likely to take place over the next 25 years. With the Upper Reservoir constructed there will be a large increase in the usable water resources of the region with great potential for large scale irrigation. If the option mentioned immediately above were adopted then a further 42 000 hectares could be developed in the Lower Tana Basin in addition to the 6 700 hectares of Phase I, Stage I of the Bura Project.

CHAPTER 5 IRRIGATION REQUIREMENTS

5.1 Introduction

The rate at which irrigation water is required in any irrigation project depends upon a wide variety of factors: these include, the climate of the region, the soil conditions, the crop type and the methods of irrigation. The calculation of project irrigation requirements is usually simplified by reducing the problem to a balance equation:

Water supplied by irrigation network = water required by crop
– effective rainfall + losses + leaching requirement

The "effective rainfall" is the rainfall that can be used by the crop, and it can be calculated from an analysis of available daily rainfall data for the area, employing one of many empirical techniques. The "water required by a crop" incorporates both initial crop watering and crop water consumption by evapo-transpiration. The consumption of water is usually calculated by the application of "crop factors" to an estimate of the "open water" evaporation which can be calculated from climatic data or based on pan or tank evaporation records.

The balance equation quoted above will produce the amount of water that needs to be supplied to the plant roots by the irrigation system. Thus, to calculate the flow of water required at the head of the irrigation system allowance has to be made for the losses that are inevitable due to evaporation, seepage, wastage, inefficient application, etc.

5.2 Crop Water Requirements

The principal component of the crop water requirement is the water "consumed" by a plant, by a combination of surface evaporation and plant transpiration processes. For any particular stage of growth of a crop, the quantity of water consumed is very closely related to evaporation from an open water surface. This is usually expressed in the form:

$$E_T = f. E_o$$

where E_T is the amount of water transpired by the crop, E_o is the "open water" evaporation and f is known as the "crop factor". For any particular crop, the crop factor will vary throughout the growing season. For the project area these two factors, open water evaporation and crop factors, are discussed below.

(i) Open Water Evaporation

Many methods have been derived for the calculation of open water evaporation from climatic data, the most popular of which are those of Blaney-Criddle and Penman. The method generally accepted as most reliable, and adopted by ILACO in their feasibility study, is that of Penman. This method has been adapted by McCulloch (7) for use in East Africa.

The Penman method was used to calculate average values of open water evaporation over periods of 10 days throughout the year.

The calculations were based on climatic data collected at the two meteorological stations situated in Hola. Sunshine records at Garissa were used to supplement the Hola records which covered a very short period. The 10 day average climatic figures used to calculate Penman E_o are shown in Table 5.1. The results, and those of ILACO for comparison, are summarised in Table 5.2.

Table 5.1 SUMMARY OF 10 DAY MEAN CLIMATIC VALUES USED TO CALCULATE PENMAN E_o

Month	10 Day	Inrad* Cal/ cm²/ day	Sun Hours	Wind Speed KM/D	Air Temp C	Rel Hum %	Amb Press MB	Evap (R .05) E_o mm/ Day	Evap (R .25) E_t mm/ Day	Annual E_o mm/M
	1	489.6	8.2	131.3	28.8	59.4	1 000.0	6.258	4.970	
J	2	493.4	8.2	125.5	29.0	59.8	1 000.0	6.300	4.999	196
	3	499.1	8.2	131.2	29.0	59.8	1 000.0	6.404	5.087	
	4	500.5	8.1	140.0	29.2	59.1	1 000.0	6.528	5.204	
F	5	506.2	8.1	134.7	29.4	58.1	1 000.0	6.613	5.272	186
	6	509.7	8.1	136.8	29.4	58.8	1 000.0	6.660	5.310	
	7	534.1	8.7	137.6	29.5	59.9	1 000.0	6.881	5.464	
M	8	534.5	8.7	163.0	29.9	60.0	1 000.0	7.099	5.675	215
	9	531.1	8.7	143.6	29.5	63.3	1 000.0	6.834	5.425	
	10	533.0	8.9	168.7	29.7	64.5	1 000.0	6.975	5.558	
A	11	523.9	8.9	153.7	28.9	69.2	1 000.0	6.570	5.189	201
	12	515.3	8.9	200.5	28.4	70.0	1 000.0	6.522	5.203	
	13	479.0	8.2	223.5	28.3	68.3	1 000 0	6.317	5.063	
M	14	467.9	8.2	218.9	28.0	68.6	1 000.0	6.097	4.877	189
	15	460.4	8.2	220.5	27.6	70.3	1 000.0	5.899	4.704	
	16	446.3	8.0	244.0	26.8	66.3	1 000.0	5.836	4.689	
J	17	441.9	8.0	233.8	26.8	66.7	1 000.0	5.724	4.588	172
	18	441.4	8.0	239.5	26.3	67.1	1 000.0	5.655	4.527	
	19	441.8	8.0	243.3	26.1	63.0	1 000.0	5.767	4.641	
J	20	449.1	8.0	248.2	26.2	62.2	1 000.0	5.919	4.773	183
	21	455.5	8.0	261.0	26.4	64.2	1 000.0	6.029	4.863	
	22	479.5	8.4	263.9	26.2	63.0	1 000.0	6.274	5.051	
A	23	489.6	8.4	261.2	26.0	61.8	1 000.0	6.389	5.143	197
	24	496.9	8.4	258.5	26.1	65.0	1 000.0	6.383	5.117	
	25	504.2	8.4	267.0	26.3	65.0	1 000.0	6.545	5.257	
S	26	510.1	8.4	255.9	26.2	63.4	1 000.0	6.599	5.298	199
	27	513.9	8.4	246.9	27.1	62.0	1 000.0	6.798	5.472	
	28	537.8	9.0	239.1	27.4	62.9	1 000.0	6.987	5.594	
O	29	536.3	9.0	222.6	28.1	62.2	1 000.0	7.928	5.628	216
	30	534.8	9.0	199.7	28.0	63.0	1 000.0	6.860	5.465	
	31	515.6	8.6	141.5	28.7	63.5	1 000.0	6.503	5.147	
N	32	510.6	8.6	132.3	28.4	66.3	1 000.0	6.310	4.972	190
	33	507.7	8.6	106.9	28.4	67.1	1 000.0	6.148	4.148	
	34	482.8	8.0	106.1	28.4	65.8	1 000.0	5,933	4.668	
D	35	480.7	8.0	109.3	28.4	64.6	1 000.0	5.936	4.677	185
	36	481.5	8.0	113.0	28.5	63.9	1 000.0	5.989	4.726	
ANNUAL TOTAL								2329	1857	

VALUES MARKED * - CALCULATED

Table 5.2 - Penman Open Water Evaporation ($E_o$mm)

MONTH	Daily Average, 10 day Periods 1	2	3	Monthly Totals MMP	ILACO
JAN	6.26	6.30	6.40	196	218
FEB	6.53	6.61	6.66	186	201
MAR	6.88	7.10	6.83	215	232
APR	6.98	6.57	6.55	201	198
MAY	6.32	6.10	5.90	189	197
JUN	5.84	5.72	5.66	172	176
JUL	5.77	5.92	6.03	183	176
AUG	6.27	6.39	6.38	197	181
SEP	6.55	6.60	6.80	199	185
OCT	6.99	7.03	6.86	216	204
NOV	6.50	6.31	6.15	190	194
DEC	5.93	5.94	5.99	185	208
		Annual Total		2 329	2,370

(ii) Crop Factors

The rate of consumption of water by crops depends upon many factors such as the type and variety of the crop, the stage of growth, rate of growth and other similar variables. Consequently, the estimation of suitable crop factors is often somewhat subjective. However, field measurements taken at a pilot scheme near the project area have provided a reasonable basis for assessing appropriate crop factors. ILACO based their estimates of crop factors on experimental and field experience obtained from the Hola Experimental Station. As such these values should provide the best estimate available.

Comparison of the ILACO crop factors and those calculated for similar schemes within our experience has confirmed that the ILACO figures are within the expected range of values.

The crop factors adopted are given in Table 5.3.

Table 5.3 - Crop Factors by Months of Growth

Growth Month	Cotton	Groundnuts	Crop Maize	Cowpeas
1st	0.40	0.40	0.40	0.50
2nd	0.70	0.70	0.80	0.95
3rd	0.90	0.95	1.00	0.90
4th	1.00	0.90	0.80	–
5th	0.90	–	–	–
6th	0.70	–	–	–

A comparison between FAO and ILACO estimates for maize and cotton is reasonably consistent though differences do arise during growth and at full maturity (see Table 5.4).

Table 5.4 - Comparison With Crop Factors Published by FAO (8)

Crop	Period	FAO	ILACO
Cotton	1	0.4	0.4
	2	0.4	0.8
	3	1.05	1.0
	4	0.65	0.7
Maize	1	0.4	0.4
	2	0.4	0.8
	3	1.05	1.00
	4	0.55	0.8

5.3 Effective Rainfall

Hershfield (9) defined effective rainfall as the total rainfall during the growing season which is available to meet the consumptive water requirements of a crop. To calculate the effective rainfall for the "design" period two problems exist – first to estimate the expected rainfall for the period and secondly to estimate the proportion of that rainfall tha will be effective.

For the design of an irrigation scheme, irrigation requirements are usually based upon the one in 5 dry year. This was calculated by ranking the annual rainfall figures for the Hola rain gauge station and fitting a Gumbel-type extremal distribution, which is shown in Figure 5.1. The value corresponding to a 5 year return period is 380 mm.

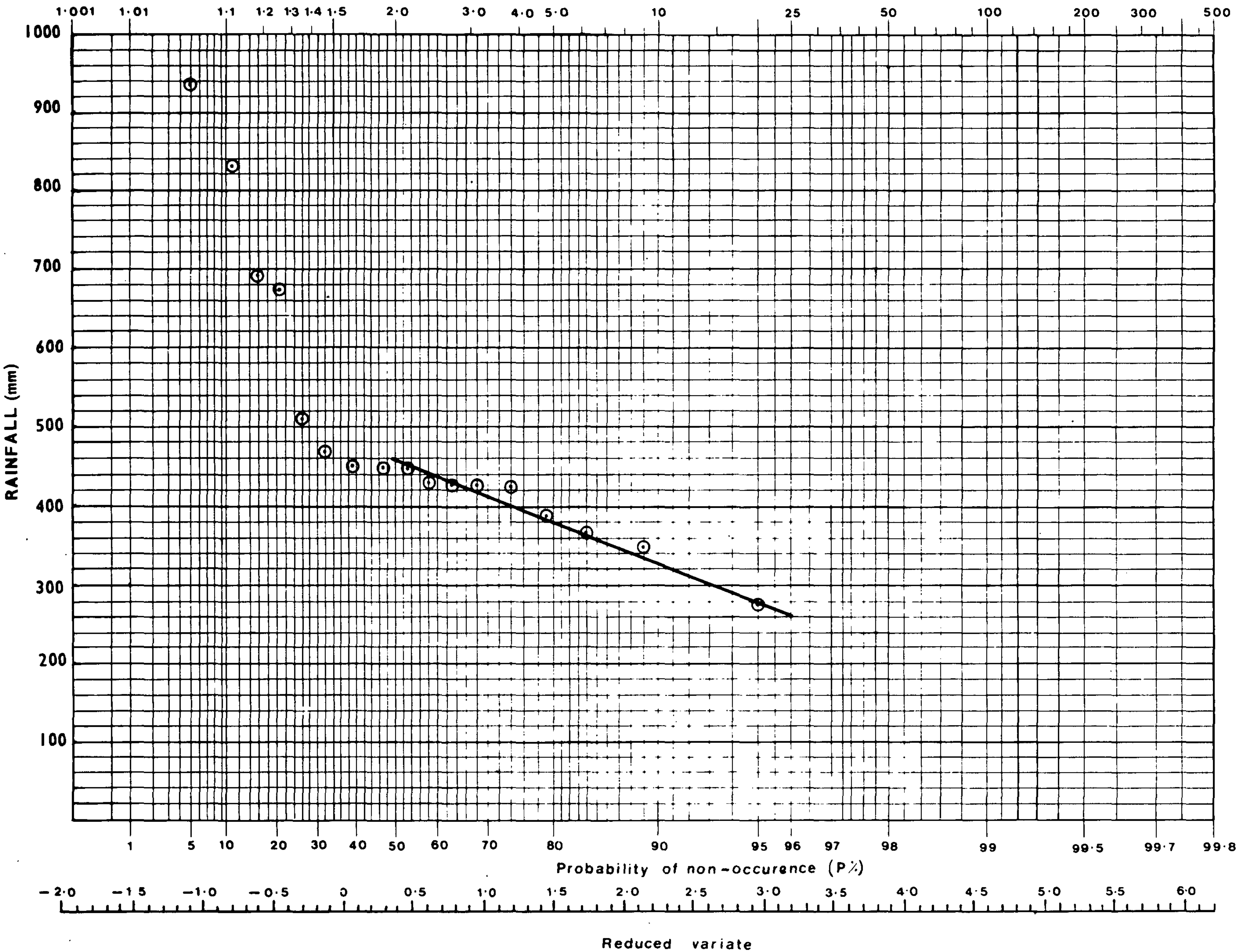
The method adopted for distributing this rainfall throughout the year on a month-by-month basis was based upon the analysis of the typical monthly distribution of rain in the five years with an annual total nearest to that of the design year. This method of calculation allows for the unequal distribution of rainfall in a typical year, and accurately reflects it (see Table 5.5).

Table 5.5 - Estimated Monthly Rainfall for a 1 in 5 Dry Year based on Ranked Monthly Value at Hola (1959-1976)

Ranked percentage of annual rainfall in typical dry years %	26	18	13	11	9	8	6	3	3	2	1	0	100
Month	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Design year (mm)	11	5	35	27	42	13	8	2	23	29	67	50	382
Design month (mm)			11		14	5							

However, when considering the water requirements in a particular month, the approach is different. For example, when designing the size of the delivery canals the analysis should be carried out on requirements for the most critical month and a frequency analysis made of monthly rainfall.

The percentage of rainfall that can be considered to be effective is a function of both the amount and intensity of rainfall, crop cover, potential open water evaporation in the area and the soil moisture at time of irrigation application. The relationship of the field water balance is



FREQUENCY DISTRIBUTION OF ANNUAL RAINFALL RECORDED AT HOLA (1959 - 1976)

FIGURE 5.1

necessarily a complex one, and difficult to determine experimentally.

Several different approaches are available. The most realistic is to simulate the water balance in the soil and at the ground surface using recorded rainfall data and allowing for irrigation at the planned frequency and application. It is questionable whether or not this approach is too sophisticated and an unnecessary detail, when arbitrary field efficiencies and conveyance losses of far greater magnitudes are applied. Numerous rule-of-thumb methods have been developed on a national basis ranging from straight percentage reductions of seasonal rainfall to others which ignore rainfall following irrigation application, whilst others introduce threshold values below and above which rainfall is considered non-effective; others introduce antecedent conditions. A common approach is to use the tables prepared by the Sprinkler Irrigation Association (1969) developed from USDA Soil Conservation Service (10).

The estimates of effective rainfall following these tables are summarised in Table 5.6.

Table 5.6 - Effective Rainfall for a 1 in 5 Dry Year

	Effective Rainfall (mm)						
Month	JAN	FEB	MAR	APR	MAY	JUN	Annual
Design Year	11	5	34	81	37	11	
Design Month			11		14	5	
Month	JUL	AUG	SEP	OCT	NOV	DEC	
Design Year	7	2	19	26	58	45	336
Design Month							

It was found that the critical months for the design of the irrigation network were May/June and for water availability was March. As a result, the 1 in 5 dry year monthly rainfall values for these months alone were calculated and processed.

5.4 Irrigation Efficiency

Irrigation efficiency can be defined as the quantity of water supplied by the irrigation network which is available to meet the consumptive water requirements of a crop, expressed as a proportion of the quantity of water supplied at the head of the irrigation system. The losses involved in effecting the transfer of water from the head of the system to the crop are usually considered to comprise of two parts: the conveyance losses and the field losses. The division between the two occurs at the unit channel level.

The conveyance losses involved in carrying water in unlined channels over a distance of more than 50 kilometres are expected to be quite large. The calculation of the probable conveyance losses is very sensitive to the estimate of the average permeability of the bed of the canal. Using values based upon the ILACO field measurements, an estimate of 30 per cent for the conveyance losses is reasonable. This value compares with ICID studies (8) for rotational supply on a predetermined schedule. However, this figure might well be reduced in time due to the sealing effect of silt deposited on the canal bed. ILACO proposed in their feasibility report an efficiency of 67.5 per cent.

The field efficiency of a project is dependent upon the standard of management and individual farmer skill, and as a result is usually a subjective assessment. Quackenbush et al. (10) estimate that field efficiency for furrow irrigation lies within the range 55-70 per cent, based on their experience in the United States. Experience in the Sudan indicates that field efficiencies of 70 per cent are possible with good management and experienced operators. ILACO estimated the probable field efficiency of the Bura Project to be 87.5 per cent, based on evidence from Hola. It would appear unlikely that these high efficiences will be realised in practice and to allow for field efficiencies higher than 70 per cent could well lead to problems associated with the under-design of an irrigation system. ICID (8) estimate field efficiencies ranging from 27 per cent to 53 per cent depending on method of operation.

As a result, it is estimated that the overall irrigation efficiency of the scheme will be 50 per cent, compared to the ILACO estimate of 60 per cent.

5.5 Intake Requirements and Field Irrigation Schedules

Before calculating the intake requirements of the project, other water needs have to be examined; these include domestic and industrial water supply, and the use of water in land preparation.

It is proposed that the water needs of the new settlements and any minor industrial users be met by abstraction from the main canal adjacent to the rural centre. A demand of 0.1 m^3/s has been estimated for the whole project area. The use of water in land preparation, control of weeds, application of herbicides, etc. depends on crop type and farm management. Usually, a pre-planting irrigation is applied to the fields, and it is estimated that 150 mm be used for the Bura area. However, due to the nature of the soils, this would be applied after the initial land preparation, and be, as a result, more of a substantial first irrigation allowance.

When calculating the supply schedule allowance should be made for soil moisture depletion at the end of the growing season: this is assumed to amount to 50 mm.

The cropping pattern assumed for the purposes of this calculation is identical to that suggested by ILACO: 100 per cent cotton followed by 32 per cent maize undersown with cowpeas and 16 per cent groundnuts. The cropped area is again assumed to be the same as that used by ILACO: 6 440 hectares under cotton and 260 hectares for garden produce.

Typical 1 in 5 dry year irrigation water requirement calculations are summarised in Table 5.7. When considering the sizing of canals, the month of May is critical. As a result, the "effective rain" allowed in the calculations was reduced to 14 mm (see Table 5.6) and the necessary supply was calculated to be 9.6 m^3/s. Similarly, for calculations involving the residual flow left in the Tana River, the March abstraction was recalculated to peak at 8.1 m^3/s.

TABLE 5.7
Monthly Irrigation Requirement Schedule

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CROP : COTTON												
E_o (mm)	196	186	215	201	189	172	183	197	199	216	190	185
Crop Factor		0.4	0.55	0.80	0.95	0.95	0.80	0.7				
Consumptive use (mm)		25	99	161	180	163	146	138				
First irrigation (mm)		150	75									
End of season depletion (mm)							25	50				
Effective rain (mm)		5	34	81	37	11	7	2				
Monthly irrigation supply (mm)		170	140	80	143	152	114	86				
Area planted (ha)		3220	6440	6440	6440	6440	6440	3220				
Water required ($m^3 \times 10^3$)		5474	9016	5152	9209	9789	7342	2769				
CROP : GROUNDNUTS												
E_o (mm)	196	186	215	201	189	172	183	197	199	216	190	185
Crop Factor	0.90								0.4	0.65	0.90	0.90
Consumptive use (mm)	176								40	140	171	167
First irrigation (mm)									150	38		
Depletion (mm)	50											38
Effective rain (mm)	11								19	26	58	45
Irrigation supply (mm)	115								171	152	113	84
Area planted (ha)	258								773	1030	1030	1030
Water required ($m^3 \times 10^3$)	297								1322	1566	1164	865
CROP : MAIZE & COWPEAS												
E_o (mm)	196	186	215	201	189	172	183	197	199	216	190	185
Crop Factor	0.8								0.4	0.7	0.95	0.9
Consumptive use (mm)	157								40	151	181	167
First irrigation (mm)									150	38		
Depletion (mm)	50											38
Effective rain (mm)	11								19	26	58	45
Irrigation supply (mm)	96								171	163	123	84
Area planted (ha)	515								1545	2060	2060	2060
Water required ($m^3 \times 10^3$	494								2642	3358	2534	1730
TOTAL WATER REQUIREMENTS ($m^3 \times 10^3$)												
Cotton		5474	9016	5152	9209	9789	7342	2769				
Groundnuts	297								1322	1566	1164	865
Maize, etc.	494								2642	3358	2534	1730
Total	791	5474	9016	5152	9209	9789	7342	2769	3964	4924	3698	2595
Water required (m^3/s)	0.30	2.26	3.37	1.99	3.44	3.78	2.74	1.03	1.53	1.84	1.43	0.97
Gardens	0.07	0.07	0.07	0.07	0.07	0.08	0.09	0.12	0.13	0.13	0.09	0.07
Total	0.37	2.33	3.44	2.06	3.51	3.86	2.83	1.15	1.66	1.97	1.52	1.04
50% Efficiency	0.74	4.66	6.88	4.12	7.02	7.72	5.66	2.30	3.32	3.94	3.04	2.08
Water supply	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Drinking pools	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TOTAL	0.8	4.7	6.9	4.2	7.1	7.8	5.7	2.4	3.4	4.0	3.1	2.1

CHAPTER 6 DRAINAGE REQUIREMENTS

6.1 Introduction

The design flow for estimating the capacity of the drains was calculated assuming that water surplus would be temporarily stored in the fields. A simple water balance method was used whereby:-

$$Q = RF - SMD - E_O - I \text{ (mm)}$$

Where	Q	=	run-off
	RF	=	areal rainfall
	SMD	=	soil-moisture deficit
	E_O	=	open water evaporation
	I	=	infiltration

The drainage design flow rate was assessed for areas ranging from 300 hectares to 3 000 hectares assuming a uniform rate of run-off from the fields over a duration of 24 hours.

