The World Bank

Some Lessons from Water Harvesting in Sub-Saharan Africa

Report from a workshop held in Baringo, Kenya 13–17 October 1986

Eastern and Southern Africa Projects Department
SOME LESSONS FROM WATER HARVESTING IN SUB-SAHARAN AFRICA

REPORT FROM

A WORKSHOP HELD IN

BARINGO, KENYA

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PREFACE

As land pressure rises in Sub-Saharan Africa, more and more marginal areas are being used for agriculture. Much of this land is in the sub-humid or semi-arid belts. Rain falls irregularly here, often as heavy showers or brief storms, and much of the precious water is soon lost as surface runoff. Recent droughts have highlighted the risks to humans and livestock, and the rapid degeneration of Africa's fragile natural resources, which can occur when these rains falter, or fail. The vicious circle of vegetation loss leading to even higher runoff, and to soil erosion and flooding when the rains return, has been highly publicized.

While irrigation may be the most obvious response to drought it has proved costly, slow to take root, and can benefit only a fortunate few. There is now increasing interest in a simpler alternative: localized channeling of the surface runoff from micro-catchments directly to food crops, fodder, pastures or trees, or into small storage structures in which it can be retained for domestic or livestock use. Although usually unable to guarantee a crop's full water requirement, such water harvesting systems are in principle cheaper, easier to adopt, and can benefit many more people in semi-arid areas than formal irrigation. The drinking water collected may protect humans and livestock from drought-related migrations.

The need to explore in more depth the possibilities for practical application of water harvesting techniques in Africa led the World Bank to organize a workshop on the subject at Baringo, Kenya, in October 1986. Financing for the workshop was provided by the Ministry of Development Cooperation of the Norwegian Government. It was ably chaired by Mr. John Gatheru, Deputy Director, Ministry of Agriculture, Kenya. Ms. Jeri Larson had responsibility for the administrative arrangements.

During the five-day workshop participants reviewed their practical experiences with water harvesting in five African countries. Discussions covered the socio-economic factors which determine the acceptability of water harvesting to rural people, agronomic considerations, and the matching of engineering designs to local circumstances. Their findings are summarized in this report, which was prepared by Mr. W. Critchley, a consultant with Hydrotechnica with considerable field experience in this topic. He was assisted by another consultant, Mr. M. Finkel. Both participated in the workshop.

Most of the literature available on water harvesting relates to non-African experiences. A major recommendation of the workshop is that more effort is needed to bring out practical lessons from Sub-Saharan Africa. The sponsors of the workshop hope that the findings of these practitioners can help guide policy makers and technicians in the future, in their struggles to reduce rural hardship and arrest the degradation of Africa's marginal lands.

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I. INTRODUCTION

A. The Workshop

1.01 A workshop on water harvesting in Sub-Saharan Africa was held on Island Camp, Baringo District, Kenya between 13 and 17 October 1986. There were twenty-one participants made up of country/project representatives, resource persons, and staff from international organizations. A full list of the participants is in Annex 2 of this report.

1.02 The workshop took the form of presentations on projects in the countries involved, and discussions led by the resource persons on the topics of design, agronomic factors and socio-economic considerations. Several participants gave slide presentations in the evenings. At the beginning of the week a short field trip was organized to look at some of the relevant work being carried out under the Baringo Pilot Semi-Arid Area Project (BPSAAP), and after the workshop a few participants were able to visit the Fuel and Fodder Project on the shores of the lake. This working paper reports the presentations, discussions and conclusions of the workshop.

B. Scope of Workshop

1.03 The workshop was convened to review some recent experiences with water harvesting in Burkina Faso, Kenya, Lesotho, Somalia and Sudan. The various systems being tested or implemented were discussed, and specific consideration was given to design, agronomic factors (where relevant) and socio-economic considerations. It was not intended that the workshop should prepare detailed formulae for each situation where water harvesting could be applied. Neither was it planned that this working paper should reach outside the confines of the deliberations and become a literature review. The objective was to analyze the various experiences and condense the discussions into a practical document which would be of interest and assistance to a wide audience of technicians and policy makers.

1.04 The subject matter, water harvesting, in the context of the workshop, can be defined as follows:

Water harvesting is the collection and concentration of runoff before it reaches seasonal or permanent streams, for the production of crops, fodder, pasture or trees, for livestock or domestic water supply or for other productive purposes.

1.05 Definitions used elsewhere, particularly in North America, specify artificially treated catchments as integral to water harvesting schemes. However, in semi-arid Africa, runoff does not generally need to be induced; substantial runoff occurs naturally due to the combination of intense rainfall and poor ground cover. Furthermore, catchment treatments can be expensive and add significantly to the cost of water harvesting systems; thus they are appropriate only in special situations.

1.06 All water harvesting systems comprise a catchment area and a storage component. Thus, they can be categorized on the basis of the catchment (water source) or the type of storage used. There are three
categories of water source: **rooftop harvesting**, **runoff harvesting** (collection of overland flow, or flow in rills) and **floodwater harvesting** (use of channel flow, for example flash floods). The two basic categories of storage are **short term storage**, which is storage in or just above the soil profile, and **long term storage** which is deep ponding of water. Short term storage techniques are usually for plant production, fodder, pastures and trees, and long term storage for water supplies.

1.07 The main focus of the workshop was on runoff harvesting for both short term and long term storage systems in the semi-arid regions of Sub-Saharan Africa.

1.08 Systems which harvest runoff can simultaneously improve production, directly or indirectly, and reduce erosion. Such systems are particularly appropriate in semi-arid areas where water is usually the primary limiting factor to production, and erosion commonly severe. However, all systems are ultimately dependent on local rainfall and are thus vulnerable in years of severe and long-term drought.

1.09 Although there are many traditional systems in Sub-Saharan Africa which use water harvesting, and a number of projects developing improved techniques, there is a dearth of information on the topic. Where information is available it is rarely supported by adequate facts and figures. Information on the subject is required not just to assist field workers, but to give a better basis for project identification and funding.

1.10 Soil conservation and irrigation, which stand, figuratively, to either side of water harvesting, are relatively well documented - but the gap between them needs to be filled. There is reason to believe that greater attention is indeed being given to water harvesting. A recent publication, "Rainwater Harvesting" (Pacey and Cullis, 1986) is a welcome contribution and indicative of the growing interest in the subject.
Despite the limitations of the workshop it was hoped that it would add to the body of information available and give some guidance to the types of systems which are relevant in given situations, based on project reports from the various countries. It may be that the most significant outcome is to help put water harvesting more firmly on the map as a respectable technique with considerable potential in Sub-Saharan Africa.
II. COUNTRY REPORTS

A. Kenya

1. General

2.01 Mr. M. Thiongo of the Ministry of Agriculture and Livestock Development gave an overview of water harvesting in Kenya. Over 80% of Kenya's land area is classified as "Arid and Semi Arid Lands" (ASAL). These are areas where the rainfall: evaporation ratios are lower than 50% on an average annual basis. The Government has, within the last ten years, taken decisive steps to develop these areas. The first step was the formation of the "Marginal Lands Pre-Investment Study Project" in 1977, followed by the commissioning of an interministerial task force in 1978 which laid down the framework for ASAL development. Several projects have been implemented under this framework, all of which have included soil and water conservation as a major component, and some of which have tested water harvesting techniques with varying success.

2.02 Systems making use of water harvesting technologies in these areas include the following:

a. Water Supply Systems

Earth Dams

Earth dams, ponds, tanks, pans or reservoirs fed from ground catchment, have been constructed in many ASAL areas since pre-Independence days. It was acknowledged from an early stage that the provision of a water supply was a prerequisite to the initiation of any program of land utilization improvement in these areas.

Design lessons have been learned from the failure of some of the early structures, with particular respect to spillways, and the design of current construction is of a much improved standard.

Sub-Surface Dams

Sub-surface dams are constructed in sand rivers to retard subsurface flow and to preserve water within the coarse sand held behind the concrete or masonry dam. These structures have been an important component of the ASAL programs especially in Eastern Province.

Rock Catchments

Bare rock outcrops, common in Eastern Province, are used to develop domestic water supplies by impounding runoff from the rock in basins constructed on the lower reaches of the outcrop.
Roof Catchments

Where corrugated iron roofs are found in semi-arid areas, these are increasingly used as catchments to provide domestic water.

A variety of materials are used for tank construction.

b. Crop Production Systems

Contour Terracing

A variety of techniques are used to build terrace banks to preserve both soil and moisture, in situ. The principal recommendation in these areas is the "fanya-juu" terrace where a channel is dug on the contour and soil thrown on the uphill side to form a terrace bank.

Used in conjunction with terracing, cutoff drains prevent water from an outside catchment reaching and damaging the terraces below.

Micro-catchment systems

These systems have been tested in several of the ASAL areas for improvement production of both crops and trees. There are two basic types of system: diamond shaped "Negarim" for trees and "contour ridges" principally for crops.

Macro-catchment systems

In contrast to the micro-catchment systems these utilize a relatively large external catchment area to supply a cultivated area which is impounded by earthen structures. Excess water is drained over stone spillways in contour bunds, or around the tips of trapezoidal structures.

