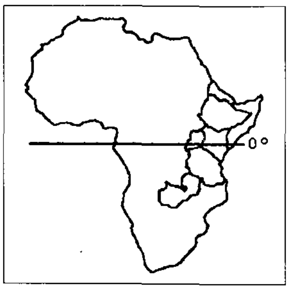
Technical Handbook No.16

Water Harvesting

An Illustrative Manual for Development of Microcatchment Techniques for Crop Production in Dry Areas



M.T. Hai

published by Sida's Regional Land Management Unit, RELMA, 1998

WATER HARVESTING

An Illustrative Manual for Development of Microcatchment Techniques for Crop Production in Dry Areas

RELMA Technical Handbook No. 16

The Technical Handbook Series of the Regional Land Management Unit:

1. *Curriculum for In-Service Training in Agroforestry & Related Subjects in Kenya.* Edited by Stachys N. Muturi, 1992
ISBN 9966-896-03-1

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ISBN 9966-896-07-4

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ISBN 9966-896-11-2

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Top: Admiring a farmer-improved infiltration ditch used for banana production in AEZ 4, Machakos;
Left: A 3-year-old guava planted using a *negarim*;
Right: New possibilities are opened up using water harvesting—a vineyard in Mwingi district.

Published by:
the Regional Land Management Unit (RELMA/Sida),
ICRAF House, United Nations Avenue, Gigiri.
P.O. Box 63403, Nairobi, Kenya.

Editing, design, layout and production:
Development Communications Ltd., (DevCom)
P.O. Box 39486, Nairobi, Kenya

Editor of RELMA series of publications: Alex Oduor/RELMA

Printed by:
Signal Press Ltd.
P.O. Box 12714, Nairobi

Cataloguing-in-Publication Data:
Water Harvesting: An Illustrative Manual for the Development of Microcatchment Techniques for Crop Production in Dry Areas/Mwangi Hai.
Nairobi, Kenya: Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida), 1998
(Regional Land Management Unit (RELMA) Handbook Series; 16)

Bibliography: p:

ISBN 9966-896-33-3

Tech. Handbook No. 16.

WATER HARVESTING

An Illustrative Manual for Development of Microcatchment Techniques for Crop Production in Dry Areas

Mwangi T. Hai

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Department of Agriculture**

Regional Land Management Unit, RELMA
Swedish International Development Authority
Nairobi
1998

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ACRONYMS

AEZ	Agro-Ecological Zone
ASAL	Arid and Semi-Arid Lands
DAREP	Dryland Applied Research and Extension Project
DPT	Division Planning Team
FAO	Food and Agricultural Organization
GTZ	German Agency for Technical Cooperation
KARI	Kenya Agricultural Research Institute
MOA	Ministry of Agriculture
NDFRS	National Dryland Farming Research Station
RSCU	Regional Soil Conservation Unit
SIDA	Swedish International Development Authority
SCS	United States Soil Conservation Service
UNEP	United Nations Environmental Programme
UM4	Upper Midland 4, mean annual temp. 18-21°C
LM3	Lower Midland 3, mean annual temperature 21-24°C
LM4	Lower Midland 4 (temperature as above)
LM5	Lower Midland 5 (temperature as above)
IL5	Inner Lowland 5, mean annual temp >24°C

FOREWORD

This manual was prepared in response to a general feeling that we do not yet have adequate information on various technologies for use in the development of sustainable agriculture in dry areas. Large portions of the countries under the RSCU mandate are arid to semi-arid. As the most limiting factor in dryland agriculture is soil moisture, and in the new thinking of SIDA, we needed a publication that shifts focus from resource conservation to productivity of farmlands within the Eastern Africa region. Thus the objective of this manual is:

To compile technical data on common and popular water harvesting structures for agricultural production to guide extension workers for improvement on the current water harvesting practices in dry areas.

Most agricultural curricula in Kenya remain silent on water harvesting technology. This manual provides useful first hand information never before widely available in Kenya in this form and detail. It should be useful to those interested in dryland agriculture and water resources, and to college students in soil and water management at diploma level and above. Besides a thorough coverage of the most common techniques, the author has also developed a simple methodology for sizing rainwater/runoff storage structures.

The primary target group for this manual are the Division Planning Teams (DPTs) which are headed by diploma holders; this is why further simplification of the manual is not advisable at this stage. However, possibilities of a scaled down "pocket" version of the manual for other extension workers can be explored in future.

We highly commend Mr. Mwangi Hai for devoting much time and effort towards producing this manual. I trust that it will stimulate interest among the users (in Kenya and within the region) to do further exploration and field testing of these and other techniques.

Eric Skoglund
Director, Regional Soil Conservation Unit
Nairobi, May 1997

PREFACE

Water harvesting development for crop production is the simplest way in which food security can be improved in dry areas. It has been tried in various parts of Kenya such as Turkana, Baringo, Kitui and Taita Taveta. Most of the work done so far has been financed by donors. In some cases heavy machinery have also been used. It seems that in most of these projects, the object was to choose techniques of interest and demonstrate that they work, rather than extension to farmers. Although the results have been encouraging, little adoption has been achieved except in Taita Taveta where clearly the objective has been different. From 1993/94, water harvesting targets have been set every year by the Ministry of Agriculture, Livestock Development and Marketing in ASAL districts. The reported achievements have been very low. The main reasons for poor adoption can be summarized as follows:

1) the field staff are technically ill-prepared. No single public university, college or institute has to date adopted water harvesting training. This is singly the biggest drawback to progress in water harvesting development.
2) there are no instruction materials explaining how to implement the techniques on the ground.
3) use of unavailable and unaffordable heavy machinery.
4) inappropriate objectives and approaches.

With the frequent cycles of drought and subsequent crop failures, there is an urgent need for a conscious development of this technology for extension and adoption by farmers. This manual therefore aims at bridging these deficiencies. It does this by providing first-hand information to those charged with agricultural development in dry areas. Hence it has been simplified as much as is practical for effective technology dissemination. Secondly, there are very few source books for this technology. For this reason, the manual is intended to be useful to certificate, diploma and undergraduate students of natural resource management and agriculture.

The manual deals with design and implementation of within-field techniques for crop and fodder production, rehabilitation, and for establishment of forest and fruit trees. Specifically, it covers twelve distinct water harvesting techniques for crop development. The design of simple runoff storage structures has also been included; such water can be used for bucket irrigation, livestock or human use. The manual consists of five chapters:
Introduction; Technical requirements for water harvesting; Water harvesting design; Water harvesting techniques; Design of runoff storage structures

The material includes important socio-economic considerations, basic design criteria and considerations, required design data and finally design, layout and construction procedures. The techniques are explained in a simple language and with diagrams, design nomographs and tables. To make the manual more practical, the techniques are explained using 29 diagrams and 19 tables; moreover, 8 examples have been done for various techniques to show the user how to proceed. The designs are sizes commonly used in Kenya, but the given procedures also show the user how to make a design site-specific. Many of the current water harvesting designs are based on trial and error. For that reason, empirical design criteria has been developed in this manual. This should be used with flexibility to fit individual farm conditions and farmer needs. Some appendices are provided to expound on the methods used to develop the design procedures.

This manual is mostly based on local experiences, engineering principles and basic agricultural sciences. Modifications can be made as more information comes in from research. Other related books and manuals are recommended as supplementary materials.

M. T. Hai
July 1997

ACKNOWLEDGEMENTS

I wish to thank the Regional Soil Conservation Unit/SIDA through the Director of the Unit Mr. Eric Skoglund for the kind offer of this fellowship. I believe that this is a sign of the Unit's deep appreciation of the problems of agricultural development in dry areas. I am sincerely grateful to Mr. H.G. Kimaru who deeply shared the original ideas about this work. He not only helped define its scope and objectives, but has made regular follow-up on its progress.

My gratitude also goes to the Soil and Water Conservation Branch of the Ministry of Agriculture, Livestock Development and Marketing for financing transport. I thank Mr. F.W. Mbote (Head, Soil and Water Conservation Branch) and Mr. Gideon Shone of RSCU for their moral support and useful reviews of several drafts of the manual. I also thank the Provincial Director of Agriculture Mr. P.T. Ibeere for providing transport facilities during the data collection phase.

I am grateful to the following for their variety of contributions to this work: Dr. Okwach and Dr. Itabari (NDFRS, Katumani) for sharing with me, respectively, their rainfall-runoff and water harvesting experiences and moral support; Mr. R.K. Muni (University of Nairobi) for his time and useful discussions; and Mr. E.K. Biamah (University of Nairobi) for runoff data and invaluable discussions on the preparation and use of nomographs; Mr. Kithinji Mutunga for a thorough technical review of the manual. On production, my thanks go to Miss Pauline Murage for diligently typing the original draft, and to Mr. Francis N. Nthukuri of DAO's Office, Embu, for preparing the sketches used in the manual.

The manual has benefited immensely from excellent inputs by these dedicated people. I hope that I have been able to put together some of their wonderful contributions.

Mwangi T. Hai
July 1997

SECTION 1
INTRODUCTION

Kenya's arid and semi-arid lands (ASAL) cover about 80% of the total land mass and have 50% of the livestock population (GOK, 1986). They cover a very significant fraction of RSCU mandate area (fig. 1). They are areas of low and poorly distributed rainfall which adversely affects growing crops. As the human population rises, the impact of drought and subsequent food shortage in these areas is increasing in severity. Food security has therefore become a major concern.

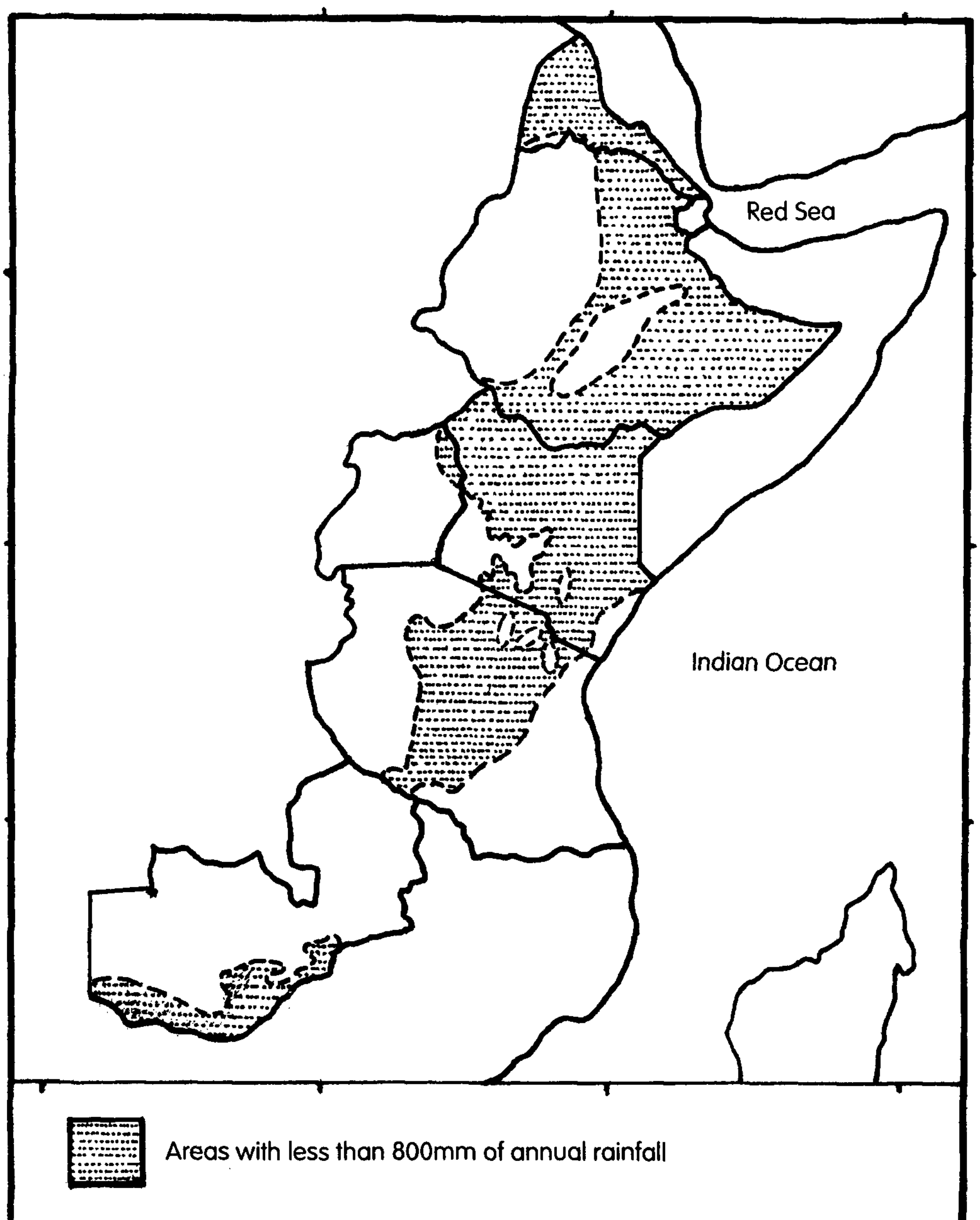

Fig. 1: Distribution of dry areas in RSCU mandate region.

1.5 Socio-economic considerations in Water Harvesting

It is always useful to consider important socio-economic issues which can hinder or enhance water harvesting development. These include:

1) Land tenure issues
   People do not want to invest on land which may in future go to someone else. Therefore ownership and right of use of land is a very important factor to consider.
2) Return to investment
   The cost of developing a technique should be recoverable in the short term - say, seasonally or annually. Trees take long for the benefits to be realized. Growing them with quicker maturing crops may be beneficial especially during tree establishment. Alternatively, one can use fruit trees.
3) Local priorities
   Local priorities should be considered. If the priority is subsistence, then a water harvesting system should try to fit in and assist to meet this objective.
4) Sustainability
   For a technology to be sustainable, it ought to be simple in design, layout, implementation, maintenance, management and use of locally available resources, e.g. family labour, animal power and materials.
5) Main economic activity
   Growing of crops may be of no immediate relevance to a pastoral community; development of small water storage structures may be more urgent to them. The technology for crop production is more applicable to settled communities already engaged in farming activities.
6) Social organizations
   Where they exist, these can be a very good base for labour supply, encouragement and hence widespread adoption. An example is the Myethya groups in Ukambani area of Kenya.
7) Community involvement
   The community should be involved in all stages, i.e. need identification, design, implementation, management, monitoring, evaluation, maintenance and system modification where necessary.
8) Gender issues
   It is important to consider the role of both men and women and their benefits from such activities.
9) Motivation
   Where possible, it is good to motivate people in any possible way, such as creating awareness on various options and the possible immediate benefits. Training and tours to similar projects can serve this purpose.

The extension worker should try to strengthen those issues that are likely to speed up water harvesting development. Issues likely to have a negative effect can be dealt with by

a) solving them,
b) collaborating with those who could solve them, or
c) changing the approach or the technique, including improvising with farmers.

SECTION 2
TECHNICAL REQUIREMENTS FOR WATER HARVESTING

The harsh cropping environment of dry areas must be clearly understood for efficient utilization of soil and water resources. The most important environmental variables are crop water requirement and the soil in which crops are sown.

2.1 Crop water requirement

This is the amount of water required by a crop to grow from planting to maturity. Different crops require different amounts of water depending on the crop type, the length of the growing season and the particular season. Dry areas have high temperatures and low humidity, two factors which raise the evaporative demand of the environment. Other factors which influence crop water use include a) wind, b) hours of sunshine and its intensity. When a season is wet, a crop tends to use more water as the supply is not limited.

2.1.1 Methods of estimating crop water requirements

The crop water requirement is estimated by the reference crop evapotranspiration, ET_o. There are many methods of estimating crop water requirements. These include Penman, Blaney-Criddle, Pan Evaporation etc. The first method is widely used but it is complicated and requires a lot of information which may not always be available. The others are straight forward. Here the third method is discussed because it is simple and easy to apply.

2.1.1.1 Pan evaporation method

Reference crop evapotranspiration can be estimated from daily water evaporation rates from a standard class A evaporation pan. Evaporation figures are obtained every 24 hours by noting how much water (mm depth) is used to top up to the 20cm mark. This figure can be corrected with a pan factor (K_{pan}) of 0.7:

$$ET_0 = E_{pan} x K_{pan} mm \quad (1)$$

This gives a good estimate for the evaporative demand of the environment. To get the crop water requirement, the above figure is multiplied with a crop coefficient (K_c). A value of 0.9 is quite sufficient for water harvesting design.

2.1.1.2 Estimation method

This method can be used when other methods are not possible. Information on water requirements for various crops has been developed in various parts of the world. It can be adjusted to suit local conditions. The best known data is that given by Doorenbos and Pruitt (1977) and covers most common crops. Dry areas grow many different crops and data for these is often lacking. Jaetzold and Schmidt (1982) have published the range of required well distributed rainfall for various crops. The figures given by both sources are quite close (table 2), implying that the much wider crop range given by the latter is quite reasonable for application in dry areas of Kenya.

Table 2: Estimated crop water requirements for local conditions.

Crop	Days to maturity/harvest	Required well distributed rainfall (mm)	
Maize:			(400-750)[1]
Dryland compite	75	240-430[2]	
Katumani	85	260-450	
Coast	105	550-700	
Wheat	110	350-530	(300-450)
Barley	55	180-350	(300-450)
Millet			
Foxtail	50	160-320	
Bulrush	70	250-450	
Finger	75	230-500	
Sorghum	75	200-500	(300-650)
Groundnuts	50	180-550	
Tepary beans	60	180-320	
Cow peas	60	190-400	
Green grams	75	190-400	
Beans	70	230-450	(250-500)
Dolichos	100	200-700	
Pigeon peas	110	370-650	
" (bimodal)	180	500-800	
Soya beans	80	350-680	(450-825)
Sunflower	75	180-550	
Simsim	90	300-600	
Sweet potato	60	350-900	(400-675)
Cassava	180	500-1000	
Cotton	170	550-950	(550-950)
Banana	365	900-1700	(700-1700)
Mango		800-1000	
Passion fruit		900-2000	
Pawpaw		1000-1500	
Citrus		800-1400	(650-950)
Coffee (Arabica)		900-1500	(800-1200)
(Robusta)		1100-2000	
Macadamia		750-1200	
Sugarcane		1250-1800	(1000-1500)
Tobacco	150	400-700	(300-900)

Source: adapted from Jaetzold and Schmidt (1982).
1) Figures in brackets from Doorenbos and Pruitt (1977).
2) compiled for very short to medium ASAL growth periods.

2.2 Soil requirements

Soil is an important factor in design. Four properties of agricultural soils are particularly important:

1) **Fertility** - once soil moisture is enough, nutrients become the next most limiting factor in crop yields. Low soil fertility can be improved by using fertilizers and manures.
2) **Storage** - soil forms the cheapest storage for soil moisture. Therefore the soil in the planting area should
   a) be deep for maximum storage, and
   b) have good water holding and releasing properties. Sands are generally not recommended because they hold very little water. On the other hand, clays store a lot of water but do not release it easily. The best soils for water harvesting are loams (soils marked with "*", table 3).

Table 3: Water holding capacity by different soil textures.

Textural class	FC (% w/w)	PWP (% w/w)	Available water capacity (mm/m depth)
Coarse sand	8	4	83
Sand	14	4	150
Very fine sand	20	4	227*
Loamy sand	18	7	158
Sandy loam	26	9	175*
V.F. sandy loam	28	9	217*
Loam	30	13	175*
Silty loam	34	10	200*
Clay loam	34	18	183*
Sandy clay	29	19	142
Clay	42	25	145

FC = soil moisture at field capacity
PWP = soil moisture at permanent wilting point
w/w = soil moisture on weight basis
V.F. = very fine

Source: Adapted from Landon (1984, p. 230)

3) **Surface crusting** - most ASAL loams have poor structure and the soil aggregates are held poorly together. On the impact of rain drops, a surface crust is formed. By rapidly reducing infiltration rate, this crust increases runoff. This is an important factor in water harvesting. Thus a smaller catchment area is needed to get the required runoff supply.
4) **Chemical properties** - saline (high salt content) and sodic (high sodium content) are not suitable for water harvesting. Such soils require more water to flush out the salts. This means a much bigger catchment area would be required to get enough runoff for
   a) the crop and
   b) leaching out the salts.