6.2 Rainfall Analysis

The 24 hour point rainfall for a five year return period was calculated by a frequency analysis of daily maximum falls recorded at Hola and found to be 73 mm (see Figure 6.1). This is in close agreement with results obtained by ILACO (72 mm) but somewhat lower than estimates based on the study by Transport and Road Research Laboratory, TRRL (11) (92 mm). However, if a median maximum annual 24 hour rainfall of 50 mm is assumed (TRRL estimate = 60 mm) then the five year return period value using the TRRL method reduces to 77 mm. All values have been adjusted by a generally accepted factor of 1.13 to convert durations from rain-days to 24 hours.

Areal reduction factors were obtained, again by using a relationship derived for East Africa by TRRL, whereby:

$$ARF = 1 - 0.044\,A^{0.275}$$

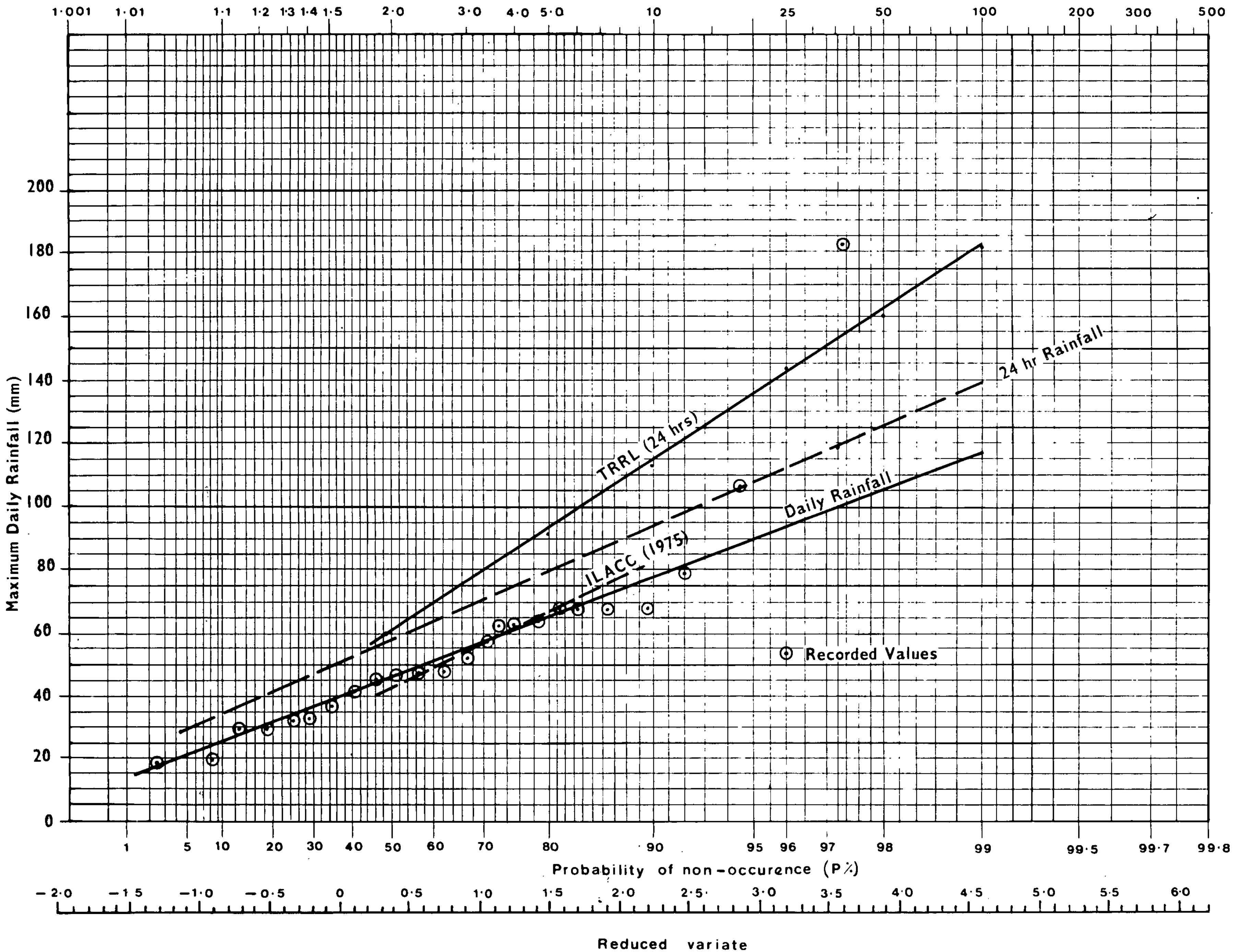
where	ARF	=	areal reduction factor
	A	=	area in km^2

Reductions using this formula are given in Table 6.2.

6.3 Surface Run-off

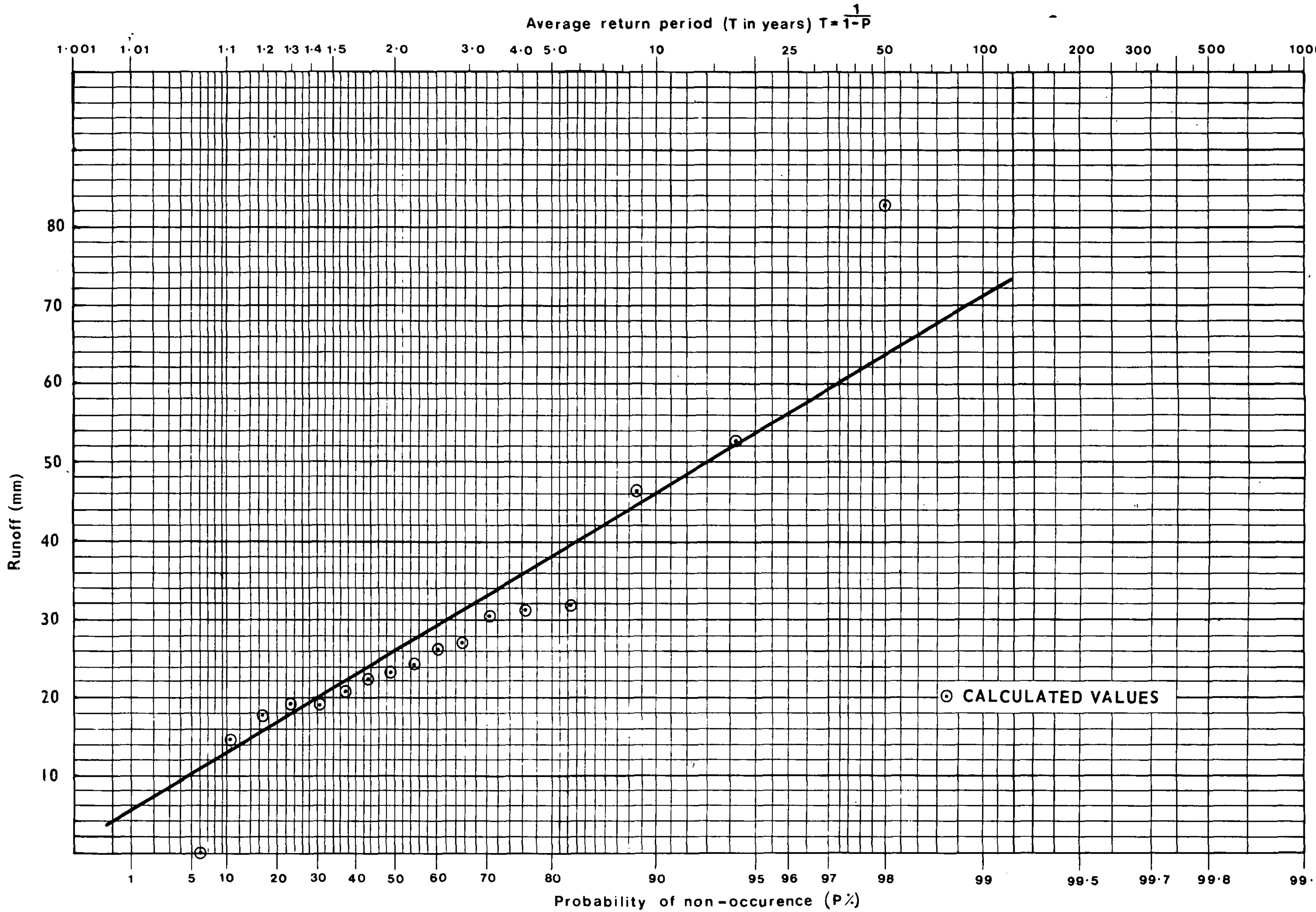
At times of peak demand irrigation applications are made at 14 day intervals with evapotranspiration losses of 6 mm per day. If, in the area being considered, no irrigation was supplied for 14 days, the maximum soil-moisture deficit would be 84 mm. However, this is an extreme case and at any one time the soil moisture deficits would range from zero to 84 mm in the event of no rainfall. An average situation is envisaged whereby one fourteenth of the area was irrigated 14 days prior to the design storm, another fourteenth 13 days prior and so on, producing an average soil-moisture deficit of 42 mm.

However, this figure is also an over-estimate since the deficit would be partly reduced by antecedent rainfall. An analysis of the mean number of rain-days (two stations, 1963-73) and of the average maximum daily rainfall (four stations, 1961-75) produced the following results (see Table 6.1).



COMBINED PROBABILITY PLOT OF ANNUAL MAXIMUM DAILY RAINFALL
AT HOLA (1959 - 1976), WAYU (1957 - 1975), BURA (1967 - 1975),
HOLA SCHOOL (1957 - 1960) AND HOLA EXPT. STN (1972 - 1975)

FIGURE 6.1



PROBABILITY PLOT OF ANNUAL MAXIMUM DAILY RUNOFF

FIGURE 6.2

Table 6.1 - Average Number of Rain-days and Mean Maximum Daily Rainfall

	J	F	M	A	M	J	J	A	S	O	N	D
Mean Number of Rain-Days	3	2	5	7	6	6	3	4	3	5	8	4
Mean Maximum Daily Rainfall (mm)	8	10	21	40	17	14	7	8	9	16	29	20

It is apparent that the design storm is most likely to occur in April, the month with the highest average maximum daily rainfall.

At Hola the average April rainfall is 83 mm. Assuming that the annual variation of April rainfall is due mainly to variations in the maximum daily fall, this leaves 43 mm to be distributed over the remaining six rain-days in the month, that is 7 mm per rain-day, or 21 mm over each 14 day period being considered assuming that 3 rain-days occur in each half month.

Not all of the 21 mm assumed average antecedent rainfall would be effective in reducing soil-moisture deficits. From tables relating evapotranspiration to rainfall given by FAO (8), 85 per cent of the antecedent rainfall would be effective, that is 18 mm. Reducing the maximum average soil-moisture deficit of 42 mm by 18 mm produces a mean soil-moisture deficit in April of 24 mm, say 25 mm.

Open-water evaporation E_o and potential evapotranspiration (P_{ET}) were calculated using the Penman equation. Since it is envisaged that water surplus to the drain capacity will be stored on the field surface, E_o is applicable and averages 6 mm/day.

No data on infiltration in the project area were available, but permeability estimates along the line of the main canal averaged 10^{-5} cm/sec, that is 9 mm/day.

Drain design flow rates were calculated using the water balance equation. The results are given in Table 6.2.

Table 6.2 - Water Balance for Estimation of Surface Run-off

					24 Hour Storage			
AREA (ha)	AREAL REDUCTION FACTOR	RF (mm)	SMD (mm)	E_o (mm)	I (mm)	(mm)	Q (l/s)	(l/s/ha)
30	0.968	71	25	6	9	31	108	3.6
60	0.962	70	25	6	9	30	208	3.5
100	0.956	70	25	6	9	30	347	3.5
200	0.947	69	25	6	9	29	671	3.4
500	0.932	68	25	6	9	28	1620	3.2
1000	0.917	67	25	6	9	27	3125	3.1
3000	0.888	65	25	6	9	25	8681	2.9

Figure 6.3 shows the relationship between the drainage area and the design drainage flow for durations of on-field storage of 24 hours.

6.4 Computer Analysis

A computer programme was employed to calculate the drainage surplus using the complete records of daily rainfall at Hola station. The water balance calculations were performed on a daily basis for the period 1960 to 1976.

The method of calculation adopted with the programme was a simple water balance, relating crop evapotranspiration, effective rainfall, soil moisture deficit and irrigation application in the following manner:

$$SMD^1 = SMD^0 + E_T - R - SRO - IR$$

where

SMD^1	=	soil moisture deficit
SMD^0	=	previous value of the soil moisture deficit
E_T	=	crop evapotranspiration
R	=	rainfall
SRO	=	surface run-off with SMD
IR	=	irrigation applied

Surface run-off was calculated according to the Soil Conservation Service Method before the effective rainfall (rainfall - surface run-off) was entered in the soil moisture balance. When the calculated value of SMD^1 became negative then the excess moisture was assumed to be available for either surface run-off or percolation to groundwater. The point area under consideration was assumed to be irrigated once every 14 days and the application being that required to bring the soil moisture deficit to zero or 84 mm, whichever was the smaller.

The annual maximum daily run-off values calculated were then fitted to a Gumbel distribution (see Figure 6.2) and the value corresponding to a five year return period was deduced to be 38 mm, before allowance had been made for percolation losses.

The analysis was made employing daily rainfall figures. In order to allow for a true '24 hour' storm the rainfall figure was increased by the generally accepted factor of 13 per cent and, as a result, the run-off was increased by eight millimetres.

No data on percolation in the project area were available, but permeability estimates along the line of the main canal averaged 10^{-5} cm/sec, or 9 mm in 24 hours. The 'net' point run-off figure was in this way deduced to be 37 mm.

As previously, areal reduction factors for the rainfall were obtained from a relationship derived by the Transport and Road Research Laboratory, TRRL (11), whereby:

$$ARF = 1 - 0.044\,A^{0.275}$$

where

ARF	=	areal reduction factor
A	=	area in square kilometres

The calculated drain design flow rates are given in Table 6.3, and the relationship between design flow rate and drainage area is shown in Figure 6.3.

FIGURE 6.3

RELATIONSHIP BETWEEN DRAINAGE AREA AND DESIGN DRAINAGE FLOW

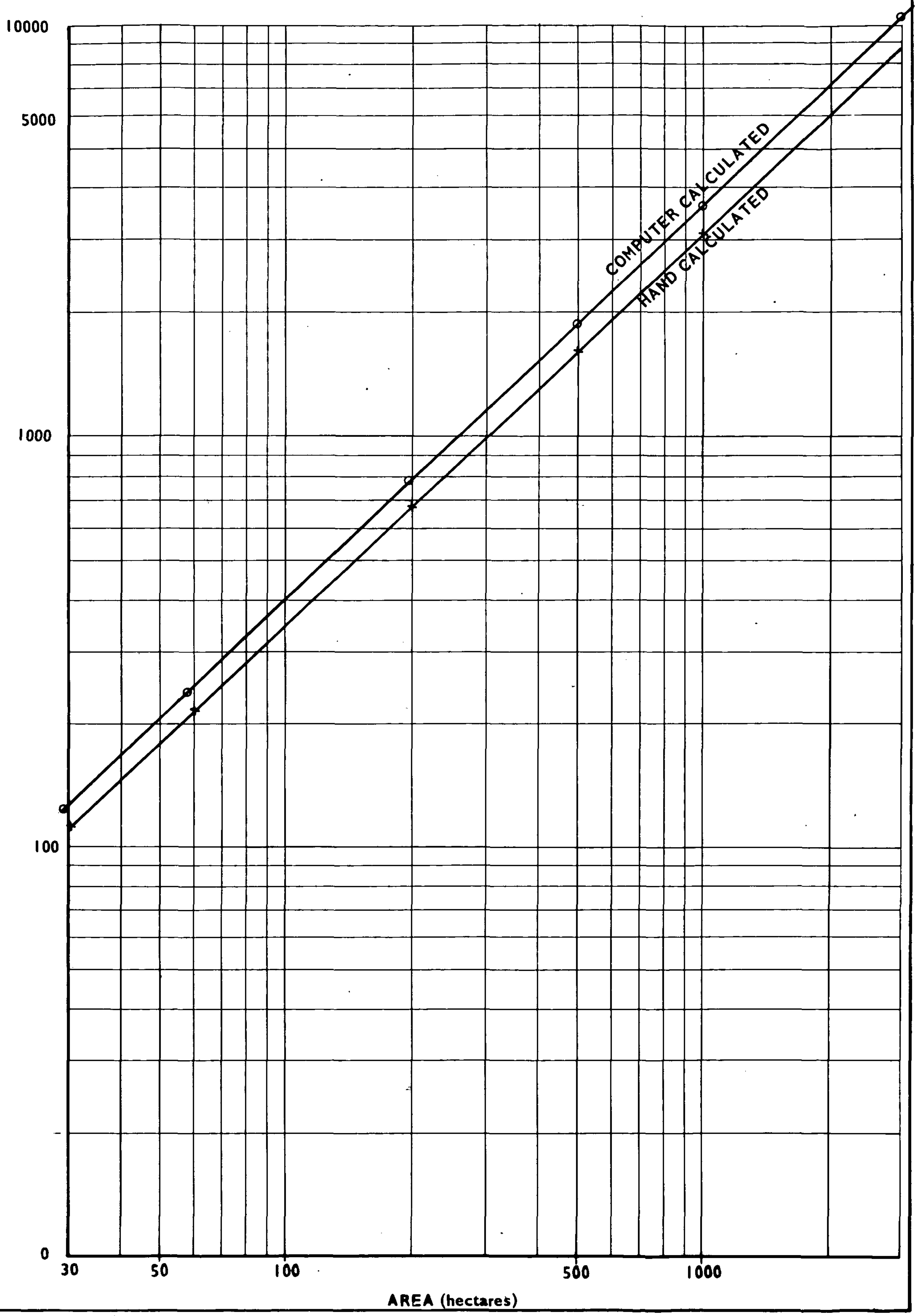


Table 6.3 - Drainage Design Flow Rates

Area (ha)	(mm/24 hours)	Flow Rate (l/s/ha)	(m^3/s)
30	35	4.1	0.122
60	34	3.9	0.236
100	34	3.9	0.394
200	33	3.8	0.764
500	32	3.7	1.852
1 000	31	3.6	3.588
3 000	29	3.4	10.069

6.5 Conclusions

The analysis using the daily rainfall data recorded at Hola to simulate the actual daily soil moisture variations due to rainfall and irrigation is considered to be more reliable than the analysis based on return period rainfall and assumed soil moisture deficits. It is recommended therefore that the drainage rates contained in Table 6.3 should be accepted in preference to the values given in Table 6.2.

CHAPTER 7 FLOOD FLOWS

7.1 Introduction

Two aspects of flood flow in natural watercourses have been investigated: peak discharges in the Tana River for design of the weir structure, and flow in the lagas (seasonal streams) for design of the necessary crossings by the main canal.

Flow frequency analysis of peak floods in the Tana River has been done in the past by a number of different agencies: the Tana River Development Authority, the FAO/Acres/ILACO study team and by ILACO alone for the 1975 Feasibility Study. Analysis for flood magnitudes in the Lower Tana River Basin have been based on the Garissa gauging station and a comparison of results shows a large measure of agreement.

There is much less information on flood flows in the lagas. A figure was produced by the Ministry of Water Development for the ILACO study, and quoted in the IBRD Appraisal Mission Report. Officials in the Ministry seemed somewhat hazy as to the origin and reliability of the figures. Rough "order of magnitude" estimates of laga flows were also made by the FAO/Acres/ILACO team. No evidence of estimated or recorded run-off in any of the lagas, in the project area or elsewhere, were found.

7.2 Tana River Flood Flows

(i) Available Records

The proposed site of the offtake weir, just upstream of Nanigi, is sited fortunately close to one of the older established, and more reliable, gauging stations at Garissa. The daily stage records at Garissa started in 1934, and have continued with little interruption to the present time. These record have provided a series of annual maximum levels for the period 1934-1975 for analysis by probability techniques. The small proportion of missing observations is unlikely to be detrimental to the reliability of the analysis.

The gauging station at Garissa suffers by not being located at a cross section with a stable river bed and, as a result, there is no fixed stage/discharge relationship. The Ministry of Water Development has produced a number of stage/discharge curves applicable to different periods of the station's history and by using these, discharges have been estimated by the Ministry to correspond with daily gauge readings.

For the purposes of this study, and to estimate the sensitivity of the overall analysis to the stage/discharge relationship, a stage/discharge curve for higher discharges was established, and assumed to apply throughout the station's history.

(ii) Analysis of Records

The estimated stage/discharge curve is shown in Figure 7.1. This relationship was used in conjunction with the annual maximum daily stage readings, to produce an annual maximum mean daily flow series. This is given below in Table 7.1.