Fuller descriptions and illustrations of these systems are given under the specific project reports.

2. Baringo-Pilot Semi Arid Area Project, Baringo District

2.03 This project provided the setting for the workshop, so participants were able to visit some of the trials and demonstrations where water harvesting techniques were being used. A briefing paper on the relevant crop development aspects of the project was prepared and distributed by Mr. J. M. Kumu (MOALD/BPSAAP staff member) and a summary of the BPSAAP Interim Report (1984) was also available, together with the chapter entitled "Runoff Harvesting" from the full version of the same report.

2.04 Work on water harvesting, or more specifically, runoff harvesting, began on a trial basis in 1981 shortly after the inception of the project. The low and erratic rainfall (annual average approximately 650 mm) and high temperatures (mean maximum 32.4°C, mean minimum 16.6°C) ensure that rainfed
cropping is extremely unreliable. Terracing is an inadequate technique except in the relatively better areas, and supplementation of rainfall with runoff, it was found, could make a dramatic and visible impact on crop performance.

2.05 For crop production, two basic techniques were developed. The first, illustrated in Figure 1 is referred to as the "contour ridge" system. Small contour ridges (approximately 20 cm high) are dug by hand at a horizontal spacing of about 1.5 meters with the adjacent furrows on the uphill sides. No other tillage is employed at the land preparation stage. The uncultivated strips between the ridges act as micro-catchments and a crop is planted on either side of the furrow where runoff concentrates.

2.06 In the first season of trials, the yield of sorghum using this system was more than doubled compared with a normally dug control plot. On the first day of the workshop participants were able to observe the performance of sorghum under contour ridges compared with a visibly poorer control plot.

2.07 Because of the inherent capacity of micro-catchment systems to produce a high percentage of runoff, and because each crop line is served by the same catchment area, this is an efficient and even system. However, it represents a departure from conventional land preparation and planting practices, and these factors may have contributed to a slow adoption by local farmers.

2.08 The second technique, shown in Figure 2 is termed an "external catchment", or macro-catchment system, and uses a catchment of untreated land outside the cropped area. Runoff may be directed to the plot by use of collection arms. The catchment to cultivated area ratio is generally between 3:1 and 5:1. Within the plot, runoff is impounded and excess drained over stone spillways set in contour bunds. Within the cultivated area, land preparation and planting practices are standard. While these systems are able to utilize the relatively large volume of runoff generated by the sizeable catchment, it is difficult to avoid bund breakages, and erosion around the spillways, until the bunds are adequately grassed over. A further disadvantage is the graduation in water depth within the plots leading to uneven plant growth.

2.09 For improvement of rangeland, the technique adopted is to dig, by hand, semi-circular "hoops" of six meter radius (Figure 3). The tips of each hoop are sited on the contour to allow even overflow of excess runoff, and each line of hoops is offset so that the lower line intercepts overflow from the upper.

2.10 Trials with this system have been effective. After fencing, using thorn bush, and reseeding with perennial grass species, such as *Eragrostis superba* and *Cenchrus ciliaris*, grass establishment on the main trial plot within the Njemps Flats, was dramatic. A dry biomass of 1,215 kg/ha was recorded after a year, compared with a negligible yield outside the plot.

2.11 The Lake Baringo area and the Njemps Flats in particular are well suited, technically, to water harvesting. There are gentle slopes, typically between 0.5 and 1%, and soil which is potentially very fertile yet generally denuded and productive of runoff. Rainfall is of high intensity and drought periods common.
2.12 However technical answers are only part of the solution. Adoption of these apparently impressive techniques has been disappointly slow. A recent survey shows that only 75 farmers, or 15% of the total in the target area have adopted such techniques after five years of trials and demonstrations. For reseeding the response has been even poorer.

2.13 A variety of factors may have contributed to this slow uptake, including initial design errors leading to bund breakages, a shortlived on-farm demonstration program utilizing a food-for-work incentive, which was later withdrawn, and a system of contour ridging which involves a novel approach to land preparation and planting.

2.14 With respect to range reseeding the poor response is less surprising. Traditionally pastoralists maximize their individual return from a communal resource, and it is asking for a radical change in their strategy to expect spontaneous participation in communal rangeland reseeding.

3. Fuel and Fodder Project, Baringo District

2.15 A number of the participants were able to visit two planting sites of the Fuel and Fodder Project near the shores on Lake Baringo. The project falls under the Ministry of Energy and Regional Development. A total area of approximately 250 hectares have been planted with trees and grass by the project. The system used is mechanized contour ridges, established at an approximate spacing of 10 meters. Ties in the furrows at 10 meters apart then subdivide the fields into individual micro-catchments of 100 m². Within each individual micro-catchment three seedlings are planted. The preferred species, from experience, are Acacia spp. (both indigenous and introduced), and Prosopis spp. In order to make fuller use of the reafforested areas, reseeding with perennial grasses is carried out once trees have become established.

2.16 Land preparation costs are between $100 and $330 per hectare. Electric fencing around the plots is powered by solar panels, and on a ten hectare plot costs about $0.30 per meter.

2.17 Once the trees are established, management of the plots, which act principally as fodder banks, is carried out in co-operation with local groups.

4. Mutomo Soil and Water Conservation Project: Kitui District

2.18 A report on this project which covers the Southern Division of Kitui District, was presented by the Project Manager, Mr. D. Waithaka. Mutomo Soil and Water Conservation Project operates through the Ministry of Agriculture and Livestock Development as an agent to implement soil and water projects. The local community initially identifies projects and these are passed eventually to the District Development Committee for final approval. Before implementation begins, the local people are required to form a committee for each project, and must agree to provide voluntary labor. The project then provides tools, materials and skilled labor, and supervises construction.
a. Water Supply Systems

Earth Dams

The project considers that the construction of large earth dams or pans is questionable economically in view of the cost, the unreliable rainfall and the high rates of evaporation. However in some situations such structures have proved effective where inflow has been adequate. Some old earth dams have been rehabilitated under the project, and in some cases wells have been sunk next to the side walls to collect seepage.

Sub-Surface Dams and Sand Dams

Sub-surface dams and sand dams are techniques used by the project to improve the availability of sub-surface water in sand rivers during the dry season. Sub-surface dams are constructed in the river bed where there is already a depth of sand: the structure slows the flow of water within the sand. A sand dam is erected above the river bed and artificially captures sand which then forms a ground water reservoir.

Rock Catchments

Bare rock outcrops are common within Kitui District and these provide the basis for collection of runoff which is stored behind masonry walls towards the lower reaches of the outcrops. To increase the effective catchment area "gutters" or masonry collection arms may be built along the rock. Rock catchments can be costly to build, and together with the fact that the water quality is usually relatively good, they are generally reserved for domestic water. Costs of three types of rock catchments, low wall, high wall and arch are shown in Figure 4, where they are compared with other water supply structures.

Rocks are sometimes used as the catchment for earth dams.

Road Runoff

Roads form an artificial catchment with relatively high runoff coefficients. The runoff generated, which commonly otherwise causes erosion, can be collected and stored in murram pits, earth pans or ground tanks. Such water supplies tend to be relatively dirty, and need to be cleaned before human consumption. The project has developed a suitable charcoal and sand filter for this purpose. The problems of mosquitoes can be avoided by the introduction of fish into the reservoirs.

Roof Catchments

Corrugated iron roofs are becoming increasingly popular in the project area, and with runoff coefficients of about 90%, provide an obvious potential for domestic water supplies. The
project is concerned with the costs of water storage, and has found the most economical structures to be semi-spherical ground tanks made from ferrocement. At a capacity of 78 m³, such a tank, including roofing, costs approximately $9 per cubic meter of storage.

b. Crop Production Systems

Contour Terracing

"Fanya-juu" terraces are formed when a channel is excavated on the contour and the soil thrown uphill (see Figure 5). The objective is to maintain soil and rainfall between the terrace banks, and eventually to develop level benches. Terrace banks are stabilized through the planting of grass which also provides animals with fodder during the dry seasons. The project has established that yields under this system are improved by about 40%, principally due to the reduction in loss of runoff.

Contour Ridges

A similar technique to that used in Baringo has been under trial in Kitui. However the advantages of runoff harvesting have not been so pronounced due to less severe moisture stress during the period of the trials, and because of the lower soil fertility status which reduces the response to extra moisture.

Trials are continuing in Mutomo and over the District as a whole. Systems with external catchments as well as contour ridges are being tested. It is hoped to develop a recommendation for the lower zone of cultivation, agro-ecological zone 5, where "fanya-juu" terracing is inadequate. Tree micro-catchments have also been tried in Mutomo, and have improved survival rates by 60%.

5. Turkana District

2.19 Mr. Finkel, a water harvesting consultant who has worked in Turkana gave a report on the history and present status of water harvesting in the Turkana District. Water spreading schemes were attempted in Turkana as long ago as 1952. The first scheme diverted water from the Turkwell river, using a concrete weir. Apparently this, and a number of other schemes, produced good crops of sorghum for a few seasons, but despite being technically sound the schemes lapsed into abeyance.