2.3 Rainfall data analysis

Rainfall in dry areas is characterized by short duration, high intensity and poor distribution. The low duration-high intensity combination is conducive to high runoff production. The great rainfall variation with time presents the biggest challenge to dryland agriculture. Cropping seasons are usually longer than the rainfall seasons, and drought within the growing season is a common feature of most growing seasonss (see fig. 3).

In water harvesting design, the aim is to use a rainfall figure that will meet the water requirement and produce a crop with a level of certainty. Although the average rainfall value can be used, it is not a good figure since most of the rainfall consists of a few very wet seasons and many drier ones. Therefore there would be many seasons with actual rainfall figures below the average, and designs based on averages are bound to fail. A more appropriate figure is the median. This is the middle value of any set of seasonal rainfall data arranged from the biggest to the smallest. The best design value is the probability rainfall because it is related to the frequency of occurrence of such rainfall. It helps the planner to get a reasonable catchment size to supplement rainfall, rather than one which is inadequate or too large and uneconomical. More detailed criteria for selection of probability rainfall values is given in section 3.1.

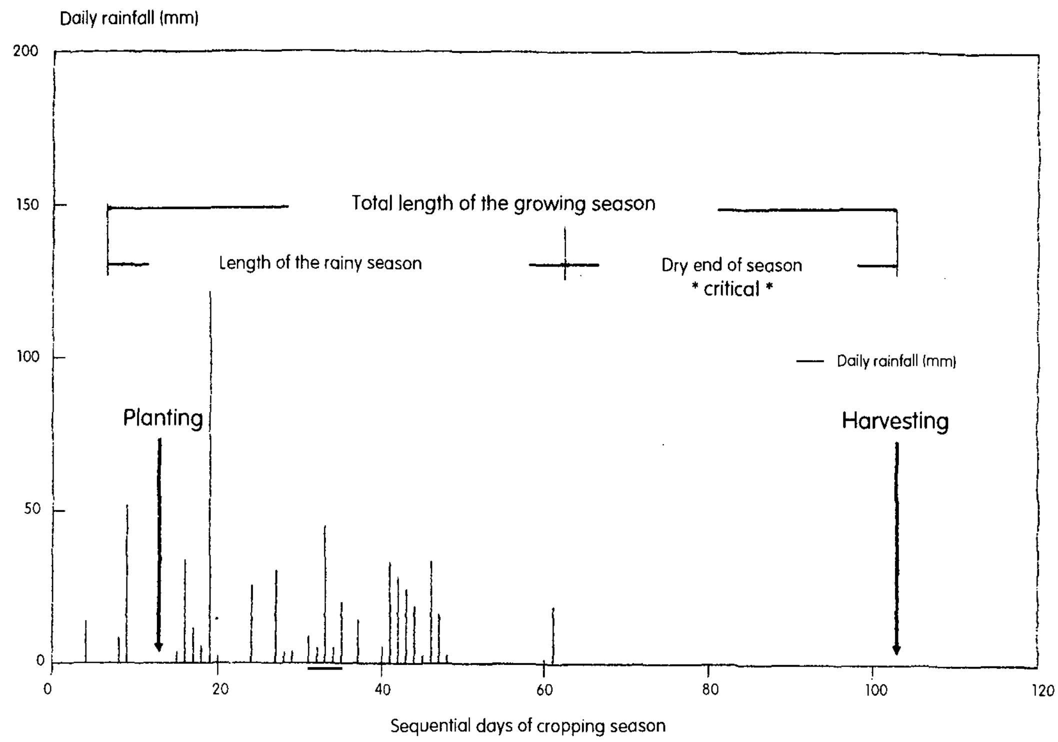

Fig. 3: Typical rainfall and growing seasons in ASAL areas: 1990 November rains, Mutomo, Kitui (Hai, 1993).

2.3.1 Computing probability rainfall

The following procedure should be followed to arrive at the required probability rainfall value.

1) identify the growing season for the particular crop, i.e. whether several months (for annual crops) or whole year (for perennial crops such as trees);
2) obtain reliable seasonal rainfall data for at least 10 years. The more the data the better. Over twenty years is preferred;
3) arrange the data in descending order, starting with the highest and ending with the lowest;
4) calculate seasonal probabilities using the following equation (Chow et. al 1988):

$$P = \frac{m - 0.375}{N + 0.25} \tag{2}$$

where P = probability of this amount of rainfall being exceeded;
m = rank of rainfall value (highest = 1; lowest = N)
N = total number of data (months, seasons or years);

5) plot the rainfall values against their probability values on a log-probability graph (see Appendix D);
6) . draw a line of best fit between these points. From this line, any desired rainfall value at a selected probability level can be read directly and used for design;
7) compute the return period for the given rainfall values:

$$T = \frac{1}{P} \tag{3}$$

where
T = return period in years of that rainfall event.

Example 1:
Table 4 (below) gives 24 year annual rainfall for Mutomo, Kitui, Kenya. A farmer in the area wishes to plant a mango orchard in his farm.

Question:
1) What is the mean, median and 50% probability rainfall level?
2) Select an appropriate design level rainfall for the farmer.

Solution:
1) Steps 1 and 2: Mango is a perennial crop, hence the season has 12 months. Rainfall values are given in table 4; the annual mean is calculated as 680mm with the median being the average of 621 and 594 (table 4), i.e. 608mm.

Step 3-7: The rainfall data is arranged in descending order and ranked. Probability values and corresponding return periods are computed for each rank using equation 2 and 3 (above). The data is summarized in table 4. The rainfall and probability values are plotted on a log-probability paper (fig. 4). The 50% probability rainfall is read from the graph as 620 mm.

Table 4: Probability rainfall and return period levels, Mutomo, Kitui.

Year (1)	Rainfall, (mm) (2)	Rank (3)	Probability (4)	Return period (T) (years) (5)
1989	1309	1	0.03	38.80
1967	1175	2	0.07	14.92
1984	1146	3	0.11	9.24
1968	1086	4	0.15	6.69
1988	1047	5	0.19	5.24
1986	1026	6	0.23	4.31
1966	960	7	0.27	3.66
1978	882	8	0.31	3.18
1979	806	9	0.36	2.81
1977	713	10	0.40	2.52
1971	647	11	0.44	2.28
1985	621	12	0.48	2.09
1972	594	13	0.52	1.92
1981	576	14	0.56	1.78
1969	576	15	0.60	1.66
1973	467	16	0.64	1.55
1982	465	17	0.69	1.46
1974	455	18	0.73	1.38
1970	422	19	0.77	1.30
1980	361	20	0.81	1.24
1976	341	21	0.85	1.18
1975	287	22	0.89	1.12
1983	216	23	0.93	1.07
1987	147	24	0.97	1.03

Source: Raw data adapted from Hai (1993).

2) A 67% probability rainfall is selected. This amount is likely to be achieved in 2 of every 3 years. The design level is therefore 480mm.

Because they are largely unavailable, probability graph papers are provided at the end of the manual. It is suggested that the user makes copies before exhausting what has been provided.

2.4 Rainfall-runoff relationships

Water harvesting depends on how much runoff can be collected from a surface. Consequently, this subject is very important. A number of rainfall-runoff relations have been used in many studies. One such relation is the threshold rainfall. This is the minimum storm rainfall observed before runoff takes place. A figure of 7.8mm was observed from crusting soils (Critchley, 1986).

2.4.1 The SCS curve number method

The second important method is the SCS curve number method. In this method, daily runoff depth is estimated using curve numbers for any given catchment condition. The possible seasonal runoff total is got by adding daily values for the whole season. The method works well with a computer or a hand-held calculator. For more details, the reader is referred to Appendix A.

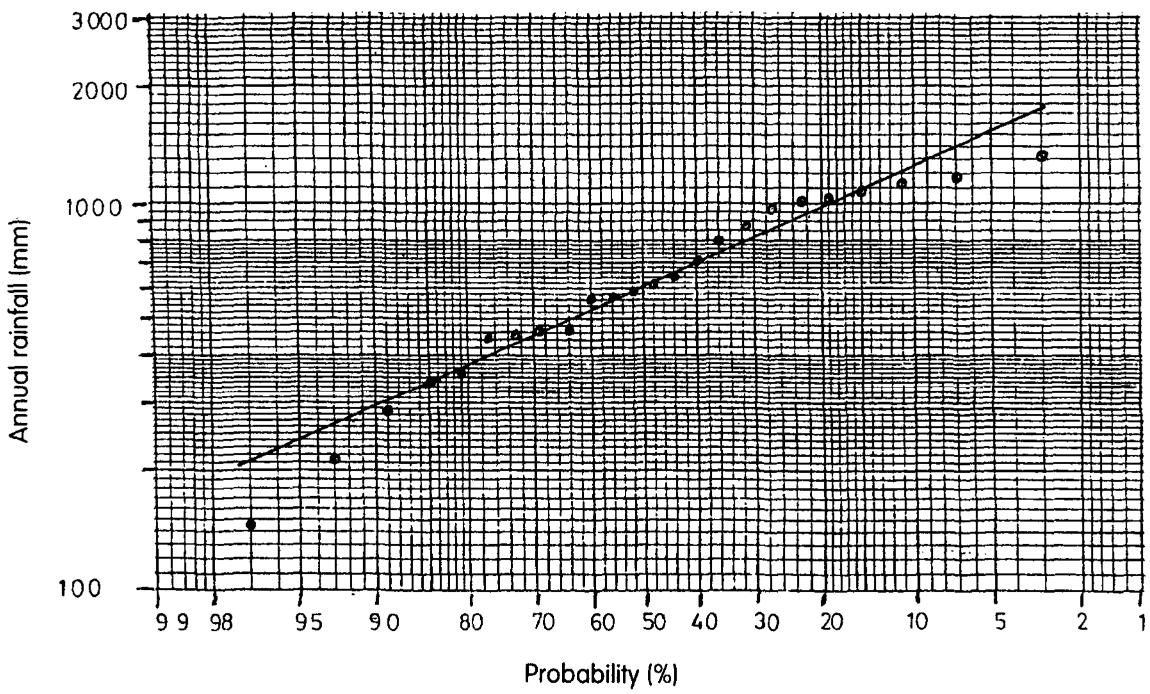

Fig. 4: Probability plot for annual rainfall, Mutomo, Kitui.

2.4.2 Runoff coefficient method

This is a relationship between total rainfall and total runoff. Because of its simplicity, it is the most important method. Runoff coefficient defines the percentage of rainfall that becomes runoff. There is limited information on coefficients for the various soils, surface conditions and slopes. However, some studies have been done on crusting soils of tropical regions.

Studies in West Africa, India and Kenya have indicated seasonal runoff rates of crusting soils of 26.5% to 45.4% (Lal, 1976; Sharma et al., 1982; Biama et al., 1993; Okwach, 1994). However, some of the findings conflict on the effect of slope on runoff.

Hudson (1981) has given runoff coefficients for use with the Rational method to estimate peak runoff rates. These values are based on soil type, land use and degree of slope. The coefficients can be extended to the estimation of runoff depth. There may be small errors, but this is the most comprehensive information available yet. It is summarized in table 5.

Table 5: Values of runoff coefficient, C.

Topography and Vegetation	Sandy Loam	Soil texture: Clay and silt loam	Clay
Woodland			
Flat (0-5%)	0.10	0.30	0.4
Rolling (5-10%)	0.25	0.35	0.5
Hilly (10-30%)	0.30	0.50	0.6
Pasture			
Flat	0.1	0.3	0.4
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.6
Cultivated			
Flat	0.3	0.5	0.6
Rolling	0.4	0.6	0.7
Hilly	0.52	0.72	0.82
Urban	30% impervious	50% impervious	70%impervious
Flat	0.4	0.55	0.65
Rolling	0.5	0.65	0.8

Source: Hudson (1981)

SECTION 3
WATER HARVESTING DESIGN

3.1 Designing for the required catchment area

A water harvesting system consists of two areas - a *cropped* and a *catchment* area (fig. 2). A cropped area is where a crop is planted and gets its moisture and nutrients. A catchment area is used to provide additional soil moisture in form of runoff. For any particular crop, this runoff plus the rainfall falling direct on the cropped area should be equal to crop water requirement:

Water requirements = rainfall + runoff

The aim of a water harvesting design is therefore to estimate the catchment area required for a given crop area so that a crop gets sufficient moisture to produce the needed grain or fruit.

Rainfall is normally not enough to meet crop water requirement. The amount of water harvested should be equal to the extra water required by a crop. This is influenced by the runoff coefficient and the amount of rainfall received. Because some water entering the soil is inevitably lost through deep percolation, an efficiency factor is considered. The catchment and the cropped areas are related by the catchment to cropped area ratio (CCAR):

$$CCAR = \frac{CWR - R}{RCE} \qquad (4)$$

where

CWR = crop water requirement, mm;
R = design rainfall, mm;
C = runoff coefficient, $0<C<1$;
E = efficiency factor, $0<E<1$.

All within-field techniques are designed based on this equation. In some cases, the design may be modified to take care of farm implement size and recommended crop spacing. Table 6 gives some guideline CCAR figures for common crops, agroecological zones and slopes for clay and silt loam soils.

Estimating the runoff coefficient factor

Experience indicates that runoff could be up to 70% for bare crusting soils under intense storms. More work is needed in this area. Table 5 should be used until there is better information.

Selecting design rainfall level

The selection of design rainfall is a very important decision. The objective is to select a seasonal rainfall value that best suits a design. The preferred method of rainfall analysis is given in details under section 2.3.1. What is important is to understand the implication of a selected level of rainfall with respect to

1) the frequency of the system performing as desired, and
2) the size of catchment area required.

Table 6: Guideline CCAR values for cultivated clay and silt loam soils at different land slopes.[1]

AEZ	Rain	Crop	Mean CWR	Slope of land (%) 2	4	6	8	10
LM4,	E=60%							
	210	Maize (Kat)	355	2.3	2.3	1.9	1.9	1.6
		F. Millet	365	2.5	2.5	2.1	2.1	1.7
		B. Millet	350	2.2	2.2	1.9	1.9	1.5
		Wheat	375	2.6	2.6	2.2	2.2	1.8
		Sorghum	475	4.2	4.2	3.5	3.5	2.9
		C. Peas	295	1.3	1.3	1.1	1.1	0.9
		G. Grams	295	1.3	1.3	1.1	1.1	0.9
		Soya	638	6.8	6.8	5.7	5.7	4.7
		Sunflower	365	2.5	2.5	2.1	2.1	1.7
	560[2]	Cotton	750	1.1	1.1	0.9	0.9	0.8
		Citrus	800	1.4	1.4	1.2	1.2	1.0
		Mango	900	2.0	2.0	1.7	1.7	1.4
		Pawpaw	1250	4.1	4.1	3.4	3.4	2.9
LM5,	(E=50%)							
	148	Maize (Kat)	355	5.6	4.7	3.9	3.9	3.2
		F. Millet	365	5.9	5.9	4.1	4.1	3.4
		B. Millet	350	5.5	5.5	3.8	3.8	3.2
		Wheat	375	6.1	6.1	4.3	4.3	3.6
		Sorghum	475	8.8	8.8	6.1	6.1	5.1
		C. Peas	295	4.0	4.0	2.8	2.8	2.3
		G. Grams	295	4.0	4.0	2.8	2.8	2.3
		Soya	638	13.2	13.2	9.2	9.2	7.7
		Sunflower	365	5.9	5.9	4.1	4.1	3.4
	350	Cotton	750	4.6	4.6	3.2	3.2	2.6
		Citrus	800	5.1	5.1	3.6	3.6	3.0
		Mango	900	6.3	6.3	4.4	4.4	3.6
		Pawpaw	1250	10.3	10.3	7.1	7.1	6.0
L5,	(E=40%)							
	123	Maize (Kat)	355	9.4	9.4	7.9	7.9	6.5
		F. Millet	365	9.8	9.8	8.2	8.2	6.8
		B. Millet	350	9.2	9.2	7.7	7.7	6.4
		Wheat	375	10.2	10.2	8.5	8.5	7.1
		Sorghum	475	14.3	14.3	11.9	11.9	9.9
		C. Peas	295	7.0	7.0	5.8	5.8	4.9
		G. Grams	295	7.0	7.0	5.8	5.8	4.9
		Soya	638	20.9	20.9	17.4	17.4	14.5
		Sunflower	365	9.8	9.8	8.2	8.2	6.8
	328	Cotton	750	6.4	6.4	5.4	5.4	4.5
		Citrus	800	7.2	7.2	6.0	6.0	5.0
		Mango	900	8.7	8.7	7.3	7.3	6.1
		Pawpaw	1250	14.1	14.1	11.7	11.7	9.8

[1]Based on 60% probability rainfall in LM4, LM5 and L5 as given by Jaetzold and Schmidt (1983), p202. The lower of the two seasonal rainfall is used for design.
[2]For cotton and other perennial crops, rainfall values for both seasons are added.

A short return period storm is the most frequent, hence it has a high probability. Technically, the selection of such a rainfall level enables a design which should work at all longer return periods. However, such rainfall levels result in very large catchments and are therefore impractical as they waste land. On the other hand, a very long return period is not useful. The amount of rainfall is very high, which is a rare occurrence. The designed catchment is therefore too small and fails to raise a crop in most of the years. A balance between the two extremes is clearly desired. The selected rainfall level depends on better technical information regarding the crop and a discussion with the farmer. Notice the negative catchment area in the last column (table 7), implying that drainage, rather than water harvesting, is desired instead.

Table 7: Variation of return period and catchment area with selected probability rainfall levels[1].

Selected annual rainfall (mm)	Probability of rainfall (%)	Return Period (years)	CCAR	Catchment Area (m^2)
1300	5	20.0	-0.5	-5.1
1070	10	10.0	0.1	0.9
870	20	5.0	0.9	8.8
740	30	3.3	1.6	16.2
650	40	2.5	2.3	23.1
575	50	2.0	3.0	30.4
500	60	1.7	4.0	40.0
440	70	1.4	5.0	50.0
380	80	1.3	6.3	63.2
300	90	1.1	8.9	88.9
250	95	1.1	11.3	113.3

[1]*Table based on citrus (CWR=1100), silt loam soil, 5% slope, C=0.5, E=0.6 grown in LM4.*

Estimating the Efficiency Factor

This factor is used because not all water put in the root zone is used by the plant. The factor varies greatly from season to season. Low rainfall seasons have high efficiency values because there may be very limited deep percolation. In the design of surface irrigation systems, an efficiency factor of 0.4-0.85 is commonly used. Because of poor rainfall distribution, a figure of 0.4-0.6 is suggested, with the lower figure for drier areas.

3.2 Design for runoff control and retaining embankments

Two types of embankments are used in water harvesting i.e. stone and earth bunds. Stone bunds are porous and can allow some overtopping. Therefore, they may not require a freeboard. They also silt quickly and may lose their effectiveness in holding runoff unless they are increased subsequent to silting. When loose stone is available, it should be preferred to earth bunds. Stones can be used together with grasses; this helps to slow runoff and deposit suspended soil while allowing the water to slowly flow down the land slope.

Soil is the most abundant construction material. Soil bunds are made by spreading the soil in uniform layers and compacting at optimum moisture until the required height is achieved. For field conditions, the most practical construction period is when the soil is moist, such as:

1) immediately after harvesting the crop;
2) after a few showers at the beginning of the main season;
3) making bunds during the minor season; that is, for areas where November is the main rainfall, bunds can be made in the April rains. This removes competition for labour in the main season.

Because of the relatively low ponding time in water harvesting systems, the design considerations for the bunds are quite simple. The minimum recommended side slopes are 1:1 on both sides to ensure stability of the structure.

SECTION 4
WATER HARVESTING TECHNIQUES

4.1 Negarims

Description

Negarims are regular squares made of soil bunds turned by 45° from the contour to concentrate runoff water at the lowest corner of the square. At this corner, an infiltration basin is made. At the centre of this basin a planting pit is made. The whole square consists of a catchment area and a cropped area. Runoff collects from the catchment area and flows into the cropped area where it ponds, infiltrates and is stored in the soil. The technique requires deep soils up to 2m to store the harvested runoff. The technique is mainly used for tree establishment in dry areas with seasonal rainfall as low as 150mm. When used for fruit trees, it is designed to provide sufficient moisture to a producing tree. When used in uneven topography, it is recommended that the blocks of negarims should be subdivided to smaller units.