FIGURE 7.1

RATING CURVE FOR GARISSA GAUGING STATION

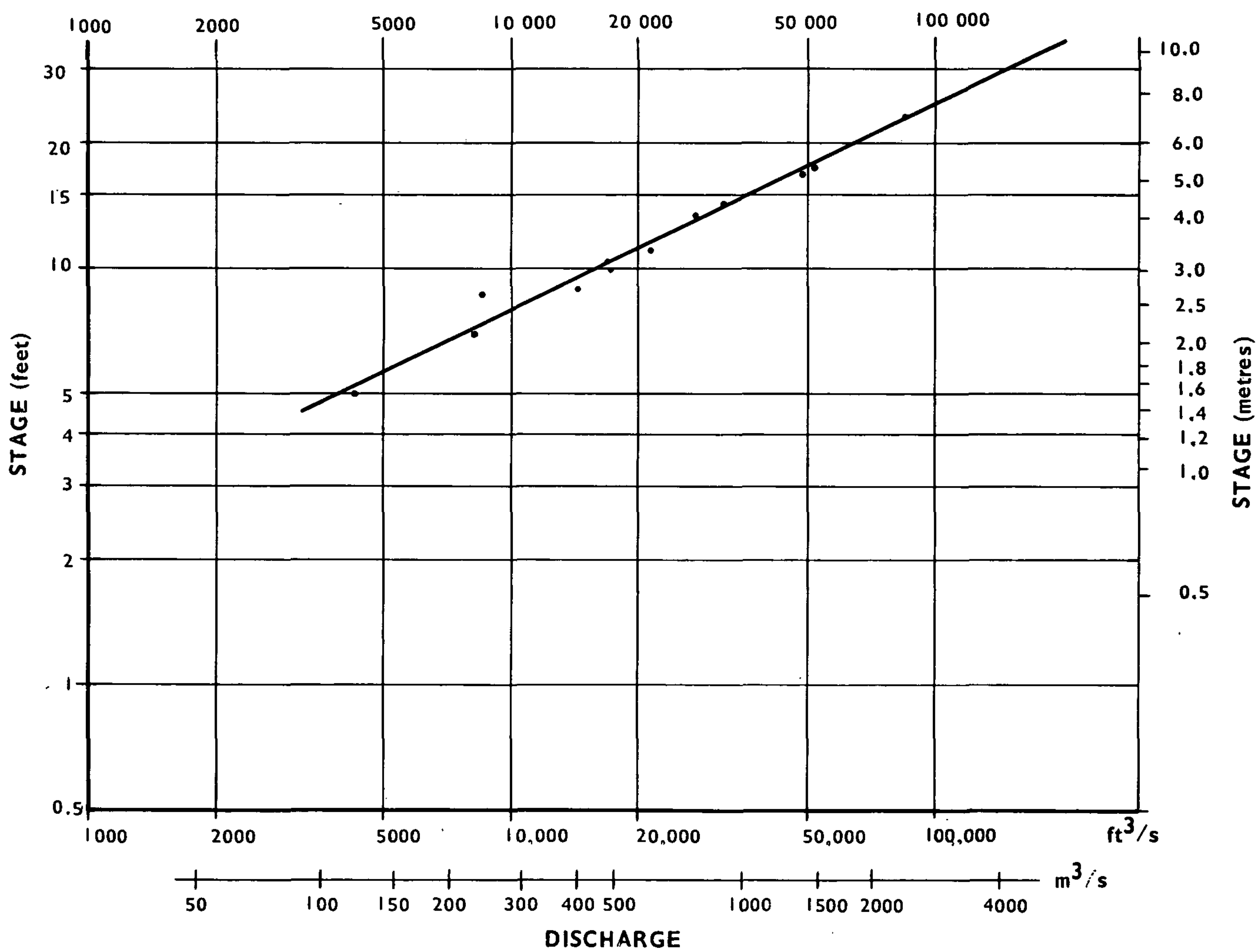


Table 7.1 - Annual Maximum Daily Discharges at Garissa

Year	Max Water Level (metres)	Discharge (m^3/s)	Year	Max Water Level (m^3/s)	Discharge (m^3/s)
1934	3.14	481	1955	3.05	343
35	2.68	364	56	5.33	1 420
36	3.66	631	57	4.45	991
37	4.33	892	58	4.60	1 080
38	3.02	448	59	3.81	680
39	2.68	364	1960	4.69	1 100
1940	4.08	781	61	7.01	2 830
41	5.27	1 470	62	4.08	835
42	4.36	910	63	5.00	1 230
43	3.81	681	64	4.79	1 160
44	3.66	631	65	3.54	623
45	3.05	381	66	4.79	1 160
46	4.02	734	67	5.46	1 470
47	4.85	1 185	68	6.00	1 840
48	3.51	522	69	3.20	510
49	2.62	243	1970	4.27	909
1950	4.21	809	71	4.08	835
51	5.09	1 370	72	4.39	963
52	3.44	474	73	3.26	538
53	3.41	462	74	3.60	661
1954	3.96	692	1975	3.60	654

This series was then ranked, and fitted to a Gumbel distribution (see Figure 7.2). From the probability plot the estimated maximum daily discharge for various return periods was estimated for comparison with previous results. A comparison is shown in Table 7.2.

Table 7.2 - Probability of Occurrence of Maximum Daily Flows at Garissa

Return Period	Discharge (m^3/s)		
	MMP 1977	ILACO 1975	FAO/ILACO/Acres 1967
1 in 20 years	1 800	1 850	2 010 (1 780*)
1 in 100 years	2 500	2 530	2 830
1 in 1 000 years	3 450	3 500	3 700 (4 110*)

*Log - normal probability distribution

As the same basic data have been used it is not surprising that similar estimates of peak flows are obtained. It is noticeable that the FAO analysis produces higher flows which reflects the influence of lower peak flows recorded since 1966. The magnitude of the largest recorded flood events at Garissa in November 1961 has been the cause of much discussion. Grundy (12) in his paper on the 1961 floods, has estimated the peak flow at Garissa to be of the order of 110 000

ft^3/s. This flow rate was a substantial reduction in the estimated peak flow rate of 200 000 ft^3/s, 96 kilometres upstream of Garissa. This could partly be explained by the considerable inundation experienced above the town, with the old road bridge also aggravating the flooding problem. Recent re-design of this bridge could well influence the flood characteristics of the Tana River below Garissa, but to an extent that it is not possible to quantify. However, comparisons between the Garissa flood analysis and that of other stations on the Tana River indicate that any changes in the calculated magnitude of more extreme events is unlikely to be significant.

The actual magnitude of the 1961 flood at Garissa has been estimated by both the Ministry of Water Development and ILACO to be about 2 410 m^3/s (85 000 ft^3/s) with a return period of 80 years (see Figure 7.3). Recently members of the current TAMS Water Resource Study have estimated the peak to be closer to 4 570 m^3/s (150 000 ft^3/s) with a return period in excess of 1 000 years. Rainfall analysis (1) suggests that the rainfall causing the 1961 floods had a return period of about 100 years. Should the TAMS study confirm that the 1961 flood peak was in excess of 2 500 m^3/s, then it may be necessary to revise the frequency curve plotted in Figure 7.2; depending on the reliability of the extreme rainfall analysis.

At Garissa the flood hydrograph follows a seasonal pattern familiar to many of the world's larger rivers especially those fed from sources with a high degree of natural storage. Minor fluctuations are superimposed on the main hydrograph but generally it is fairly regular in shape with a time base of about two months. Figure 7.4 shows two typical seasonal floods during the main wet season April-May in 1956 and 1958.

7.3 Flood Flows and Water Levels at Nanigi

Below Garissa the Tana River enters the Ngangerabeli Plains, and the floodplain through which the river meanders will provide considerable attenuation on peak flows. However, no allowance has been made for this attenuation in this report nor indeed in the other reports under review. There is therefore an inbuilt safety factor in applying Garissa flood peaks to the site of the offtake structure at Nanigi.

Based on local flood level information and Chezy flow computations, ILACO (1975) produced a stage-discharge curve for the high flood range. This curve is reproduced in Figure 7.5.

The lower part of the curve is consistent with the stage-discharge relationships based on actual measurements (see Figure 3.2) and suggest that the level of the staff gauge zero is approximately 108 metres. On present evidence the ILACO design flow and flood level of 2 418 m^3/s and 114.4 metres, respectively, are acceptable.

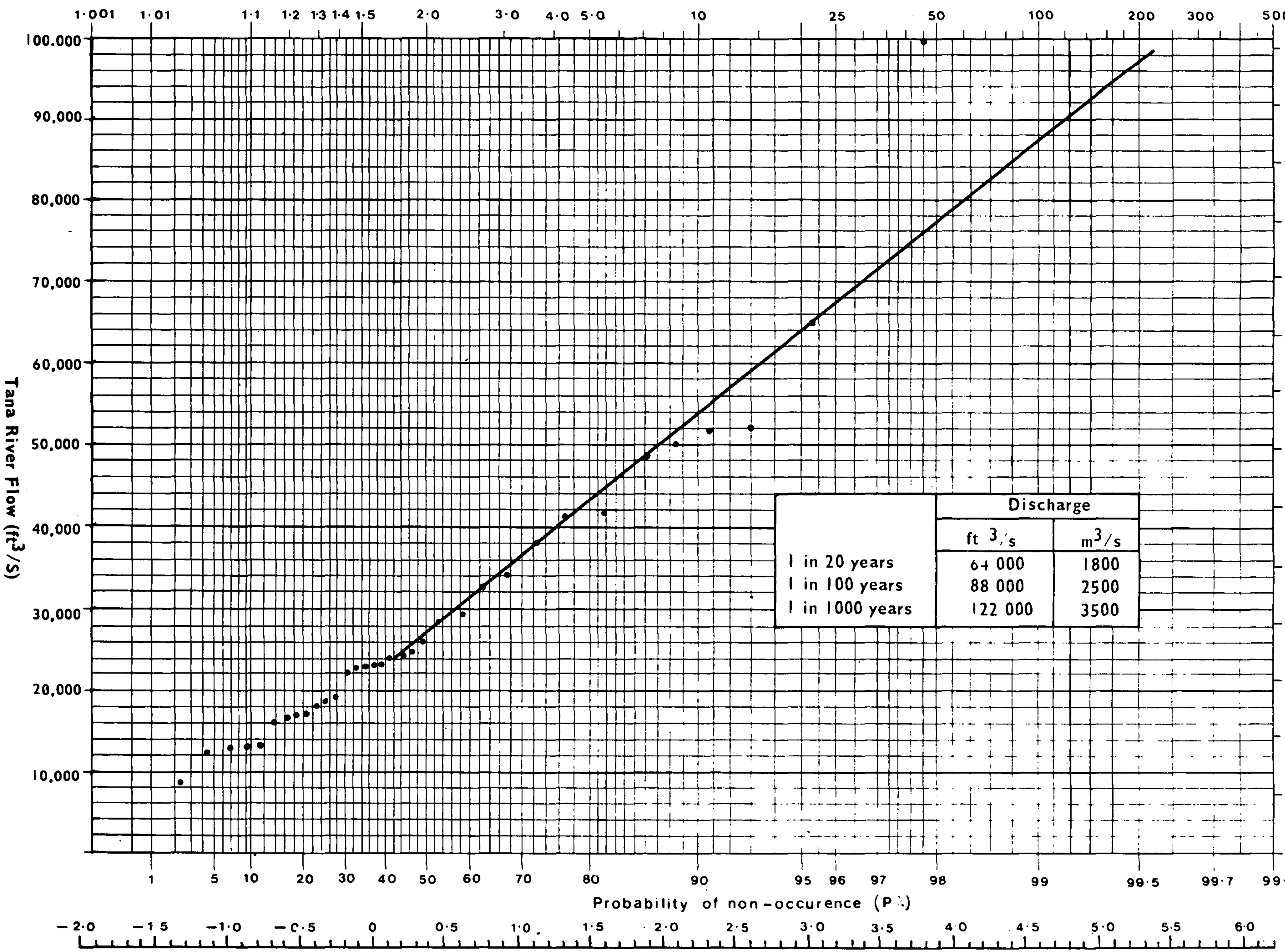
Dunne (13) prepared a duration curve for daily flow at Garissa and this is reproduced in Figure 7.6. Also, Table 7.1 and Figure 7.2 show the frequency of maximum flows which can be approximately related to level by reference to Figure 7.5. Figures 7.3 and 7.4 also give some indication of how peak daily and peak monthly flows are related. Duration curves for monthly Nanigi flows for May and March are also given in Figure 4.2, cases (1) and (2).

7.4 Natural Drainage Channel (Laga) Flows

(i) Introduction

There is no recorded information concerning the flood flows in the seasonal watercourses crossing the project area. As a result, any estimate of the flows in the lagas at specific points, such as the site of the main canal crossing, will inevitably rely on empirical methods, such as slope-area or the relationship between run-off and rainfall based on catchment parameters.

FAO/Acres/ILACO (1967) produced estimates of the volume of run-off and peak flow rate for



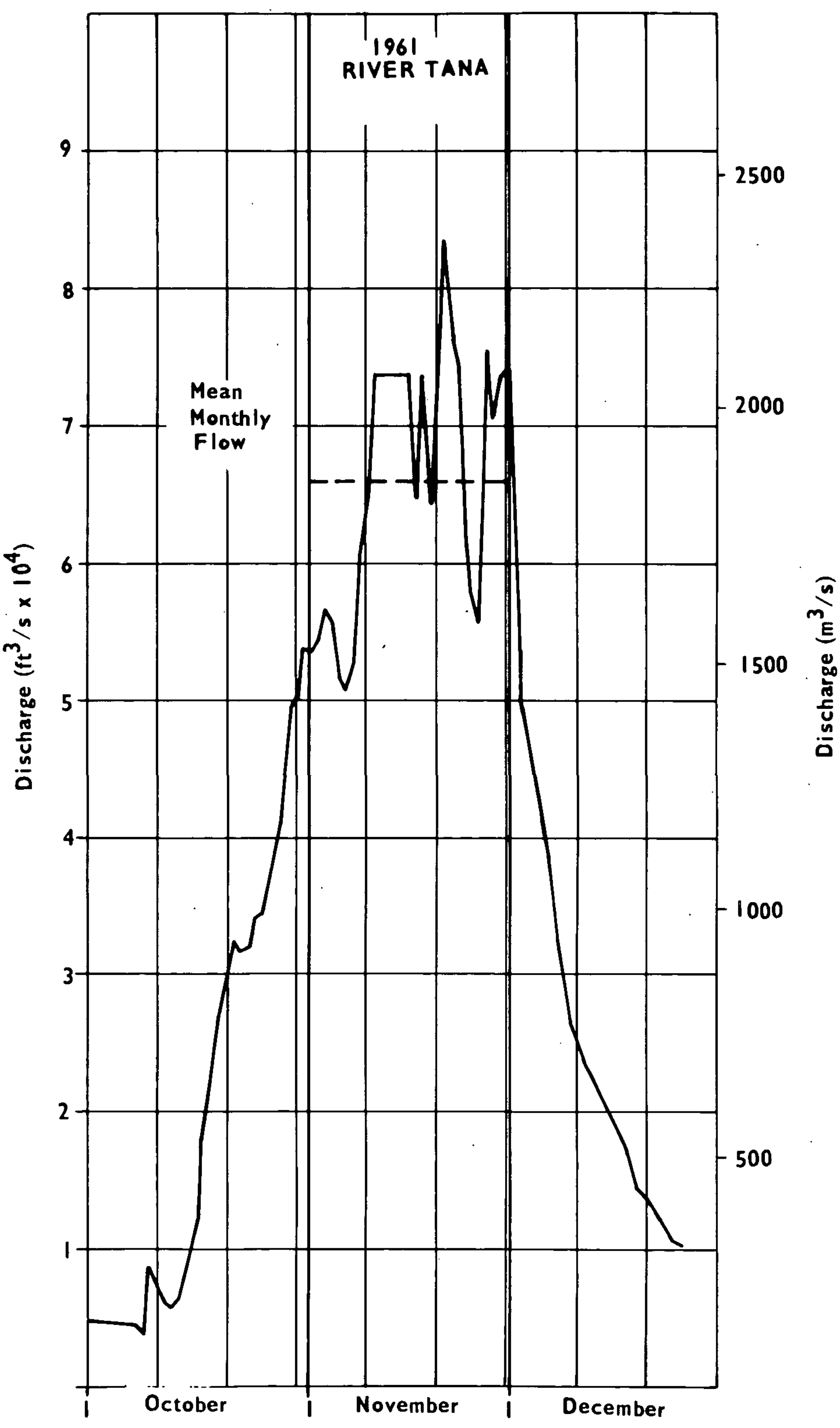
	Discharge	
	ft ^{3}/s	m^3/s
1 in 20 years	64 000	1800
1 in 100 years	88 000	2500
1 in 1000 years	122 000	3500

FREQUENCY CURVE OF ANNUAL MAXIMUM DAILY FLOWS AT GARISSA (1934 - 1975)

FIGURE 7.2

FIGURE 7.3

RECORDED TANA FLOWS AT GARISSA FOR HISTORICAL FLOOD OF 1961



some lagas in the Lower Tana River area. The means of arriving at these figures is not described, and the likely recurrence interval for the flood peak is not given. However, the estimates relevant to the present project are summarised in Table 7.3.

Figure 7.5 - Constructed Flood Stage-Discharge Curve for Nanigi

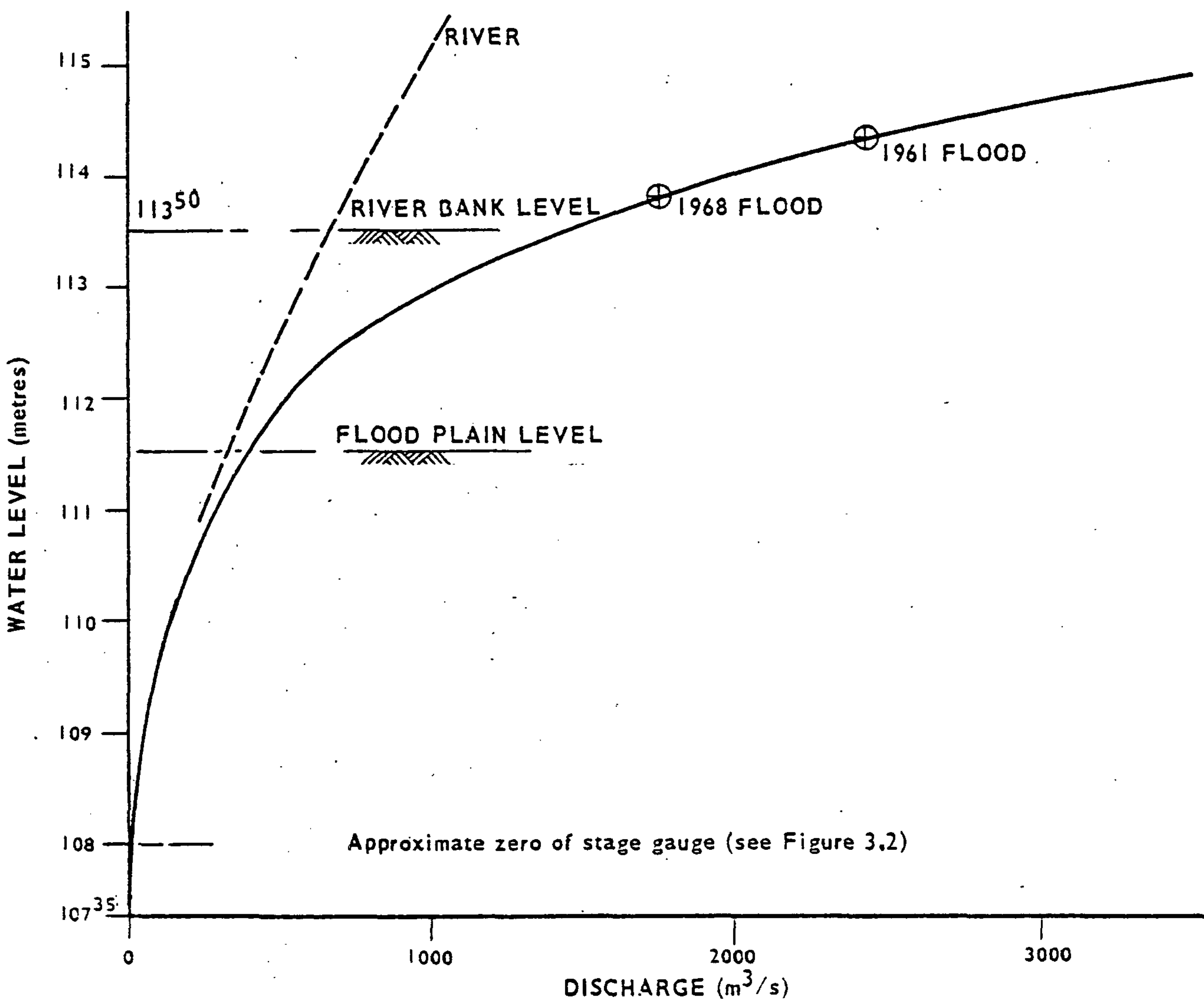


Table 7.3 - Estimated Laga Flood Peaks and Volumes - FAO/Acres/ILACO (1967)

Drainage Channel	Flood Peak (m^3/s)	Flood Volume (Mm^3)
Tula	113	10
Gelmathi	28	2.5
Hiraman (Walesa)	100	6

The general validity of these estimates was confirmed by the FAO/Acres/ILACO team by inspection of the channels.