2.20 In 1963 a scheme was built at Lorengippe, diverting flow from a sand river and spreading it over about six hectares. The diversion weir was well designed and built of gabions which remain intact today. Water was spread by bunds which were sited on a slight grade. Similar schemes had been constructed with success in other parts of the world. However this scheme, like the others before it, was abandoned after a few seasons.

2.21 The failure was not attributed to technical problems, but to the planners total disregard for the community’s acceptance of the scheme. An
important lesson can be derived from Lorengippe - the need to involve local people in all stages of project development.

2.22 The more recent history of Turkana has seen a severe drought in 1979/80 and the establishment of the Turkana Rehabilitation Project (TRP) in 1980. The primary objective of TRP was to end the famine by food distribution, then to embark on a five year rehabilitation program, making use of food aid as food-for-work.

2.23 Between 1979 and 1980 a few, small schemes were constructed near Lokitaung, and despite limited success, stimulated further work on water harvesting. In 1983 bund building became a major program under TRP and within 10 months, 120 km of bunds were constructed by hand using food-for-work. However these were designed poorly, with many "contour" bunds incorrectly surveyed and spillways which commonly eroded. The failure served to discredit water harvesting.

2.24 Mr. Finkel spent six weeks in Turkana during 1984 and produced a report for FAO and NORAD. A proposal for a new water harvesting policy was developed.

2.25 The policy sought to provide a strategy which was in harmony with the pastoral culture, and one which would achieve social credibility. The schemes developed would not necessitate permanent settlement, and the majority of structures were to be for fodder rather than crop production.

2.26 Although there was no machinery available for construction, there was a potential workforce of 20-30,000 people, each capable of moving one cubic meter of soil per day. One serious constraint was the lack of trained personnel to supervise implementation.

2.27 It was reasoned that structures should be simple and small scale. It was considered paramount to minimize risk of technical failure and to keep maintenance requirements low. To this effect the structures eventually selected were "overdesigned" since cost was not a factor.

2.28 Two standard designs were proposed: Semi-Circular Hoops and Trapezoidal Bunds.

a. Semi-Circular Hoops

These had already been recommended for Turkana by Powell (1982) and a similar design had proved successful in Baringo. The bunds are made from earth and each "hoop" encloses approximately 300 m². As far as possible they are maintenance free, the main usage of the hoops being for grasses and trees where the establishment vegetation acts to consolidate the structure. Dimensions are given in Figure 6.

b. Trapezoidal Bunds

Similarly proposed by Powell these are large bunds enclosing approximately 3200 m². The principal use is for production of sorghum, millet and short maturity legumes. Excess water is
drained round the tips of the arms which are surveyed on the contour. Dimensions are given in Figure 7.

It was further recommended that a data collection system should be established and a training course for local technicians was proposed and held during the early part of 1985. The eight week course trained 40 participants to select sites, calculate catchment: cultivated area ratios, and to select and implement the recommended techniques. The course material was collected to form a "Turkana Water Harvesting Manual".

The site where most of the first bunds were constructed was Lowerenjak. One hundred trapezoidal bunds were built in 1984. In the first season the structures worked effectively, and the crop of local Turkana sorghum yielded up to 1000 kg/ha. However there were several breakages of bunds in the 1986 season. This was attributed to poor compaction of the sandy soils during construction. Experience elsewhere with the semi-circular hoops indicated their performance, after being seeded with grass, was promising.

Recently two spate irrigation schemes have been constructed in Turkana. However it appears that they are neither technically sound, nor have social factors been taken into consideration. The first flooding experience of each scheme was unsuccessful.

A two year program is now being considered with a target of 2,000 trapezoidal bunds and 10,000 semi-circular hoops. This would use the experience of Lowerenjak to improve the production capacity of the whole region.

6. Discussion

2.29 Although water harvesting techniques theoretically preserve soil and reduce erosion, the use of spillways in the "external catchment" systems in Baringo has led to criticism that they may concentrate water and actually cause erosion. This could also be true, though to a lesser extent, of the overflow from semi-circular hoops or trapezoidal structures. The contour ridge system in Baringo is preferable from this point of view as it is designed to contain all runoff generated. However in drier areas this system is not appropriate, because it is necessary to utilize a large catchment in order to trap considerable volumes of runoff from infrequent storms.

2.30 From the Kitui presentation it was evident that "fanya-juu" terracing is a success story. Farmers are prepared to put in the structures for themselves (usually on a group basis) with a minimum of outside assistance, apart from tools and persuasion. It was pointed out that the committed support of the Government is an important factor, and the farmers believe that such terracing is giving them benefits in the short term. The approach of persuasion and demonstration of benefits is in contrast to the colonial policy of mandatory terracing which, despite technical suitability, led to resentment of the structures.
2.31 Although terracing is outside the specific definition of water harvesting there are many attributes in common. Level "fanya-juu" terracing is designed to preserve soil and rainfall in situ, but the immediate effect is to improve plant performance by increasing moisture availability in areas where rainfall limits production. Such techniques however are limited in their applicability, to the favored zones.

2.32 The excellent response of farmers to schemes for improved water supplies, both domestic and for livestock, was noted, and it was felt that such schemes must be a priority for development in semi-arid areas. Part of the reason for slow uptake of techniques for improved crop production in Baringo may have been the inability (through lack of funds) of the project to satisfy the demand for accessible drinking water, which was a local priority.

2.33 The high cost of various structures drew comments, particularly in light of the approach to water harvesting measures in Turkana. Several participants felt that a major priority was the development of low cost structures. However it was pointed out that the Turkana situation was rather unique. The Turkana Rehabilitation Project had a history of food aid; the over-riding concern was that the food-for-work program was effective in creating structures which, albeit "overdesigned" would function effectively with the minimum maintenance requirement. Comparative work rates for structures were given as follows:

<table>
<thead>
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<th>Location</th>
<th>Structure Type</th>
<th>Work Rate per Man Day</th>
<th>Unit Area</th>
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<tbody>
<tr>
<td>Turkana</td>
<td>Semi-circular hoops</td>
<td>25*</td>
<td>300 m²</td>
</tr>
<tr>
<td></td>
<td>Trapezoidal bunds</td>
<td></td>
<td>3200 m²</td>
</tr>
<tr>
<td>Baringo</td>
<td>External catchment systems</td>
<td>100</td>
<td>1 hectare</td>
</tr>
<tr>
<td></td>
<td>Contour ridge system</td>
<td>50**</td>
<td>1 hectare</td>
</tr>
<tr>
<td></td>
<td>Semi-circular hoops</td>
<td>10</td>
<td>1 hectare</td>
</tr>
<tr>
<td>Kitui</td>
<td>&quot;Fanya-juu&quot; terracing</td>
<td>185***</td>
<td>1 hectare</td>
</tr>
</tbody>
</table>

* lower work rates per man day assumed in Turkana
** including cutoff drain (not always necessary) no further tillage required under this system
*** including cutoff drain - 20% slope assumed.

2.34 Although it was acknowledged that structural design should be as simple as possible, it was suggested that a range of designs be tested before a definite recommendation is made for wide scale implementation. In this context, the importance of improved monitoring of structural performance is essential.

2.35 The rehabilitation of rangeland gave rise to considerable discussion. In the case of Baringo it was suggested that fencing with thorn bush, may lead to a problem outside the plot where bush had been cut. However, it was pointed out that the bush had been polled rather than cleared. Live fencing was proposed as an alternative. Another concern was the use of relatively expensive structures to increase rangeland productivity where the potential return from livestock was inherently limited. This argument favored the use of structures, even in the Turkana example, for cropping. It was suggested that fodder banks, possibly on an
individual basis may be a more realistic proposition than reseeding of rangeland.

2.36 Finally it was recorded that there had been considerable work recently in Turkana with tree establishment using micro-catchments (Negarim), ranging in size between 100 m² and 250 m².

B. Burkina Faso

1. General

2.37 Mr. I. Kargougou reported on Burkina Faso. Burkina Faso can be divided into three vegetation and ecological zones. These are the Sudano-Guinean (annual average rainfall 900 - 1200 mm), the Sudanian (500 - 900 mm) and the Sahelian (<500 mm). The predominant soils are ferruginous. These are shallow and easily eroded despite a fair moisture retention capacity. In the Sahelian zone, soils are mainly sandy. Irrigation is limited both in practice and potential with only 5400 hectares currently being under full water control. 2.5 million hectares are under rainfed cultivation, but yields are low. Average yields of the most common crops, sorghum and millet are 500 - 600 kg/ha and 350 - 450 kg/ha respectively. Runoff is a serious problem especially in the lower rainfall zones. Estimates of the annual runoff percentage range from 29% to 44%. The main limiting factor to increased production in rainfed agriculture is rainfall.

2.38 Traditionally systems to counteract erosion and increase crop yields by improving infiltration include restrictions on burning, preservation of trees and hedges and the establishment of stone and vegetative terrace lines. In the Yatenga area, deep planting holes filled with manure trap runoff and make better use of early rain.

2.39 Government intervention in soil and water conservation began with the GERES (Groupement Europeen de Restructuration des Sols) program which ran between 1962 and 1965 and put in 120,000 ha of graded terraces by machine. However the program was a complete failure, and most structures disappeared within a few years. The reason for failure was attributed to the lack of involvement of the local farmers from the planning stage onwards.