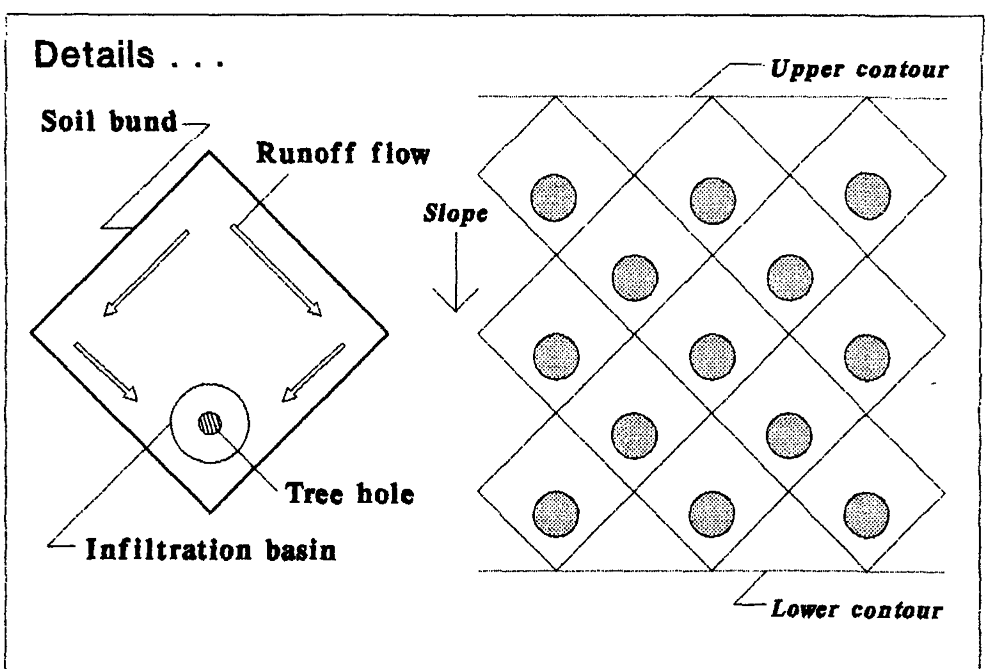

Fig. 5: Field layout of negarim microcatchments.

The bunds should be at least 25cm high to avoid overtopping. The top width is at least 20cm wide and the side slopes 1:1. On steeper land slopes, the bund height should be increased especially near the infiltration pit. The pit should be 60cm x 60cm x 60cm with the subsoil being used for bund construction. The infiltration basin is mostly round, but the planting pit can be either round or square.

Design, layout and construction details

Requirements: line level, measuring tape, cotton string, pegs

1) design the dimensions of the negarim - length of the sides and the height of the soil bunds (see example 2);
2) where necessary, protect the field from external runoff with a cut-off drain at a maximum gradient of 0.25%;

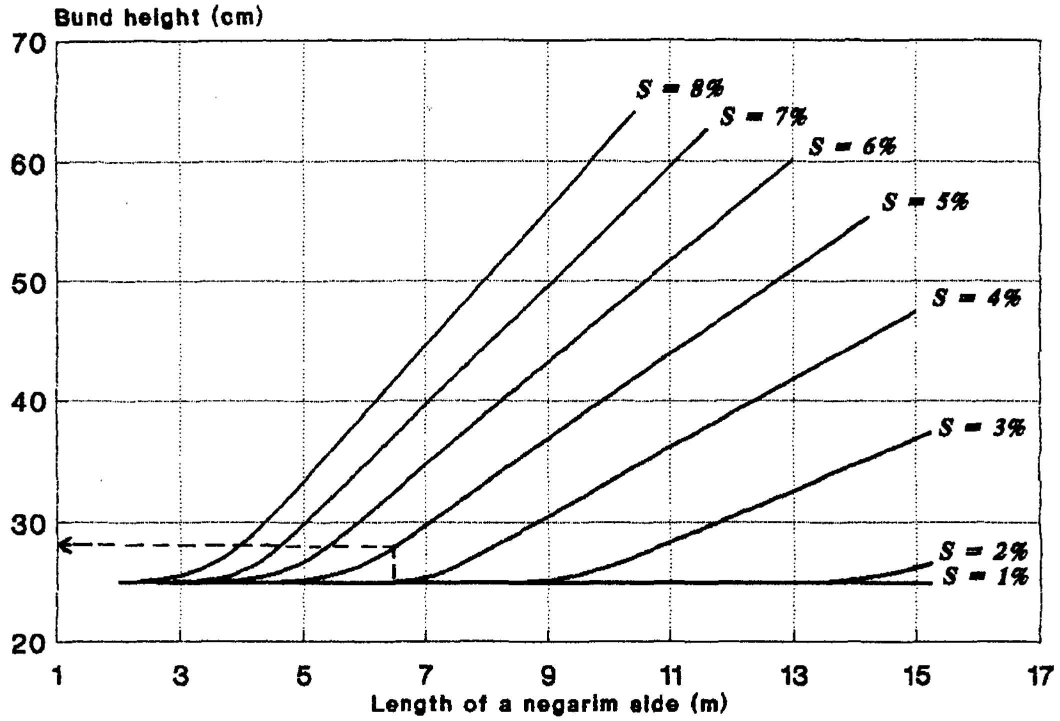

Fig. 6: Minimum height of soil bunds for negarims.

3) clear dense vegetation from the area to leave a catchment cover as specified by the design;
4) stake out a contour line below the cut-off drain and smooth it out to roughly a straight line;
5) make pegs with height marks for indicating bund height during soil placement;
6) using the pegs, mark bund tips along the contour by spacing them at a distance equal to the diagonal of the negarim;
7) measure a string twice the length of a side of the negarim. Mark the centre of the string. Hold the tips of the string on the contour at the pegs and pull the mid-point tight downslope. This marks the lower corner of that negarim. It becomes the contour of the next row of negarims;
8) complete the row and do the other rows as in (6) above;
9) mark the infiltration basin and planting pit at its centre according to the recommended size about 50cm from the bund. Replace the fertile top soil into the planting pit and use the subsoil for making the bunds;
10) make the bunds by placing soil in 10cm layers one at a time and compact with a stick. Repeat this until the desired bund height is achieved;
11) plant a suitable grass on the bunds to avoid erosion.

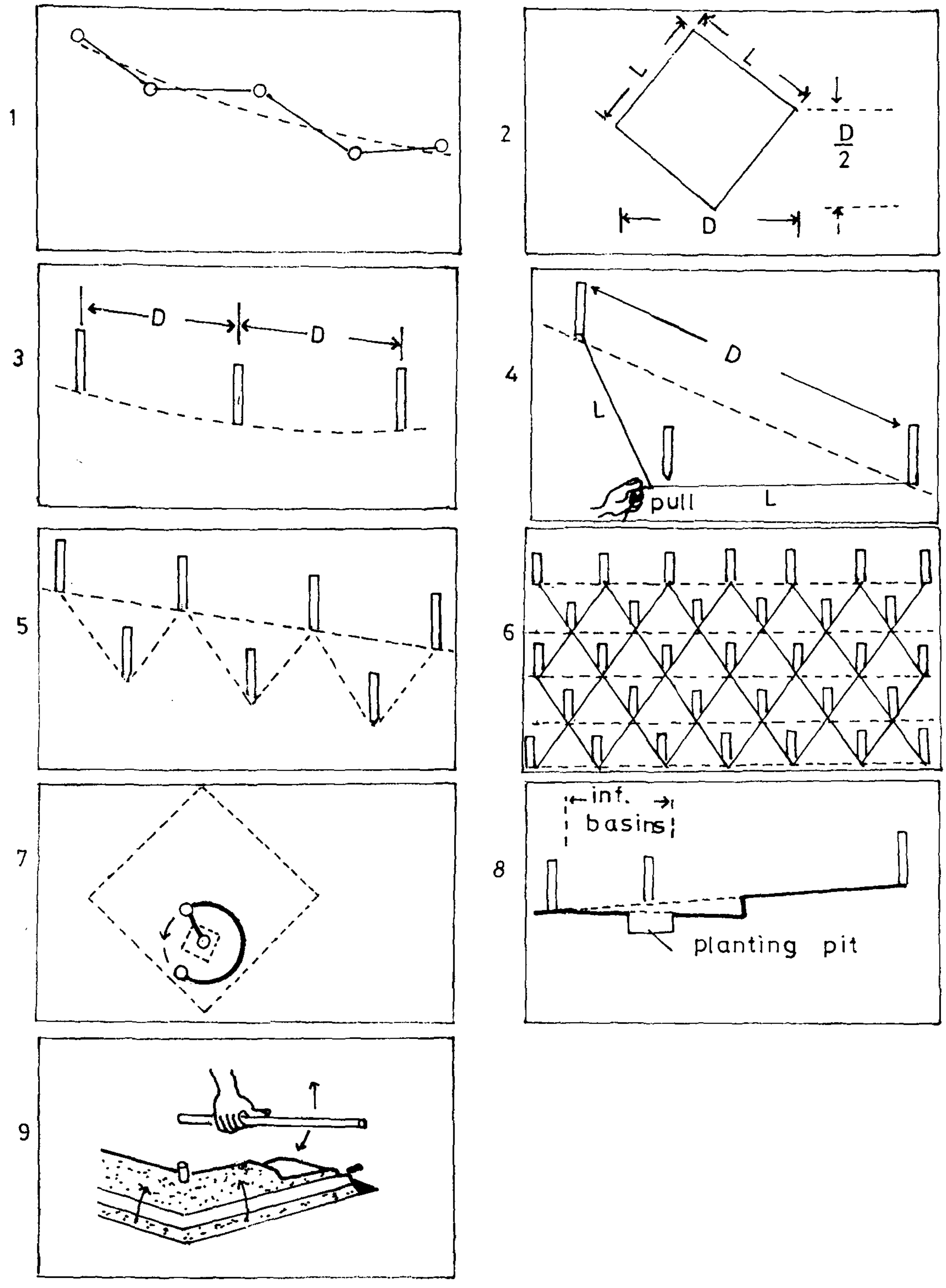

Fig. 7: Negarim field layout procedure.

Plate 1: A healthy pawpaw plant grown in AEZ 5 using a negarim. Notice the young mango trees in the background.

Table 8: Minimum height of soil bunds for negarims.

Microcatchment Size	Ground slope (%)									
	1	2	3	4	5	6	7	8	9	10
2 x 2										
3 x 3			*Use a bund height of 25cm*							26
4 x 4								28	31	33
5 x 5						26	30	33	37	40
6 x 6					26	31	35	39	43	47
7 x 7				25	30	35	40	45	50	55
8 x 8				28	33	39	45	50	56	62
9 x 9				31	37	43	50	56	62	
10 x 10			26	33	40	47	55	62		
11 x 11			28	36	44	52	59	67		
12 x 12			31	39	47	56	64			
13 x 13			33	42	51	60				
14 x 14		25	35	45	55	64		*Not recommended*		
15 x 15		26	37	47	58					

Example 2:
A farmer in an AEZ LM4 has land sloping at 2% on one side and 5% on the other. The soil is a clay loam. He wishes to plant a citrus orchard to finance school fees. As the extension agent of the area, you recommend to him negarim microcatchments.

Question:
1) what is the required spacing of negarims?
2) what is the height of the soil bunds?
3) how many trees fit in a hectare? Can this be justified?

Solution:

1) The rainfall is similar to that given in fig. 4. The selected 67% probability annual rainfall is 460mm. Oranges require 1100mm annually (table 2). From table 5, C=0.5. Assuming E=0.5,

$$CCAR = \frac{1100-460}{460x0.5x0.5} = 5.6 \quad (5)$$

A mature orange tree canopy is roughly 4m wide. The tree roots primarily extract moisture from a root area of 12.6 m^2. The total area (catchment and cropped area) for a single tree is given by

$$Total\ area = 12.6\ (1 + CCAR) = 83.2\ m^2 \quad (6)$$

The sides of each negarim are therefore the square root of the total area, or 9.1m.

2) The height of the bund can be read from fig. 6 or table 8 for 5% slope. Half the diagonal of the negarim is 6.4m. Using this figure, the bund height is about 28cm (5% slope) and 25cm (2% slope).
3) There would be a maximum of 120 orange plants in a hectare compared to 156 for the normal spacing of 8m x 8m. This can be justified by the design for a better moisture supply and an economically productive orchard.

4.2 Semi-circular bunds

Description

This is a network of earth bunds shaped as half-circles with the tips facing upslope and on the contour. They can be used for trees, fodder and improvement of range productivity. They vary depending on the crop type, soil and the rainfall amount.

Semi-circular bunds are used in areas of 200-750mm rainfall, deep soils and low slopes. They require even topography. The space between tips of consecutive bunds is used for discharge of excess runoff. The top width of the bunds is usually 10cm and the height may be uniform where the topography is flat. The side slopes are 1:1 although flatter sides have also been used. As the slope increases, the heighι is increased accordingly from the tip to the lowest point. The minimum height at the tip is 0.1m.

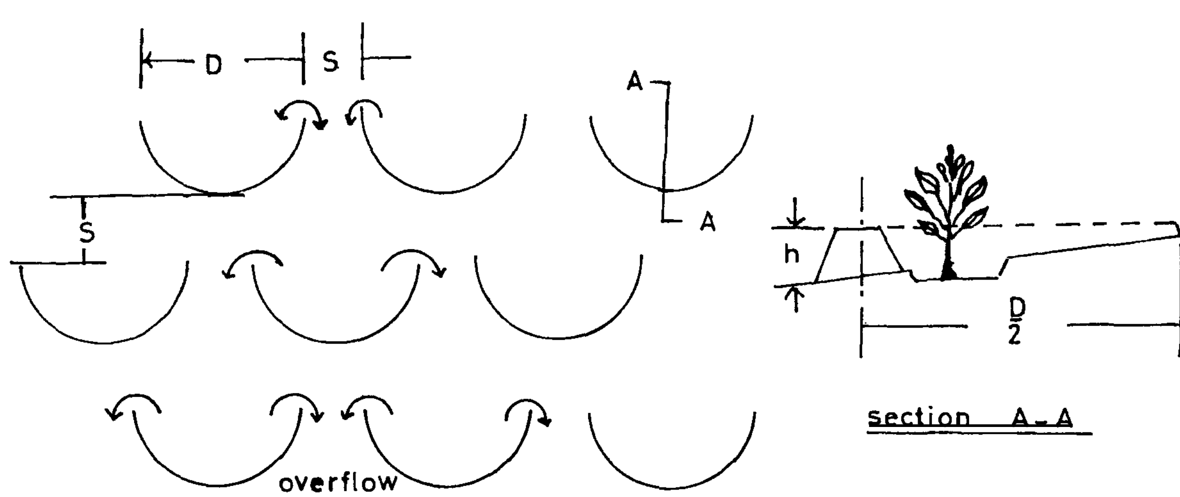

Fig. 8: Field layout of semi-circular bunds.

Two distinct designs are used depending on whether the crop is a tree or a row crop. While the geometry of the bunds is the same, the shape and size of cropped and catchment areas differ. The reader is referred to Appendix B for design details.

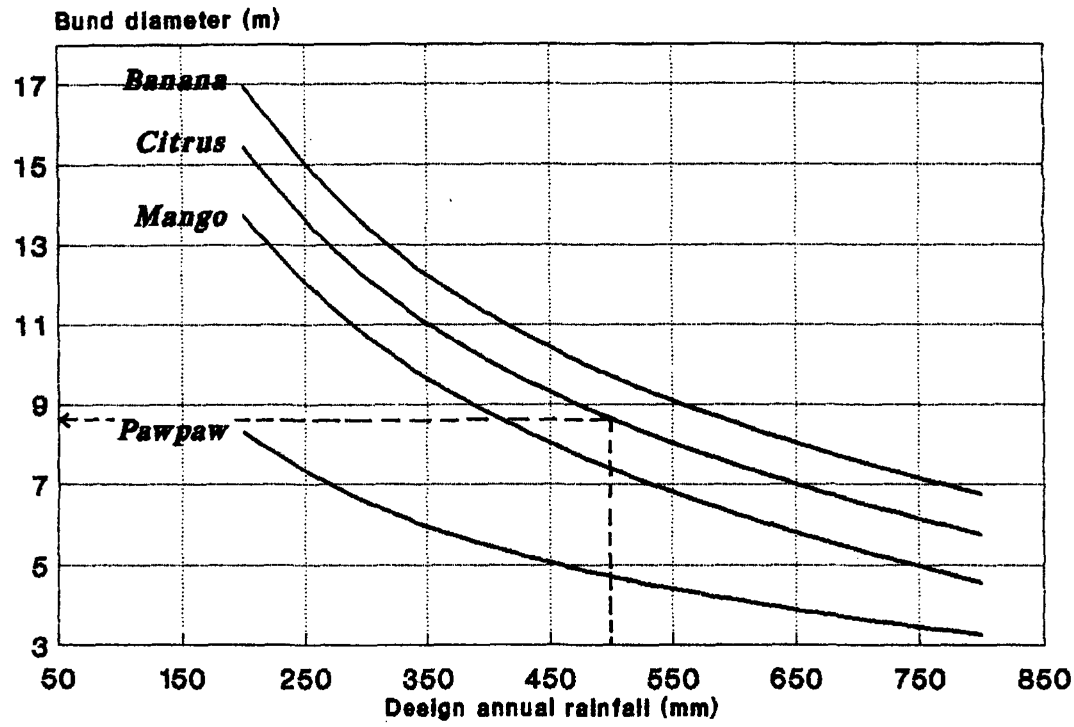

Fig. 9: General nomograph for sizing the diameter of semi-circular bunds for common fruit trees for C=0.5, E=0.6 and canopy diameter of 2-4m.

Design, layout and construction details

Requirements: line level, measuring tape, cotton twine, pegs.

1) design the diameter, spacing and height of the bunds (see Example 3);
2) where necessary, stake out a cut off drain above the bunds to protect them from excess runoff from outside the field;
3) stake out a contour line at the top of the field just below the cut-off drain;
4) cut a string equal to a diameter and a half, marking into three equal parts. With it, mark the tips of a bund, its centre and the spacing on the contour;
5) with a peg tied at two ends of the half diameter portion, inscribe the bund below the contour. Similarly, complete the row of bunds on the contour;
6) measure the position of the next row from the bottom of the row above using the calculated spacing. The centres of bunds in this row should vertically line with the mid-point of the space between the bunds in the first row. Repeat until all rows are done;
7) dig a small trench outside the bund to get soil. Make the bunds in layers of up to 10cm and compact each until the required height is achieved;
8) protect bund tips with stones to avoid erosion. If stones are not available, plant a suitable dense grass instead.

Example 3:
A farmer intends to use the semi-circular bunds for orange production in his farm which is in an area with a 60% probability rainfall of 500mm. The land slopes at 6%.

a) what is the diameter of the bunds, and
b) what is the height of the bunds?

Table 9: Minimum height for semi-circular bunds.