For the ILACO Feasibility Study, estimates were produced by the Ministry of Water Development. These are reproduced in Table 7.4.

Table 7.4 - Estimated Laga Flood Peaks - MWD/ILACO

Catchment	Area (km^2)	Flood Peak (m^3/s) 1 in 25 years	1 in 100 years
Tula	3 666	85	127
Gelmathi	544	30	45
Bilbil	338	27	40
Walesa	838	37	54
Hiraman	5 631	113	170

(ii) Available Methods

The least empirical method available for estimating flood flows in the lagas is the "area-slope" method. By measurement of a typical cross-sectional area of the laga and the bed slope, estimating a roughness coefficient and using an acceptable channel flow equation, an estimate of the "bank-full" flow of the laga can be made. However, following these measurements there remains the problem of assigning a recurrence period to the flow, and estimating flows for different return periods. Due to these problems and the short time available for the study, this method of approach was not followed. The great size of the laga catchments and the minimal slopes of the area effectively eliminate most of the methods that might be employed.

The method of calculation finally adopted was that developed by the U.S. Department of Agriculture Soil Conservation Service, and described in their "National Engineering Handbook" (15). This method has therefore been used to calculate the volume of run-off. To calculate the peak run-off, a triangular unit hydrograph concept was adopted with the time-to-peak of the hydrograph being calculated according to the formula derived by Kirpich (16).

(iii) Method of Calculation

The Soil Conservation Service (SCS) found that run-off could usually be expressed as a function of two variables, the storm rainfall and a catchment parameter or "curve number". The numerical value of the curve number was found to vary with three main factors - the land use, the soil type and the antecedent moisture condition. Tables were produced to enable users rapidly to identify the "curve number" for any catchment. The method was later updated by including, for larger catchments, an allowance for "channel losses" which would cause a reduction in the size of run-off. The extent of the losses would be dependent upon a climatic index and the catchment size.

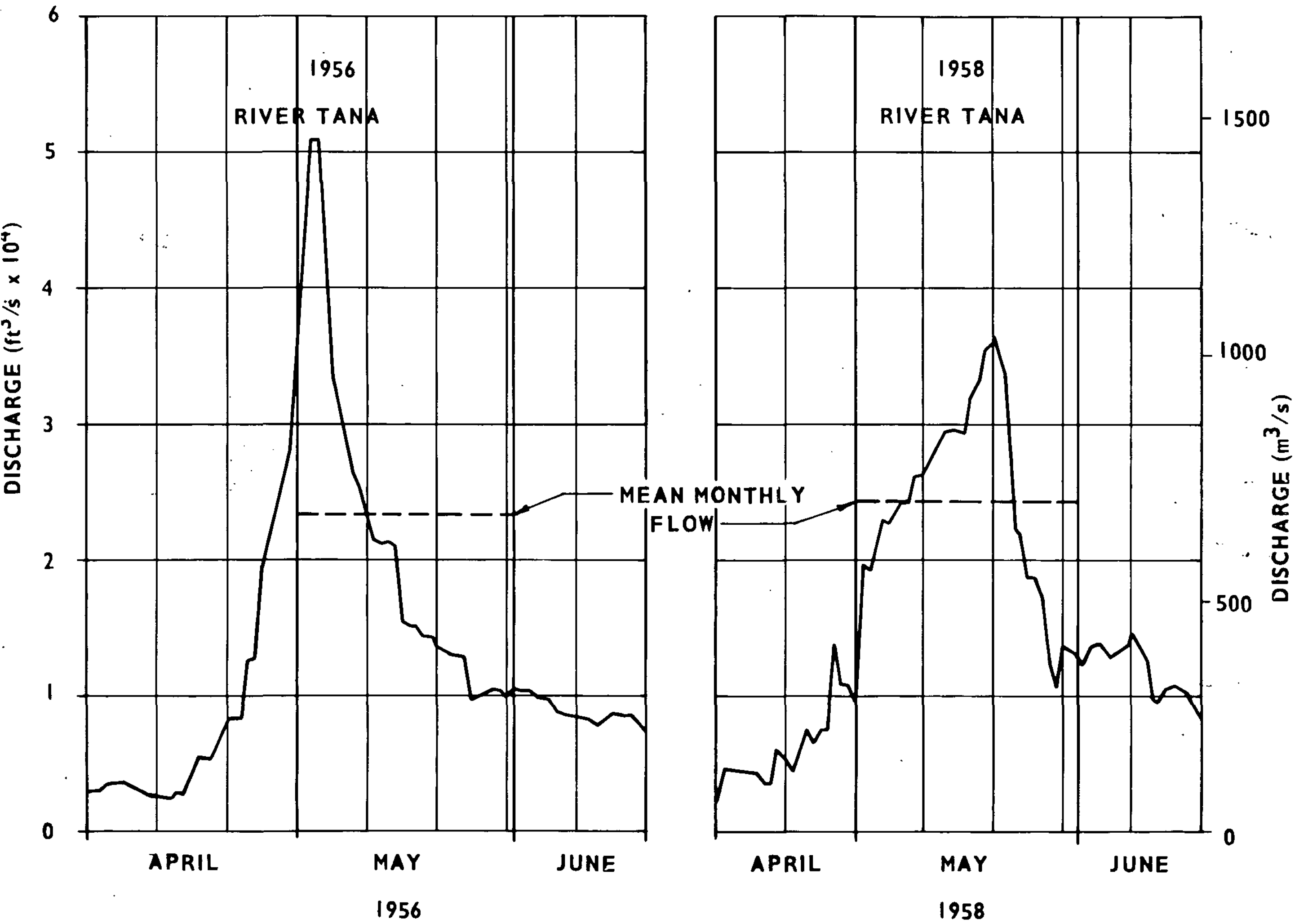
To calculate the peak flow rate, a technique using idealised triangular unit hydrographs was evolved. A typical storm rainfall profile corresponding to a convective storm was assumed, and the calculated storm rainfall sub-divided into hourly amounts. Following the use of the basic SCS method to calculate the run-off, an effective rainfall profile is calculated. Each hourly increment in the effective rainfall profile is then convoluted with a triangular unit hydrograph. The principle of superposition is then employed to produce a composite hydrograph, from which the peak flow rate can be abstracted.

(iv) Calculation of Areal Rainfall

The method of calculating laga run-off adopted, requires as basic input information an average catchment rainfall figure for each laga. The laga catchments are not at all well covered by rain gauges with four rain gauges situated close to the Tana River, and one or two at the extreme

FIGURE 7.4

TYPICAL FLOOD HYDROGRAPHS AT GARISSA - 1956 & 1958



upper end of the catchments, around Kitui. Analysis of the information available from these gauges would not necessarily yield a representative catchment areal rainfall figure, due to the lack of information from the middle of the catchments.

The British Transportation and Road Research Laboratory (TRRL) (11) have developed a method of estimating storm rainfall for catchments within East Africa. This method was adopted for calculation of areal rainfall for the laga catchments, and the results compared with estimated areal rainfall from individual rain gauge records. The two methods were quite compatible.

To estimate laga flows corresponding to different frequencies of occurrence, TRRL "growth" factors to adjust catchment rainfall figures to different return periods were used.

The TRRL methodology has been developed from studies of rainfall records within East Africa, for durations up to 24 hours. A rainfall depth/duration relationship has been found to be applicable to most of East Africa, which can be used to adapt the basic 24 hour rainfall figure (on which the method is based) to obtain rainfall amounts for different durations.

For the larger laga catchments, the time-base for the run-off hydrographs are well in excess of 24 hours and, as a result, an increase in duration is necessary. The TRRL method for increasing duration did not yield satisfactory results: producing an increase of five per cent for the difference between one day and two day rainfall. ILACO (1975) estimated an increase in rainfall amount of the order of 20 mm for the same increase in duration. This estimate appeared somewhat conservative, but was adopted in our calculations.

(v) Results

The SCS method for calculating run-off is quite sensitive to the value selected for the catchment parameter, or curve number. Because of the gentle slopes of the laga catchments, a curve number value of 55 was adopted. Analysis based upon this value produced estimated flood peak flow magnitudes somewhat larger than those estimated by MWD/ILACO, especially for the larger catchments. Due to the problems involved in, and general unreliability of estimated floods in totally ungauged catchments, it is recommended that the revised peak flows should be used in the design of the cross drainage structures.

The revised estimated flood peak flows, and associated return periods, together with the ILACO (1975) results, are given in Table 7.5.

Table 7.5 - Estimated Laga Peak Flow Rates

	Peak Flows (m^3/s)			
	Return Period - 25 years		Return Period - 100 years	
Laga	MMP	ILACO	MMP	ILACO
Tula	150	85	250	127
Gelmathi	30	30	60	45
Walesa	50	37	100	54
Hiraman	200	113	300	170
Bilbil	30	27	50	40

CHAPTER 8 SEDIMENT TRANSPORT AND WATER QUALITY

SEDIMENT TRANSPORT

8.1 Existing Information

The volume and type of sediment carried by the Tana River is important when considering the design of the river headworks and, more particularly, the sand traps at the heads of the canals. The records of measurement of suspended sediment carried in the lower reaches of the Tana River are somewhat intermittent. Once again, the bulk of the data has been collected at Garissa. Due to the practical difficulties involved, there has been very little measurement of bed load.

Investigations into the history of suspended sediment sampling at Garissa have been made by a number of agencies. Of these, the most comprehensive were made by the FAO/Acres/ILACO team and by Thomas Dunne of the University of Washington. The results of these two investigations are somewhat contradictory, which is probably due to the wide scatter in the observed data.

In the earlier FAO/Acres/ILACO report an attempt was made to allow for the variations in observed data by producing three discharge/sediment transport rate relationships, each applicable for a different period of the record, as shown in Figure 8.1. Sub-division of the data in this way indicates a reduction in silt load after 1961. This trend could be produced as a result of higher seasonal rainfall with increased vegetative cover though this has not been confirmed.

The FAO/Acres/ILACO relationship produced for the "pre 1961" data has been adopted in the ILACO feasibility study (1967), and would seem to result in rather conservative designs. The "pre 1961" relationship produces results that would be an order of magnitude higher than those obtained employing, for example, the "post 1961" curve.

The Tana River Development Authority have produced, in their report of the study of the Upper Reservoir Scheme, an estimated sediment/discharge relationship for a number of gauging stations along the Tana River. In the report, only minimal information concerning the relationship developed for Garissa is given, and this is in close agreement with the FAO/Acres/ILACO "pre 1961" relationship.

The other principal investigation into the Garissa records was made by Dunne. He identified 224 "observations" of the suspended sediment concentration made at Garissa, and, by computer, established a "line of best fit" through the data making no allowance for the date of the observations. The relationship he derived is also shown in Figure 8.1.

8.2 Analysis and Comparison of Results

Due to the short time available for the investigation, it was not possible thoroughly to pursue the difference between the two principal analyses of the Garissa sediment records. However, the simple adoption of the "pre 1961" relationship derived by FAO/Acres/ILACO appears to be very conservative, and its adoption would need to be justified by a conclusive explanation of the post 1961 trend in the records.

Comparison of the Garissa and Grand Falls sediment/discharge relationships suggests that the FAO/Acres/ILACO relationship over-estimates the volume of sediment carried by the river. The TRDA report estimates the mass of sediment carried by the Tana River at Grand Falls to be of the order of seven million tonnes per annum. The FAO/Acres/ILACO relationship produces an estimate of 23 million tonnes per annum, and the Dunne relationship 8.5 million tonnes per annum.

The amount of sediment carried by the river in the future will depend upon a number of factors.

The development of agriculture, both in the Upper Tana and in the floodplain of the lower catchment will tend to increase the suspended sediment load of the river unless a strict programme of soil conservation measures is adopted. However, this trend will be offset by the probable development of a series of dams along the Tana River for hydro-power generation. The proposed "cascade" of hydro-power stations should prove to be a fairly effective sediment trap, greatly reducing the concentrations of sediment in the lower river. FAO/Acres/ILACO have estimated that the effect of such a series of dams is to reduce sediment concentrations by 30 per cent.

8.3 Conclusions

Two sediment yield/discharge relationships have been derived, by FAO/Acres/ILACO and Thomas Dunne. The former produces an estimate of the average sediment transport rate of 23 million tonnes per year, the latter 8.5 million tonnes per year. When this is coupled to the probable development of the hydro-power potential of the Tana River, the adoption of the FAO/Acres/ILACO relationship seems over-conservative.

The relationship produced by Dunne would appear to give as reliable an estimate as it is at present possible to obtain of the sediment transport/discharge characteristics of the Tana at Garissa and thus has been used in the design of the sand trap at the head of the west bank canal. Due to the lack of alternative sources of information, the grading curve of suspended sediment produced for the FAO/Acres/ILACO report is accepted as the most reliable available (see Figure 8.2). The whole problem of sediment transport in the Lower Tana River should be investigated in much greater detail in the additional studies required for the second stage of development on the East Bank.

WATER QUALITY

8.4 General

Chemical analyses of samples of Tana River water taken at Hola and a number of points upstream were undertaken between 1955 and 1963 as part of the FAO/Acres/ILACO study (1). The analyses are reproduced in Table 8.1. They indicate that the quality of the Tana River water is excellent: the salt content is very low, EC_W 0.30 mmhos/cm; and the sodium absorption ratio SAR of 0.4 is unusually low. In consequence, the Tana River water is ideally suitable for irrigation. The effect of this quality of water on the improvement of marginal soils is discussed in the Soils Annexe.

Table 8.1 - Chemical Composition of Tana River Water

Location	Date	pH	EC	TSS	Milli-equivalents per litre							Boron	Fluor	Iron	SAR	RSC
				ppm	Ca**	Mg**	K*	Na^-	CL^-	SO_4^-	HCO_3	ppm	ppm	ppm		
Grand Falls	14- 2-63	7.3	0.09	75	0.40	-	0.05	0.43	0.17	0.04	-	0.11	0.20	nil	-	-
Adamson Falls	14- 2-63	7.1	0.10	90	0.40	-	0.05	0.47	0.17	0.24	-	0.10	0.30	nil	-	-
Koreh Falls	27- 1-63	7.0	0.13	100	0.45	-	0.05	0.70	0.34	0.08	-	0.16	0.20	nil	-	-
Jibicha Rapids	26- 1-63	7.0	0.13	95	0.40	-	0.05	0.52	0.28	0.12	-	0.20	0.20	nil	-	-
Mbala	24- 1-63	7.1	0.13	100	0.45	-	0.05	0.56	0.28	0.12	-	0.03	0.30	nil	-	-
	20- 7-62	6.5	0.26	120	0.50	0.41	0.05	0.56	0.22	0.33	-	0.04	0.30	nil	0.8	0.4
	10- 7-62	7.5	0.31	185	0.85	0.32	0.05	0.86	0.28	0.58	-	0.04	0.40	nil	0.5	1.1
Garissa	23- 1-63	7.1	0.16	105	0.65	-	0.05	0.65	0.28	0.04	-	0.14	0.30	nil	-	-
	16- 1-63	7.5	0.19	160	1.50	-	0.05	0.69	0.33	0.20	-	0.21	0.30	0.2	-	-
		8.8	0.16	-	0.71	0.19	0.05	0.75	0.75	0.20	0.90	-	-	-	3.2	0.1
	1964	8.6	0.18	-	0.14	0.34	0.05	0.83	0.88	nil	0.75	-	-	-	1.1	0.3
		8.0	0.22	-	0.62	0.74	0.02	1.20	0.06	0.30	0.38	-	-	-	1.4	1.0
		8.5	0.18	-	0.62	0.57	0.05	0.80	0.80	0.06	0.78	-	-	-	3.0	0.4
		8.3	0.19	-	0.69	0.30	0.06	0.87	0.87	0.16	0.97	-	-	-	3.7	-
Bura	1- 7-63	7.3	0.29	170	0.70	0.49	0.05	0.73	0.22	0.43	-	0.05	0.40	0.1	0.4	1.0
	6- 7-63	7.3	0.30	165	0.75	0.32	0.05	0.78	0.25	0.47	-	0.04	0.40	0.1	0.4	1.1
	3-10-63	7.2	0.16	-	0.12	0.68	0.09	0.28	0.30	-	1.45	-	-	-	0.4	-
		7.6	0.15	-	0.08	0.68	0.06	0.32	0.46	-	1.45	-	-	-	0.5	-
Hola	19- 7-58	7.6	0.11	-	0.56	0.39	0.16	0.80	0.46	-	1.30	-	-	-	0.6	-
		7.8	0.12	-	0.60	0.40	0.14	0.82	0.48	-	1.34	-	-	-	0.6	-
	26- 2-58	8.2	0.14	-	0.73	0.31	0.06	0.41	0.06	-	1.23	-	-	-	0.7	-
	18- 1-58	7.6	0.16	-	0.78	0.39	0.18	0.48	0.46	-	1.36	-	-	-	0.6	-
	16-11-57	7.9	0.14	-	0.66	0.31	0.06	0.37	0.40	-	1.30	-	-	-	0.5	-
	4-55	7.8	0.16	-	0.09	0.43	0.08	0.39	trace	-	1.38	-	-	-	1.4	-

SAR = Sodium adsorption ratio
EC = Electrical conductivity in mmhos/cm
TSS = Total soluble salts
RSC = Residual sodium carbonate value
ppm = parts per million

FIGURE 8.1

SEDIMENT RATING CURVE, GARISSA

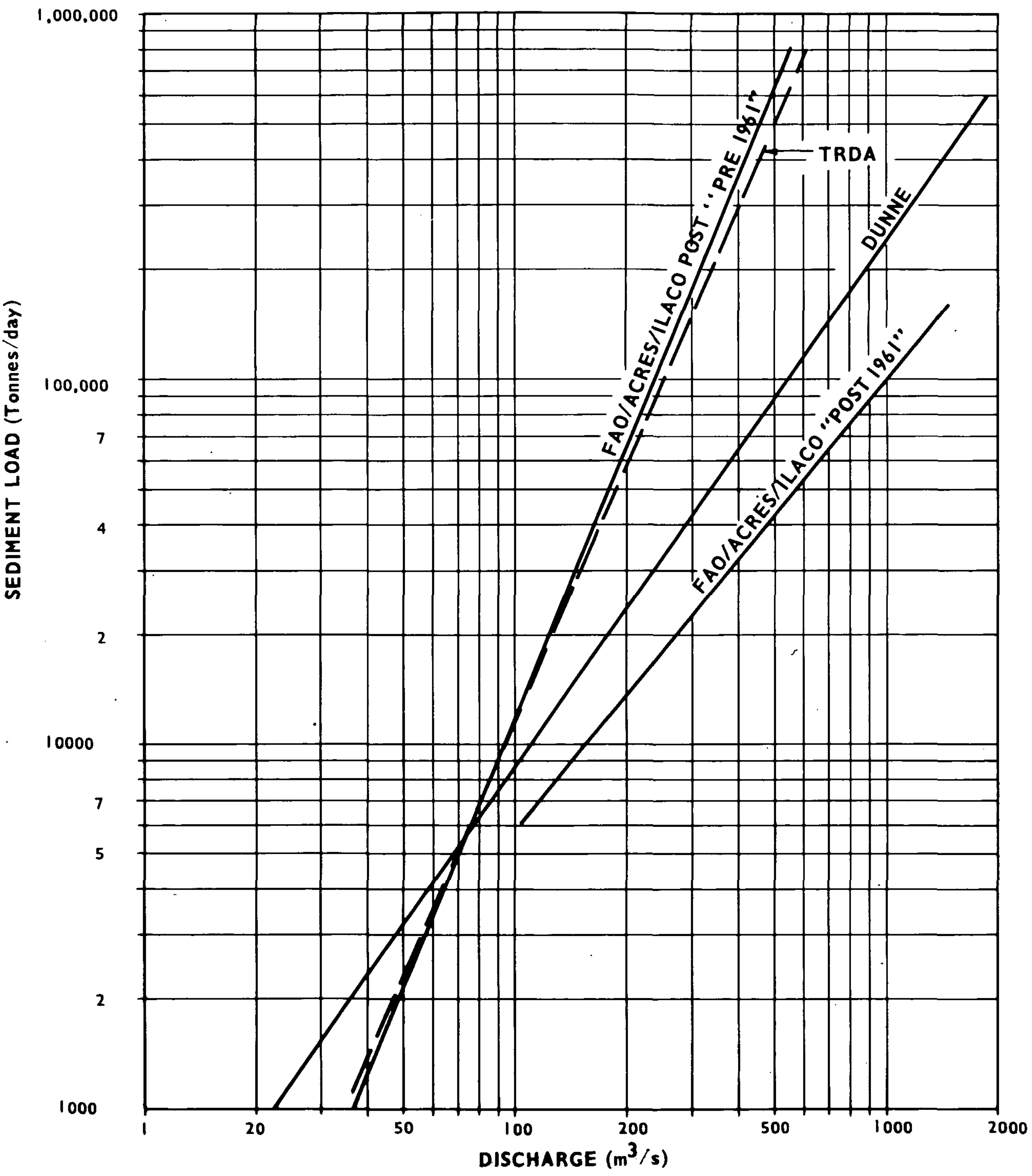
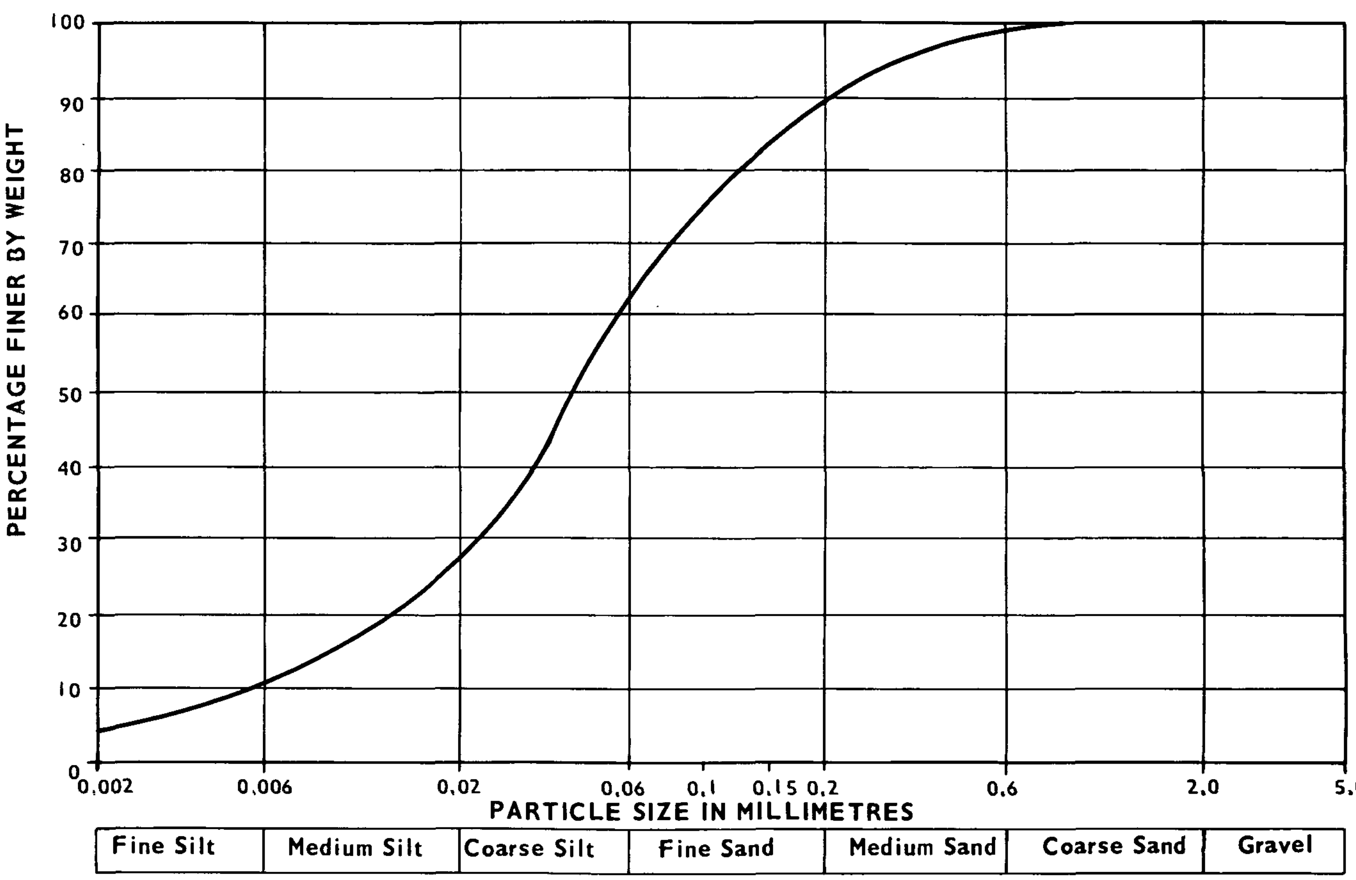