2.40 In 1972 a Fonds de Developpement Rural (FDR or FEER) program introduced a system of making contour bunds on a complete catchment basis. Bunds were initially designed to be 30 cm in height and set at vertical intervals of 40 - 60 cm. However breakages were common, especially in the uppermost bunds. A second phase between 1977 and 1981 introduced the concept of open ended bunds to allow drainage of excess runoff (Figure 8). Latterly bund stabilization by planting of grass has also been encouraged. Alternative strategies to prevent bund breakages are grading of the top bund or making the upper bunds of stone to allow some runoff to filter through. By 1986 these anti-erosion works covered 58,600 hectares.

2.41 Within the same program are lowland development schemes, in which runoff is channelled into low lying areas, and its progress controlled by bunding, for rice production. Contour bunds with wing walls contain the water and excess drains through flumes in the wing walls (Figure 9). Such lowland development schemes covered approximately 2,500 hectares by 1985.
Improved lowland development schemes consists of damming valleys and providing supplementary irrigation to crops lower down.

2.42 A recent innovation has been trials with the use of "demi-lunes" (semi-circular micro-catchments) for tree establishment.

2.43 Non-government organizations play a significant role in soil conservation within Burkina Faso. However there is no common standard for vertical interval or size of structures. One organization, Projet Agro-Foresterie, is involved in harvesting runoff from catchments for crop production. This project has developed a successful stone bunding technique and is also testing other types of structures.

2.44 The FDR program has been successful and has now entered a third phase. This project has answered the expressed needs of the local communities and has required, and acquired, the active participation of the beneficiaries in the execution of the projects.

2.45 Yields have improved as a result of the various strategies. Anti-erosion contour bunding has resulted in yield increases in the order of 20 - 40% according to a 1979 survey and similar increases are attributable to the lowland development schemes. A survey carried out between 1982 and 1986 showed that sorghum yields had increased by 30% compared with controls and millet yields by over 40%.

2.46 Though a successful program, and one which has increased popular consciousness about environmental degradation, there are constraints to its progress. Technically the most serious problems are the lack of trained manpower and the limited working capacity of farmers groups. Social constraints are also significant and include the poor organization of many groups, land right disputes and the inordinate influence of some traditional leaders.

2.47 Technical training programs are now becoming increasingly important and increased farmer motivation through on-farm trials and demonstrations is a further objective.

2. Discussion

2.48 The problem of bund breakage led to a suggestion that stone lines should be increasingly substituted for earth bunds. This would result in a greater labor requirement as earth bunds can be partially made mechanically whereas stone lines involve collection of stones and placement by hand. Apparently the demand by farmers for stone lines is considerable despite the extra work. A compromise solution may be the construction of the upper few contour lines of stone to allow some seepage, and some protection for the lower earthen bunds. This would also improve the moisture status of the upper part of the fields by harvesting, rather than excluding runoff.

2.49 The importance of the policy to train farmers to lay out contours themselves was underlined and commended as a significant attempt to address one of the main constraints to accelerated implementation.

2.50 A further point was that improved husbandry needs to be stressed alongside soil and water conservation to exploit the improved growing conditions. Soil fertility is particularly important in this respect.
2.51 The "demi-lune" initiative was briefly discussed. This is on a trial basis and is being used for planting of indigenous trees, for example Balanites sp and Accacia albida.

C. SOMALIA

1. North West Region Agricultural Development Project

2.52 Mr. Mohamed Abdi Ali reported on systems of water harvesting being implemented under the North West Region Agricultural Development Project (NWADEP). The North-West and Awdal regions in which the project is situated, consist of 3.5 million hectares of which only 100,000 hectares are suitable for cropping. Stock rearing is the most important activity. The climate is semi-arid and rainfed cropping is a risky activity with an annual average of only 400 mm rainfall. Most rain comes in short intensive storms causing rapid runoff. The need for water harvesting as part of a successful dryland farming policy is crucial, as is the need for simultaneous soil conservation.

2.53 In the drier localities, each farm requires a catchment area of approximately twice the cropped area in order to produce adequate yields. The system designed to harvest runoff and conserve soil is termed "bunding".

2.54 Bunding became a recommended practice in the 1950's after other techniques proved unmanageable or inadequate. Trials with spate irrigation were abandoned due to the difficulties involved in the control of flood flows, the risk of flooding and heavy maintenance costs. Grass strips, broad based terraces and contour stone lines retained the soil effectively, but did not hold enough water to make a appreciable difference to the yields.

2.55 The essential feature of the bunding system is a series of earth bunds built on the contour to a height of 1 meter before settling. On a typical slope of 2% bunds would be 30 meters apart, using the design recommendation of a 60 cm vertical interval.

2.56 These bunds are turned uphill at each end for a vertical distance of approximately 30 cm. Thus the maximum depth of flooding is 30 cm, and when this is reached, overflow occurs around the tips of the "wings". Bunding is illustrated in Figure 10.

2.57 After initial attempts in the early years to use oxen for bunding, it was found much quicker to use machinery which was first introduced under USAID funding in 1963. NWADEP utilizes bulldozers which made bunds by pushing up earth from below.

2.58 Sorghum is the most popular crop in this region, and one of the main reasons for its popularity is the stover which is used for animal fodder. Yields of sorghum are reportedly increased by up to 80% using bunding.

2.59 Human and livestock water supply are also concerns of the project. 60 livestock water points, and 108 human water points have been constructed, utilizing runoff collection methods.
2. The Bay and Lower Shabelee Region of Somalia

2.60 Mr. K. Siegert of FAO presented the problems and possible solutions to livestock watering in one of the most productive grazing lands of Somalia, the inter-riverine area between Shebelli and Juba rivers.

2.61 The main constraint to livestock production in this area is lack of water. Most water points in the region are natural ponds which have been enlarged and deepened by local initiative. Much of the work was done using primitive tools, and took decades to complete. Proper design was lacking, and many of the ponds become silted up rapidly. An FAO project financed by FAO’s Technical Co-operation Programme has been, since 1986, providing material, tools and technical assistance to village communities for the rehabilitation and improvement of their ponds on a self-help basis. A large UNDP/UNCDF project on the same subject is planned to start in 1987.

2.62 Since these ponds are not adequate to bridge the period between the two rainy seasons, the European Development Fund financed a project in the 1970’s to construct 40 larger artificial reservoirs based on the same water harvesting principle. These reservoirs were designed to have a capacity of 22,000 cu m and are lined with PVC sheet membranes. Runoff is collected from a catchment of 5 - 6 km² and led to the reservoir through a series of channels. Water is lifted to a distribution tank in each reservoir by a diesel pump.

2.63 Figure 11 shows the plan of the Reservoirs. Inadequate rainfall and runoff data meant that the calculation of catchment area had to be based upon observations by local people. This proved surprisingly accurate and all reservoirs are filled twice a year.

2.64 In the dry season these reservoirs, when operational, are the only water sources in vast parts of the region. However, since their construction there has been virtually no maintenance until, in 1981, not one reservoir was still in use. This led to a UNCDF funded project, executed by FAO, aiming to rehabilitate the reservoirs and draw up maintenance programs. The target by the end of 1986 is to have 33 reservoirs in working order.

2.65 One of the main reasons for the lack of maintenance of these Government owned reservoirs was the centralized project management from Mogadishu. Therefore, one of the principal project objectives has been to decentralize operations. An improvement in the system of revenue collection was also necessary.

2.66 The crucial technical constraint to efficient operation is the reliance on diesel pumps which, even with proper maintenance, have a life of only three years. Other technical constraints include the need for skilled labor and machinery for maintenance.

2.67 Although the reservoirs provide a solution to the major constraint to livestock production within the area, they contribute to local degradation of rangeland. The most critical issue is the need to integrate management of the reservoirs into the overall management of rangeland in the area. The best solution to this problem would be the construction of numerous small ponds within the area and not to permit stock to utilize the
reservoirs until these ponds become exhausted in the later part of the dry season.

3. Discussion

2.68 It was of considerable interest to the participants that the farmer response to the bunding under NWADEP is apparently very positive. However it was pointed out that there is a considerable element of subsidy in payment for bunding. Initial down payments are small and the final payment amounts to only 50% of the final cost. Despite this farmers are clearly impressed with the effectiveness of the bunds to improve crop yields by increasing moisture availability. Another possible reason for the popularity may be the security of tenure implicit in bunding on a farmers plot. Nevertheless there was concern about the sustainability of such a subsidized and mechanized scheme.

2.69 The project appeared to have an effective structural technique, but it was pointed out that the agronomic input had not kept pace, and this was now the major constraint to improved yields.

2.70 On the question of livestock water supply it was suggested that some method be devised to allow animals to approach the reservoir directly, by means of a concrete ramp for example, so that the need for a pump would be obviated. However it was demonstrated that the practicality of such a plan was not as straightforward as it sounded. Furthermore water would still need to be pumped for human consumption. The potential of windmill pumps is to be tested on a pilot basis.

2.71 A suggestion - which was very much in keeping with the theme of the workshop - for the problem of overgrazing around the reservoir, was the establishment of fodder banks and trees in this vicinity using water harvesting technology.