Radius (M)	Ground slope (%): 1	2	3	4	5	6	7	8	9	10
1		*Use a height of 20cm*								
2								21	23	25
3						23	26	29	32	35
4				21	25	29	33	37	41	45
5				25	30	35	40	45	50	55
6			23	29	35	41	47	53		
7			26	33	40	47	54			
8		21	29	37	45	53				
9		23	32	41	50		*Not recommended*			
10		25	35	45	55					

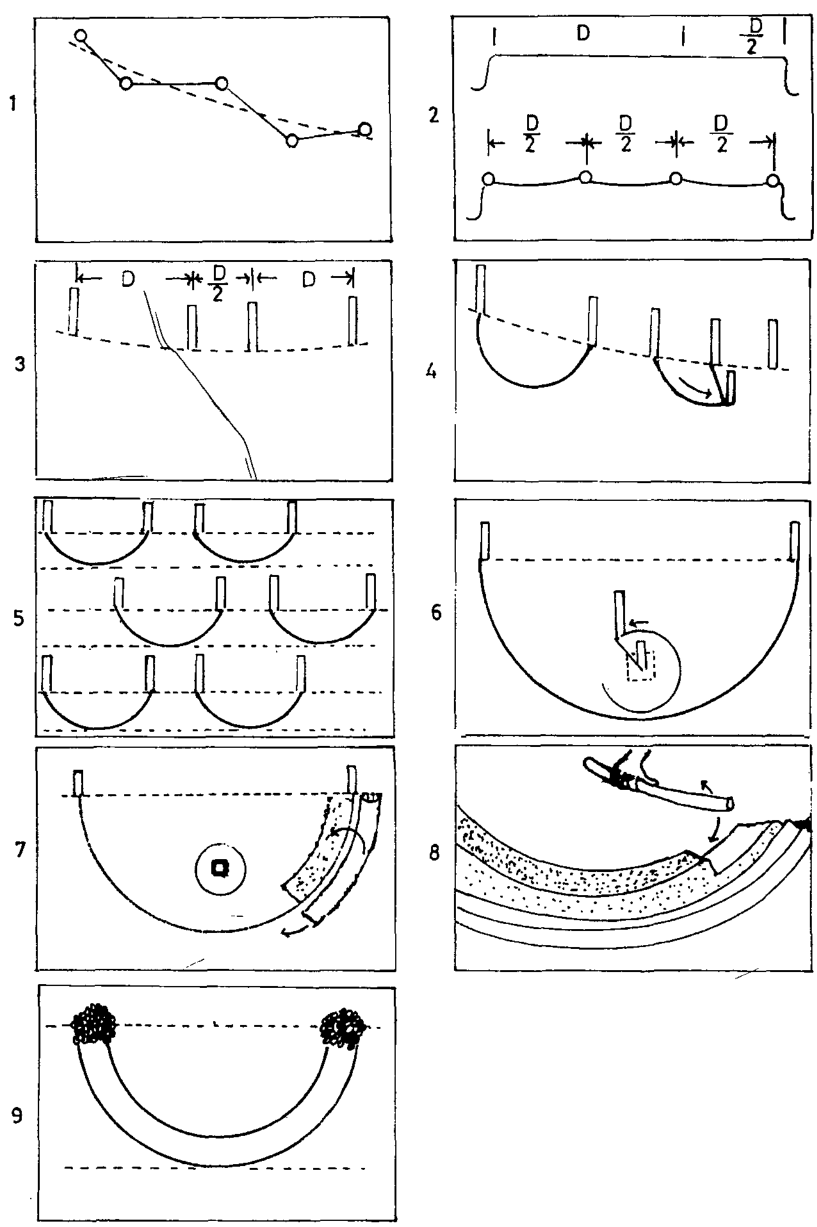

Fig. 10: Semi-circular bunds field layout procedure.

Solution:

a) Oranges require an average of 1100mm per year (table 2). Going to fig. 9, for 500mm rainfall we read the bund diameter as 8.6m. A more specific design can also be done.

b) read bund height from fig. 11 or interpolated between h=29 and h=35 in table 9 for 4.3m (half of 8.6) as 32cm.

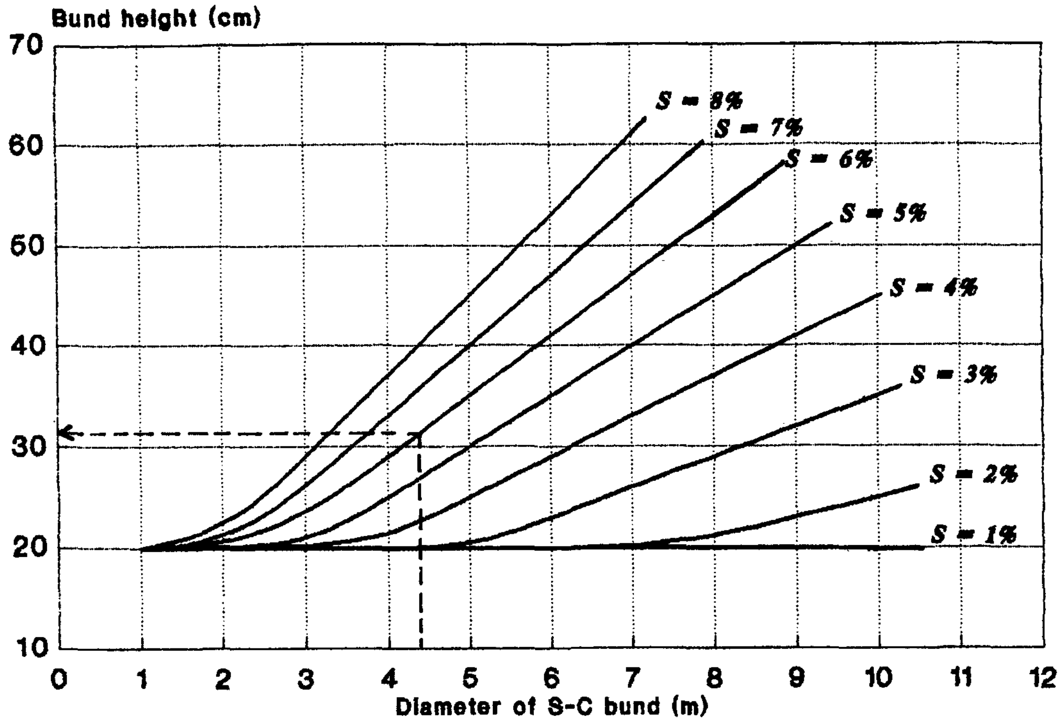

Fig. 11: Minimum height for semi-circular bunds.

4.3 Contour ridges

Description

The technique is used for row crops in areas of 350-700mm of annual rainfall and requires even topography. Furrows are dug on a contour and ridges formed immediately on the lower side. The ridges are spaced at 1-2m and are usually 15-20cm or higher. This forms a catchment which produces runoff that collects at the furrow. A cereal is planted on the lower side of the furrow and a pulse on the upper side. The furrows are tied every 5m to ensure that in case of a defective spirit level, runoff does not flow laterally and concentrate on one side causing erosion. Contour ridges can be made with oxen. The technique is therefore suitable in areas with a well developed use of draught power.

The design follows the standard procedure. Assuming that the crop is planted in a 50cm strip, the catchment area can be calculated for the crop, soil type and rainfall. For drier areas, the distance between ridges and the ridge height increase. Design, layout and construction details Requirements: line level, measuring tape, cotton twine, pegs.

1) design ridge spacing and height (see Example 4);
2) where necessary, protect the field using a diversion ditch at the top of the field at a maximum 0.25% gradient;
3) stake out contours and smooth them out;
4) stake out contour keylines at a distance which is a multiple of the ridge spacing. Mark the ridge positions between and along the keylines;
5) excavate the furrows leaving 30cm earth ties every 5 metres. Place the soil downslope immediately below it.

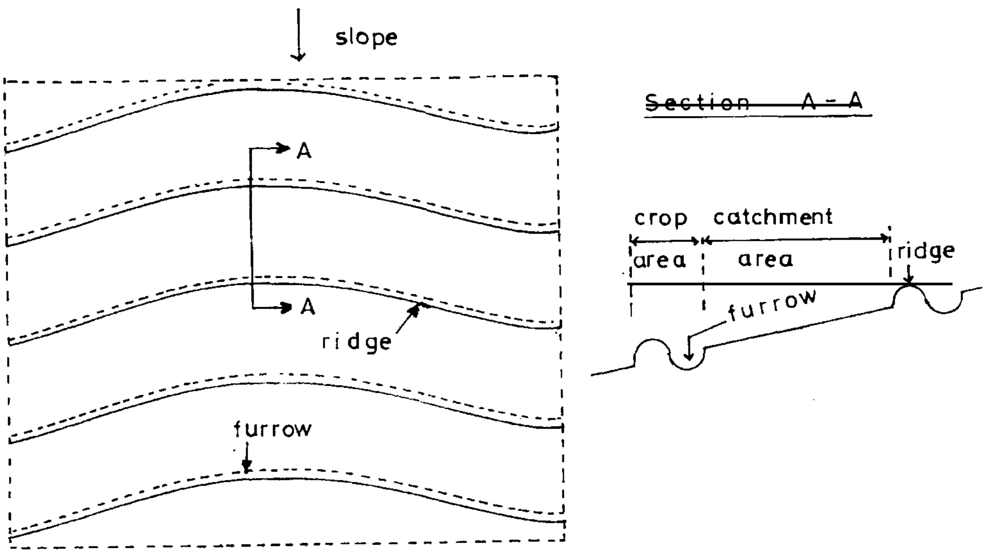

Fig. 12: Field layout of contour ridges.

Example 4:
A farmer wants to plant a mixed maize-green gram crop in an area with a 60% reliable seasonal rainfall of 150mm. The field slopes at 4%. Field examination and discussion with the farmer leads to the selection of contour ridges as the most suitable method. If the soil is a sandy loam, determine a) the ridge spacing and b) the required height of contour ridges.

Solution

a) from table 1, the mean seasonal water requirement for a dryland composite maize/green grams are extrapolated to 430 and 200 mm, respectively; the mean for both is 315mm. From table 5, C=0.3; assuming E=0.5, the CCAR is:

$$CCAR = \frac{315-150}{150x0.3x0.5} = 7.3:1 \tag{7}$$

Taking the crop area as 0.5m wide, the catchment is 0.5 x 7.3 = 3.6m wide and the total area is 3.6 + 0.5 = 4.1m wide.

b) the height of the ridge is read from fig. 13 or table 10. For a slope of 4%, the ridge height should be at least 21cm high.

Table 10: Minimum ridge height (cm) for contour ridge bunds.

Ridge Spacing						Ground slope, %				
	1	2	3	4	5	6	7	8	9	10
0.5		*Use a height of 20 cm*								
1										
1.5										
2								21	23	25
2.5							23	25	28	30
3						23	26	29	32	35
3.5					23	26	30	33	37	40
4				21	25	29	33	37	41	45
4.5				23	28	32	37	41	46	50
5				25	30	35	40	45	50	
5.5			22	27	33	38	44	49	*Not*	
6		23	29	35	41	47			*recommended*	

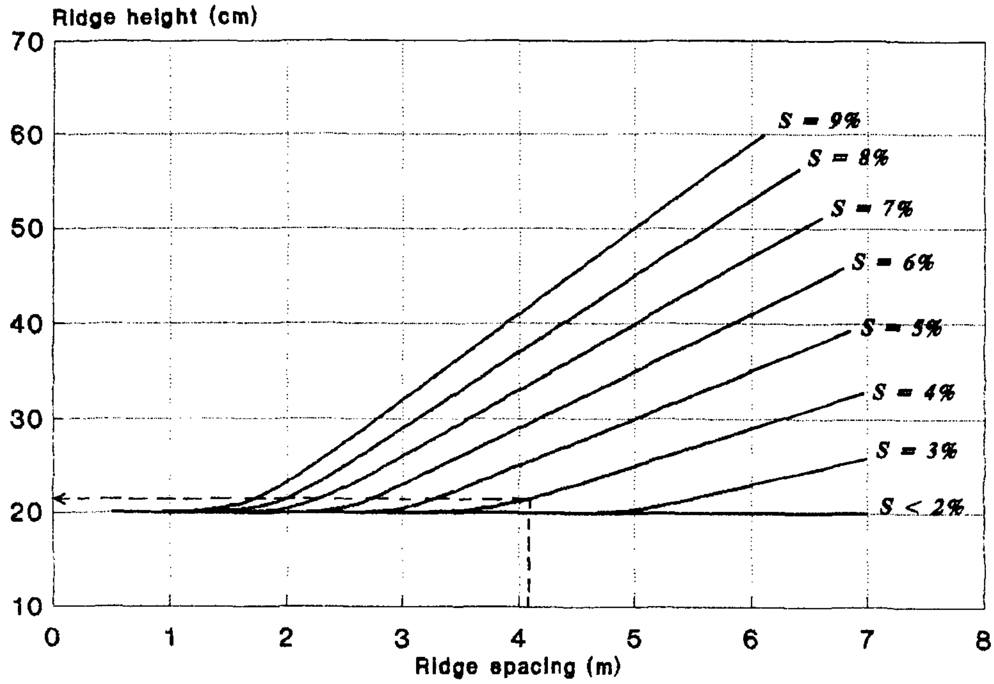

Fig. 13: Minimum height for contour ridge bunds.

4.4 Trapezoidal Bunds

Description

This technique is suitable for area with 250-500mm of annual rainfall. It consists of large structures enclosing up to 1 ha and impounding large amounts of runoff from an external area. Crops are planted in the cropping area enclosed by soil bunds. The impounding bunds are laid on the contour but staggered down the slope to allow for release of excess runoff. Excess runoff is discharged around the tips of the bunds.

The most suitable slopes are 0.25-1.5% on even topography and on non-cracking soils such as black cotton soil. The maximum bund height is 0.6m decreasing to 0.2m at the tips. The technique can be used for trees and grass but is best suited for row crops where manual work is the mode of cultivation. The standard design method is used to size the required catchment area.

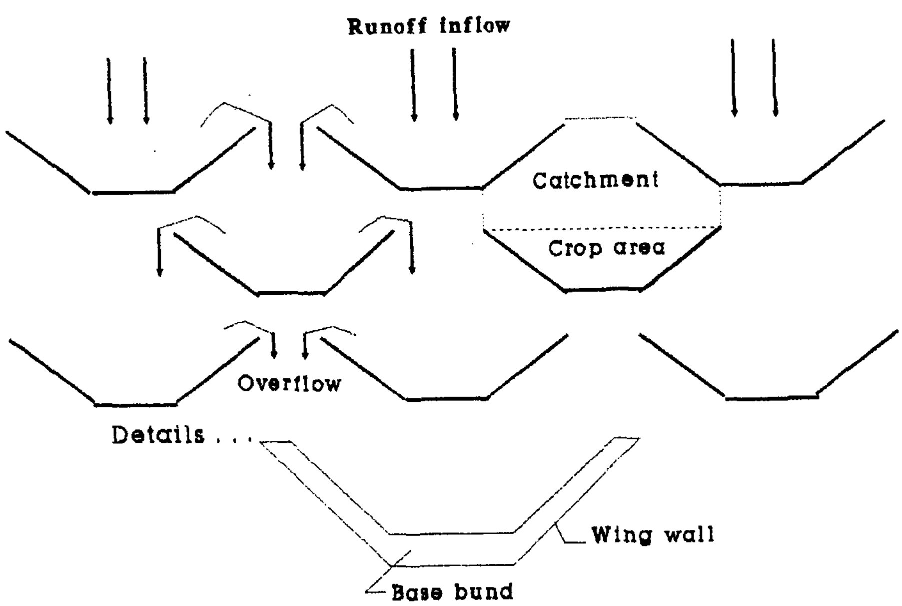

Fig. 14: Field layout of trapezoidal bunds and details of a single bund.

The need for variation

This technique was initially developed in Turkana District where machinery was used for construction of the large structures. The use of machinery is not sustainable due to their unavailability and high cost. Therefore the structure needs to be modified

1) for manual implementation,
2) to enable implementation on slopes exceeding 1.5%, and
3) to reduce waste on land especially in more intensely cultivated semi-arid areas.

The suggested changes are:

1) reduction of the side slope from 4:1 to 1:1;
2) taking a standard 0.2m top width, and
3) a method of sizing the base bund and the wing walls.

It is suggested that the base bund be equal in length to the wing wall. The height of the walls depend on land slope. The reader is referred to Appendix C for design details.

Design, layout and construction details

Requirements: line level, measuring tape, cotton twine, pegs.

1) determine the dimensions of the bund - the height, the length of the base bund and the wing walls, spacing along contour and down the slope (see Example 5);
2) where necessary, protect the field with a diversion ditch placed just above the field at a maximum gradient of 0.25%;

Table 11: Minimum height for trapezoidal bunds.

VL (M)	AWL (M)	Ground slope (%)								
		1	1.5	2	2.5	3	4	5	6	7
3	4.2								23	26
4	5.7	*Use a height of 20 cm*					21	25	29	33
5	7.1						25	30	35	40
6	8.5					23	29	35	41	47
7	9.9				23	26	33	40	47	54
8	11.3			21	25	29	37	45	53	61
9	12.7			23	28	32	41	50	59	
10	14.1			25	30	35	45	55		
11	15.6		22	27	33	38	49	60		
12	17.0		23	29	35	41	53			
13	18.4		25	31	38	44	57			
14	19.8		26	33	40	47	61			
15	21.2		28	35	43	50		*Not*		
16	22.6	21	29	37	45	53		*Recommended*		
17	24.0	22	31	39	48	56				
18	25.5	23	32	41	50	59				

VL = vertical (normal) length of the wing wall (m) upslope
AWL = actual wing wall length along the 135o angle.

3) stake out other contours downslope according to design;
4) make string A. Its total length is made up of
   a) base bund length,
   b) 2 times the actual wing wall length (AWL), and has an allowance of 30cm for tying. Folding it into two, measure half the base bund length on each side from the centre and mark these two points. Tie a loop on each end of the string using 15cm string length;

5) make string B. Its total length is made up of
   a) base bund length,
   b) spacing length (on the contour),
   c) 2.82 times the vertical length (VL). Mark the string as follows:
      - half the spacing length at extreme ends of the string
      - half base bund length on each side from the centre
6) starting from the left boundary of the field, mark with a peg points P1, P2, P3 and P4 using string A. P1 is the edge of the field/mid-point between bunds. P2 and P3 are the tips of the bund. P4 is like P1;
7) hook one loop at P2 and the other at P3. Pull the string tight downslope at the two marks. Peg the ends of the base bunds at the two marks;
8) repeat steps 6 and 7 to complete the row of bunds. Repeat downslope to complete all the rows of bunds. The centre of the base bund is made to correspond to the mid-point of the spacing between bunds on the contour immediately above;
9) make and compact each bund in 10cm layers. For any additional fill material, excavate outside the bund;
10) protect bund tips with stones and grass.

Example 5:
A farmer has a gently sloping land (3%) of deep silt loam soil and uniform topography. As a water harvesting expert, you have proposed trapezoidal bunds to the farmer for sorghum (CWR=350mm) to improve on crop yields. The 67% reliable seasonal rainfall for the area is 185mm.

a) what is the CCAR and bund dimensions? (use C=0.4, E=0.4)
b) how many bunds fit in a hectare?

Solution
a) For the given information, the CCAR is 5.6:1. Sorghum is planted at 60cm between rows. The normal wing wall would be a multiple of this interrow spacing. We can choose any convenient length of wing wall. Selecting a normal wing wall length (VL) of 6m (table 11) for 11 crop rows, the actual length is 8.5m and the bund height 23cm. The base bund is also 8.5m long. For a 0.2m top width, the maximum bottom width of the bund is 0.2m + 2 x 0.23m = 0.66m.

b) Appendix C is used to complete the design. The trapezoidal cropped area is given by A_1 and A_2.
   For a normal wing wall of 6m, $A_1 = 6^2 = 36m^2$ and
   $A_2 = 1.41 \times 62 = 50.76m^2$ for a total cropped area of $86.76m^2$.

   Catchment area = crop area x CCAR = 86.76 x 5.6= $485.86m^2$.
   This includes area A_3, which is $A_3 = 485.86-86.76 = 399.1m^2$.

   Since the distance between bund tips (T) is known, bund spacing downslope is:

$$V = \frac{A_3}{T} = \frac{399.1}{3.41x6} = 19.5m \qquad (8)$$

There would be 18 bunds of $1562m^2$ cropped area per hectare.