FIGURE 8.2

GRADING CURVE OF SUSPENDED SEDIMENT, GARISSA



REFERENCES

(1) FAO/Acres/ILACO (1967), Survey of the Irrigation Potential of the Lower Tana River Basin, Vol. 2, Appendix A - Hydrology and Meteorology, January 1967.

(2) ILACO (1975), Bura Irrigation Scheme Feasibility, Volume II, Annexes A and B - Climate, Hydrology and Potamology, July 1975.

(3) Tana River Development Authority (1976), Upper Reservoir Scheme, Appraisal Report, Volume I, Project Proposal, September 1976.

(4) Flare, F.K. (1961), The Restless Atmosphere, Hutchinson University Library.

(5) Meteorological Office (UK) (1967), Tables of Temperatures, Relative Humidity and Precipitation for the World, Part IV, HMSO.

(6) East African Meteorological Department (1966), Monthly and Annual Rainfall in Kenya during 30 Years 1931 to 1960, July 1966.

(7) McCulloch, J.S.E. (1965), Tables for the Rapid Computation of the Penman Estimate of Evaporation, East African Agricultural and Forestry Journal, Vol. XXX, No.3, January 1965.

(8) FAO (1975), Crop Water Requirements, Irrigation and Drainage Paper No.24, Rome.

(9) Hershfield, D.M. (1964), Effective Rainfall - Irrigation Requirements, Jour. Irrig. and Dr. Div. ASCE 90 : 3920 : 33-47.

(10) Quackenbush, T.H. and others (1957), Conservation Irrigation in Humid Areas, US Soil Conservation Agricultural Handbook 107.

(11) Fiddes, D. and others (1974), The Prediction of Storm Rainfall in East Africa, TRRL Laboratory Report 623.

(12) Grundy, F. (1963), Rainfall and River Discharge in Kenya during the Floods of 1961-62, Government of Kenya.

(13) Dunne, T. (1974), Suspended Sediment Data for Rivers of Kenya, Dept. of Geol. Sc., University of Washington, July 1974.

(14) Woodhead, T. (1968), Studies of Potential Evaporation in Kenya, EAAFRD, Nairobi, p.69.

(15) US Soil Conservation Service (1957), National Engineering Handbook, Sec. 4, Supplement A, Hydrology, 1957.

(16) Kirpich, Z.P. (1940), Time of Concentration of Small Agricultural Watersheds, Civil Eng. (N.Y.), Volume 10, No.6, June 1940.

APPENDIX A

TABLE A1

RECORDED KAMBURU FLOW (1948-72) (UNITS IN Mm^3) - NO REGULATION

YEAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	TOTALS
48/49	205.0	332.0	247.0	168.0	139.0	114.0	138.0	286.0	269.0	121.0	60.1	53.0	2132.1
49/50	209.0	147.0	110.0	81.3	84.6	66.3	72.1	101.0	134.0	87.6	50.5	99.4	1242.8
50/51	465.0	550.0	284.0	181.0	201.0	238.0	136.0	185.0	152.0	71.9	56.1	82.0	2602.0
51/52	810.0	682.0	570.0	287.0	240.0	159.0	257.0	582.0	602.0	310.0	141.0	95.2	4735.2
52/53	159.0	578.0	224.0	149.0	140.0	128.0	174.0	204.0	149.0	86.7	50.5	57.6	2099.8
53/54	101.0	333.0	184.0	106.0	111.0	92.1	181.0	226.0	198.0	108.0	64.5	52.6	1757.2
54/55	279.0	863.0	526.0	257.0	209.0	154.0	145.0	162.0	201.0	99.7	84.1	68.5	3048.3
55/56	133.0	267.0	177.0	116.0	138.0	127.0	163.0	168.0	168.0	290.0	165.0	115.0	2027.0
56/57	539.0	797.0	387.0	210.0	176.0	146.0	141.0	239.0	159.0	110.0	95.3	89.0	3088.3
57/58	321.0	1029.0	490.0	228.0	175.0	141.0	155.0	262.0	267.0	194.0	151.0	155.0	3568.0
58/59	241.0	1111.0	572.0	398.0	276.0	168.0	149.0	174.0	216.0	139.0	83.4	84.2	3611.6
59/60	222.0	544.0	297.0	177.0	163.0	174.0	123.0	184.0	169.0	97.0	76.4	104.0	2331.3
60/61	313.0	390.0	192.0	134.0	96.0	91.5	143.0	324.0	152.0	80.0	56.8	60.3	2032.6
61/62	159.0	447.0	151.0	158.0	200.0	254.0	1070.0	2786.0	1044.0	662.0	281.0	217.0	7429.0
62/63	313.0	1008.0	350.0	233.0	196.0	193.0	232.0	207.0	227.0	227.0	132.0	161.0	3479.0
63/64	859.0	1558.0	662.0	319.0	229.0	150.0	137.0	262.0	593.0	312.0	144.0	192.0	5417.0
64/65	967.0	911.0	425.0	246.0	274.0	188.0	261.0	275.0	397.0	250.0	130.0	115.0	4439.0
65/66	240.0	524.0	234.0	153.0	125.0	98.2	156.0	612.0	339.0	179.0	115.0	194.0	2969.2
66/67	807.0	817.0	391.0	235.0	168.0	145.0	141.0	594.0	207.0	116.0	77.9	79.9	3778.8
67/68	276.0	1331.0	573.0	365.0	275.0	249.0	434.0	735.0	482.0	206.0	178.0	479.0	5583.0
68/69	858.0	1017.0	663.0	393.0	293.0	194.0	215.0	832.0	1133.0	312.0	217.0	280.0	6407.0
69/70	188.0	569.0	223.0	146.0	171.0	148.0	124.0	185.0	131.0	148.0	110.0	150.0	2293.0
70/71	736.0	78.10	419.0	230.0	192.0	159.0	171.0	190.0	123.0	89.8	54.1	48.6	3193.5
71/72	259.0	794.0	354.0	236.0	215.0	150.0	132.0	132.0	152.0	127.0	156.0	100.0	2807.0
Averages	402.5	724.2	362.7	216.9	186.9	155.3	210.4	412.8	319.3	184.4	113.7	130.5	
											Average of Totals		3419.6

TABLE A2

RECORDED THIBA FLOW (1948-72)(UNITS IN Mm^3) - NO REGULATION

YEAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	TOTALS
48/49	58.7	87.7	78.4	55.9	52.2	38.4	59.1	57.0	45.3	26.9	17.6	13.7	590.9
49/50	30.0	28.2	23.3	24.2	27.0	20.4	27.3	29.5	27.1	22.8	21.7	27.1	308.6
50/51	117.0	92.1	71.1	62.7	75.1	73.7	49.2	48.6	41.7	22.1	19.2	23.8	696.3
51/52	227.0	319.0	134.0	102.0	80.4	57.7	73.7	104.0	93.5	61.1	39.1	27.3	1318.8
52/53	38.7	112.0	64.8	46.7	52.5	53.8	62.2	49.5	42.5	28.7	18.8	17.6	587.8
53/54	26.2	67.8	52.9	37.5	46.6	37.7	74.3	66.0	47.0	34.0	24.4	21.9	536.3
54/55	58.7	213.0	131.0	85.4	68.0	55.6	57.8	52.5	62.5	50.9	30.0	25.3	880.7
55/56	46.1	95.6	73.1	49.7	56.2	45.0	55.0	52.7	42.6	52.9	36.2	28.7	627.2
56/57	94.3	174.0	114.0	74.5	66.3	53.7	61.8	52.1	41.2	30.2	28.6	23.4	600.2
57/58	53.1	181.0	94.2	57.8	51.0	49.4	54.0	64.4	47.4	39.5	38.2	32.2	762.2
58/59	58.6	150.0	155.0	102.0	72.9	46.2	42.2	50.4	36.1	25.4	20.9	19.3	779.0
59/60	50.8	115.0	66.9	56.6	50.4	54.7	41.5	45.0	38.5	26.2	20.6	29.5	595.7
60/61	66.5	101.0	63.9	43.0	28.7	26.1	54.7	84.8	44.2	21.0	12.8	21.8	568.5
61/62	49.6	88.6	42.9	66.2	61.2	98.6	314.0	444.0	229.0	129.0	67.0	51.8	1641.9
62/63	58.0	150.0	73.3	54.7	51.4	53.4	58.7	51.4	57.3	39.2	24,7	30.1	702.2
63/64	89.2	339.0	1440	83.8	53.1	42.6	37.9	50.0	76.5	41.2	24.7	44.1	1026.1
64/65	119.0	136.0	98.8	58.4	62.8	46.0	74.8	70.7	62.8	50.0	29.4	28.9	837.6
65/66	57.1	62.4	58.8	34.3	43.9	28.0	51.4	100.0	77.4	45.1	30.3	45.0	633.7
66/67	128.0	131.0	100.0	62.4	48.9	50.6	63.3	189.0	71.1	38.2	24.4	23.6	1040.5
67/68	58.0	518.0	142.0	96.6	81.5	87.0	122.0	173.0	96.4	51.3	43.0	71.5	1540.3
68/69	123.0	190.0	180.0	110.0	94.3	65.5	72.2	172.0	184.0	82.4	86.3	64.3	1424.0
69/70	78.4	79.0	52.7	39.0	60.3	57.4	55.0	49.6	47.8	38.0	28.5	32.7	618.4
70/71	112.0	186.0	92.4	57.8	54.8	56.2	55.7	53.5	39.0	29.3	19.1	17.9	773.7
71/72	53.0	123.0	81.1	66.3	60.0	45.8	42.8	38.1	35.0	30.9	33.3	23.7	633.0
Averages	77.1	155.8	91.2	63.6	58.3	51.8	69.2	89.2	66.1	37.8	30.8	30.7	
									Average of Totals				821.6

TABLE A3

RECORDED GARISSA FLOW (1948-72) (UNITS IN Mm^3)-NO REGULATION

YEAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	TOTALS
48/49	251.0	612.0	331.0	230.0	199.0	151.0	160.0	550.0	651.0	271.0	128.0	87.0	3621.0
49/50	279.0	276.0	212.0	138.0	142.0	123.0	116.0	177.0	223.0	170.0	93.4	209.0	2158.4
50/51	897.0	939.0	559.0	328.0	317.0	339.0	223.0	312.0	305.0	155.0	86.9	108.0	4568.9
51/52	2440.0	1288.0	998.0	412.0	333.0	243.0	294.0	1504.0	1701.0	630.0	311.0	186.0	10340.0
52/53	234.0	820.0	392.0	246.0	213.0	172.0	227.0	349.0	333.0	190.0	93.0	103.0	3372.0
53/54	142.0	561.0	294.0	189.0	166.0	144.0	247.0	615.0	506.0	270.0	152.0	116.0	3402.0
54/55	391.0	1297.0	798.0	396.0	317.0	229.0	205.0	359.0	522.0	243.0	173.0	128.0	5058.0
55/56	253.0	458.0	319.0	201.0	224.0	194.0	267.0	353.0	362.0	426.0	289.0	210.0	3556.0
56/57	580.0	1589.0	577.0	337.0	258.0	200.0	179.0	701.0	432.0	244.0	163.0	168.0	5428.0
57/58	417.0	1469.0	632.0	366.0	266.0	204.0	217.0	650.0	717.0	349.0	304.0	267.0	5885.0
58/59	377.0	1782.0	791.0	463.0	240.0	191.0	178.0	261.0	427.0	239.0	226.0	148.0	5323.0
59/60	234.0	707.0	415.0	222.0	203.0	208.0	171.0	285.0	364.0	181.0	140.0	277.0	3407.0
60/61	546.0	619.0	275.0	200.0	164.0	148.0	373.0	704.0	317.0	172.0	123.0	114.0	3755.0
61/62	439.0	740.0	250.0	217.0	264.0	323.0	1405.0	4706.0	1731.0	1039.0	450.0	365.0	11929.0
62/63	560.0	1412.0	591.0	372.0	285.0	277.0	334.0	364.0	371.0	312.0	203.0	234.0	5315.0
63/64	905.0	2127.0	1074.0	447.0	335.0	206.0	187.0	800.0	1519.0	912.0	392.0	394.0	9328.0
64/65	1539.0	1324.0	611.0	332.0	335.0	222.0	323.0	334.0	1076.0	521.0	240.0	183.0	7040.0
65/66	326.0	665.0	324.0	210.0	178.0	124.0	180.0	843.0	493.0	268.0	177.0	286.0	4074.0
66/67	1107.0	1088.0	490.0	333.0	217.0	208.0	212.0	1083.0	383.0	228.0	143.0	143.0	5635.0
67/68	430.0	1897.0	789.0	499.0	404.0	361.0	521.0	1581.0	1015.0	481.0	296.0	962.0	9218.0
68/69	1900.0	1851.0	1083.0	613.0	439.0	266.0	307.0	1481.0	2481.0	633.0	354.0	549.0	11957.0
69/70	449.0	810.0	356.0	222.0	168.0	138.0	165.0	376.0	331.0	185.0	152.0	144.0	3496.0
70/71	1179.0	1136.0	610.0	335.0	239.0	206.0	145.0	303.0	202.0	131.0	90.3	77.9	4654.2
71/72	545.0	1147.0	500.0	305.0	240.0	190.0	105.0	395.0	347.0	207.0	190.0	135.0	4306.0
Averages	684.2	1110.0	553.0	318.5	256.1	211.1	280.9	795.2	700.3	353.1	206.2	233.1	
										Average of Totals			5701.7

TABLE A4

NANIGI FLOW (1948-72) BASED ON GARISSA RECORDS (UNITS IN Mm^3) - NO REGULATION

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	TOTALS
48/49	242.0	595.0	320.0	221.0	191.0	144.0	153.0	534.0	633.0	261.0	121.0	81.2	3496
49/50	269.0	266.0	203.0	131.0	135.0	116.0	110.0	169.0	214.0	162.0	87.5	201.0	2064
50/51	873.0	914.0	543.0	317.0	306.0	328.0	214.0	301.0	294.0	148.0	81.1	102.0	4421
51/52	2382.0	1256.0	972.0	399.0	322.0	234.0	284.0	1467.0	1660.0	612.0	300.0	178.0	10066
52/53	225.0	798.0	380.0	237.0	204.0	164.0	218.0	337.0	322.0	182.0	87.1	96.8	3251
53/54	135.0	545.0	284.0	181.0	158.0	137.0	238.0	598.0	491.0	260.0	145.0	110.0	3282
54/55	379.0	1265.0	776.0	383.0	306.0	220.0	197.0	347.0	507.0	234.0	165.0	121.0	4900
55/56	244.0	444.0	308.0	193.0	215.0	186.0	257.0	341.0	350.0	413.0	279.0	202.0	3432
56/57	563.0	1550.0	560.0	326.0	248.0	192.0	171.0	682.0	419.0	235.0	156.0	160.0	5262
57/58	404.0	1459.0	614.0	354.0	256.0	196.0	208.0	632.0	697.0	337.0	293.0	257.0	5707
58/59	365.0	1739.0	770.0	449.0	231.0	183.0	170.0	251.0	414.0	230.0	217.0	141.0	5160
59/60	225.0	688.0	402.0	213.0	195.0	200.0	163.0	275.0	352.0	173.0	133.0	267.0	3286
60/61	530.0	601.0	265.0	192.0	157.0	141.0	361.0	685.0	306.0	164.0	116.0	108.0	3626
61/62	425.0	720.0	241.0	208.0	254.0	312.0	1370.0	4599.0	1689.0	1012.0	436.0	353.0	11619
62/63	544.0	1377.0	574.0	360.0	275.0	267.0	323.0	352.0	359.0	301.0	195.0	225.0	5152
63/64	881.0	2076.0	1047.0	463.0	324.0	198.0	179.0	779.0	1482.0	888.0	380.0	381.0	9078
64/65	1501.0	1291.0	594.0	321.0	324.0	213.0	312.0	323.0	1048.0	506.0	231.0	175.0	6839
65/66	315.0	647.0	313.0	202.0	170.0	117.0	172.0	821.0	478.0	258.0	169.0	276.0	3938
66/67	1079.0	1060.0	475.0	322.0	208.0	200.0	203.0	1055.0	371.0	219.0	136.0	136.0	5464
67/68	417.0	1851.0	768.0	484.0	391.0	349.0	506.0	1542.0	989.0	467.0	268.0	937.0	8987
68/69	1854.0	1806.0	1055.0	596.0	425.0	256.0	296.0	1445.0	2423.0	615.0	342.0	533.0	11646
69/70	435.0	788.0	344.0	213.0	160.0	131.0	158.0	369.0	320.0	177.0	145.0	137.0	3377
70/71	1149.0	1107.0	593.0	324.0	230.0	198.0	138.0	292.0	194.0	124.0	84.4	72.3	4506
71/72	529.0	1118.0	485.0	294.0	231.0	182.0	98.8	382.0	336.0	199.0	182.0	128.0	4165
Averages	665.0	1082.0	537.0	308.0	247.0	203.0	271.0	774.0	681.0	341.0	198.0	224.0	5530