D. Sudan

1. General

2.72 Mr. Babiker A. Ibrahim and Mr. Dow El-Madina presented a report on experiences from the Kordofan Region of Sudan. Located in Western Sudan and within the Sahelian zone, rainfall in the southern part of Kordofan averages 600 - 800 mm per annum, but in the northern part it is as low as 100 - 300 mm. Coarse textured sands and sandy loam (Goz sands) are the predominant soils in north Kordofan. In the southern part, soils are mainly dark cracking clays- (Vertisols) with some footslope soils (Alfisols).

2.73 The established water harvesting systems in the region are mainly to provide water for man and animals. These systems are as follows:

a. Hafir: Excavated water pans, constructed by Government authorities

b. Dams: Relatively small structures on wadies, also constructed by Government
c. Fula: Holes made by excavation of building materials, used for water storage.

2.74 Other domestic and livestock water sources are lakes, "turda" (natural depressions), "gilat" (deep rock cracks) "seraf" (near surface groundwater) wells and storage in hollowed baobab trees.

2.75 Efficient design of water sources has to take into consideration a number of possible constraints to their ultimate effectiveness. Provision of water in areas of scarcity can lead to environmental degradation by attracting a large number of users. Traditional sources may be neglected, which can be serious if the new supplies are not well maintained. A major technical constraint is the very high level of evaporation, reaching above 3 meters a year in some areas.

2.76 For agricultural production fewer water harvesting techniques are practiced. Terraces and dykes however are used for water spreading, particularly on vertisols. An example is a scheme spreading water from the Khore Abu-Habil (a "wadie") onto an area targeted to reach 4,200 hectares annually.

2.77 One traditional system diverts runoff to small plots utilizing rock walls placed on hillsides.

2.78 Outside of Kordofan Region, in the eastern part of Sudan, a traditional system of harvesting runoff in "terraces" is widely practiced (Figure 12). The terraces consist of bunds with wing walls which impound water to depths of 50 cm or more at the deepest point. Sorghum is planted after the initial floodings. Within the main bund there may be smaller structures of a similar design which impound less water and can be planted earlier. The catchment to cultivated area ratios are in the region of 3:1.

2. Discussion

2.79 The presenters stressed that there was a potential, and a need, for more application of water harvesting techniques towards agricultural production. Appropriate research would begin shortly but only relatively low input schemes would be relevant to local rainfed farming systems, and economic considerations were critical. The development of traditional systems would be a component of the research.

E. Lesotho

2.80 A general background to Lesotho, its ecology, agriculture and strategy for water development was given by Mr. B. Leleka, and specific details of the FAO micro-scale water harvesting project were furnished by Mr. M. Finkel.

1. General

2.81 The Kingdom of Lesotho is situated on the highest part of the Drakensberg escarpment on the eastern rim of the South African Plateau. The terrain is rugged, soil erosion extensive, and only about 13% of the land is suitable for crop production. The largest portion of the arable acreage is found in the lowlands (1,400 - 1,800 m). Although rainfall is
usually adequate, considerable quantities are lost in runoff. Erosion is further facilitated by the Duplex soils, the severe overgrazing problem and the lack of tree cover.

2.82 Water harvesting methodology is used to supplement water supplies in two basic ways. The first is by roof catchments. Tanks to store water from corrugated iron roofs range in size from 500 liters to 4,500 liters. Secondly, the Ministry of Agriculture has constructed earth dams throughout the country for water supply and for intensive farming.

2. Micro-scale Water Harvesting Project

2.83 An FAO project has recently been established to explore the role of small scale water harvesting for supplementary irrigation of fruits and vegetables. Many of the common fruits and vegetables consumed at present are imported.

2.84 The micro-scale water harvesting project integrates three techniques into a unified system termed a "water harvesting farm" (Figure 13). The basis of each system is a "ground catchment". This consists of a cleared earth catchment of 600 m² which provides runoff, through a series of drains, to a stone masonry tank which has a concrete floor and concave sheet metal roof. The capacity of the tank is 100 m³, and the outlet a 5 cm gravity pipe. Water from the tank is utilized for the supplementary irrigation of vegetables.

2.85 Below the ground catchment are diamond shaped micro-catchments of 36 m² for fruit trees. In the lower part of the farm where the vegetables are grown, off-contour bunds, at a gradient of 0.5% are dug, alternate bunds sloping in opposite directions to allow slow drainage of excess runoff through the field. Details are shown in Figure 13.

2.86 Two water harvesting farms have been completed and the signs are that they are socially acceptable to the target groups of women, and school children. A total of 30 sites are planned, some including collection of water from rock catchments and springs.

3. Discussion

2.87 The central issue for discussion was the cost of the ground catchment system which, it was explained, would amount to $1,000 plus 1,000 days labor. This would clearly represent a high cost system and could only be applicable in rather special situations. It was pointed out that Lesotho is a relatively high income country and what might be relevant there may not be applicable elsewhere.
III. PLANNING AND DESIGN ISSUES

3.01 After the individual presentations, participants were divided into three groups to formulate major recommendations for the future development of water harvesting. Groups covered socio-economic considerations, agronomy and technical design. On the final day the groups came together to present and discuss their conclusions. The following section of this working paper is based on these discussions. Discussion leaders were as follows:

Socio-economic Considerations: Mr. M. Thiongo
Agronomy: Mr. W. Critchley
Technical design: Mr. M. Finkel

3.02 The most important factor in the planning and design of water harvesting systems is that if they are to succeed they must always reconcile these three aspects: the socio-economic factors of the community concerned; agronomic options, and the engineering alternatives.

A. Socio-economic Considerations

3.03 The success or failure of a water harvesting scheme will ultimately depend on the degree of acceptance by the local community. It is essential that the needs and aspirations of the community are clearly understood and fully provided for in the planning and design process. It is a serious mistake to impose a scheme upon a community without their acceptance or participation. Examples from Burkina Faso and Kenya illustrate how early terracing programs failed because the intended beneficiaries were not sufficiently involved. New programs implemented in both countries however built on these experiences, and were largely successful due to more appropriate techniques and approaches.

3.04 Similarly, in establishing priorities and calculating the benefits of a potential water harvesting scheme, planners must discover, and provide, what the community itself believes to be important, not what they imagine to be important. For example, in many of the potential target areas for water harvesting schemes, seasonal shortage of drinking water for domestic and for livestock use is a major problem. If a project concentrates on crop production when the community views this as a secondary priority, there will be little support for the project and low returns. This may explain the slow adoption of water harvesting techniques by farmers in Baringo, where the Baringo Pilot Semi-Arid Project initially was unable to develop adequate drinking water resources. Drinking water supply schemes will often warrant the first application of water harvesting technologies in Semi-Arid areas.

3.05 The introduction of new technology into a community cannot be an isolated development. Its success will depend on the extent to which it is technically effective, appropriate for the skills of the local people, economically efficient and applicable to the agro-ecological environment. It may also be necessary to show that a water harvesting scheme has benefits to offer the wider community. For example, in Somalia it has been shown that increasing the drinking water supply for cattle is not the complete answer to improving the productivity of the rangeland; it has to be used as one strategic tool in wider grazing management. In both Burkina
Faso and Somalia, projects which increase moisture availability for crops must also improve the standard of crop husbandry in order to achieve their full potential.

3.06 Before designing a project it may be necessary to undertake a study of what priorities and socio-economic variables are necessary to increase the adoption rate of water harvesting techniques by farmers, building on lessons learned from previous or similar projects. It may also be necessary to compare design options using cost-benefit analysis.

3.07 The ideal water harvesting system for plant production should be simple, and based on small structures which require a minimum of labor or supervision. Structures however must be designed to avoid breakages. This is particularly important to retain the confidence of a community in the beginning stages of a project when a new system is being introduced. Consequently, it is vital that durability is not sacrificed for short term cost-effectiveness. It is also important that the construction technology to be introduced is compatible with the skills of the community.

3.08 Widespread adoption of systems by local farmers will be unlikely without the demonstration of tangible and immediate benefits. Due to the site specificity of water harvesting techniques, it is essential that on-farm trials are costed and monitored, and benefits are proven to the farmers. It is also important that these adaptive trials are conducted at no cost to the farmer.

3.09 Water harvesting projects depend for their long term sustainability on the continuing, voluntary participation of farmers. If subsidies or other incentives are utilized initially to encourage the adoption of the new techniques, it is important that these inducements are not significant enough to undermine the long term development of the project when the initial support has to be tapered off. Material incentives given to farmers to construct structures in their own fields should be limited, where possible, to tools. A successful example of such a program is terracing in the Kitui District of Kenya. There may be exceptions however, such as the Turkana District, where food aid can be usefully directed towards building water harvesting structures under food-for-work schemes.

3.10 Successful, sustained development is also dependent on maintaining qualified and well motivated staff in the field. In many of the programs, such as the one in Burkina Faso, the most serious technical problem was the lack of trained manpower. It is essential that technical staff obtain the appropriate training both to establish and to maintain systems, and are given adequate field allowances to compensate them for work in what are often hardship areas. The effectiveness of farmer training will often depend on the extent of local knowledge it uses. It is therefore important that practical experience and views are exchanged between farmers and technical staff, so that problems can be detected and modified early. It is also essential to involve early on the regular refuison service in technology dissemination and feedback.