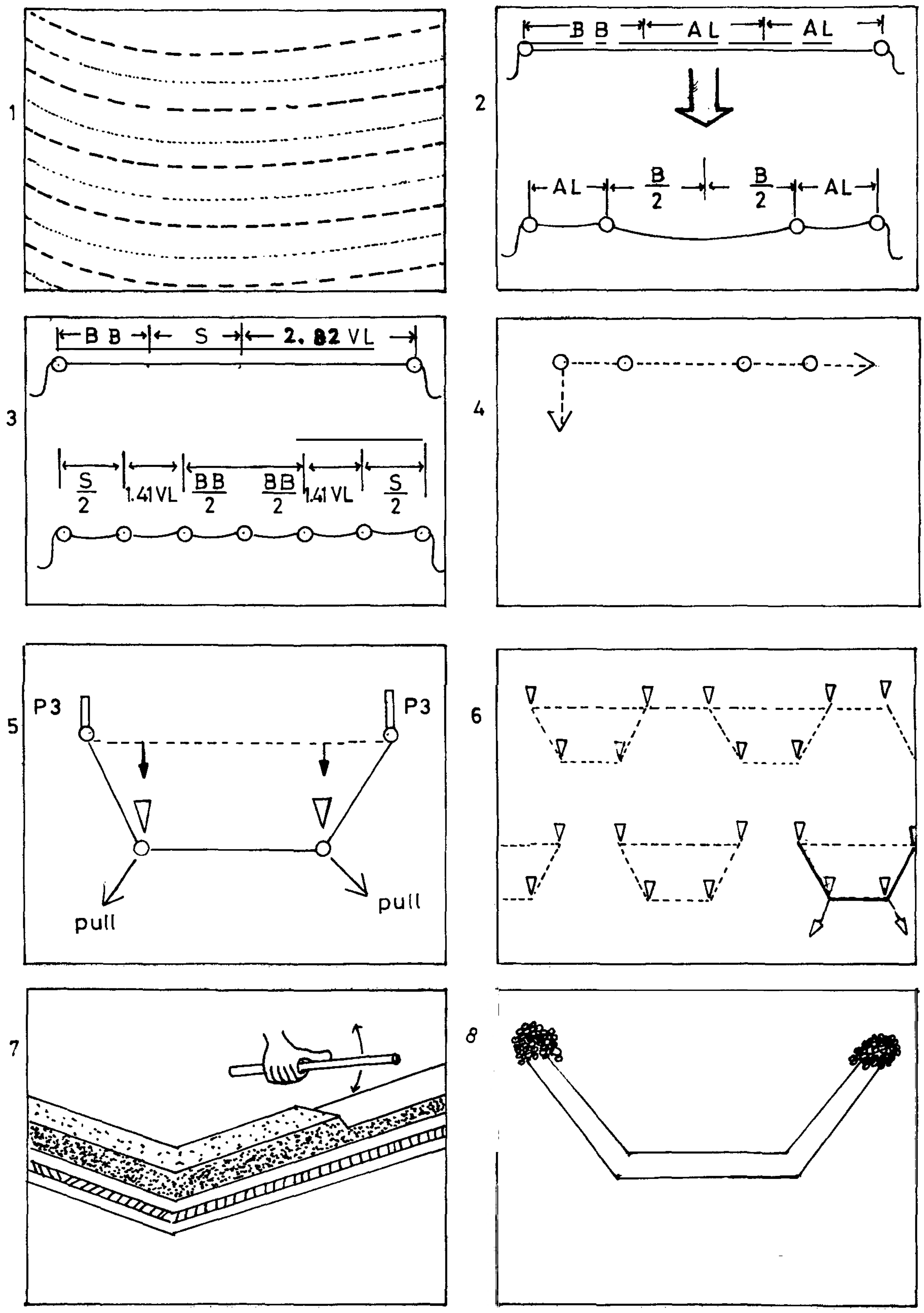

Fig. 15: Trapezoidal bunds field layout procedure.

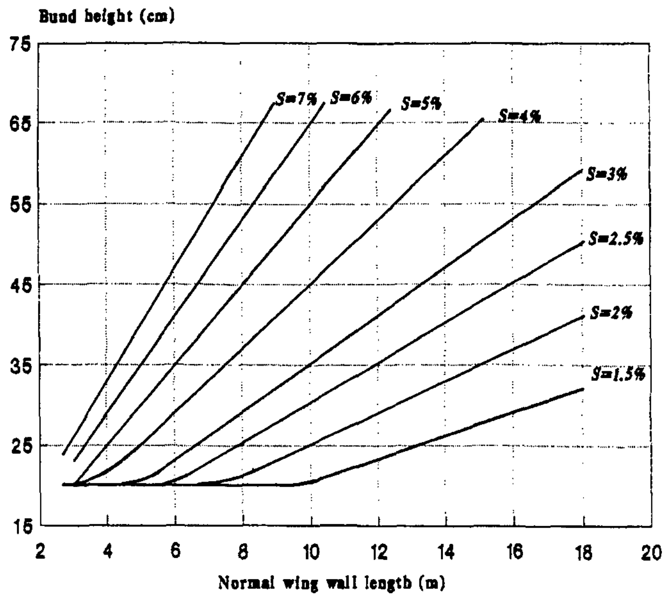

Fig. 16: Minimum height for trapezoidal bunds.

4.5 Contour stone bunds

Description

These are made of stones laid on the contour on up to 2% slope in areas of 200-750mm rainfall. They are suitable on stony land. They are used to

1) slow down runoff and filter out the soil, and
2) increase infiltration of runoff water.

They can be used without spillways and have low construction and maintenance requirements. The spacing between stone bunds is normally 15-30m but should be decreased as the slope increases. The minimum height of 25cm and a base width of 35-40cm set into a 5-10cm deep trench which acts as a key. On slopes less than 1%, bunds are spaced at 20m and on 1-2%, 15m. Bunds are made with a good mix of large and small stones to ensure that runoff is allowed to pass through slowly. The small stones are normally placed upstream and the large ones downstream.

The standard design is used for sizing the catchment area. The initial cultivated area may be small but is adjusted upwards in subsequent seasons as more experience is gained. The bunds will allow runoff through in the first few seasons. However, soil and vegetative materials will subsequently plug the spaces between the stones to make the structure to hold runoff above it.

Where stones are inadequate, they can be used in combination with other materials. Grass and other vegetative materials are planted behind stone bunds for more streng. Earth bunds can also be used, with stones making spillways staggered along the bund.

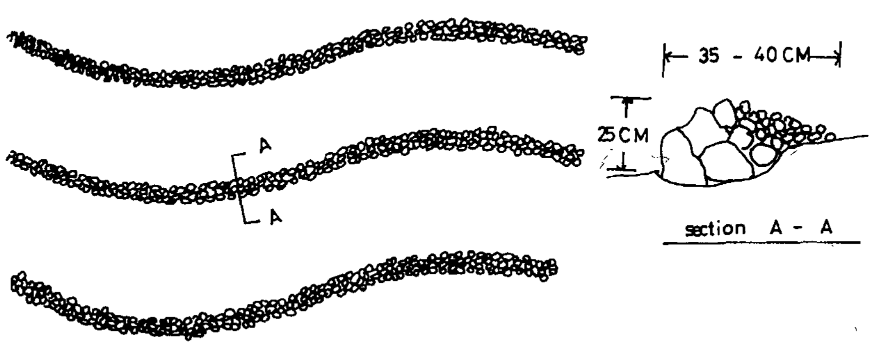

Fig. 17: Field layout for contour stone bunds.

Design, layout and construction details

Requirements: line level, measuring tape, pegs

1) design the stone bund spacing and height;
2) where necessary, protect the field from excess runoff using a cut-off drain at a maximum gradient of 0.25%;
3) mark the contour lines with pegs and smooth them out;
4) make a shallow trench along the contour lines by hand or oxen. Scoop and place the soil upslope;
5) place large stones into the base of the trench on the lower side. Place progressively smaller stones upwards, plugging gaps between large stones.

Example 6:

Sorghum is to be grown in a stony farm in an area with a design rainfall of 230mm. The land slopes at 5% and the soil is a clay loam.

a) What is the recommended design?
b) Comment on planting between the stone bunds.

Solution

a) From table 1, CWR=400; from table 5, C=0.5. Taking E=0.4 then CCAR = 3.7. Sorghum rows are 60cm apart, hence 10 lines take 6m. The catchment length is 6x3.7=22.2m. The total spacing between bunds is 22.2+6 = 28.2m. For a 6m crop area, the bund is 35cm high (table 12).

b) Initially the stone bunds will be porous to runoff, hence the whole space between the bunds can be planted. However, with time the spaces will be plugged by vegetative and soil materials, after which planting should be done according to the design with a clear catchment and cropped area.

Table 12: Minimum height of contour stone bunds.

Bund Spacing	Ground slope (%)									
	1	2	3	4	5	6	7	8	9	10
2		*Use a height of 25 cm*								
3							26	29	32	35
4						29	33	37	41	45
5					30	35	40	45	50	55
6				29	35	41	47	53	59	65
7			26	33	40	47	54	61		
8			29	37	45	53	61			
9			32	41	50	59				
10			35	45	55	65				
11		27	38	49	60					
12		29	41	53	65					
13		31	44	57						
14		33	47	61						
15		35	50	65			*Not recommended*			
16		37	53							
17		39	56							
18		41	59							
19		43	62							
20		45	65							

4.6 Contour bunds

Description These are simplified microcatchments mainly used for trees and are suitable in areas of 200-750mm annual rainfall. They can also be used for intercropping trees with fodder or crops between the bunds. The technique is easily made with oxen, hence in certain regions it may be more applicable than negarims. Contour bunds require an even topography without gullies or rills, deep soils (1.5-2m) and slopes not exceeding 5%.

Bunds are made on the contour at spacings dictated by the design. They are formed with soil excavated from a furrow on the contour and deposited downslope. Perpendicular earth ties are made at close spacing on the upslope for better runoff control. Each microcatchment can be planted with one or several trees. Planting pits are made between the ties and the bunds.

The microcatchment size is designed in the normal way. They vary from 10-50m² for each tree. The bunds are at least 25cm high, the height increasing with the slope of the land. The ties are 2m or longer and are spaced at 2-10m depending on the required size of microcatchment. The spacing of ties increases with increasing slope as the spacing of the bunds decreases.

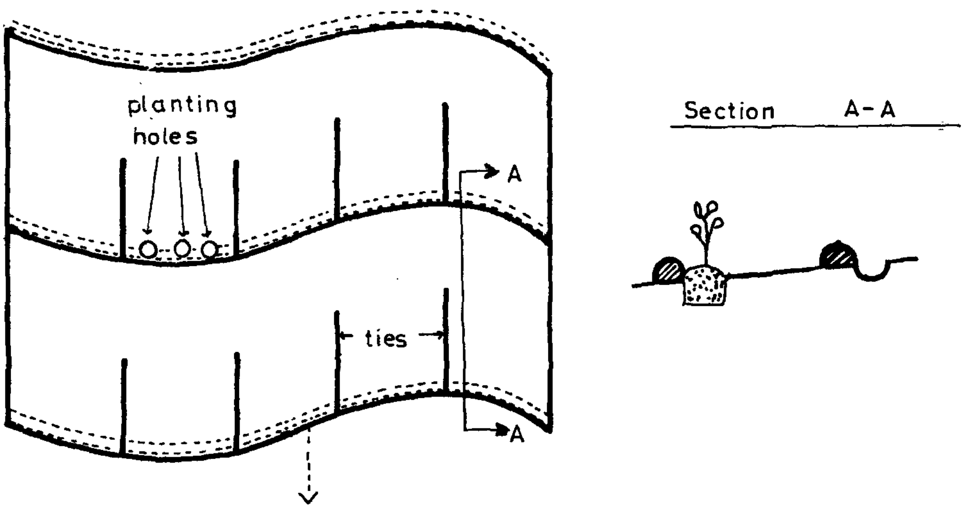

Fig. 18: Field layout of contour bunds.

Table 13: Minimum height for contour bunds for trees.

Ridge Spacing				Ground slope, %						
	1	2	3	4	5	6	7	8	9	10
2	*Use a bund height of 20cm*							21	23	25
3						23	26	29	32	35
4				21	25	29	33	37	41	45
5				25	30	35	40	45	50	55
6			23	29	35	41	47	53	59	65
7			26	33	40	47	54	61	68	75
8		21	29	37	45	53	61	69	77	85
9		23	32	41	50	59	68	77	86	95
10		25	35	45	55	65	75	85	95	
11		27	38	49	60	71	82	93		
12		29	41	53	65	77	89			
13		31	44	57	70	83	96			
14		33	47	61	75	89		*Not recommended*		
15		35	50	65	80	95				

Design, layout and construction details

Requirements: line level, measuring tape, pegs

1) design the spacing, microcatchment size and height of the bunds;
2) where necessary, provide a diversion ditch at 0.25% above the field to protect it from large external runoff;
3) stake contour lines and align them. Dig soil from the furrow and place it in layers of up to 10cm compacting a layer at a time until the desired height is achieved;
4) make earth ties to mark the microcatchments. Between the ties make planting pits of 80cm X 80cm X 40cm deep just above the bund;

5) on each side of the field, make a 25-30cm bund to prevent runoff loss from the system. Excavate the soil from within the system, with the contour bund joining the lateral bund;

Example 7:
A forest is to be established using contour bunds in an area with a 60% reliable annual rainfall of 480mm. The land is a pasture sloping at 3%. The estimated water requirement of the trees is 900mm. If the soil is a silty loam, determine bund spacing and height. Assume a 2m canopy for 4-year old trees.

Solution
From table 5, C=0.3. Taking E=0.7 (since trees take advantage of deep percolated water), CCAR = 4.2. Each tree will have an effective root zone of 3.14 m^2 and requires a total area of 3.14x(1 + 4.2) = 16.3m^2. The maximum bund spacing will be 8m for which the minimum bund height is 47cm (table 13). The ties can be at 16.33/8 = 2m. There may be very many ties along the bunds, hence tie spacing may be changed to any convenient spacing such as 8m (4 trees between ties) or 10m (5 trees between ties).

4.7 Other Important Techniques

There are other less known techniques but which have potential for application in the varied soil, topographic and climatic conditions. A farmer can be assisted to choose the most suitable technique based on the existing conditions.

4.7.1 Broad bed and furrow system

This is the recommended ICRISAT system. It is made of 1m broad beds separated by 0.5m furrows. The furrow slope is usually 0.4-0.8% on vertisols (black cotton). On each broad bed width, 2-4 rows of crops can be planted. The crop geometry is varied to suit the cultivation and planting equipment. The objectives of the technique are to:
1) encourage moisture storage in the soil profile;
2) dispose safely any surplus surface runoff;
3) provide better drained and more easily cultivated soil in the bed.

This technique has been successfully used in Taita Taveta, Kenya, where they are called cambered beds.

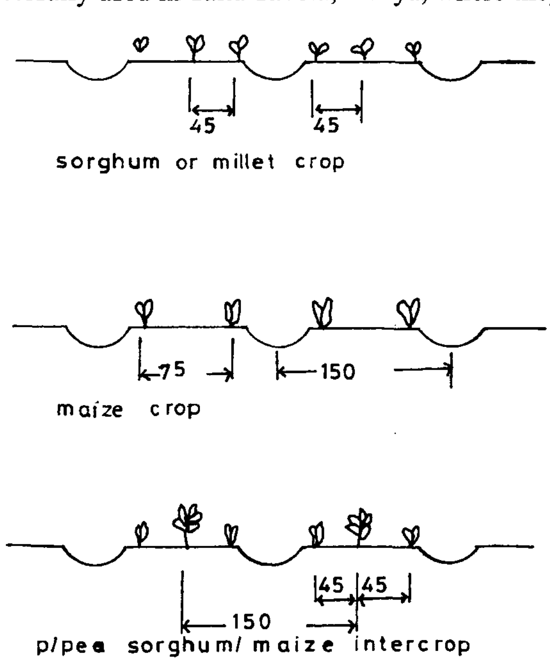

Fig. 19: Alternative crop and row arrangements on broad beds.

4.7.2 Ridging and tied ridging

The purpose of using tied ridges is to increase surface storage of rain water. Furrows on the contour are dammed with small ties down the slope to prevent runoff flow from one end of the field to another. It is a high labour requirement technique unless the farmer can first use oxen to make the ridges. The technique gives good yields generally but can also give low yields due to water logging in very wet seasons. They may not give good yields after dry seasons due to their limited runoff harvesting potential.

The technique requires high moisture storage soils of high infiltration rate. The following safety considerations should be observed:

a) the furrows should be at a gentle gradient in case the ties fail;
b) the ties should be lower in height than the ridges.

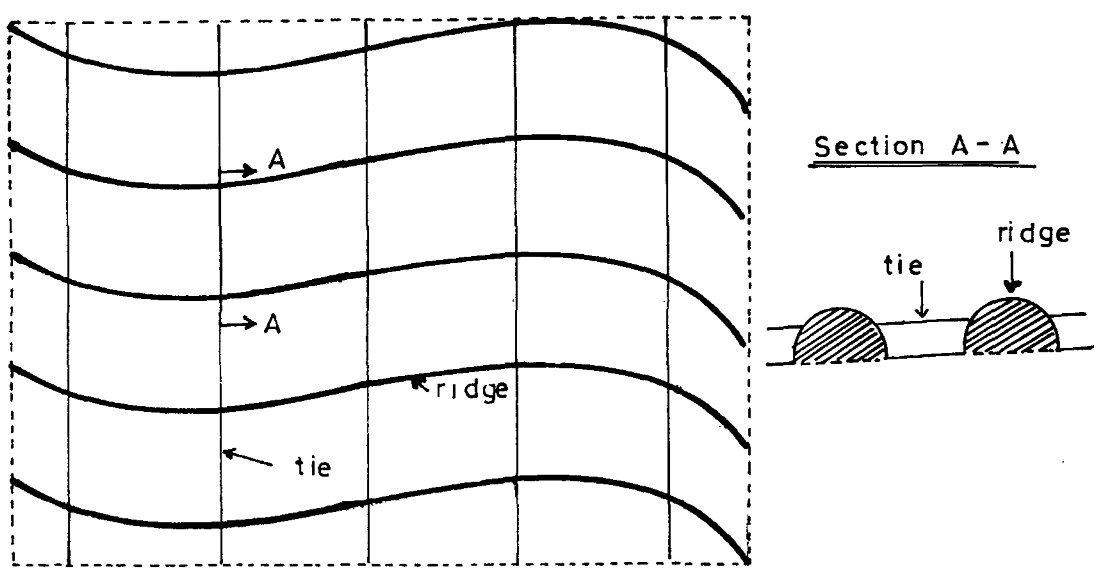

Fig. 20: Field layout and geometry of tied ridges.

4.7.3 Conservation bench

This is a rainfall multiplier technique using an adjacent catchment to provide additional runoff onto level terraces grown with crops. The technique is useful in increasing yield and its reliability in areas of 300-600mm annual rainfall. It requires a gentle slope of 0.5-1.5% but can be used up to 6% slope. A deep soil is recommended for good moisture storage and to reduce the effect of decreased soil fertility due to excessive levelling and exposure of subsoil in the crop area. There should be outlets and a waterway at the end of terraces in case of excess runoff.

The main design consists of the width of terrace and the catchment area. Typical terrace widths are 10m (on 5-6% slope) and up to 30m (2% slope) and 50m or more (1% slope). Mini terraces 9m wide are made with 1:1 CCAR. The bench can be made either level along its length, or graded at 1:400 (0.25%).

Typical CCAR are 1:1 or 2:1. The catchment area increases as rainfall decreases. A rotation can be considered to alternate cropping in the catchment in wetter seasons and fallow in the drier ones. In Kenya, this technique can easily be adapted in terraced fields where the upper part of the terrace is left as a catchment while the lower one is planted with a crop. The design follows the procedure discussed under section 4.5.

Plate 2: An above-average maize crop after low April rains, 1997, Mwingi, on Fanya Juu with external runoff.

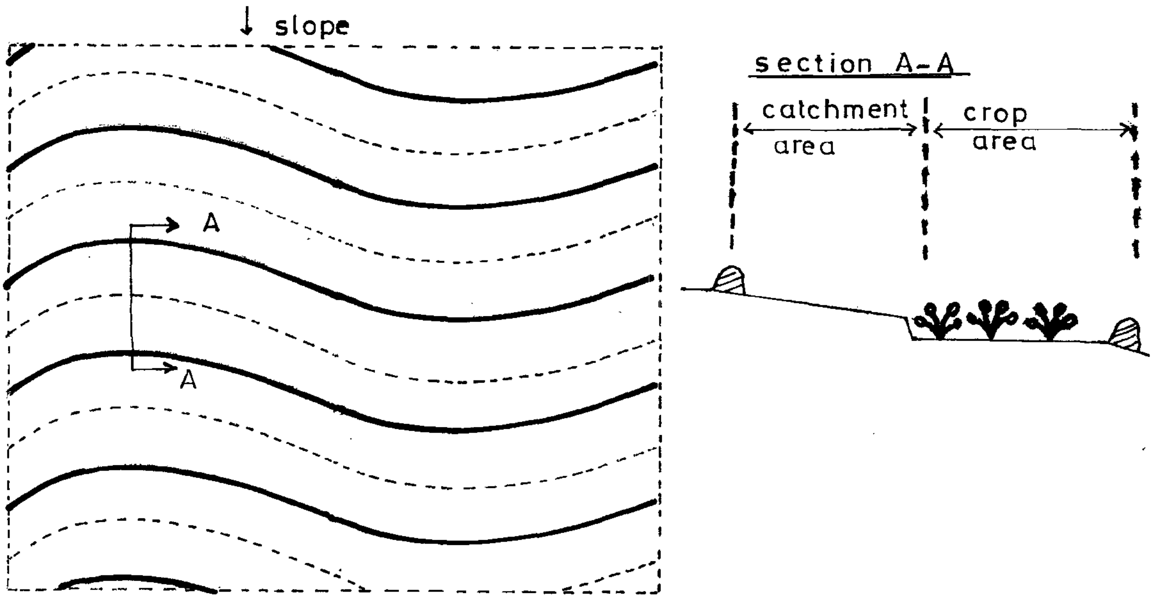

Fig. 21: Details of the layout of a conservation bench.