APPENDIX B

TABLE B1

NANIGI FLOW (1948-72) BASED ON GARISSA RECORDS WITH KAMBURU RESERVOIR AND PROJECTED 1980 ABSTRACTIONS

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	TOTAL
48/49	180.0	487.1	287.5	219.5	171.2	135.0	154.9	446.0	552.1	253.4	151.3	128.8	3171.3
49/50	213.4	170.0	150.9	120.1	116.9	128.3	114.7	143.6	129.1	148.0	124.2	188.1	1747.3
50/51	721.6	878.6	510.5	315.4	286.6	285.8	267.1	213.3	223.1	151.6	108.4	132.9	4094.8
51/52	2233.9	1220.0	939.9	388.8	290.8	269.8	221.1	1405.7	1629.3	590.3	341.8	222.8	9734.2
52/53	175.2	670.5	347.2	235.2	184.9	173.6	220.5	249.4	250.5	168.9	120.9	139.6	2936.2
53/54	85.5	408.6	262.4	188.9	139.7	148.0	236.9	509.6	419.7	242.1	175.5	158.0	2955.9
54/55	277.3	1181.4	744.3	353.2	281.9	262.0	198.9	259.2	435.3	218.1	194.7	188.5	4574.9
55/56	192.9	343.2	255.5	180.8	195.0	195.1	259.6	253.4	278.8	381.5	312.9	253.1	3101.7
56/57	422.1	1514.3	528.1	304.6	248.1	200.9	173.5	593.7	347.3	217.7	188.7	205.4	4939.6
57/58	261.3	1423.4	581.9	323.9	265.1	204.9	210.7	543.6	616.6	329.7	320.9	301.5	5388.7
58/59	302.3	1624.5	737.4	418.7	199.9	209.1	194.7	163.4	342.4	212.8	245.7	185.9	4836.8
59/60	173.8	560.0	369.7	211.7	175.1	208.8	165.7	186.8	280.8	156.2	162.2	311.2	2961.9
60/61	393.8	559.1	243.9	179.2	137.5	150.8	361.9	563.0	268.4	157.7	140.7	152.4	3308.3
61/62	372.6	588.2	219.4	195.8	234.7	253.9	1332.2	4566.7	1858.6	990.3	417.3	340.6	11170.5
62/63	519.0	1341.2	541.8	529.7	263.7	269.5	284.5	330.9	287.6	270.0	236.2	269.2	4943.3
63/64	739.9	2040.5	1014.2	432.4	292.8	242.1	185.3	890.5	1401.0	866.1	421.0	399.8	8725.7
64/65	1385.9	1255.2	561.4	290.6	292.8	219.1	249.7	290.9	1018.0	483.7	272.4	219.4	6539.1
65/66	253.5	531.0	280.7	200.0	150.6	126.9	174.2	682.1	447.9	250.5	196.7	292.1	3586.2
66/67	965.5	1024.4	443.0	291.6	217.2	208.8	205.8	916.9	340.3	211.4	165.4	181.9	5172.0
67/68	318.4	1769.1	735.5	453.9	360.3	321.1	477.0	1510.5	958.4	455.6	307.4	869.4	8536.5
68/69	1833.5	1770.6	1023.0	565.4	394.5	256.1	273.7	1379.2	2392.1	593.2	323.5	516.5	11321.3
69/70	417.1	749.8	312.0	211.7	140.8	140.3	160.2	275.5	248.5	160.0	172.3	181.2	3169.4
70/71	1007.9	1071.3	560.4	293.5	222.8	222.6	140.3	204.5	122.3	108.4	115.7	120.7	4190.3
71/72	448.6	1012.4	452.8	264.2	200.6	226.5	104.4	319.1	239.6	181.5	209.4	172.4	3831.5
MEANS	579.2	1007.3	504.3	288.7	227.6	211.5	265.3	695.7	620.3	325.0	225.9	254.6	
S.D.	549.9	514.9	253.6	106.2	72.2	52.9	241.1	917.9	590.0	231.4	93.5	162.0	

TABLE B2

NANIGI FLOW (1948-72) BASED ON GARISSA RECORDS WITH KAMBURU RESERVOIR AND PROJECTED 1985 ABSTRACTIONS

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	TOTAL
48/49	192.8	484.0	257.3	197.2	158.9	148.3	165.6	436.8	549.5	234.4	144.9	124.6	3094.2
49/50	217.0	162.4	141.3	110.5	106.4	124.4	125.6	137.2	121.3	140.2	117.3	182.7	1685.9
50/51	711.0	662.2	520.3	293.1	275.5	330.7	226.4	206.6	211.1	143.9	101.7	128.2	4009.1
51/52	2226.7	1210.5	935.5	345.5	289.6	286.8	295.5	1317.0	1626.8	590.5	319.2	218.6	9655.2
52/53	179.4	652.9	357.0	212.9	172.5	169.0	228.2	243.1	238.5	161.2	114.2	134.5	2863.8
53/54	106.2	411.6	221.1	159.3	128.8	143.5	248.0	498.7	407.7	235.0	168.6	153.8	2880.2
54/55	322.8	1119.4	739.7	373.8	273.9	223.1	208.8	252.6	423.3	210.1	187.8	164.3	4499.8
55/56	200.5	331.3	244.2	171.2	183.8	189.7	267.4	244.6	264.7	385.9	297.7	240.3	3021.5
56/57	419.5	1504.9	523.5	316.1	215.2	194.8	184.2	586.3	335.3	209.9	176.8	201.2	4867.9
57/58	354.8	1314.1	577.3	344.5	224.1	198.7	220.2	537.5	614.0	310.6	312.4	295.6	5303.9
58/59	321.5	1593.8	732.8	414.1	223.7	186.0	182.1	157.1	330.4	203.1	238.8	181.7	4765.0
59/60	176.4	542.4	379.5	189.4	162.5	202.6	176.1	179.7	288.0	148.2	155.3	307.0	2887.9
60/61	480.0	496.7	202.5	167.9	126.6	146.4	373.0	585.5	222.8	149.9	134.0	147.7	3222.0
61/62	380.2	588.3	198.9	184.5	222.1	315.1	1264.9	4565.4	1656.2	988.4	457.2	391.5	11207.7
62/63	500.4	1231.9	537.2	330.4	242.1	270.1	334.7	257.9	275.7	274.5	213.6	263.4	4752.2
63/64	737.8	2031.1	1009.6	453.1	251.6	200.7	190.9	684.2	1393.3	866.3	398.4	419.8	8676.7
64/65	1357.8	1248.7	556.8	311.8	291.6	216.3	323.9	228.5	980.0	483.9	249.8	213.9	6439.5
65/66	271.2	501.3	290.5	177.7	138.9	122.4	182.7	669.1	445.4	236.5	188.7	313.7	3538.1
66/67	935.3	1014.9	438.5	312.2	176.1	202.6	216.6	904.1	343.0	193.5	158.5	177.7	5073.1
67/68	365.2	1706.2	730.9	449.3	384.1	352.2	400.0	1509.1	955.9	444.8	304.3	854.7	8457.4
68/69	1831.3	1761.2	1018.4	560.8	418.3	259.3	308.3	1294.5	2389.7	593.5	361.3	571.4	11388.0
69/70	391.9	643.2	321.8	189.4	128.2	134.1	171.5	267.5	237.2	149.6	164.6	174.5	2973.0
70/71	1005.8	1061.9	555.8	314.2	197.7	200.7	149.8	198.2	111.0	100.3	108.8	116.5	4120.6
71/72	474.5	969.3	448.2	284.8	198.6	185.0	110.8	314.6	225.6	171.6	200.9	167.9	3752.1
MEANS	590.0	976.5	497.4	288.8	218.8	206.4	273.1	678.1	608.6	317.7	215.8	256.1	
S. D.	538.5	508.0	257.7	115.0	79.8	62.4	224.7	916.2	592.3	234.7	97.9	167.9	

TABLE B3

NANIGI FLOW (1948-72) WITH KAMBURU AND UPPER RESERVOIRS FOR PROJECTED YEAR 2000 ABSTRACTIONS (UNITS IN Mm^3)

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	TOTAL
48/49	190.4	385.0	291.2	191.8	167.8	189.8	179.8	382.8	451.6	211.5	199.4	178.5	2948.5
49/50	213.9	179.3	213.4	164.7	145.8	208.5	208.2	170.8	187.9	137.5	175.0	235.3	2183.3
50/51	587.9	469.9	420.9	281.4	244.5	272.7	245.7	242.2	224.1	141.4	163.2	170.7	3444.5
51/52	1890.0	909.1	731.4	435.1	295.8	240.4	295.0	1220.4	1390.5	601.5	456.7	381.6	8847.6
52/53	248.3	529.3	281.1	216.9	180.3	197.5	225.2	260.6	255.2	167.6	174.6	189.7	2926.2
53/54	185.5	278.2	238.8	194.2	157.0	203.8	235.5	515.4	380.8	230.2	218.6	207.3	3041.2
54/55	255.0	658.0	476.5	295.8	229.7	229.6	227.2	314.4	408.7	218.7	220.0	203.4	3735.5
55/56	262.8	299.9	292.7	208.1	196.7	218.6	260.9	302.9	265.1	223.3	254.3	238.2	3023.3
56/57	227.4	1091.0	498.6	305.9	202.6	207.2	210.1	573.2	340.9	199.1	199.3	222.5	4278.9
57/58	364.6	773.3	451.7	424.6	378.9	231.4	235.7	519.5	582.0	299.6	353.5	332.8	4947.5
58/59	327.7	972.8	558.8	383.3	256.5	315.0	321.1	348.4	293.1	197.6	288.9	223.0	4486.1
59/60	194.3	412.6	229.0	171.7	146.0	188.6	205.2	208.1	262.0	145.4	195.2	314.4	2672.5
60/61	373.7	392.4	226.0	182.9	156.2	208.3	383.2	503.4	238.3	149.0	197.8	197.8	3209.1
61/62	419.3	376.2	221.2	158.8	180.0	265.7	686.5	4199.3	1630.7	951.4	455.7	462.4	10047.3
62/63	546.3	1030.8	532.5	425.5	377.0	374.6	392.5	306.2	216.5	263.3	267.3	303.5	5036.0
63/64	350.3	1699.8	981.2	459.5	393.6	347.2	341.7	754.7	1197.5	875.4	533.9	490.7	8425.3
64/65	877.8	974.9	528.3	373.7	349.6	325.7	353.4	351.2	955.9	493.8	298.2	250.1	6132.5
65/66	279.3	430.5	201.6	165.0	141.5	178.3	181.8	489.6	359.8	222.4	234.1	341.6	3225.5
66/67	612.1	661.8	410.0	385.4	337.8	354.1	262.9	796.9	379.9	188.7	203.3	213.0	4806.0
67/68	383.8	1122.3	578.8	443.9	426.3	409.8	401.3	1288.7	930.5	557.5	405.8	790.0	7738.7
68/69	1586.2	1737.6	990.0	530.0	455.4	362.9	382.8	984.8	2364.2	621.4	438.2	555.8	11009.2
69/70	560.4	541.9	419.3	231.3	97.7	148.2	206.4	305.7	276.0	111.9	174.1	139.4	3212.2
70/71	752.0	667.1	499.6	392.3	335.9	338.4	187.3	207.0	128.1	105.9	168.4	173.9	3958.0
71/72	425.2	661.8	447.2	209.5	154.9	192.2	131.9	354.6	258.6	147.0	166.3	206.2	3355.4
MEANS	503.9	718.0	444.5	303.0	250.3	258.7	281.5	650.0	580.3	310.9	268.4	292.6	
S.D.	423.9	412.1	220.3	115.3	106.2	75.0	116.0	816.7	559.3	240.6	111.5	151.8	

BURA IRRIGATION SETTLEMENT PROJECT

PROJECT PLANNING REPORT

AGRICULTURAL PLANNING ANNEXE

BURA IRRIGATION SETTLEMENT PROJECT

PROJECT PLANNING REPORT

AGRICULTURAL PLANNING ANNEXE

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SUMMARY

The basic agricultural planning parameters, on which Phase I of Stage I of the Bura Project has been formulated, are largely those proposed by the IBRD Appraisal Mission (1977). The only aspects reviewed are those concerned with the husbandry requirements to ensure the success of the cropping pattern, the project mechanisation requirements and the research programme.

The main crop, on which the project is based, is cotton occupying the whole cropped area from February to September. The off-season crops, covering 48 per cent of the cropped area, from September to January, include maize, inter-cropped with cowpeas, initially, and later increasing areas of groundnuts. The remaining 52 per cent is fallowed, this being necessary for the timely land preparation and planting of the following cotton crop.

The project croping pattern is based on the number of tenants and the crops they grow in any year. At project maturity, from 1990 onwards, total crop areas would be:

Cotton	6 440 hectares
Maize / Cowpeas	2 060 hectares
Groundnuts	1 030 hectares
Garden crops	260 hectares

The proposed cropping pattern will only be achieved by good management and skilled husbandry backed-up by fully effective mechanisation and water supply services. Greater flexibility may be achieved by introducing shorter season crop varieties. A wider range and higher value crops would improve both tenant income and nutritional value of subsistence production. These objectives would be paramount in planning the research programme. The introduction of American cotton varieties capable of higher seed cotton yields and lint out-turn from ginning are incorporated in the cropping pattern from the start of the project.

Crop protection systems have been evolved and successfully applied at Hola. Cotton pest control is the major requirement and involves aerial application of several insecticides. Weed control is by hand hoeing in conjunction with sprayed herbicides. Bura, because of its large size, will involve greater risks of pest damage and will require skillful management of known measures, as well as the formulation of new ones. Strict adherence to a closed season at the end of the cotton crop, testing of new materials and continuous monitoring of pest populations will be important components of this activity.

The mechanisation requirements of the project have been reviewed on the basis of the crop husbandry programme and machinery capacities, with allowance being made for the introduction of tractors in the 70 to 80 horsepower class. The tractors and ancillary equipment needed, including stand-by units, are estimated to be:

Tractors (60 to 80 Hp)	72
Ploughs (3 to 4 furrow)	32
Harrows	17
Ridgers	19
Land levellers	6
Trailers (5 ton)	26
Groundnut lifter/shaker	7

Farm input requirements are estimated on the basis of rates proposed by the IBRD and the area under various crops on the project. Fertilizer application rates are projected to increase over a ten year period as the management skills of tenants improve. Total project requirements at full development would be:

Seeds (all crops)	267 tons
Fertilizer: ammonium sulphate	3 534 tons

Insecticides:	
powder forms	75 tons
emulsion forms	135 000 litres
Herbicides	5 tons

The large quantities and volumes involved will require an effective centralised purchasing and distribution system to be set up under the project management organisation.

Crop production is projected on the basis of the yields proposed by the IBRD and, at project maturity, will amount to:

	Average yield per ha (tonnes)	Total output (tonnes)
Seed cotton	3.0	19 320
Maize	3.7	7 620
Cowpeas	1.0	2 060
Groundnuts (unshelled)	2.0	2 060
Garden crops	7.0	1 820

Average project yields are related to the production capability of the Class 2 soils, but are expected to vary, for other soil classes, by up to 40 per cent in accordance with their inherent quality differences. Under adverse conditions, or during the early development years, the differences might be greater. Later with continued irrigation the differences should decrease as soils improve.

The research programme requirements are foreseen in terms of the following:

(a) The research station being established at Bura by 1981 would serve as the main centre for the whole Lower Tana River area.

(b) Four irrigated blocks covering the main soil types in the project area have been identified for the main research operations. In addition, performance of the various soils and land classes would be monitored over the whole project area.

(c) The research programme would be orientated to the operational needs of the agricultural programme aiming to aid the development of profitable farming systems. It will encompass evaluation of on-going operations as well as foreward looking activities.

(d) Early priorities include the assessment of the behaviour and potential of the shallower, marginal soils as a basis for making decisions about Phase II of Stage I on the West Bank.

(e) Activities which the agricultural programme should specifically cover include soil and water management, crop selection and agronomy, entomology and weed control.

The requirements of the programme are discussed in terms of its technical content, staffing and organisation. It is seen as an integral part of the project agricultural management operation under the direction of a Senior Research Officer.

INTRODUCTION

The terms of reference do not mention any specific technical agricultural aspects to be covered by the Project Planning Report. The Consultants have therefore considered that the basic agricultural components as proposed in the IBRD Appraisal Report (1977) be accepted as the basis for the detailed planning. Nevertheless, it has proved necessary to review certain elements, to amplify the information provided and to draw attention to defects or hazards attached to the proposals.

No working papers of the feasibility study were made available covering the basic agronomic aspects of the project, such as the selection of crops, cropping patterns, husbandry requirements, and these were not generally examined. The following aspects were reviewed as being pertinent to the preparation of the detailed plan for the Phase I area:

Cropping pattern,
Mechanisation requirements,
Research programme.

CHAPTER 1 THE CROPPING PATTERN

1.1 Basic Crops Selected

The cropping pattern proposed for Stage I (West Bank) of the Bura Project is based upon investigations and experience gained at Hola. The main components of the cropping pattern are outlined below:

(a) Cotton is the main cash crop because it is well adapted to the soils and environment generally in the Lower Tana River Basin, as indicated by the good results achieved at Hola. There is little evidence to indicate what the long-term effects of growing cotton on the Hola soils will be, although laboratory analyses indicate that in the saline/alkaline soils some lowering of the salinity levels has been achieved. It is proposed that the whole cropped area would be planted to cotton during the main season.

(b) The 'off-season' crops included are maize, cowpeas and groundnuts because progress made so far has indicated that acceptable performance can be achieved in terms of their seasonal suitability, yield and pest incidence, and due to their demand as cash or subsistence crops.

(c) A fallow break of 52 per cent has also been included in the off-season period as proposed by the IBRD appraisal mission in 1976. Thus the overall cropping intensity achieved will be 148 per cent.

1.2 Cropping Development Programme

The cropping patterns followed by tenants in their first year will depend on the time of their arrival on the project. Two typical patterns are proposed by the Consultants, as depicted in Figure 1.1, which may be summarised as follows:

(a) Tenants arriving on the project in the months of February through to August would plant a first crop of maize on 0.6 hectare in September of that year, followed by 1.25 hectares of cotton in the following February.

(b) Tenants arriving from September through to January would plant both maize and cotton as their first crops in February, 0.65 hectare and 0.6 hectare respectively being planted.

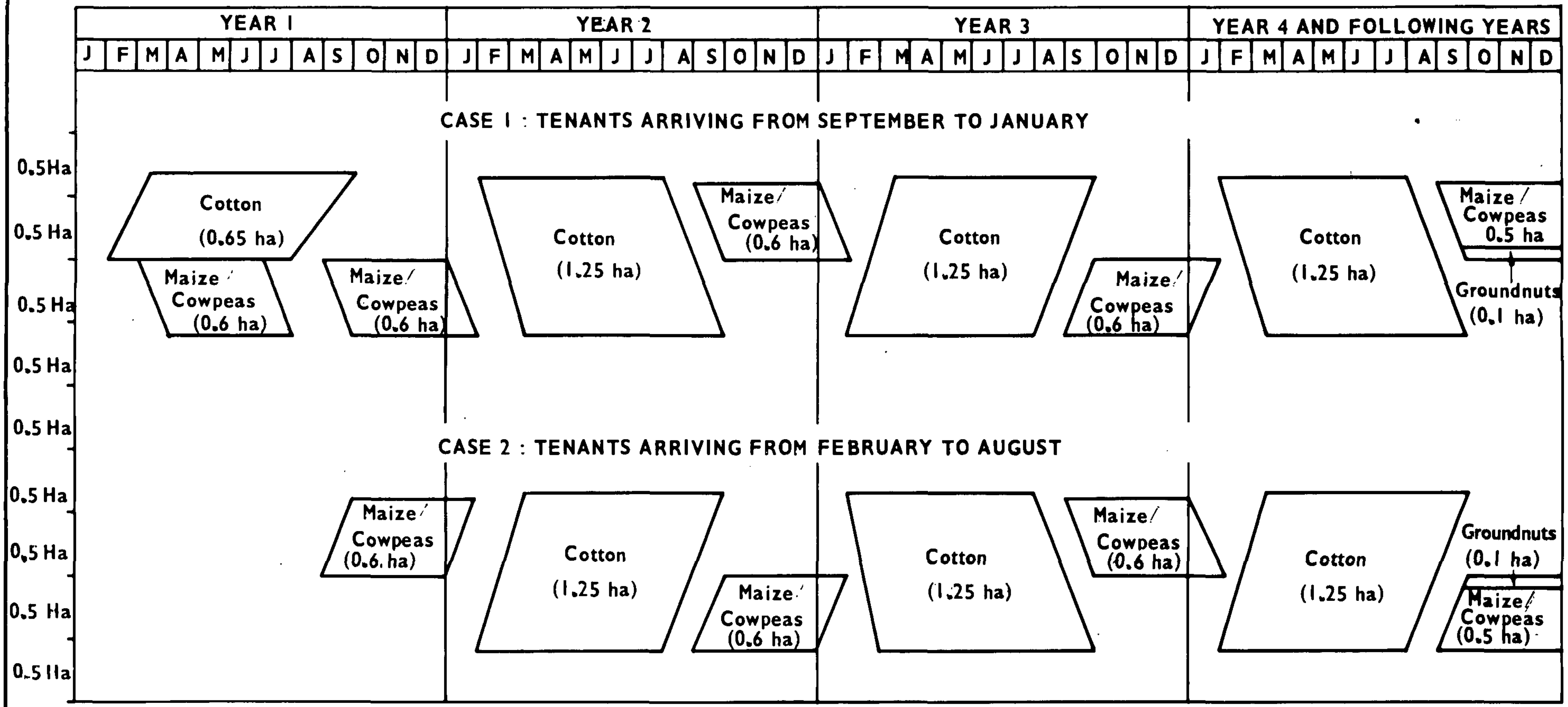
The overall project cropping development programme is given in Table 1.1. This takes account of the rate of settlement proposed and the gradual introduction of groundnuts to replace part of the maize/cowpea area, commencing in the third year after settlement for each tenant. The whole project area would be under crops by the fifth year under this programme. The final 'mature' project cropping pattern would be achieved by 1990.