3.11 Economic considerations are always important in justifying a particular water harvesting scheme. Water harvesting systems must relate likely costs to potential benefits, even in areas which are often net
recipients of aid. Although in these areas there may be difficulties justifying any initiatives on strict financial grounds, there is always a case for looking at the opportunity cost of various approaches - in this context the comparison of alternative types of structures. However this does not exclude projects which are primarily oriented to adaptive field research. Here money is spent as an investment in a body of knowledge which, it is hoped, will bear fruit later. It is important also to analyze costs not directly borne by the farmer but which affect others in society, such as conflicts concerning land use, and to consider the alternative cost of periodic famine relief.

3.12 Water harvesting techniques can be used for a variety of purposes. Drinking water supply and improved production of food crops are the most obvious. But in semi-arid areas livestock are usually the basis of economy, and the possibility of increasing production of grass and fodder is also important. However, economics and the social organization of pastoralists may make organized, community based re-seeding schemes difficult in many situations. Perhaps it is more valid to consider water harvesting techniques for individual fodder plots close to the homestead.

3.13 Tree planting projects in semi-arid areas using water harvesting techniques are becoming more common. Most of the trees planted are multi-purpose, potentially useful for fuel, for fodder, as windbreaks or as a weapon against desertification. However, objectives often need to be more clearly defined - once again with a view to long term sustainability. The potential for high value tree crops is worthy of further exploration.

B. Agronomic Factors

1. Crop Response to Water

3.14 Water harvesting techniques are intended to increase the availability of water to plants grown in conditions where moisture is the primary limiting factor. These areas can be broadly defined on a climatic zone basis. In Kenya, Agro-Ecological Zones 5 and 6 (rainfall:open pan evaporation ratios 15 to 40% on an annual basis) are the zones where water harvesting techniques become relevant. In AEZ 4, (r/Eo 40 to 50%), techniques designed to maintain soil moisture in situ such as contour terracing will generally be adequate.

3.15 The response of crops to extra moisture where other factors are not limiting, can be dramatic, especially at the lower levels of water availability. Figure 14 shows the calculated response of maize and sorghum to different moisture regimes under rainfed conditions in a semi-arid part of Kenya.

3.16 Calculations of crop water requirements are well documented, for example in FAO Irrigation and Drainage Paper No. 24. Tables of crop coefficients are available for the various growth stages of various crops. This coefficient (kc) is multiplied by the local pan evaporation figure (Eo pan) which in turn is corrected by a pan coefficient (kp). The water requirement, for maximum yield per Land unit under optimum conditions (Et crop), is given by:
A calculation of the seasonal water requirement of a crop is a valuable tool in the design of appropriate systems of water harvesting.

3.17 The response of crops to diminishing moisture availability is quantified by the yield response factor (ky). The greater this factor, the greater the yield reduction. Maize, for example, has a ky value of 1.25 whereas sorghum has a corresponding value of 0.9. Details of values for selected crops are given in FAO Irrigation and Drainage Paper Number 33.

2. Soil Factors

3.18 A suitable soil is crucial to the success of water harvesting systems. The catchment soil should produce adequate runoff, either by sealing or crust formation, and the soil in the cultivated area should be deep, with a satisfactory available water capacity so that runoff can be stored within the profile. Sandy soils are particularly unsatisfactory, both because of their low moisture storage capacity and their poor generation of runoff.

3.19 The structural properties of soils used for bund building are also very important. Soils which lose their structural integrity on drying can lead to serious problems with bund breaches early in the season. From this respect a considerable clay content is a desirable characteristic. However, not all soils with a high clay content are automatically suitable; cracking soils such as vertisols are a case in point.

3.20 Soil fertility is an essential component of a successful system. There is little point increasing water availability to plants which are seriously limited by fertility.

3. Crop Choice

3.21 Water harvesting will commonly be used for improving the performance and the reliability of food crops already grown in the area. In Sub-Saharan Africa, the favored crop is normally a cereal. An ideal crop combines drought adaption with a degree of tolerance of temporary waterlogging. Brief notes on the crops most likely to be grown under such systems follow.

Sorghum

Although sorghum requires between 450 and 650 mm rain for maximum yields, it has several mechanisms for responding to drought, and hence has a relatively low yield response factor (ky = 0.9). Another important attribute is its capacity to produce a ratoon crop; and in the context of water harvesting, where runoff is often ponded, its ability to withstand temporary waterlogging is also very valuable.

Pearl Millet

Millet requires less rain than sorghum, tolerates drought better, and is able to produce reasonable yields in poor soils. However its yield potential is lower, it is intolerant of waterlogging and it does not ratoon. In systems with unequal flooding, millet can be profitably planted in the "drier" sections.
Maize
Maize is potentially the highest yielding of the cereals, but it requires more water than sorghum or millet, and it is very intolerant of waterlogging and drought stress. It is poorly suited to the semi-arid areas, unless under fully controlled irrigation.

Grain Legumes
Although none of the major grain legumes tolerate waterlogging, many display drought tolerance and their rapid maturity is often an advantage. Cowpeas are a particularly versatile crop being productive and indeterminate. Green grams and tepary beans are very quick maturing. Groundnuts have a low yield response factor (ky = 0.7), but are rather late maturing.

Cash Crops
Although food crops, largely for subsistence, will be the usual choice for water harvesting systems, there is an argument to support the production of cash crops, if this can be done at a comparative advantage to farmers. There are examples of these crops being important sources of income to poor farmers. Such crops are likely to be the more "unusual" ones, like Acacia senegal (gum arabic) or Jojoba.

4. Husbandry

3.22 While water harvesting systems can improve the moisture availability for crops, it is important that this response to water is exploited by good husbandry. The marginal response to extra water is considerably less under low fertility or poor management.

3.23 The time of planting can be critical in areas with short rainy seasons. Rapid establishment may be facilitated by systems which have trapped runoff from early showers, but early planting is necessary to make full use of this. However, in situations where water is impounded to considerable depths, planting after flooding is the correct practice. Pre-germination of seed is a technique which can shorten the maturity period of a crop, and trials on its applicability for water harvesting are warranted.

3.24 Generally the locally recommended spacing and plant populations should be followed. However, under the contour ridge system, as described in Baringo, Kenya, the planting configuration is altered, with crops being planted either side of the furrow (see Figure 1). This avoids the problem of waterlogging, and because each crop line is served by an equal catchment area, an even crop results, unlike trapezoidal systems on slopes where part of the crop receives a greater depth of flooding. In these systems it may be necessary to make ridges in the lower areas to avoid waterlogging.

3.25 Normal recommendations for crop rotation under rainfed systems should generally be followed. Sorghum, however, because it is such a suitable crop for water harvesting, may be included more often than normally recommended. In this case, pest control should be stressed to avoid the build up of infestations in the stover; stalk borer, for example.
3.26 Intercropping will often prove advantageous. In seasons with adequate moisture, a mixture will exploit the favorable growing conditions, and in drier seasons the legumes in a cereal/legume mixture may succeed where the cereal fails. Relay cropping - the planting of a crop into one which is already established - could be a useful "opportunistic" measure to maximize use of extra moisture.

3.27 Poor weeding is one of the major constraints to production in Sub-Saharan Africa, and its importance cannot be overstressed. It is particularly important to weed early as the crop is very vulnerable to competition at this stage. Weeds act like holes in a bucket - they "leak" water out of the soil profile. In situations where lack of water has been identified as the primary limiting factor this is clearly a loss which must be avoided.

5. **Fodder and Grass**

3.28 Fodder and grasses are usually much more tolerant than food crops of moisture stress. The implication for water harvesting systems is that design can be modified to allow smaller catchment areas. The relatively low economic return from livestock in these areas means that only the cheapest structures can be justified. However the perennial root systems of grasses and fodder tend to hold structures together and reduce the maintenance burden.

3.29 Weeding is again an important factor. The improved growing conditions often give rise to vigorous growth of unproductive bush species, which must be controlled, at least in the early stages. Choice of suitable grass species is relatively straightforward: seed collection and planting of the most productive indigenous perennial grasses is likely to be the safest policy.

3.30 In Kenya the grasses suitable for reseeding using water harvesting techniques include Eragrostis superba, Cenchrus ciliaris, Chloris roxburghiana and Chloris guyana. Suitable fodder species include Pennisetum purpureum, Atriplex spp., Stylosanthes spp., and Dolichos lablab.

6. **Trees**

3.31 Trees in semi-arid areas are commonly established under micro-catchment systems, whether the classical "negarim" (diamond shaped structures), or contour ridges divided into individual catchments by strategic placement of ties in the furrows. Contour ridges are the system of choice for large scale planting or mechanized systems. Individual catchment areas must be designed to meet the requirements of the mature tree, and hence in the early years the problem of overwatering or even waterlogging the seedling/sapling must be addressed. The planting position of the seedling is critical. Only species which are tolerant of waterlogging can be planted at the bottom of the hole where runoff concentrates. Planting on a ledge within the hole, or on the bund behind are alternatives. Early establishment is enhanced by mulching and weeds removed from the catchments can be used for this purpose.
3.32 Fodder species grown successfully in Kenya include Prosopis spp. and local Acacia spp. Under trials in Burkina Faso are Balanites sp. and Acacia albida, and in Sudan, Acacia senegal is grown for production of gum arabic.