4.7.4 Zay pits

Description

This is a technique commonly used in the Sahelian region of West Africa for growing sorghum and millet. Zay pits increase crop yield by a cómbination of moisture conservation and harvesting of runoff from the space between the planting pits.

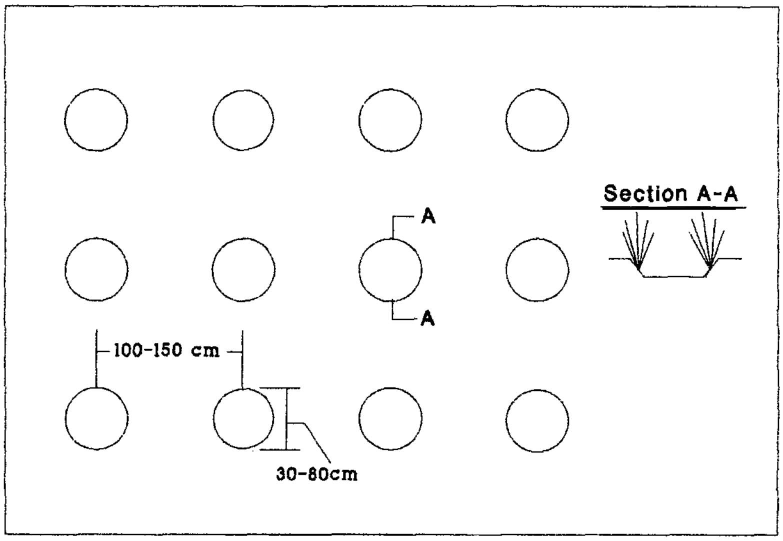

Fig. 22: Field layout and dimensions of Zay pits commonly tried in Kenya.

Local experience In Kenya, the technique is also referred to as planting pits. It has been tried by the Dryland Applied Research and Extension Project (DAREP) in Embu and by the National Dryland Farming Research Station (NDFRS) Katumani. The preferred soil is sandy loam as pit preparation is easier. However, pits can be used on a wider range of slopes due to their small size. Manure is spread on the whole pit to improve on soil fertility. Seeds are planted around the edge of the pit halfway up the side to avoid waterlogging and "burning" by manure.

The size refers to the diameter of the pits and varies from one place to another. The researchers at Katumani used a diameter of 30cm, an interrow spacing of 60cm and a depth of 15cm. On the other hand, DAREP used an 80cm diameter, with 100cm and 150cm between centres of pits and 15cm depth. With these pit spacings, the maize plants per pit are 4 and 8, giving populations of 40000 and 28800 plants per hectare, respectively. With regard to cow peas, the plants per pit are 6 and 12, giving 60000 and 43200 plants per ha. The spacing around the pits depends on the recommended spacing. However, farmers participating in DAREP modified these dimensions to 80cm diameter pits and 20cm spacing between pits to reduce "waste on land".

The major disadvantage of Zay pits is high labour requirements; they cannot be done using animal draught power. But where farmers have seen their benefits, they are willing to implement them.

Plate 3: Comparison between maize planted with and without pits barely 5m apart in the same field, lower Embu. Note the deep green colour and large cobs where pits have been used.

Table 14: Values of CCAR for different diameters and spacing of Zay pits.

Pit Size (m)	Pit Spacing (m)	Crop	Seeds per pit	Pit Area (m^2)	Total Area (m^2)	Catch. Area (m^2)	CCAR	Plant Pop.
0.3	0.6	maize	3	0.07	0.81	0.74	10.5	37037[1]
		maize	5	0.07	0.81	0.74	10.5	61728
		C/Peas	3	0.07	0.81	0.74	10.5	37037
		C/Peas	4	0.07	0.81	0.74	10.5	49383
0.8	0.2	maize	4	0.50	1	0.50	1.0	40000
		maize	6	0.50	1	0.50	1.0	60000
	0.7	C/Peas	8	0.50	2.25	1.75	3.5	35556
		C/Peas	12	0.50	2.25	1.75	3.5	53333

[1] The seeds per pit, hence plant population, were estimated for these dimensions used by Katumani.

4.7.5 Runoff harvesting from the road

A number of local techniques have been devised by farmers for reducing serious erosion hazards caused by road runoff. This runoff is subsequently put into some good use. These techniques have been developed without any technical input from extension but seem to be working. Although they have resulted in improved crop yields, they would benefit from some research, engineering and extension input. Some of these are discussed below.

4.7.5.1 Root storage basins

These are structures which hold runoff on the cultivated surface allowing it to infiltrate. The source of runoff can be a road, grazing field, shopping centre, hill etc. The basins are made of earth bunds 20-40cm high and are most useful on low slopes of 0.5-5%. The bunds are provided with spillways which allow discharge of excess runoff without causing erosion.

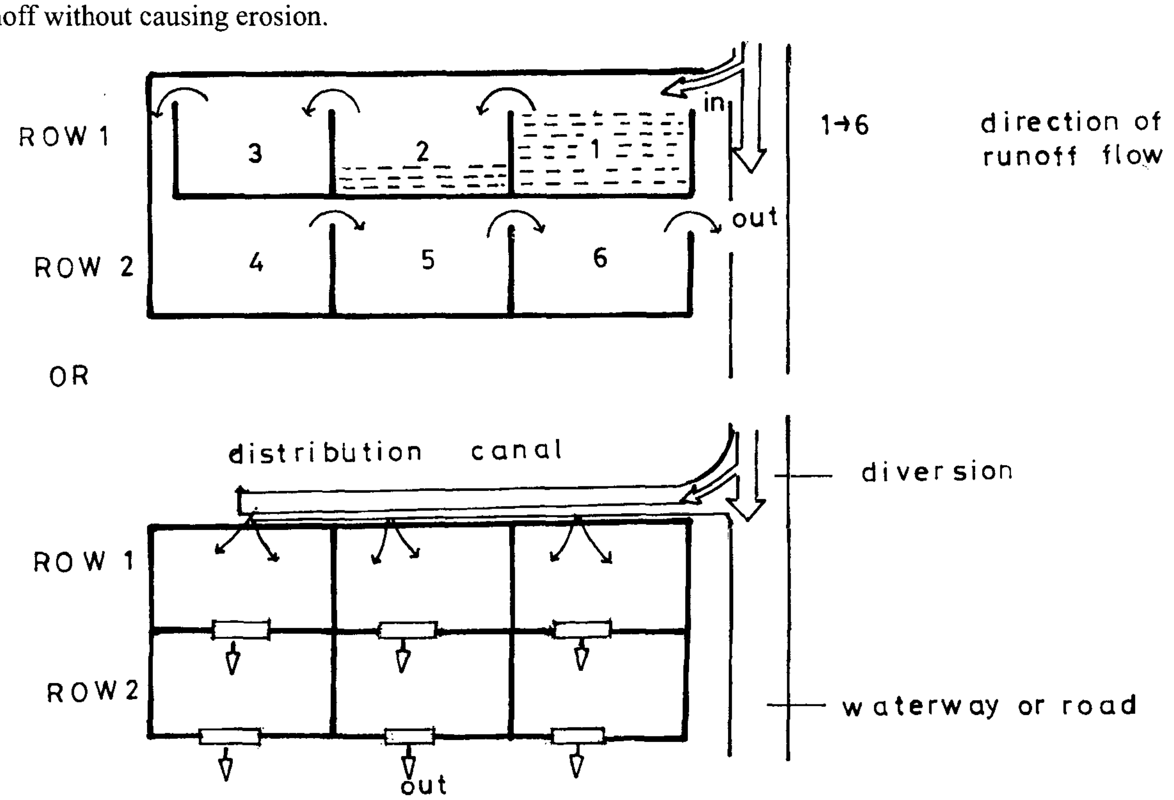

Fig. 23: Road runoff harvesting and distribution into basins.

Two variations have been used in Taita Taveta. In the first method, runoff fills the first basin in the row before extra runoff flows into the next basin laterally until the entire row is covered. Runoff flow changes direction and in a similar manner covers the next row of basins. Excess runoff leaves the system at the end of the last row of basins. The other method diverts runoff and allows a uniform distribution and infiltration in the first row of basins. When water ponds beyond a pre-determined depth, it flows into the lower row of basins row after row until all basins are covered (fig. 23).

Both methods result in poor distribution of runoff. The first row of basins get more water and is subject to waterlogging. The last rows may not get enough water. An improvement would be to have each row fed by a separate diversion. Subject to adequate runoff flow, equal diversions are possible if channels are made of equal side slopes, gradient and dimensions (fig. 24).

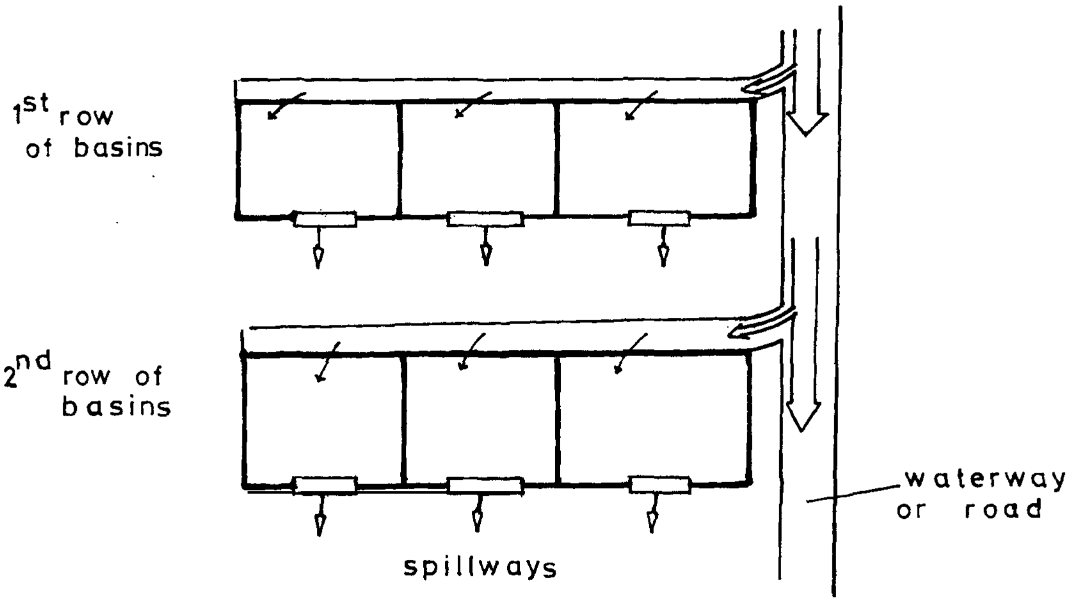

Fig. 24: Improved road runoff harvesting and distribution technique.

4.7.5.2 Banana channel

This is a common technique in Ukambani in areas of 500-800mm of annual rainfall. Similar to a cut-off drain, it is mostly used for banana production. In dry areas, retention ditches are preferred to cut-off drains. These hold a lot of runoff. Bananas are planted into the channel and benefit from the additional runoff. The technique can be improved in at least two ways:

1) Reduction of "dead" storage:

Most of the ditches used today are similar to a level cut-off drain. The standard size of a cut-off drain is 1.52m (top), 0.92m (bottom) and 0.61m depth for a cross-section area of $0.74m^2$. It would store $7.4m^3$ of runoff for every 10m when full. If the depth is reduced to say 0.2m, the stored volume of the structure would be reduced by 74% to $1.9m^3$, saving $5.5m^3$ of runoff. This additional runoff can be spread in the field to benefit other crops rather than be lost as deep percolation. The current ditch depth is therefore wasteful on runoff. It would be a more efficient water harvesting structure if the depth is reduced to make it a conveyance rather than a storage structure.

Two variations of runoff spreading observed in the field are:

a) having a shallow channel which conveys runoff to the end of the field. Once full, it allows runoff to overflow the channel and spread into the field below;
b) digging a zigzag channel to circulate runoff water from the top to the bottom banana row.

2) Increasing the size of planting holes:
Currently some farmers dig just a small hole in the channel or none at all. A large hole is desirable to permit for manure application for improvement of organic matter, hence better moisture storage and soil fertility.

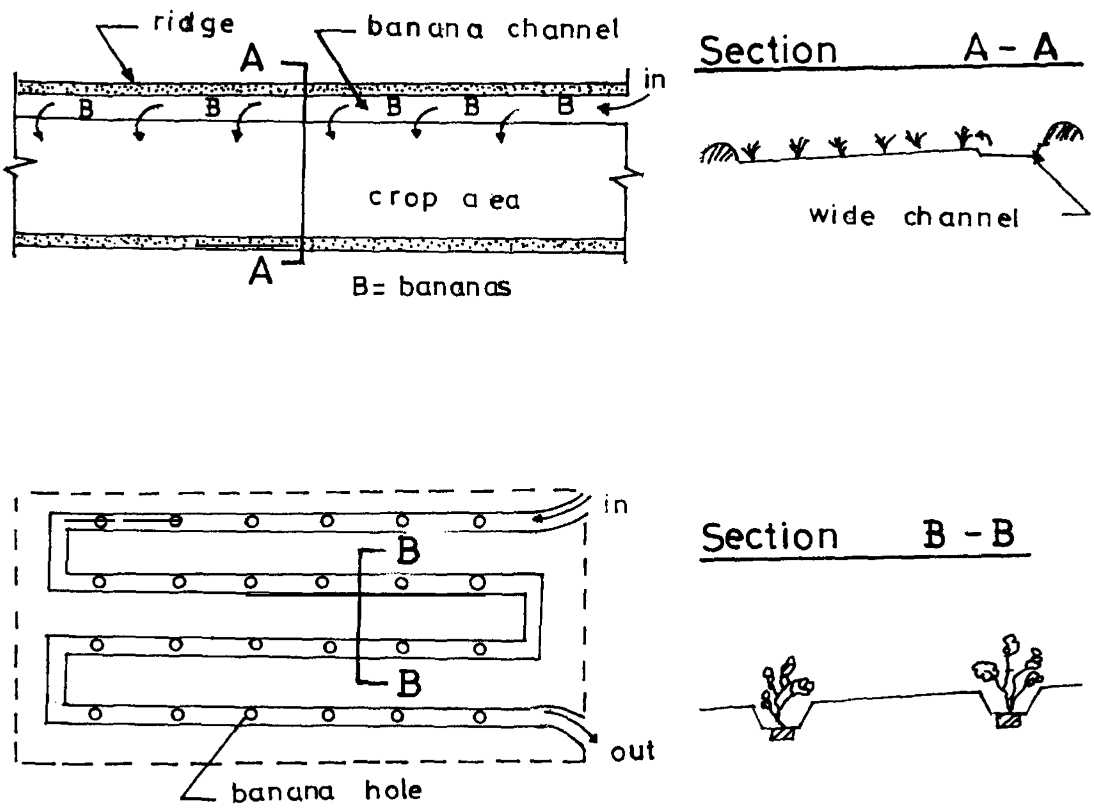

Fig. 25: Runoff benefitting a line of bananas and a cropped field (a) and zigzag variation for bananas alone (b).

SECTION 5

DESIGN FOR SIMPLE RUNOFF STORAGE STRUCTURES

Introduction

When it rains, large amounts of runoff water collect from roads, grazing areas and homesteads. This runoff may not all infiltrate when diverted into cultivated fields; if it does, most is lost as deep percolation. Crops suffer from water stress just days after rainfall ceases. Simple storage structures dug into the ground can temporarily store this runoff. A farmer can subsequently apply this water on a crop.

Besides runoff water for crop production, there are serious water supply problems in dry areas. Some of these problems can be solved rather easily if people had the technology. In this section, a simple design methodology is presented for water harvesting from a known size of surface area. This method can be applied to develop water supply for homes and institutions such as schools and hospitals. A different method would be required if the catchment area was unlimited.

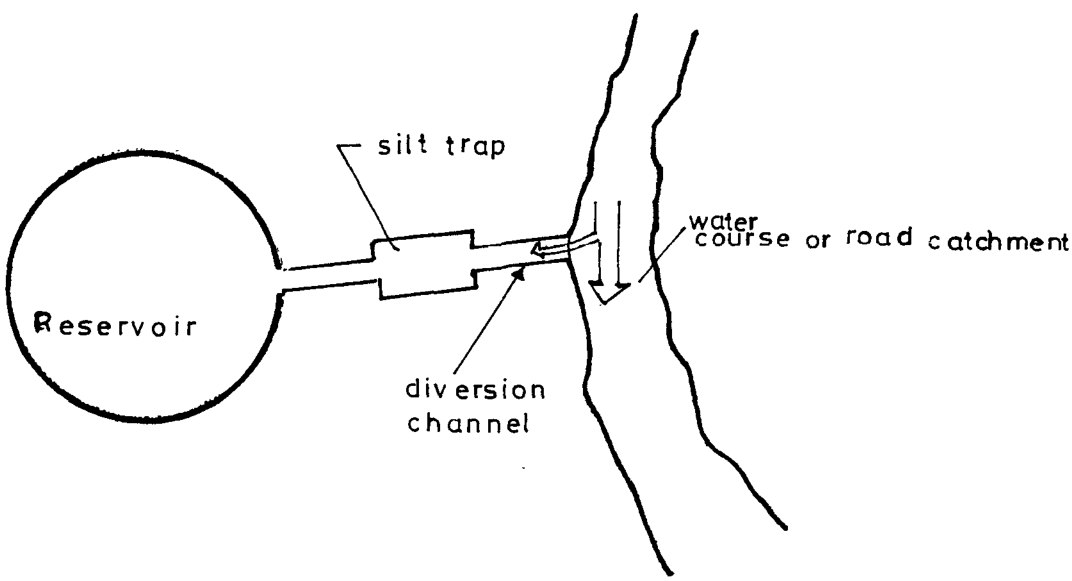

Fig. 26: Runoff diversion into simple underground reservoirs. Water could also be harnessed from a roof rather than a water course.

5.1 Sizing the reservoir capacity

The size of storage reservoir is very important because of

1) the cost implication, and
2) its ability to meet water needs.

Because of lack of design procedures, most reservoirs are made either too large or too small. Although more rigorous methods may be possible, the following simple procedure can be applied to determine the most economical reservoir to meet the water needs:

1) select the wettest month of the year as the starting month. This ensures that there is large storage space available;

2) compute the water supply (litres) for each month. This is done by multiplying the monthly rainfall (R) by the total surface area (A) and a coefficient (C), and converted to m3 by dividing by 1000;

$$Volume = 0.001\ R \times A \times C\ m^3 \tag{9}$$

3) list all the water demand components (cooking, drinking, washing, livestock, kitchen garden etc) and the daily demand for each (table 15);
4) compute the demand for each month including allowance for evaporation and seepage losses (all in litres). Seepage loss can be estimated from the soil type if the reservoir is not cemented, but is otherwise zero. Convert all the figures to m3 by dividing the total monthly demand by 1000;

Table 15: Guidelines for estimation of domestic water demand

User category	Daily consumption (litres) in the following rainfall regimes: high	medium	low	unclassified
Sanitation and ablution				75[1]
Cooking and laundry				45[1]
Hospital, school				25[1]
Human	20	15	10[2]	15-35[3]
Dairy cattle	50	50	50[2]	
Local cattle	17	17	17[2]	
Sheep/goats	4	4	4[2]	

[1] *Barnes et al (1983)*
[2] *Ministry of Water Development (1992)*
[3] *Argawal et al (1980)*

5) from the starting month, accumulate both the supply and the demand month after month;
6) compute the monthly differences between the accumulated supply and demand. If the annual supply is much larger than the demand, then the reservoir size is controlled by surface area rather than demand and this criteria should be used. For example, a trial and error of surface area can be done until the monthly differences of all the months are positive with one of the differences just above zero;
7) the largest monthly difference between total supply and total demand is the most economical reservoir that can meet the water needs. This procedure will be used in an example to show how the method works. This is a real-life example of Obuolo Primary School. The school is about 8km north east of Kisumu town centre and currently has a population of 900 students.