1.3 Management Implications of the Cropping Proposals

One of the key factors influencing the success of the proposed cropping pattern is the length of growing season of the component crops and the period over which they may be planted without subsequent loss of yield. Highest yields of cotton have been obtained when the crop is planted between the beginning of February and the middle of March. This period must be used for planning purposes and the availability of fallow land for the earliest planting is crucial. The earliest planted cotton will be off the land by mid August and land preparation for maize/cowpeas, and in later years groundnuts, should commence immediately. Planting of the former should commence during the first half of September and the crop harvested four months

Table 1.1 - Development of the Cropping Programme (hectares)

Crop	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/9	1989/90
Cotton	–	437	2 262	4 782	6 440	6 440	6 440	6 440	6 440	6 440	6 440
Maize/Cowpeas	403	1 344	2 554	3 023	2 866	2 631	2 464	2 328	2 204	2 104	2 059
Groundnuts	–	–	–	67	224	459	626	762	886	986	1 031
Garden crops	17	90	150	260	260	260	260	260	260	260	260



Note : The above is a diagrammatic presentation of cropping patterns, timing and areas cropped, it is not intended to represent a farm plan

TENANT CROPPING PATTERNS

FIGURE 1.1

later in mid-January. Land preparation for the succeeding cotton crop would then follow immediately and land would be available for planting within a month. Meanwhile, however, cultivation will have already been started on the fallow land thus allowing timely planting and land preparation to be achieved.

The cropping pattern as presently designed has very little latitude or flexibility, in terms of the time available for completion of the various farming operations, during the year. It will demand good management in the field, sustained effort by settlers at harvest and planting times and a full complement of machinery available for operation at the peak periods of land preparation and planting from December through to March. Greater latitude in the timing of operations should be sought by selection of suitable crop varieties particularly those with shorter growing seasons. The possibility of introducing bunch-type groundnuts maturing in 90-100 days and 90 day maize varieties is important in this respect.

In addition to the above the main factors involved in achieving success with the cropping pattern proposed are early dry land preparation, early planting, proper application of the requisite nitrogenous fertilisers, early and regular weeding, application of water at the determined frequencies, quantities and depth to meet the crop water requirements, regular and ultimately complete picking or harvesting of the crops and disposal of the residues.

Bearing in mind the lack of experience likely to be found amongst project staff in the early years following its inception and the lack of skills and experience of the tenants during the same period, the operational programme will have little latitude for manoeuvre in achieving the projected yields in the initial development period. To minimise these constraints to the greatest possible extent, certain further investigational work should be undertaken with the least delay. This should be directed towards trial and selection of crop varieties to produce both higher yields and earlier maturity and greater production per unit (e.g. greater boll size or lint out-turn in conformity with acceptable quality).

In the medium term it is desirable that a wider range of crops should be examined - in regard to their place in the cash crop areas; as subsistence crops grown in the off-season or as activities suitable for farmers' gardens. Here again the Acres/ILACO Report points to some possibilities. Sesame falls into the first category; for planting on Class 1 soils, onions and chillies may prove to have a market potential; sorghum, already mentioned, as a subsistence crop; tomatoes, green and red peppers, egg plant (brinjal), melons and bananas, may also have a place in the garden plots.

1.4 Alternative Cropping Possibilities

Maize has been selected as an off-season crop on the grounds of its importance as a subsistence crop. Nevertheless it must be recognised that conditions for its growth are below optimum at Hola and Bura, and it will be affected by conditions of high alkalinity. In trials, yields of the local variety have not been high and several introduced varieties such as Coast Composite have out-yielded it.

Sorghum is better suited to the environment and, in keeping with the general view of IBRD (Agricultural Sector Study 1973), it appears to be neglected. Substitution of this crop for maize should be considered on the following grounds:

(a) The Acres/ILACO Report (1967) refers to yields of some 4 000 kg/ha at Hola. This yield is as high as the best yields of maize planted during trials and nearly as high as those resulting from interplanting of maize with cowpeas.

(b) Sorghum has the advantage of rapid growth and early maturity.

(c) It may also be expected that it would be an acceptable food crop to settlers from Western Kenya and Southern Regions.

Cowpeas, is rapidly proving to be a valuable off-season crop in trials at Hola on grounds of yield, active nodulation, human acceptability and adaptability to interplanting. It has been shown under trial to mature at 8 weeks and produce yields of 580 kg/ha.

Groundnuts are included in the cropping pattern for planting four years after the first settler intake. Although trials have been in progress since 1974, less attention has been paid to this potential cash crop than cotton. Currently results from the higher yielding varieties are promising, but as previously mentioned its continued choice as a crop must substantially depend upon the selection of quicker maturing varieties.

A fallow break of 52 per cent allows some latitude in land preparation for timely planting of cotton. In theory its inclusion also allows for cultivation to suppress weeds. In practice at Hola this is not done. The Acres/ILACO Report draws attention to increased yields of the succeeding cotton crop following a green manure crop of Sunnhemp or Velvet Beans. In the interests of raising cash incomes this system should be considered but it must not interfere with the timing of cotton planting, nor place excessive burdens on machinery resources. The system to be considered should involve minimal land preparation, e.g. a harrowing with cutaway discs, simultaneous seed broadcasting from a box mounted on the harrows immediately following the harvest of the later planted cotton (mid September to mid October) and towards the end of the maize/cowpeas planting season. A single irrigation would follow. Two to two and a half months later the green manure should be turned under as part of land preparation (including ploughing) for the succeeding cotton crop. Such a system should be tested in trials at Hola or Bura.

1.5 Plant Protection Requirements

Maintenance of full crop growth can only be achieved by early and regular weed control - this is presently carried out at Hola by a combination of hand weeding and herbicidal spraying. This system, if well supervised, achieves its purpose of controlling those weeds identified under trials and for which control has been proven. There is only one exception, that of nutgrass *(Cyperus spp.)* which infests some five per cent of the Hola Irrigation Scheme. One, *Cyperus tuberosus* produces a single bulb which can be eradicated by hand weeding. The second, *C. grandibulbosus* produces multiple bulbs and requires control by spraying. Glyphosate has proved successful but at very high cost. At present nutgrass is a potential threat to irrigated land at Hola and no doubt will be at Bura.

A further factor in maintenance of full crop growth is control of diseases and pests. Effective control measures have been worked out at Hola and applied successfully. An important step still to be taken however is to establish the status of 'black arm' incidence in the Hola/Bura area. It is of particular significance because, as far as has been determined, it is the only potential technical constraint to the introduction of American cotton varieties which have regularly demonstrated their superiority of yield, lint out-turn and boll size. The introduction of these varieties to Bura from the outset of the project could lead to lower costs of picking because of larger boll size, and greater economic benefits owing to yield in the field and economy in the ginnery operation.

Studies are now to be made of material infected with 'black arm' disease to assess its capability to survive in the environment. In addition to these studies during the next two or three seasons, steps should be taken to import American black arm resistant varieties which are available. Once the decision to introduce American varieties is taken, a bulking programme should be started as soon as possible, even if two or three blocks must be denied to settlers in the early stages of the project. Initial bulking would be carried out at Hola. Discussion of the most suitable varieties in terms of future market potential and processing are described in the Processing Annexe.

Whatever variety of cotton is finally produced the strict maintenance of the close season for cotton must be observed to minimise the possible transmission of cotton diseases to the succeeding or other crops.

CHAPTER 2 MECHANISATION REQUIREMENTS

2.1 Introduction

Estimates of mechanisation requirements were detailed in the Bura Feasibility Study (ILACO 1975). These basic figures have been used to estimate the mechanisation needs of the smaller area of Phase I of the Bura Project, with the following modifications:

(a) Experience at Hola and elsewhere indicates the need to employ larger machines to achieve the most effective land preparation in the available time. Tractors used will thus include machines in the 70 to 80 horsepower range, with tools to match their capability.

(b) Machine working rates have been modified to allow for the tractor type envisaged. Times required for operations, based on experience at Hola, and under similar conditions in other countries are set out in Table 2.1 below.

Table 2.1 - Basic Times for Various Tractor Operations

Operation	Hours per hectare Cotton	 Off-season Crops
Ploughing	2.5	2.5
Harrowing	1.3	-
Levelling*	0.5	-
Ridging	1.5	1.5
Lifting groundnuts	-	1.5

*1.0 hour per ha required every two years.

In addition to the above time spent directly on the operation indicated, about 15 per cent of a tractor's time would be spent on 'unproductive' work, i.e. travelling between plots, to servicing and parking. Thus a tractor working on 'double shift' with a potential 12 working hours available would in practice achieve 10.2 working hours.

2.2 Number of Tractor Units Required

The number of units required is determined by the peak period of work during the year, this is shown by the figures given in Table 2.2 to occur in January.

Table 2.2 - Tractor Work Programme and Requirements

Month	Operation (1)	Area (ha)	Tractor hours (2)	Working days available	Average (hours/ day)	Number of units (3) required
December	Prepare fallow area (20%)	670	4 858	20	242	20
	Lift groundnuts	1 030				
January	Prepare fallow area (80%)	2 680	17 870	24	744	62
February	Prepare off-season area (80%)	2 470	16 480	33	624	52
March	Prepare off-season area (20%)	620	4 140			

Notes: (1) Preparation includes ploughing, harrowing, levelling and ridging.
(2) Includes 15 per cent unproductive time allowance.
(3) Estimated on basis of double shift working 12 hours total per day.

On the above basis 62 units would be required to cope with the peak work period in January. To achieve the 62 'operational' units a 15 per cent stand-by allowance is made bringing the total requirement to 72 units or approximately one tractor to 90 hectares of land. The phasing of equipment is related to the area cultivated in each year, as shown in Appendix A.

2.3 Implement Requirements

A similar procedure to the above was followed to estimate the requirements for various implements as shown in Table 2.3.

Table 2.3 - Implement Work Programme and Requirements

Period/days	Implement	Total hours worked	Average hours per day	Number of machines required (1)
December (24)	Groundnut lifter	1 545	64	6
	Plough	6 700	279	27
January (24)	Harrow	3 484	145	14
	Leveller	1 340	56	5
	Ridger	4 020	168	16
February/ March (33)	Plough	6 175	187	18
	Harrow	3 211	97	9
	Leveller	1 235	37	4
	Ridger	3 705	112	11

Note: (1) Calculated on the basis of double shift working: 12 hours per day less 15 per cent unproductive hours.

The final number of implements required has been determined by allowing a reserve of stand-by units set out in Table 2.4 below.

Table 2.4 - Estimated Implement Requirements

Implement	Basic No.	Reserve	Total
Plough	27	5	32
Harrow	14	3	17
Leveller	5	1	6
Ridger	16	3	19
Groundnut lifter	6	1	7

2.4 Cotton Transport Requirements

Cotton being a bulky crop requires vehicles capable of dealing with the volume involved. The tractor - trailer combination appears suitable for Bura due to the short distance involved from villages to the ginnery (average 7 km). The transport requirements have thus been estimated as follows:

- (a) Average distance village to ginnery = 7 km
- (b) Average inwards time 0.75 hour per load.
- (c) Average outwards time 0.3 hour per load.
- (d) Average loading/unloading/weighing time 1.0 hour per load.
- (e) Average time per load 2.0 hours for 2.1 tons/load*.
- (f) Thus each unit of tractor and trailer would complete 5 trips per day and would haul 10.5 tons.
- (g) Total crop (19 400 tons) requires 2 351 trips in 70 days.
- (h) Number of units required would be 26.

*Based on 5 ton trailer unit.

CHAPTER 3 FARM INPUT REQUIREMENTS

3.1 Seed and Fertiliser

All crops will be hand planted at Bura because holdings are small and it is necessary to maintain the height of ridges. Cotton planting will require supervision to reduce the rate of seed use as indicated by the Hola situation where excessive numbers of seeds are planted at each site. Competition between plants then develops if there is any delay in thinning as was observed to occur on occasions. Plant population in maize crops will similarly require attention to ensure that optimum stands are achieved. Seeding rates required to achieve the required plant population for each crop are shown in Table 3.1.

The main nutrient applied will be nitrogen probably in sulphate of ammonia form. Rates of application projected by the World Bank increase as shown in Table 3.1, keeping pace with the rise in management standards which will occur over the first ten years of project operation. Careful monitoring of the use of seed and fertiliser inputs will be essential to ensure their effective use and in particular cost effectivness of fertilisers applied.

Table 3.1 - Seed and Fertiliser Rates

Crop	Seed (kg per ha)	Sulphate of Ammonia (kg per ha)
Cotton	20	285 increasing to 380 over 10 years
Maize	15	240 increasing to 475 over 10 years
Cowpeas	30	–
Groundnuts (shelled)	90	50

3.2 Crop Protection

Effective pest control will be essential if the projected seed cotton yields are to be attained. A variety of pests occur at Hola and these are bound to be encountered at Bura and it is probable that the challenge will be greater here due to the larger area of crop planted. Considerable care will have to be exercised in applying the appropriate control measures, which have been evolved at Hola, including scouting and application techniques.

A variety of insecticides are applied by aerial spraying, the current NIB programme involves 10 sprays with the materials given in Table 3.2. The importance of timeliness of application is paramount both in achieving effective control of pests and avoiding unnecessary sprays. The stationing of aircraft at Bura throughout the cotton season will be necessary and provision is made for landing strips to be constructed at appropriate sites in the project area (see Village Planning and Design Annexe).

Weed control measures will be largely by hand hoeing and will require continuous attention to timing and frequency. Effective programmes have been worked out and applied at Hola for all crops. These include the application of herbicides for which provision is made in the Bura projections. As indicated later in this Annexe, further trials will be needed under the research programme covering this husbandry field.

3.3 Project Input Requirements and Supply Systems

The Bura Project Management will organise the procurement and distribution of all farming inputs to tenants. The estimated total quantities of inputs required for the project at full development (1990) are shown in Table 3.3. The detailed build-up of input requirements is given in Appendix B. Bulk ordering and transportation will be important in keeping supply costs to a minimum in the Bura situation due to its remoteness from major supplier depots. A system of village storage points from which tenants will draw their requirements is provided for in the village infrastructure plans.

The operation of this system will be under the control of the Supply Officer in the project management headquarters.

Table 3.2 - Plant Protection Requirements

Insecticide	Cotton Spraying No. Sprays	 Qty. per ha	Qty. per ha
Endosulfan 35%	6	20.0 litres	Diuron 1.5 kg
DDT 75% W.P.	3	3.9 kg	
Carbaryl 85% W.P.	5	7.7 kg	
Dimetheote	2	1.0 litres	

Table 3.3 - Project Input Requirements at Full Development
Phase I, Stage I, Bura Project

Crop	Seed (tonnes)	Ammonium Sulphate (tonnes)	DDT (tonnes)	Carbaryl (tonnes)	Endosulfan (1000 litres)	Dimetheote (1000 litres)	Diuron (tonnes)
Cotton	129	2 505	25.1	49.6	128.8	6.4	4.8
Maize/Cowpeas	45	980	–	–	–	–	–
Groundnuts	93	49	–	–	–	–	–
Total	267	3 534	25.1	49.6	128.8	6.4	4.8

CHAPTER 4 CROP YIELDS AND PRODUCTION PROJECTIONS

4.1 Potential Yields

Basic yield potential is determined primarily by the environmental factors of climate and soils, and the extent to which this is realised in practice depends on management factors. For Bura the experience at Hola provides reliable evidence of yield potential as determined by environmental factors and under the management obtaining there. There is no evidence to suggest that conditions at Bura will differ markedly from Hola, in fact the majority of soils, based on the ILACO assessment will be somewhat better.

The potential yields of the main crops to be grown at Bura have been estimated by the World Bank and are shown in Table 4.1.

4.2 Projected Farm Yields and Project Production

The average yields which farmers at Bura are likely to achieve have been projected by the World Bank on the basis of experience at Hola. In making their projections allowance has been made for yields to increase over five to six years as experience and farming expertise of tenants improve. The expected crop yields are given in Table 4.1 and the overall projection of production in Table 4.3.

Table 4.1 - Potential and Expected Crop Yields (tonnes/ha)

Crop	Potential Yield	Expected Yield in Year of Production 1	2	3	4	5	6
Seed Cotton	5.5	2.5	2.6	2.7	2.8	2.9	3.0
Maize Grain	5.0	2.0	2.5	2.8	3.1	3.4	3.7
Cowpeas	1.5	0.5	0.6	0.7	0.8	0.9	1.0
Groundnuts (unshelled)	4.5	1.4	1.6	1.8	1.9	2.0	2.0
Home garden crops	–	7.0	7.0	7.0	7.0	7.0	7.0

4.3 Possible Yield Variations

The actual level of yield achieved by tenants is bound to vary over the project due to differing soils, management ability and the incidence of climatic, input supply situations and pests or disease outbreaks.

In the Soils Annexe attention is drawn to the variation in the quality of soils over the project area. It is probable that these variations will also reflect in the yields attained by farmers located on the different soil types. The average project yield is equated to the yield on Class 2 land and the yields from the other three classes can be derived, taking into account the proportions of the project area on each class of land. These yields are shown in Table 4.2 below.

Table 4.2 - Crop Yields Related to Soil Classes (tonnes/ha)

Crop	Soil Classes: Class 1	Class 2	Class 3	Class 4
Cotton	3.4	3.0	2.6	2.3
Groundnuts	2.4	2.0	1.4	1.2
Maize	4.1	3.7	3.1	2.8
Cowpeas	1.2	1.0	0.9	0.6

Table 4.3 - Overall Project Crop Production

Crop	Estimated Production by Cropping Season * (in tonnes)										
	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
Seed cotton	1 092	5 703	12 319	16 996	17 640	18 284	18 844	19 208	19 320	19 320	19 320
Maize	810	2 890	5 900	7 770	8 300	8 410	8 550	8 480	8 150	7 780	7 620
Cowpeas	200	710	1 450	1 920	2 100	2 190	2 270	2 280	2 200	2 100	2 060
Groundnuts (shelled)	—	—	—	61	212	463	1 689	913	1 115	1 273	1 340
Home garden crops	119	630	1 050	1 820	1 820	1 820	1 820	1 820	1 820	1 820	1 820

* Crop output related to fiscal year in which production will occur.

The average project yields are for Year 6. It should be noted that the yields in the above table represent only one solution. In terms of relative yields it corresponds to the figures shown in Table 4.4.

Table 4.4 - Relative Levels of Crop Yields

Crop	Ratios for Soil Classes			
	Class 1	Class 2	Class 3	Class 4
Cotton	1.15	1.00	0.85	0.75
Groundnuts	1.19	1.00	0.68	0.61
Maize	1.12	1.00	0.85	0.75
Cowpeas	1.18	1.00	0.85	0.63

It could be argued that the yield differences between the land classes are too large. For the first three classes they are close to the ILACO Feasibility Report estimates, with a further reduction for Class 4. It seems likely that in a bad year, or in the early years of settlement, yields 20 per cent below the projected figures may well occur if newly trained farmers on shallow soils are confronted by adverse climate and pest situations. As has been indicated earlier it is expected that continued irrigation will improve the soils of the project area, and it is hoped that this improvement will be most effective on the shallow soils which comprise most of the Class 3 and Class 4 land. There should therefore be some closing of the yield gap between the soil classes.

CHAPTER 5 RESEARCH PROGRAMME

5.1 Introduction

These proposals are based upon ideas and requirements found in the Acres/ILACO Report of 1967, Progress Reports of the Dutch Research Team at Hola since 1974, the Dutch Programme for additional research effort at Hola and Bura which has just started and continues to 1980/81, and the IBRD Appraisal Report of 1977. It has not been possible to study the Research Progress Reports of the period between 1967 and 1974, nor was the final report of the present research specialist at Hola made available.

Two points should be mentioned in regard to development of research in the Hola/Bura areas. First, IBRD states that the centre at Bura will become the main focus for research efforts in the Lower Tana River Basin while the Dutch programme refers to Bura as a substation, implying that the main research effort will continue at Hola. Taking account of the size of the Bura Project, its differing soils pattern and its greater security of water supply, it is assumed that the IBRD view will prevail. Second, it is a condition of IBRD financing for the project that research facilities at Bura should be established by July 1981. An early start to research work at Bura in advance of the arrival of settlers and the farming activities is in all ways desirable, but will have to take account of the delivery of water on the Project at the beginning of 1980. Hence the planting of uniformity trials could commence at the earliest in the first season of 1980. Some consideration might be given to providing a temporary water supply in advance of 1980 or (and more likely) guidance to management and tenants, based on research results, which will only be forthcoming for two or three seasons after the water and the first settlers arrive.

Finally, the investigations at Bura are evidently to be supported by staff and resources from two different financing agencies and it is essential, to achieve maximum benefit from the research activities, that they should be clearly and fully co-ordinated to avoid either duplication of effort or lack of coverage of desirable lines of research.

5.2 Selection of Areas for Investigation

Four areas of land, shown in Figure 5.1, have been identified for use in the research programme. Their selection has been made by superimposing the irrigation layout over the soils maps of the Phase I area at a scale of 1:5 000. The areas correspond to four irrigation blocks each of 33 hectares and comprising the equivalent of 24 settlement units. Two blocks served by the Pumwani canal are adjacent and convenient to the rural centre. The third block is served by the Chewele canal and the fourth by the Bura canal.

Sufficiently large areas should be obtained in each block to afford adequate opportunity for experimentation on the principal soils of the Phase I area. These include the Camborthid (C) soils, Halorthid (S) soils, the Grumerstert (GU) and the N41 type of Natrargid Soils. Units of the soils of Phase II area occur in large enough blocks for observational work. The occurrence and distribution in the Phase I area of the soils typical of the Phase II area is such that adequate land could only be found by selection of four blocks whose total area is greater than that required for research alone. Even in the long term it should not be necessary actually to use more than some 100 hectares for research purposes. It is further proposed that behaviour of all soil types should be studied by the careful monitoring of their use on tenants' holdings.