C. Design and System Selection

1. Initial Considerations

3.33 Appropriate engineering design criteria cannot be developed in isolation from the intended end use of the proposed system, nor from socio-economic considerations. Design should seek to provide a technical solution to the constraints imposed by these factors.

3.34 Where possible, water harvesting structures should be designed to satisfy the following requirements:

Versatility: the techniques employed should be capable of use for a variety of purposes over a range of conditions, and be readily replicable.

Simplicity: structures should be small, suitable for construction using hand labor or animal draught, and require a minimum of supervision.

Durability: structures should require a minimum of repair and maintenance.

3.35 There will be justified exceptions to the first two requirements. Rock catchments, for example, have to be designed individually, and supervision of construction must be thorough. Large scale, mechanically built reservoirs which do not answer the requirement for simplicity are relevant in certain situations.

3.36 However the requirement for durability and minimal maintenance is common to all schemes. When water harvesting systems have failed, it is often attributed to early breakages due to poor design. Proper designs, meeting accepted engineering standards and farmer acceptability, are required for all structures. Nevertheless, care must be taken to avoid high-cost over design.

3.37 The choice among the types of system will again be a compromise between the engineer and the other relevant parties. Availability of machinery, for example, will influence system selection as will the scale of implementation.

3.38 Although systems with larger bunds may be preferred for durability and to minimize the danger of breaching, a linear increase in bund height is associated with an exponential increase in the labor required to build it. And for crops there is little to be gained from designs which lead to flooding at a depth greater than that required to replenish the root zone - typically not more than 30 cm. Another consideration is the need to strike a balance between designing a system able to provide the total crop water requirement on a reliable basis, as opposed to a cheaper system which recognizes the ability of the sort of crops normally grown in semi-arid areas to perform adequately with sub-optimum moisture.
3.39 For water supply systems which store water, economic considerations are the starting point for comparison of alternatives. A simple calculation of cost per unit volume stored is a useful tool. However there are other factors to consider such as the relationship between the stored volume and surface area, which can be critical in situations where evaporation losses are very high. Designs which seek to maximize the catchment area to ensure filling reservoirs in dry years, may encourage siltation and erosion of spillways in wetter years. In the context of range management, planners may prefer a series of smaller, strategically situated ponds to a few larger centralized units.

2. Technical Design and Design Parameters

3.40 The design principles of a water harvesting project are identical to those of other water development projects and hydraulic structures which require a wide range of inputs. However water harvesting projects are usually in remote areas for which hydrological data may be limited or simply unavailable. In these situations it will not be possible to calculate exact hydrological models and consequently there will have to be a reliance on "rules of thumb". It may therefore prove advantageous for schemes to be designed for flexibility, so that they may be modified if the original design proves to be inappropriate.

3.41 An example of a design model illustrates the type of calculations required in the design of appropriate water harvesting structures.

3.42 Fundamental to the design of water harvesting systems for crop production is the catchment:cultivated area ratio. The size of the catchment in relation to the cultivated area will determine how much supplementary "irrigation" by runoff the crops will receive.

3.43 The ratio of catchment to cultivated area can be calculated from the following formula:

\[
\text{Ratio of Catchment to Cultivated Area} = \frac{\text{Crop Water Requirement} - \text{Design Rainfall}}{(\text{Design Rainfall} \times \text{Runoff Coefficient}) \times \text{Efficiency Factor}}
\]

These parameters will be considered in turn.

**Crop Water Requirement**

The crop water requirement is the total amount of water required over the crop season to produce the maximum yield per unit of land. It depends on the crop to be grown and the climatic conditions. Calculations of crop water requirements have already been covered in the previous section; in the absence of evaporation pan data, readings from areas in similar climatic zones will suffice to give an estimate. The net water requirement is the total crop water requirement as calculated above minus the design rainfall for the season.
Design Rainfall

This is the minimum seasonal rainfall for which the project is designed to operate optimally. The procedure used is to calculate the amount of rainfall that can be relied upon to occur in a given percentage of seasons (for example 75% reliability, that is the amount which should be equalled or exceeded three years out of four). The lower the design rainfall, the larger will be the catchment required and the better the crop performance in the poorer years. However, there will be a corresponding problem of inundation with runoff in seasons with average or above average rainfall, and a less efficient land use system.

Runoff Coefficient

This is the percentage of incident rainfall which leaves the catchment as runoff. It varies with a number of factors, including slope, soil type, ground cover, the degree of soil saturation due to previous rain, and rainfall intensity. Furthermore, even where these factors remain constant, the runoff coefficient is highly sensitive to the length of catchment. Due to conveyance losses there is an exponential reduction in the percentage of runoff as the catchment length increases.

Runoff coefficients for micro-catchments can be estimated from the results of "runoff plots" set up for this purpose, but an extrapolation of these results to a much larger, longer catchment can be very inaccurate. For larger catchments, in the absence of field data, estimates will have to be made from observations and experience. An alternative starting point is to use the USDA Soil Conservation Service "Runoff Equation", which gives runoff percentages for given storm sizes based on combined catchment characteristics, but technicians are, dubious about the accuracy of these figures in African conditions.

Example runoff coefficients used in Kenya are 30% for microcatchments in Baringo and 13 to 19% for large catchments in Turkana.

Efficiency Factor

This factor relates to the efficiency of the crop's utilization of the water delivered to the plot. If calculations are based on seasonal rainfall, distribution of rainfall needs to be allowed for. All the rain may fall in one or two storms, and clearly this would lead to a poorer efficiency of utilization by the crop, due to overflow, deep drainage, evaporation losses, and, perhaps, waterlogging. Even under optimal conditions the crop will not be able to utilize more than about 75% of the water for evapotranspiration. A typical efficiency factor, used in calculations for Turkana District of Kenya is 50%.
It will be clear from the nature of the variables in the above calculation that the optimum level will seldom be reached, given available data, by paperwork alone. This leads to the argument for adaptive research, which depends on an efficient system of monitoring field performance as well as gathering data on the various parameters. However the calculation does at least provide a "best estimate" and establishes the framework for initial design.

3.44 Some details of the applicability, construction methods, labor requirements and typical dimensions for the various system design referred to in the country reports are given in Annex 1.
IV. CONCLUSIONS

4.01 There was broad agreement among workshop participants that water harvesting is a technique which is likely to be of increasing significance in the future within the semi-arid areas of Sub-Saharan Africa. It has been demonstrated to be an effective technique when systems are designed appropriately and its role inevitably becomes more important as people are forced into drier areas through population pressure.

4.02 Despite covering only a few Sub-Saharan countries - and within these, only a limited number of projects - enough information was gathered in the workshop to warrant a grouping of systems, provide basic design guidelines and indicate areas of possible applicability. From the experiences related it was also possible to draw some useful general conclusions about techniques and approaches. It is clear that a wide range of techniques are used, for a number of purposes, and that these can vary considerably even within countries. It was also evident that water harvesting in Sub-Saharan Africa differs in many ways from systems developed in other continents. Artificially treated catchments are generally not required and technology is seldom directly transferable.

4.03 Proper engineering design is essential to the success of all water harvesting schemes. Appropriate design can only be developed after careful consideration of the intended end use and socio-economic factors as well as climatic and edaphic soil criteria. The designer must ensure that systems operate efficiently - bund breakages and high maintenance demands will jeopardize the chances of wide adoption. Technical efficiency should not be sacrificed for short term economies, nor should it be achieved at unreasonable costs.

4.04 Among the designs discussed, one basic system stands out as being particularly versatile for Sub-Saharan Africa. This is the "trapezoidal bund", variations of which are described from four of the countries represented. It is relevant as a crop production technique which impounds runoff from a catchment external to the plot. However, a range of other systems have potential and are appropriate in specific situations.

4.05 While contour terracing is a technique which falls outside the strict definition of water harvesting, it too has contributed substantially to improved crop performance by increasing moisture availability in marginal areas. Its record of successful adoption in the countries cited makes it of interest in the planning of water harvesting programs, with particular respect to the motivation and organization of farmers.

4.06 Although there was an emphasis on water harvesting for food crop production during the workshop, it was agreed that the development of drinking water supplies in semi-arid areas is almost always a priority, and without it little else may be achieved. It is for drinking water development that water harvesting techniques can often make their initial impact in a community; public response to such schemes is usually very positive.
4.07 The potential of water harvesting techniques for fodder production is worth further exploration, as the economies of semi-arid areas are usually dominated by livestock. A further area for research is the possible contribution of cash crops - and, particularly, high value tree crops.

4.08 Adoption of systems and sustainability of development are only likely if system designs are appropriate, benefits are both rapidly realized and substantial, and where the local population is involved in planning and implementation. The introduction of water harvesting should be part of a wider program, and it is important that projects have a long term perspective and commitment.