Example 8

During a normal school day, Obuolo Primary School uses 400 litres of water daily for drinking and cleaning. Because of a broken down water supply, the school spends KSh. 400 every school day to buy water. For sustainability, a more reliable and cheaper alternative water supply was deemed necessary.

a) design a roof water harvesting system for the school.
b) in your opinion, is this project justifiable?

Solution

a) The school consists of 3 blocks of buildings - tuition (320 and 288 m^2) and the office/staff room (80 m^2) for a total of 688m^2. The first computation involves total roof area of the school and is summarized in table 14. Computations were also done for the other roofs, i.e. 320, 288 and 80 m^2 to see if any of them would be adequate. These results are summarized in table 16.

Table 16: Calculation of required tank using total roof area.

Month (1)	Rain (mm) (2)	Total area (m^2) (3)	Supply (m^3) (4)	SumSup (m^3) (5)	Demand (m^3) (6)	SumDem (m^3) (7)	Difference (5-7) (m^3) (8)
3	168.8	688.0	104.5	104.5	37.9	37.9	66.6
4	171.8	688.0	106.4	210.9	7.9	45.8	165.1
5	163.8	688.0	101.4	312.3	37.9	83.7	228.6
6	91.7	688.0	56.8	369.1	36.7	120.4	248.7
7	48.9	688.0	30.3	399.4	37.9	158.3	241.0
8	53.3	688.0	33.0	432.4	10.5	168.8	263.5
9	70.3	688.0	43.5	475.9	36.7	205.5	270.4
10	88.5	688.0	54.8	530.7	37.9	243.5	287.2
11	83.9	688.0	52.0	582.6	18.4	261.8	320.8
12	74.3	688.0	46.0	628.7	0.0	261.8	366.8
1	78.3	688.0	48.5	677.1	37.9	299.8	377.4
2	80.1	688.0	49.6	726.7	35.5	335.3	391.4

Notes:
1) Demand figures as obtained by groups during the practicals
2) A1 = block 1 area (320); A2 = office area (80); A3 = block 2 area (288); A4 = area for optimal design (317.5)
3) 20% was added to the demand for losses and increased demand

Interpretation of the design (tables 16 and 17)

1) By tapping water from the whole school roof, the storage continues increasing unbounded every month to a maximum of 391.4m^3 (table 17 col.)
2) If this size of tank was made, an equivalent volume of water would have to be poured out at the end of the water year. As the largest capacity, this storage is clearly uneconomical to make.

Table 17: Summary of reservoir capacity by different roof areas.

Month	Roof areas of different building blocks, m^2				
	688	320	317.5	288	80
(1)	(2) Total	(3) A1	(4) Optimal	(5) A3	(6) A2
3	66.6	10.7	10.3	5.9	-25.7
4	165.1	52.3	51.5	42.6	-21.2
5	228.6	61.5	60.4	47.1	-47.3
6	248.7	51.3	49.9	34.1	-77.4
7	241.0	27.4	25.9	8.9	-111.9
8	263.5	32.3	30.7	12.2	-118.5
9	270.4	15.8	14.1	-6.3	-150.2
10	287.2	3.3	1.4	-21.3	-181.7
11	320.8	9.2	7.0	-17.9	-194.0
12	366.8	30.6	28.3	1.4	-188.7
1	377.4	15.2	12.7	-16.3	-221.0
2	391.4	2.7	0.0	-31.0	-250.8

2) If the office area was used, there would be a water deficit every month increasing to a maximum of 251 m^3 by the end of the year (table 17 col. 6). Hence this tank would not solve the problem. From this column, it is not possible to determine the reservoir capacity.
3) If the 288m^2 block was used, the maximum storage required would be 47.1 m^3. However, the school would have to buy water in 5 of 12 months, namely January, February, September, October and November (table 17 col. 5).
4) The water demand for the school can however be met by using the 320 m^2 roof alone. We may be tempted to make a tank of 338.2 m^3 (to collect all the water) or 335.3 m^3 (to meet the total demand). This would be wrong because total supply and demand do not come simultaneously. The most economical tank for the

school is, however, 61.5 m^3, leaving 2.7 m^3 at the end of the water year, which is used for cleaning the tank. This procedure reduces tank capacity by 82%.

Notice that at the optimal roof area of 317.5 m^2, the final storage at the end of the water year would be 0 m^3 and the reservoir capacity slightly less at 60.4 m^3. However, there should be some water left for cleaning.

b) The school already has a large roof; the only cost to be incurred are labour and materials. Roof water harvesting would be the most reliable source of water. Moreover, it would save the school about KSh. 80000 annually. This justifies the option.

5.2 Design of simple underground storage structures

Having established the reservoir size, the next step is to design its shape and dimensions. There are various shapes of underground reservoirs used, but they are of unknown capacities. Other tanks such as above ground and other variations of underground reservoirs can also be used. Here, two types of circular plan reservoirs are considered because of their simplicity:

a) a parabolic cross-section; and
b) a trapezoidal cross section of 1:1 side slopes.

The first reservoir is flatter and more stable. The storage volume can be estimated for various diameters as outlined in table 11. For both reservoirs, the quoted capacity is reduced when the reservoir is lined as recommended to reduce seepage.

Layout and construction procedure

1) select a suitable site near the water course, leaving sufficient distance for at least one silt basin;
2) using two pegs and a string, stake out the edge of the circle from the centre and mark it with a small trench;

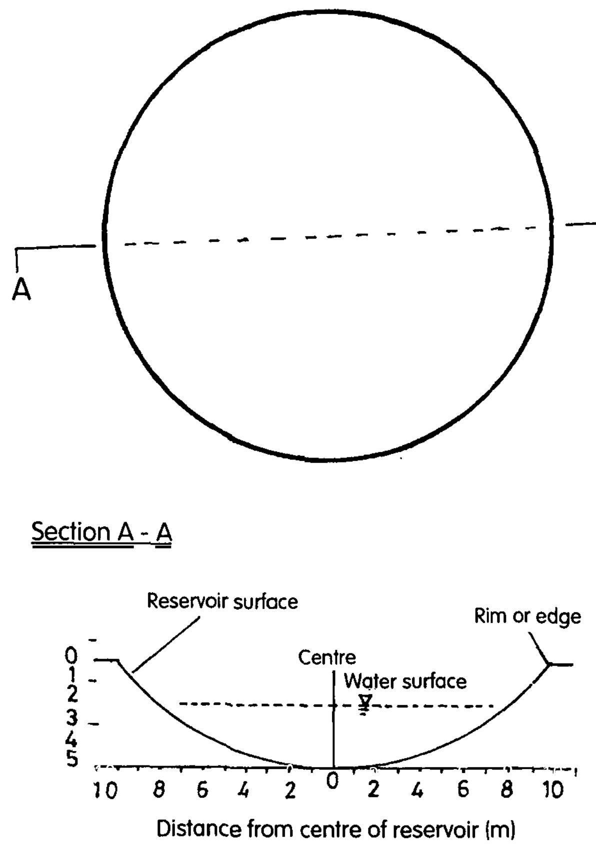

Fig. 27: Plan and section of a parabolic underground reservoir.

3) mark the short distances indicated (in bold italics, table 18) starting with the shortest distance from the centre;
4) dig to the required depth starting at the centre. Continue digging until the edge (brim) is reached. Digging several trenches radiating outward would help get the depth right.

The second reservoir is simpler to lay out but may be less stable. The bottom of the reservoir should be dug to a level rather than sloping surface. The dimensions can be estimated using table 19 for the design volume computed in section 5.1.

Layout and construction procedure
1) select a suitable site near the water course, leaving sufficient distance for at least one silt basin;
2) using two pegs and a string, layout the bottom and top circles from the same centre, marking each circle;

Table 18: Runoff storage volume for a parabolic cross-section reservoir.

Radius (m)	Depth (m) for indicated distance from centre: Centre 0	20	40	60	80	Brim 100	Volume (cu.m)
1	0.05	0.048	0.042	0.032	0.018	0[A]	
	0	***0.2***	***0.4***	***0.6***	***0.8***	***1.0***[B]	***0.1***[C]
2	0.2	0.192	0.168	0.128	0.072	0	
	0	***0.4***	***0.8***	***1.2***	***1.6***	***2.0***	***1.3***
3	0.45	0.432	0.378	0.288	0.162	0	
	0	***0.6***	***1.2***	***1.8***	***2.4***	***3.0***	***6.4***
4	0.8	0.768	0.672	0.512	0.288	0	
	0	***0.8***	***1.6***	***2.4***	***3.2***	***4.0***	***20.1***
5	1.25	1.2	1.05	0.8	0.45	0	
	0	***1***	***2***	***3***	***4***	***5.0***	***49.1***
6	1.8	1.728	1.512	1.152	0.648	0	
	0	***1.2***	***2.4***	***3.6***	***4.8***	***6.0***	***101.8***
7	2.45	2.352	2.058	1.568	0.882	0	
	0	***1.4***	***2.8***	***4.2***	***5.6***	***7.0***	***188.6***
8	3.2	3.072	2.688	2.048	1.152	0	
	0	***1.6***	***3.2***	***4.8***	***6.4***	***8.0***	***321.7***
9	4.05	3.888	3.402	2.592	1.458	0	
	0	***1.8***	***3.6***	***5.4***	***7.2***	***9.0***	***515.3***
10	5	4.8	4.2	3.2	1.8	0	
	0	***2***	***4***	***6***	***8***	***10.0***	***785.4***

A = depth of reservoir at various distances
B = distance of various points from centre to the brim
C = volume of reservoir in cubic metres.

3) first dig inside the middle circle to the required depth; place the soil downslope at least 1m below the outer circle, starting farthest from the edge of the circle;
4) finish by sloping the sides from the bottom of the inner circle to the top of the outer circle.

For both types of reservoirs, fig. 29 is provided to give the volume for various tank diameters since not all possible volumes are listed in tables 18 and 19. The following considerations should also be made:

1) **Diversion** - this is a raised earth dyke which diverts runoff from the main water course into an intake channel. It should be used when the catchment area is known and a spillway of adequate capacity designed.
2) **Intake channel** - this is a furrow intake of sufficient size which conveys diverted runoff into the reservoir. It should be shallow and wide to reduce the kinetic energy of moving water. The channel should be planted

with a suitable short grass and also have check structures if the slope is high. The channel gradient should be less than 0.25% (sandy and silty soils) and 0.5% (clay soils).

Table 19: Dimensions and storage volume for a circular plan, trapezoidal cross-section ground reservoir.

Top Diameter (m)	Bottom Diameter (m)	Depth (m)	Volume (m^3)
2	0.86	0.57	1.1
3	1.29	0.86	3.6
4	1.71	1.14	8.5
5	2.14	1.43	16.6
6	2.57	1.71	28.7
7	3.00	2.00	45.6
8	3.43	2.29	68.0
9	3.86	2.57	96.8
10	4.29	2.86	132.8
11	4.71	3.14	176.8
12	5.14	3.43	229.5
13	5.57	3.71	291.8
14	6.00	4.00	364.4
15	6.43	4.29	448.2
16	6.86	4.57	544.0
17	7.29	4.86	652.5
18	7.71	5.14	774.5
19	8.14	5.43	910.9
20	8.57	5.71	1062.5

3) Silt trap - this is a rectangular hole dug before the reservoir and used for holding heavy soil materials. It ensures a longer reservoir life by reducing siltation rate. A convenient strainer just below the silt trap helps keep away wood planks and dead vegetative materials.

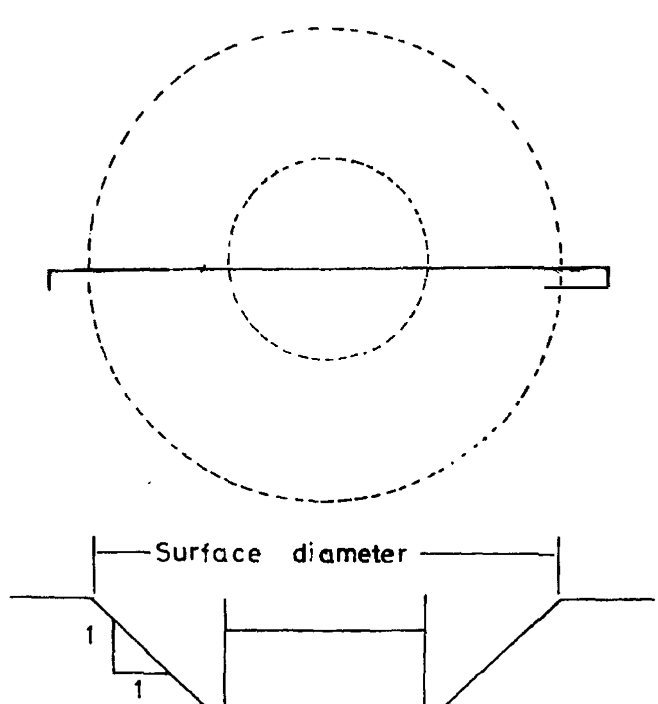

Fig. 28: Plan and section of a trapezoidal reservoir.

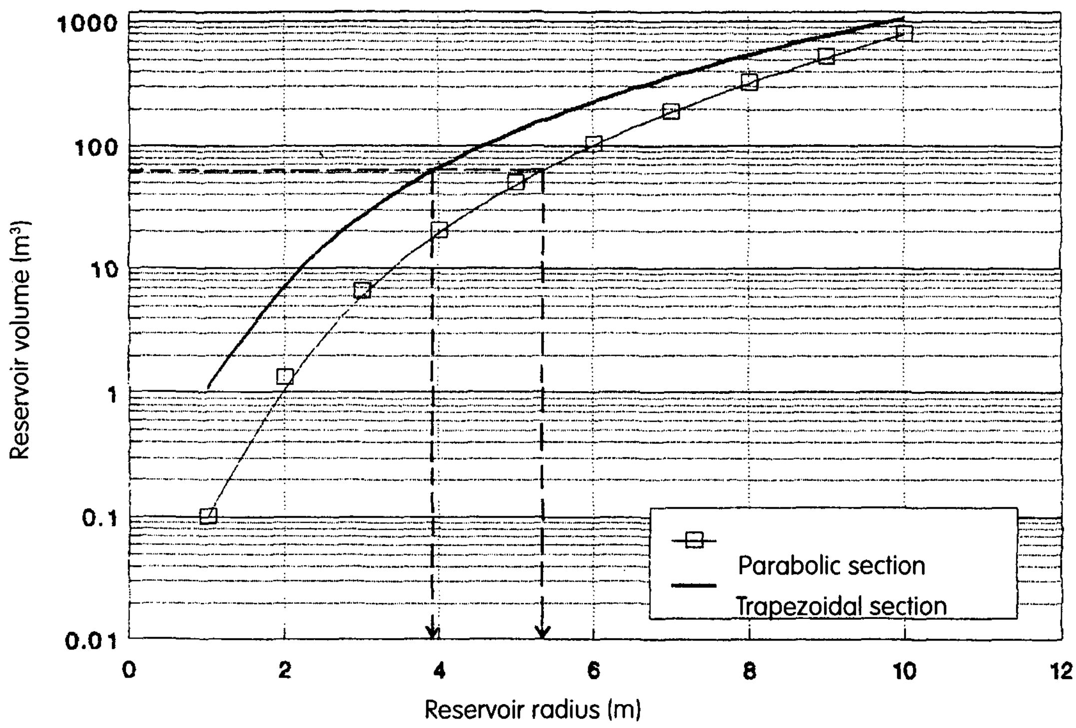

Fig. 29: Relationship between diameter and capacity of underground reservoirs.

4) **Lining** - where possible, lining should be considered to reduce seepage losses especially in sandy soils. It can be done using a clay "blanket" of about 15cm placed and compacted a little at a time starting at the centre. Where affordable, this soil layer may be preceded by a layer of plastic sheet laid inward from the edge of the reservoir. For domestic water supply, concrete lining could be considered to improve water quality.
5) **Covering** - evaporation losses are very high in dry areas. It is often necessary to reduce direct sunlight on the water. Sisal poles can be used for making a covering structure. Gunny bags can be patched together to make a mosaic which can be tied with ropes to hang above the water surface. A thin grass thatch may be the most sustainable.
6) **Maintenance** - silt traps do not remove all soil materials. Larger silt and sand particles settle at the bottom of the reservoir. This should be removed periodically between rainfall seasons when the reservoir is empty and dry.

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APPENDIX A
APPLICATION OF THE SCS CURVE NUMBER METHOD

The amount of runoff produced by a given storm depth is given by the following relation:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad \text{(AP.1)}$$

where

Q = daily runoff depth, mm
P = daily rainfall, mm
S = maximum difference between rainfall and runoff, mm

and S is given by:

$$S = \frac{25400}{CN} - 254 \qquad \text{(AP.2)}$$

where

CN = curve number for soil, cover and moisture condition

Curve numbers range from 0 to 100. These values reflect the soil type, the vegetation and the antecedent soil moisture status. For the ASAL, recommended values are given in table A1. The most reasonable runoff estimates are those based on a curve number that is dynamic throughout the season. By assuming dependence between CN in consecutive days, it can be shown that the curve number for each day is (Hai, 1993):

$$CN_{i+1} = \frac{30480}{\frac{30480}{CN_i} - R_i + ET_i + Q_i} \qquad \text{(AP.3)}$$

where

CN_{i+1} = curve number, mm-1
ET_i = evapotranspiration from the catchment, mm
R_i = daily rainfall, mm
Q_i = daily runoff, mm

This method requires the following information for it to work:

daily rainfall data
daily evapotranspiration estimates
soil moisture estimates especially at the beginning
actual runoff (measured)
initial curve number at the beginning of rainfall

When calibrated, the method has good potential as a rapid water harvesting design tool.

Table A1: Runoff curve numbers for arid and semi-arid rangelands.

		Curve number for hydrologic soil group			
Cover description	Condition	A	B	C	D
Grass + weeds and low growing bush	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Mountain brush mixture	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

Conditions:
Poor: 30% cover *Fair*: 30-70% cover *Good:* 70% cover

Soil group	**Description**
A	Lowest runoff potential. High infiltration rates in deep sands with little silt and clay.
B	Moderately low runoff potential. Above average infiltration after thorough wetting. Mostly sandy soils shallower than A.
C	Moderately high runoff potential. Below average infiltration. Shallow and clayey soils.
D	Highest runoff potential. Mostly swelling clays, shallow soil with nearly impermeable sub-horizon.

Source: Hromadka and Whitley (1989)

APPENDIX B
DETAILS OF THE DESIGN OF SEMI-CIRCULAR BUNDS

1. Design for trees

The designs presented here have been proposed by Hai (1997) as a more systematic and efficient approach compared to the existing one. The diameter of a semi-circular bund for a fruit or forest tree is found using the following equation:

$$D = 0.898 B^{1/2} \left(1 + \frac{A}{B} \right)^{1/2} m \qquad \text{(AP.4)}$$

where
A = required catchment area, m^2;
B = cropped area, m^2.

The ratio A/B is the catchment to cropped area ratio (CCAR) which depends on the type, rainfall, soil, slope and land use. The cropped area for a tree is the area where a tree gets soil moisture supply. This can be estimated using the canopy diameter for a mature producing tree in the case of fruit trees. The design for a tree crop is rather straight forward and is outlined as follows:

1) determine the CCAR for the particular tree crop;
2) determine the crop (or canopy) area, and
3) compute the bund diameter.