A considerable quantity of Camborthid soil has been included in the experimental blocks to allow for its study under a wide range of circumstances and in particular under intensive cropping trials. The outcome of these trials will be of particular benefit if the Stage II development on the east bank of the Tana River is undertaken, where large areas of C soils have been identified in a reconnaissance soil survey by the Soil Survey of Kenya. However, the similarity of the soil types on both banks should be confirmed at an early stage.

It is known that within a mapped unit a relatively wide range of soils has been included. Some of these differing soils will have similar crop production capabilities; with others this will not be the case and in interpreting field trial results, and also in planning trials, it will be necessary to have detailed soil maps of the experimental areas.

We propose that the necessary detailed survey should initially be at a scale of 1:2 500 and would involve one sampling site per 1.25 hectares. The results of this survey should be tested by detailed observations of crop performance in early uniformity trials. Pronounced differences in crop performance unrelated to management may indicate the need for more detailed sampling. It is expected that the first crop will be maize. This is likely to be more sensitive to saline and alkaline conditions than cotton.

Although an eventual total of 100 hectares may be required for research it is not anticipated that all this land will be put under trials for several years. It is nevertheless necessary to make long-term arrangements for additional experimental areas beyond those needed for immediate soil and water and agronomic investigations. Long-term rotation trials will be needed and areas for observation plots of crops likely to be suited to the cropping pattern in the longer term. Variety breeding and selection work, multiplication of planting material should all be provided for; and in the longer term land may be needed for livestock and fodder trials.

During the early years of research programme development it will be undesirable to leave unused land within the research area under its original bush cover or under continuous fallow. It may be used in the normal way by allocation temporarily to tenants. This method would result in the transfer of such tenants to new blocks after a few years, possibly at a time when high yields had been achieved on their original holdings. The prospect then of being moved to new undeveloped blocks would be a disincentive to them and would be socially undesirable, even unacceptable. The alternative, which we recommend, is that the balance of unused land, probably two blocks in the first instance, rapidly decreasing to one block and then nothing, should be put under the normal cropping pattern for production and managed by the research team, or the project management and progressively released for investigational work as required.

5.3 Research Objectives

The policy aims of the Bura Project are to settle as many families as possible commensurate with the potential of the soil and water resources, providing them with a greater income in the future and an improved quality of life. At the same time the essential values of the environment should be maintained.

To meet these aims it is essential that the research programme should be operationally orientated towards developing manageable, efficient and profitable smallholder farming systems at Bura, and to provide maximum opportunities for production from the garden areas. To meet the former need, evaluation should be made of the outcome from all agricultural inputs used and of the potential effect of each change in technology on the farmer's budget and net income.

Other aspects of research are proposed or may be contemplated in the near future, notably trials of tree species suitable for inclusion in the afforestation programme. Trials may also be undertaken to find out suitable technologies for milk and meat production including a selection programme for improved cattle to be used in the neighbourhood.

It is desirable that these and the agronomic trials should comprise a co-ordinated programme for the project as a whole and its adjacent farming population. It is also likely that by doing so, some economy in the use of resources will be achieved. It is assumed that the livestock and forestry trials will be carried out in the research area.

5.4 Programme Priorities

Early trials at Bura are necessary to establish the behaviour under cropping of the soils of the area - in particular the C soils which do not appear at Hola, the 'capped' Natrargids, the shallow phases of the S soils, and to a less extent (since they are less frequently encountered) the GA and GU series. In addition it will be necessary to establish the production potential of the marginal Class 4 soils which predominate in the area proposed for extension of the project under Phase II on the west bank.

It is also necessary to develop in greater detail the work commenced in the mid 1960's by the Acres/ILACO team at Hola to identify suitable additional crops to replace or augment those presently included in the cropping pattern. This work has continued under the present programme at Hola but in a modest way from which final conclusions may not yet be drawn. The aim should be to determine the extent to which the cropping intensity and/or the cash crop component of the off-season may be increased. Allied to this is the need to develop a wider range of crops suited to small-scale production in the garden areas.

Next, in keeping with the provision which allows tenants to keep livestock on the project, it will be necessary to carry through a series of production trials with emphasis on small stock and the establishment of suitable husbandry techniques for milk and meat production. If as a policy decision it is necessary to provide quantities of milk for the Project, production trials based on dairying will be required and a programme for improvement of dairy cows instituted. Proposals for these activities are described in some detail in the Livestock Annexe.

Proposals are also to be found in the Forestry Annexe indicating the research requirements preparatory to the afforestation development plan. These trials and their early commencement are particularly important. In the light of the small amount of evidence available, the successful production of fuelwood and building poles on the scale needed at Bura will not be achieved unless these trials can give at least some preliminary indications soon after settlement starts in 1980.

Finally, it will be desirable for the research team to retain under its control the multiplication of improved planting material before it is passed to selected farmers for further bulking. Reference has already been made to bulking facilties for American cotton varieties.

5.5 The Soil and Water Programme

The characteristics of the soils of Bura, their variability, defects and differences from the Hola soils, are discussed in the Soils Annexe.

The Camborthids (C) soils appear quite widely in the Phase I area. They are thought to be some of the best soils and are known, following a preliminary reconnaissance, to occur extensively in the east bank of the Lower Tana River Basin (Stage II) area. Trials on this series therefore would provide needed information on their use which would be relevant not only at Bura but in the development of Stage II if it is agreed. It will be necessary however to confirm that the soil types are indeed similar on both banks, this should be an early priority under the Feasibility Study proposed by the World Bank. A series of fertiliser trials should be laid down to establish responses to the major elements, nitrogen, phosphorus and potash. Their behaviour under irrigation should also be examined including studies of moisture depletion, rooting depths and distribution, as well as the implications of long furrow irrigation. Similar trials should be carried out on the Halorthid and Grumustert soils of the research area both as regards fertilisers and water status*.

*Since these soils display a distinct 'capped' layer in the horizon it is desirable that tillage trials to test the effect of chisel ploughing or ripping on crop yield, root penetration and on permeability should be carried out. It should also be noted that some field observations of Natrargid profiles indicate narrow banding of the capping and the presence of rooting systems, suggesting only a minor limitation to agricultural production.

Regular annual or biennial measurements should be made of salinity and alkalinity status of the soils on the research station and of possible changes in soil structure and permeability.

5.6 Crop Agronomy Programme

Cotton

The behaviour of cotton has been well tested under Hola conditions. It will however be necessary to carry out confirmatory yield trials on the Bura soils. Varietal work should also continue, especially with American varieties which have done well at Hola. New strains are being made available to Kenya which are considered to be 'black arm' resistant, and these should be tested against the best of the American varieties from Hola.

Early planting as a feature of high yield has been demonstrated but cotton still occupies the land for at least six months imposing restrictions on attaining higher cropping intensities. Varietal selection should include the length of growing season as a factor. Large boll size should also be taken into consideration because of its effect on labour requirements at harvesting, and those varieties demonstrating higher lint out-turns than those currently used should be included.

Groundnuts

Groundnuts have been under trial for three years at Hola as a second cash crop and the yield results so far achieved have led to its inclusion in the proposed cropping pattern. The crop has not been subjected to such detailed work as cotton. Bearing in mind that groundnuts will be an unaccustomed crop to many of the new tenants, it will be necessary to prove their value as a cash crop.

Variety trials should form part of the programme with emphasis on the selection of short-term varieties to give greater time for land preparation between crops. A study should be made to assess whether confectionery or oil types should be produced. Cultivation trials should aim at labour saving operations particularly to reduce hand weeding.

Fertiliser trials, and the use of gypsum additives, should be carried out to assess crop response on the Bura soils. It will also be necessary to keep under review the yellowing characteristics of the crop thought to be an alkali-induced iron deficiency. Although this condition has not yet been shown to affect yield, it may be necessary to study it more closely.

Maize

Conditions at Bura are below optimum for this crop but trials at Hola have shown that, with good management and the requisite inputs, yields are high enough to warrant its inclusion initially in the cropping pattern. Total output value has been raised by the interplanting with cowpeas.

The main features for study are yield and short growing period. Further varietal work is still required on these counts and for the Bura soils. Coast Composite would seem to be the type against which others should be tested, rather than the local White.

Fertiliser trials based initially on nitrogen, phosphorus and potash should be conducted aimed at maximising yields under project conditions. Interplanting trials with cowpeas should be repeated to confirm suitable spacing and timing. The agronomic practices on tenants' holdings should be kept under review to ensure that they are both economic and suited to labour supply.

It has been noted at Hola that maize is susceptible to conditions of high salinity and alkalinity. This condition should also be kept under review on the Bura soils.

Cowpeas

This crop has been shown to be a valuable interplant at Hola and has the additional merits of short-growing season and modest husbandry demands.

Of immediate interest is the need to test improved varieties. IFE-Brown has produced better yields at Hola than the Malindi selection, and should be tried at Bura against further introductions. Planting dates should also be tested to confirm whether the eight week season obtained in 1976 at Hola can be repeated at Bura. Fertiliser trials should also be carried out for phosphorus and potash to observe yield responses on the Bura soils.

The possibility of using some of the leaves as a green vegetable without detriment to yield (tested successfully elsewhere in East Africa) may merit attention later.

Sugar Cane

The present series of trials on sugar cane, commenced at Hola in 1974, are expected to last a further two years in order to observe the third ratoon crop. A decision will then be taken on the continuation of these trials.

The soils considered to be most suitable for cane production in the Lower Tana Basin are those of the Camborthid series which are not found at Hola. They do not occur, however, in sufficiently large areas on the west bank to warrant large scale production but have been widely identified in the east bank area. Should the latter be opened up as Stage II of the Project, and the soils prove suitable for cane following more detailed economic examination, information on its agronomic requirements should be readily available. It is therefore desirable that a full programme of research should be undertaken.

The programme should include the testing of varieties; fertiliser trials with particular emphasis on response to major nutrients, crop cycle and maturity trials, with monitoring of potential sugar yields per hectare and related factors.

Other Crops

Although the Acres/ILACO work reports favourably on several additional crops tested between 1964 and 1967, little additional effort has been possible except during the past three years. The following crops have been mentioned - onions, sweet peppers, tomatoes, egg plant, spinach and sweet melons. Sorghum has also produced high yields in the past.

Whilst most of these crops are best suited to garden cultivation, the possibilities of onions and sorghum as off-season field crops should not be overlooked. Onions if they can be successfully grown, travel well and might supply either internal or external markets. Sorghum, better suited to the environment, should be considered as a possible food crop. For those crops selected for trial, planting dates should be established by a series of successive sowings. Thereafter, variety and fertiliser trials should be carried out and irrigation practices examined.

Observation plots on rice at Hola harvested recently suggest that some varieties should be further tested. Further observations should be undertaken on the heavier soils of Bura as a possible precursor to more detailed work on varieties, fertilisers, water application and soil behaviour.

Fallow and Rotations

It has already been demonstrated at Hola that the use of Sunnhemp and Velvet Beans as green manures, prior to the cotton crop, increases yields. This should be tested on the Bura soils with particular emphasis on the minimum number of operations required to give subsequent yield increases and planting dates relevant to the November rains and/or irrigations. Essentially the benefits derived from the cotton crop should not be at the expense of timely destruction of the previous year's residues or the timely preparation of land for cotton following the green manure break.

At present the cropping pattern proposed for Bura is based upon results achieved at Hola, the supply of labour anticipated at Bura and adequate mechanical inputs. Futher management and production trials at Bura may reveal suitable additions or substitutions to the pattern which will lead to economy in these inputs. Before such crops are incorporated in the tenants' cropping pattern they should be tested in rotation trials and their yields, mechanisation and labour requirements, and effects on farmers incomes should be analysed.

Pests, Diseases and Weeds

Control measures for the range of pests and diseases encountered at Hola have been identified through trial and effective measures are in routine use. These should be applied also at Bura, but as new formulations appear on the market these should be put under test for effectiveness, operational demands, frequency and level of application and economic viability.

Regular monitoring of crops for pests will be a standard practice at Bura and, with the help of the entomologist who will be working there and at Hola, new pests and diseases will be identified by tenants and/or management. In these circumstances, if effective control measures are not already known it will be ncessary to devise trials to provide them.

Weed control measures - by sprayed herbicides and hand hoeing - have been developed at Hola and will be introduced at Bura. Notwithstanding, work should continue on the project to eradicate Nutgrass *(Cyperus spp.)* if it should appear.

Monitoring

Apart from the controlled studies of both soils and crop behaviour which will take place on the research centre as part of the experimental programme, it is desirable that a monitoring system should be set up to record the behaviour of the various soil units and crops under field conditions and tenant management, particularly on the Phase II Stage I soils. This could be undertaken either by junior staff within the management of the project or by junior staff of the research team. Whichever is the case, the procedure should ensure that the observations on the tenant farms chosen for monitoring are correlated with those of the research area.

Such a monitoring programme should include observations on crop growth and yield; pH, alkalinity and salinity changes and possible influences of capped and shallow soils. Further detail on monitoring programmes is included in the Soils Annexe.

5.7 Research Organisation and Staffing

The Netherlands programme provides for two irrigation and water management specialists, an agronomist, and an entomologist to work at Hola/Bura. It also provides for a total of three research officers and three assistant research officers for Hola/Bura to be provided by the Kenya Government.

The location of the staff to be provided under the Netherlands programme will initially be at Hola but it is assumed that once operations commence at Bura they would transfer to the main research station being developed there.

The range of tasks necessary or desirable to establish and maintain a successful research programme at Bura requires a team which would build up to a minimum of four specialist research officers as the programme and the project itself develops. It is suggested that the following specialised disciplines should be represented at Bura:

- (a) Cotton - both breeding and agronomic aspects
- (b) General crop agonomy - all other crops but particular attention to 'off-season' and possible sugar-cane development
- (c) Irrigation and water use - all aspects of crop water and irrigation and drainage requirements

(d) Entomology - covering all crops but with particular attention to cotton requirements

The research programme will only function efficiently if it is well organised and co-ordinated with on-going farming operations on the project; to achieve this, the programme should be controlled by a Senior Research Officer who would be a member of the Agricultural Management Team. Furthermore, the specialist research officers can only operate effectively if they are supported by suitably motivated, qualified and experienced local officers - the full staffing requirement of the proposed programme is given in the Organisation, Management and Training Annexe.

Finally, the need to ensure that the research organisation receives the physical services it requires to undertake its work must be mentioned. It is envisaged that the project agricultural services would be responsible for providing these needs, but it will be essential that their availability should not be subject to any constraints imposed by peak demands elsewhere on the project.

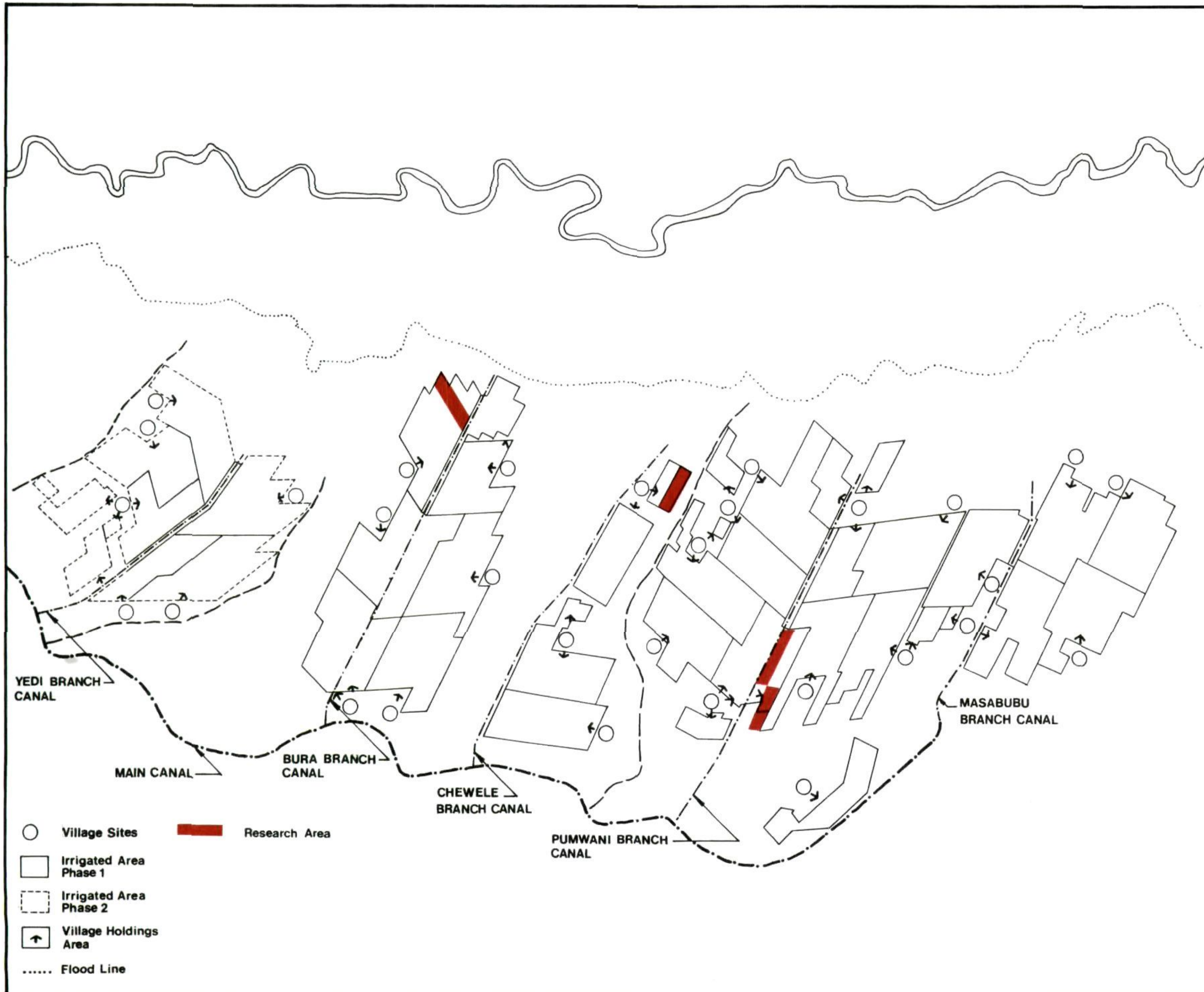


FIGURE 5.1

LOCATION OF AREAS SELECTED FOR RESEARCH

APPENDICES

APPENDIX A : AGRICULTURAL MACHINERY REQUIREMENTS

Detail	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89 and following
Main season crop area (hectares)	840	2 790	5 320	6 440	6 440	6 440	6 440	6 440	6 440	6 440
Percentage of final total	13	43	83	100	100	100	100	100	100	100
Machines in use: (number units)										
Tractors	10	33	63	76	76	76	76	76	76	76
Ploughs	5	14	27	32	32	32	32	32	32	32
Harrows	3	7	14	17	17	17	17	17	17	17
Ridgers	3	8	16	19	19	19	19	19	19	19
Land levellers	2	4	6	6	6	6	6	6	6	6
Trailers	3	11	22	26	26	26	26	26	26	26
Groundnut lifter/shaker	—	—	—	1	2	4	5	6	7	7
Mobile workshop	—	1	1	1	1	1	1	1	1	1
Lubrication/fuel units	1	1	2	2	2	2	2	2	2	2

APPENDIX B : FARM INPUT REQUIREMENTS

Item	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92 and following
Seed: (tonnes)													
Cotton	8.7	45.2	95.6	128.8	128.8	128.8	128.8	128.8	128.8	128.8	128.8	128.8	128.8
Maize	6.0	20.2	38.3	45.3	43.0	39.5	37.0	34.9	33.1	31.6	30.9	30.9	30.9
Cowpeas	12.1	40.4	76.6	90.7	86.0	78.9	73.9	69.8	66.1	63.1	61.8	61.8	61.8
Groundnuts (shelled)	—	—	—	6.0	20.2	41.3	56.3	68.6	79.7	88.6	92.8	92.8	92.8
Total:	26.8	109.8	210.5	270.8	278.0	288.5	296.0	302.1	307.7	312.1	314.3	314.3	314.3
Ammonium Sulphate: (tonnes)													
Cotton crop	125	654	1 400	1 925	1 986	2 048	2 109	2 175	2 245	2 330	2 413	2 480	2 505
Maize/Cowpea crop	96	330	649	818	841	834	841	849	858	876	917	963	980
Groundnut crop	—	—	—	3	11	22	30	37	43	47	50	50	50
Total:	221	984	2 049	2 746	2 838	2 904	2 980	3 061	3 146	3 253	3 380	3 493	3 535
Insecticides:													
DDT 75% W.P. (tonnes)	1.7	8.8	18.6	25.1	25.1	25.1	25.1	25.1	25.1	25.1	25.1	25.1	25.1
Carbaryl 85% W.P.(tonnes)	3.4	17.4	36.8	49.6	49.6	49.6	49.6	49.6	49.6	49.6	49.6	49.6	49.6
Endosulfan 35% emul. (litres)	8 700	45 200	95 600	128 800	128 800	128 800	128 800	128 800	128 800	128 800	128 800	128 800	128 800
Dimetheote emul.(litres)	440	2 260	4 780	6 440	6 440	6 440	6 440	6 440	6 440	6 440	6 440	6 440	6 440
Herbicide:													
Diuron (tonnes)	0.3	1.6	3.5	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8