2. Design for field crops

In the row crop, the cropped area is determined by the area covered by roots. It may be estimated by the recommended spacing of the specific crop. The corresponding bund diameter for a row crop is given by:

$$D = 1.087 B^{1/2} \left(1 + \frac{A}{B} \right)^{1/2} m \qquad \text{(AP.5)}$$

with A and B as defined above. For a row crop, the cropped area is a half circle which is completely cropped. The design procedure is as follows:

1) assume the size of the cropped area;
2) calculate the value of CCAR, and
3) calculate the bund diameter.

In both designs, note that the diameter depends on the slope of the land - the higher the slope the smaller the diameter. The radius of the bund should always be checked against the bund height given in (fig. 11).

Both of these equations are based on diameter to bund spacing ratio of 2:1 and are therefore unique. Other ratios would give different equations.

APPENDIX C
DETAILS OF THE DESIGN OF TRAPEZOIDAL BUNDS

This design considers within field small catchments with the design bunds in the middle of a field. The bunds at the top, right and left boundaries may require additional catchment areas. The basic assumption is that the length of the wing wall is equal to that of the base bund (fig. C1).

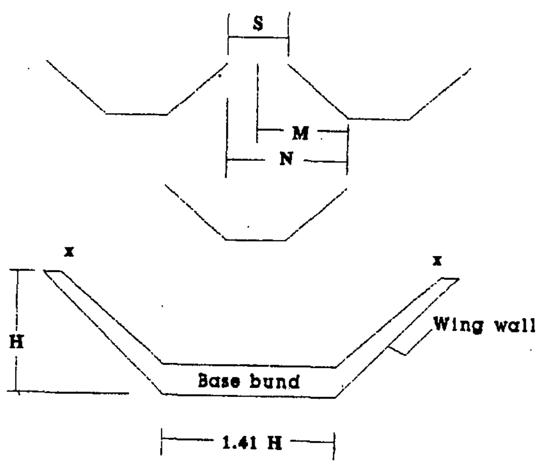


Fig. C1:

Let the length of the wing wall be L and its vertical length H. Because the wing wall is sloping at 135°, L is approximately 1.41H. Thus the distance between the tips of the wing walls of a bund (X to X) is T = L + 2H = 3.41H.

The layout should be simplified as much as possible. The selected layout is with the tips of a lower bund vertically corresponding to the ends of the base bund of the upper row of bunds.

Now let the space between the tips of two consecutive bunds be S. Let the distance from the mid-point of S to the lowest point of the wing wall be M. Let the distance between the lower end points of wing walls of corresponding bunds be N, i.e. N=2M. For the design to be simplest, then N = 3.41H. Calculations for M and N are done in terms of H until this is achieved. It can be shown that this requirement is met when bund spacing on the contour is S=1.41H for which N=3.41H.

So far we have dealt with the geometry of the bunds. To complete the design, this geometry is related to the water harvesting design, that is the crop area, the catchment area and the CCAR. Note that the cropped area is made up of areas A1 and A2. Areas A1 and A2 are given by

$$A_1 = H^2 \quad and \quad A_2 = 1.41H \times H = 1.41H^2 \qquad \text{(AP.6)}$$

To get the catchment area, we also have area A3, which is given by

$$A_3 = VT \qquad \text{(AP.7)}$$

where

V = the vertical spacing of the bunds, m

T = spacing between tips of bunds m

and works out to 3.41V. When all three areas (A1, A2 and A3) are added, the value of V can be computed. It depends on the selected value of H and the CCAR. Details of this are given in example 5.

APPENDIX D
LOG-PROBABILITY PAPERS FOR RAINFALL ANALYSIS

Notes on the use of log-probability graph paper

Because some users of this manual may not be used to log-probability graphs, the following notes are provided as a guide.

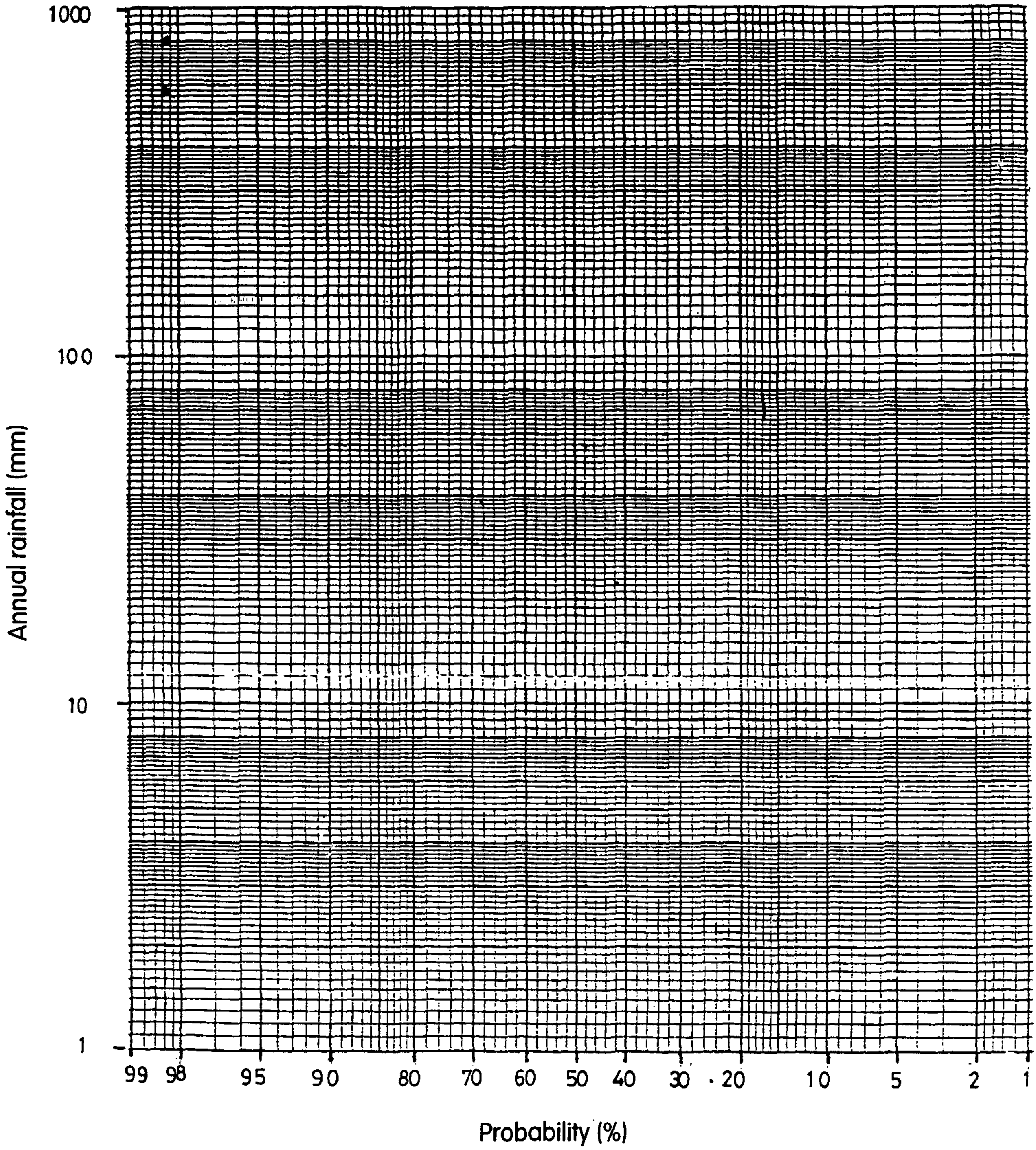
1. A log-probability graph paper has a probability scale on the horizontal axis and a logarithmic scale on the vertical axis. These are not normal scales.
2. Probability is given in percentage e.g. 98%, 60%, 10% etc. On the privided graph papers, the range is 1%-99%. When calculating, the probability values will be in decimal, e.g. 0.15, 0.82, 0.45 etc. To get the probability values on the graph paper, multiply these figures by 100% as follows:

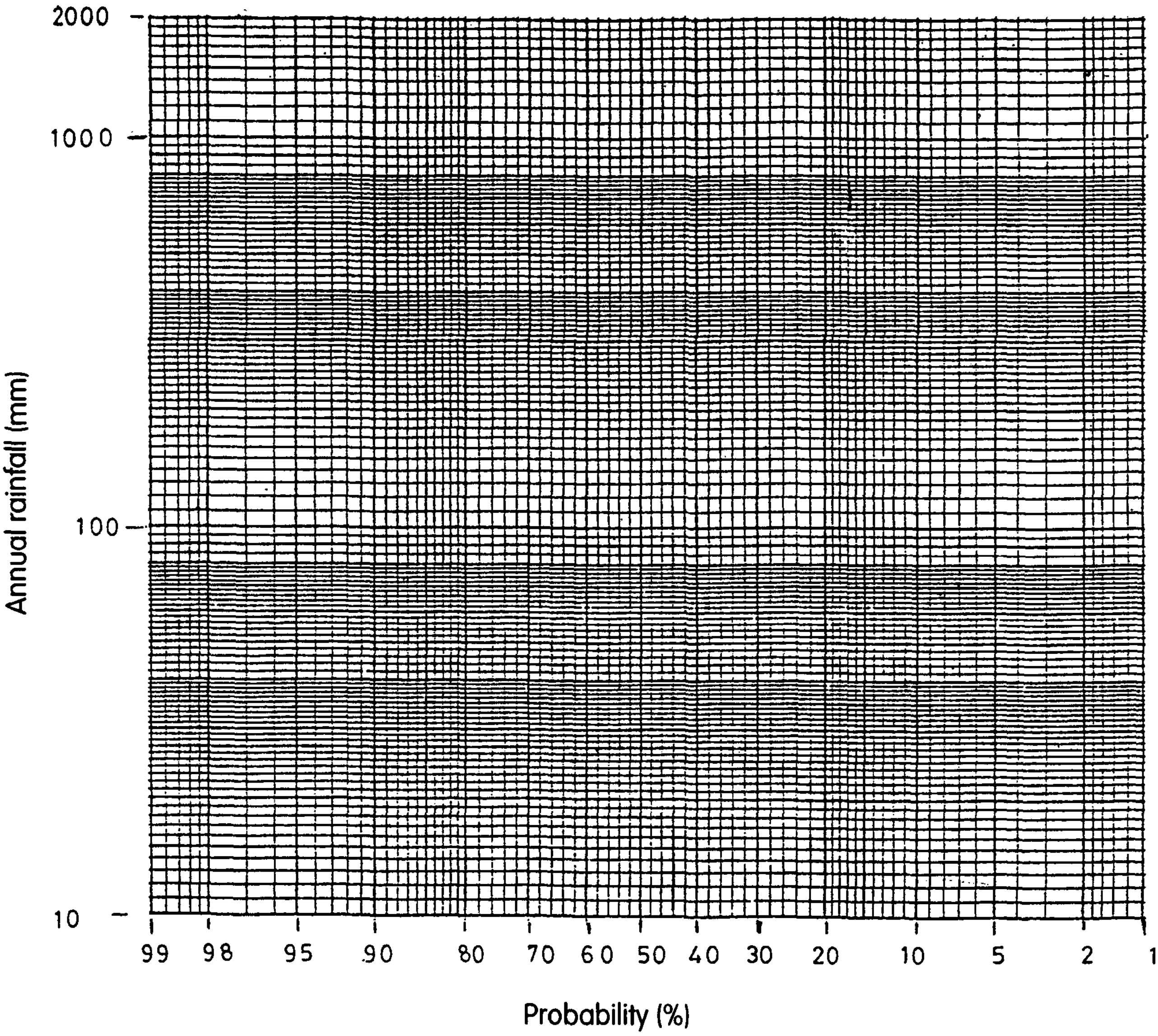
   0.15x100% = 15%
   0.82x100% = 82%
   0.45x100% = 45%

3. The vertical scale is where rainfall figures are read. This is a three-cycle scale. The figures used on the vertical scale depends on the range of the rainfall values. Note that no zeroes can be put in a logarithmic graph; instead, positive figures are used from 1 increasing by a factor of 10 according to the cycles. For simplicity, the graphs have been made in three categories as follows:

Period	Cycles	Range (mm)
Monthly	3	1-1000
Seasonal	3	10-2000
Annual	3	100-3000

When drawing the graph, mark all the rainfall values according to the corresponding probabilities. Then mark two points at approximate probability values of 16% and 84%. Draw a straight line through these two points. Any rainfall can now be read from this line according to the desired probability level.


1000
100
10
1
Annual rainfall (mm)
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1
Probability (%)


2000
1000
100
10
Annual rainfall (mm)
99
98
95
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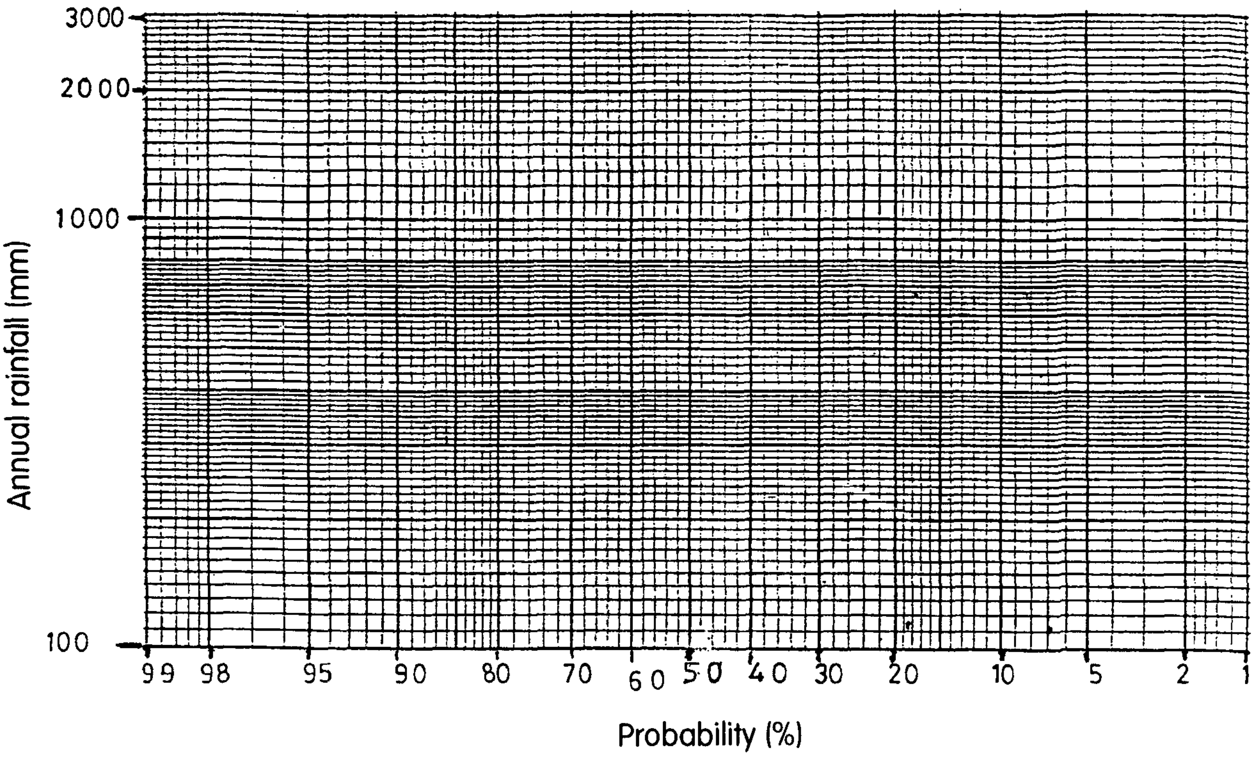
2
1
Probability (%)


3000
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Annual rainfall (mm)
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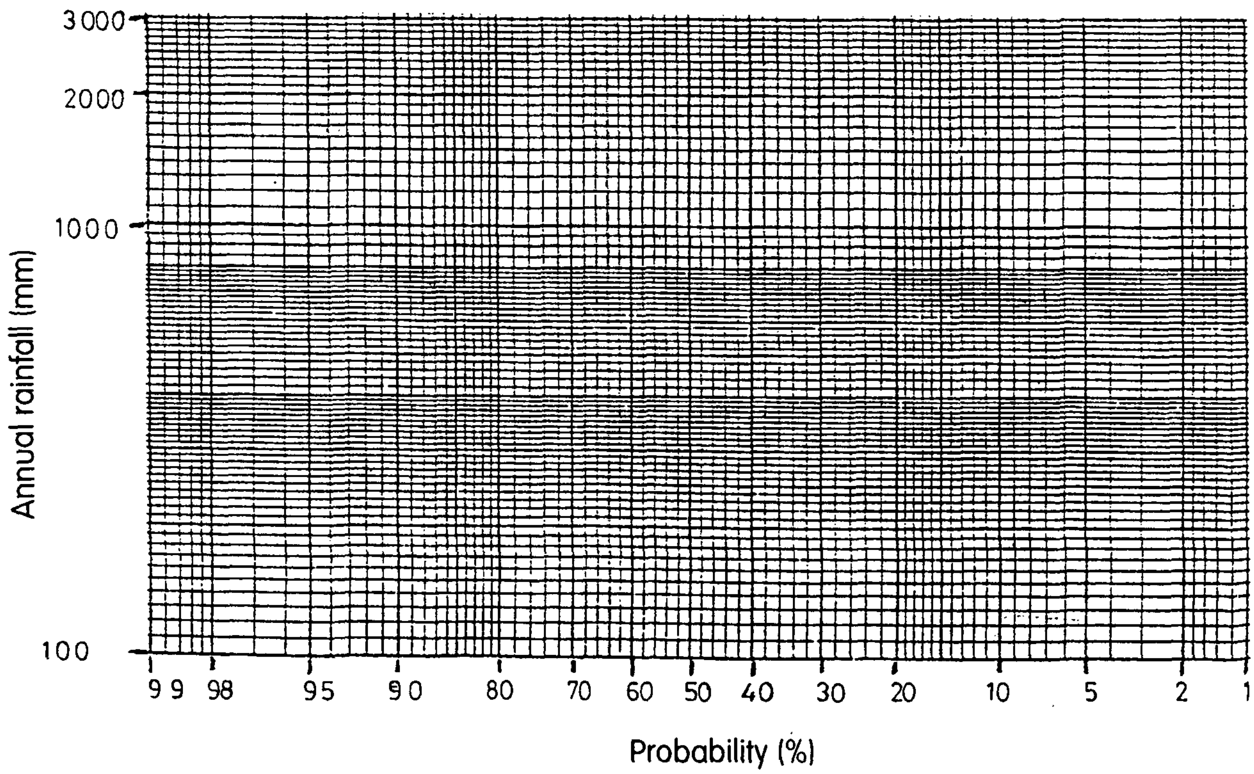
Probability (%)


3000
2000
1000
100
Annual rainfall (mm)
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
Probability (%)

The Swedish International Development Cooperation Agency, Sida, has supported rural development programmes in countries in Eastern Africa since the 1960s. It has been recognized that conservation of soil, water and vegetation must form the basis for sustainable utilization of land, and increased production of food, fuel and wood.

In January 1998, Sida launched the Regional Land Management Unit, RELMA, based in Nairobi. RELMA arises from the Regional Soil Conservation Unit, RSCU, that has been facilitating soil conservation and agroforestry since 1982. RELMA's objective is to increase the quality of technical and institutional competence through improved contents of both Sida-supported activities as well as other programmes, projects and institutions of the land management sector in the region. RELMA's mandate reads: **"To contribute towards improved livelihoods and enhanced food security among small scale land users in the region."**

RELMA organizes training courses, workshops and study tours, prepares and distributes manuals and textbooks, gives technical advice, facilitates exchange of expertise and initiates pilot activities for the development of new knowledge, techniques and approaches. The geographical focal area remains the same as previously for RSCU and covers Eritrea, Ethiopia, Kenya, Tanzania, Uganda and Zambia.

In order to publicize the experiences from practical land management activities, RELMA issues a series of publications consisting of reports, technical handbooks and training materials produced in the region.

About this publication

The semi-arid regions occupy a very large percentage of land for most of the countries in the tropics. The foregoing is that water becomes the major limiting factor for crop production, hence the need for harvesting and utilization of green water becoming inevitable.

This manual is mainly targeted to soil conservation and extension staff. The author, Mwangi Hai, presented concepts and some case studies on water harvesting in simplified language. The recent decades have witnessed massive migration to the arid and semi-arid areas. Hai's efforts could therefore not have come at a better time.

Sida

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ISBN 9966-896-33-3