4.09 Adaptive field research is undoubtedly useful in the development of water harvesting. But to improve systems and learn from project experience it is essential that information, both technical and socio-economic, also continues to be gathered through regular monitoring and surveys of projects and traditional systems.

4.10 The workshop has contributed substantially to the body of information on water harvesting. It is hoped that this report will be of use to many, and will stimulate further interest in a technique thought to have considerable potential in Sub-Saharan Africa.
WATER HARVESTING WORKSHOP: PARTICIPATING COUNTRIES

- Sudan
- Somalia
- Kenya
- Lesotho

Tropics of Cancer and Capricorn

Scale: 0 500 1000 2000 km
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FIGURE 1: CONTOUR RIDGES - Baringo District, Kenya.

GENERAL LAYOUT

Uncultivated Catchment Area Between Ridges

Contour Ridges at 1.5m apart (approx) with Cross-ties

SECTION a-a'

Cereal, Legume

20cm

1.5m

LAND SLOPE: < 2%
RIDGE/BUND HEIGHT: 20 cm
HORIZONTAL INTERVAL: 1.5m approx.
VERTICAL INTERVAL: N.A.
SOILS: Deep fertile Alluvium.

CONSTRUCTION: Hand or Machine
CATCHMENT: CROPPED AREA RATIO: up to 3:1
ZONE: AEZ 5
NOTE: Similar System used for Trees with Larger Ridges at a Wider Spacing
USE: Crops
FIGURE 2: EXTERNAL CATCHMENT SYSTEM - Baringo District, Kenya

LAND SLOPE: < 2%
RIDGE/BUND HEIGHT: 40cm
HORIZONTAL INTERVAL: 10m
VERTICAL INTERVAL: N.A.
SOILS: Deep Fertile Alluvium

CONSTRUCTION: By Hand
CATCHMENT:CROPPED AREA RATIO: 5:1 approx
ZONE: AEZ5/AEZ6
USE: Crops
FIGURE 3: SEMI-CIRCULAR HOOPS - Baringo District, Kenya.

- Land Slope: < 2%
- Ridge/Bund Height: 20 cm
- Horizontal Interval: Varied
- Vertical Interval: N.A.
- Soils: Deep Fertile Alluvium
- Construction: By Hand
- Catchment: Cropped Area Ratio: ≥ 2:1
- Zone: AEZ 5 / AEZ 6
- Use: Grass / Fodder
WT  WATER TANKS
RC  ROCK CATCHMENT DAMS
SD  SAND DAMS
ED  EARTH DAMS
SSD SUB-SURFACE DAMS

Storage period assumed: 3 Months
(with evaporation and seepage)

Costing includes value of self-help (40%)
but not transport and supervision

16 Ksh = approx. $1 u.s.
INITIAL STRUCTURES

RAINFALL

Terrace Bank

Channel

Example Slope 20%

AFTER FORMATION OF BENCHES

Cutoff Drain Stabilised with Grass

Grass Established on Terrace Bank

Bench Developed between Banks

LAND SLOPE : 5% to 50%
RIDGE/BUND HEIGHT : 50cm
HORIZONTAL INTERVAL : N.A.
VERTICAL INTERVAL : Constant 1m
SOILS: Hard when dry: Low Fertility.

CONSTRUCTION : By Hand
CATCHMENT: CROPPED AREA RATIO : N.A.
ZONE : AEZ4
USE : Crops
FIGURE 6: SEMI-CIRCULAR HOOPS - Turkana District, Kenya.

RUNOFF

Interval between Rows Varied

Semi-circular Hoop

Height at Tip: 20cm

Slope 1%

Maximum Height: 35cm
Maximum Depth of Water: 15cm

LAND SLOPE: <3%
RIDGE/BUND HEIGHT: 35cm (maximum)
HORIZONTAL INTERVAL: Site Dependant
VERTICAL INTERVAL: Site Dependant
SOILS: Varied

CONSTRUCTION: By Hand
CATCHMENT: CROPPED AREA RATIO: <20:1
ZONE: AEZ 6
USE: Fodder
FIGURE 7: TRAPEZOIDAL BUND - Turkana District, Kenya.

RUNOFF

Height at Tip: 40 cm
Base Width at Tip: 420 cm

120 m

1% Slope

Maximum Height of Bund: 80 cm
Base Width at Centre: 740 cm
Maximum Depth of Water: 40 cm

SECTION a - a'

Impounded Water

LAND SLOPE : < 2%
RIDGE/BUND HEIGHT : 80 cm [maximum]
HORIZONTAL INTERVAL : Site Dependant
VERTICAL INTERVAL : Varied
SOILS: Varied

CONSTRUCTION : By Hand
CATCHMENT: CROPPED AREA RATIO : < 20:1
ZONE : AEZ 6
USE : Crops
FIGURE 8: OPEN-ENDED CONTOUR BUNDS - Burkina Faso

Example Slope 1%

SECTION a-a'

Vegetation

Slope 1%

RUNOFF

Infiltration

Within Field Ridges

LAND SLOPE: Varied
RIDGE/BUND HEIGHT: 50cm
HORIZONTAL INTERVAL: N.A.
VERTICAL INTERVAL: 40 - 60cm
SOILS: Shallow and easily eroded
CONSTRUCTION: Part Machine/Part Hand
CATCHMENT: CROPPED AREA RATIO: N.A.
ZONE: Various
NOTE: Most Bunds of Earth, Some of Stone
USE: Crops
FIGURE 9: LOWLAND DEVELOPMENT SCHEMES - Burkina Faso

SIMPLE OPEN SYSTEM (in valley bottom)

- Runoff
- Contour Bund
- Fannes to allow overflow
- Contour Lines

- Runoff
- Contour Lines

HALF OPEN SYSTEM (in valley bottom)

- Flood Protection Bank
- Runoff
- River
- Contour Bund
- Contour Lines

LAND SLOPE: Low
RIDGE/BUND HEIGHT: 50cm
HORIZONTAL INTERVAL: N.A.
VERTICAL INTERVAL: 15cm

CONSTRUCTION: Part Machine/Part Hand
CATCHMENT:CROPPED AREA RATIO: Large
ZONE: Various
USE: Crops (mainly Rice)
LAND SLOPE : < 2% (typical)
RIDGE/BUND HEIGHT : 1m
HORIZONTAL INTERVAL : N.A.
VERTICAL INTERVAL : 60cm

CONSTRUCTION : Heavy Machinery
CATCHMENT:CROPPED AREA RATIO : up to 2:1
ZONE : Semi - Arid
USE : Crops
FIGURE 11: RURAL WATER RESERVOIR - Somalia

- Land slope: ≤ 2%
- Storage Capacity: 22,000 m³
- Use: Livestock/Human Water Supply
- Soil: Varied
- Construction: Machinery
- Catchment: 5 - 6 km²
FIGURE 12: TERRACE - Sudan

LAND SLOPE: 0.5 - 1.0%
RIDGE/BUND HEIGHT: 75 - 100cm
HORIZONTAL INTERVAL: N.A.
VERTICAL INTERVAL: 50cm to tips

CONSTRUCTION: By Hand
CATCHMENT: CROPPED AREA RATIO: ≤ 3:1
ZONE: N.A.
USE: Crops
FIGURE 13: WATER HARVESTING FARM - Lesotho

GROUND CATCHMENT: 600m²

CONSTRUCTION: By Hand

USE: Water Storage for Irrigating Vegetables
FIGURE 14: CEREAL YIELD – RAINFALL RELATIONSHIPS (Illustrative)

from "SORGHUM AND MILLET AGRONOMY"
P. Whiteman, Katumani, Kenya 1981

Notes/Assumptions
- Based on conditions in AEZ 5 Eastern Kenya
- Rainfall assumed 75% effective under good management
  50% " " poor 
- Based on yield response factors of 1:2 (Maize) and 0:9 (Sorghum)
EXAMPLES OF WATER HARVESTING SYSTEMS

This annex gives examples drawn from the country reports, of water harvesting systems grouped into types, with details of their characteristics and the situations in which they may be suitable. Contour terracing, though not strictly a water harvesting technique, is included because of its importance in marginal areas and its similar goal - to improve plant performance by increasing moisture availability. Water harvesting systems are subdivided into two categories: short term techniques which store water in the soil profile; and long term storage techniques based on deep ponding.

Contour Terracing

This technique is used in Kenya as the "fanya-juu" terrace, and in Burkina Faso as "open ended contour bunds" (see Figures 5 and 8 respectively). Inflow of runoff is excluded from the system in Kenya by use of a cutoff drain, whereas in Burkina Faso stone terrace lines are sometimes used on the upper contours to allow some runoff to percolate through. The major objective of these systems is to maintain soil and rainfall between the terrace banks.

Where applicable: Appropriate for marginal ("transitional") areas eg AEZ 4 in Kenya (r/Eo= 40 - 50%) particularly where slopes are above 5%.

Construction: Can be made wholly by hand (Kenya) or part machine, part hand (Burkina Faso).

Labor required: Kenya - 185 man days per hectare on a 20% slope.

Dimensions: Kenya - earth bunded to a height of 50 cms, excavated from a channel immediately below. Vertical interval (Kitui District) constant at 1 meter. Cutoff drain to divert or impound runoff from outside catchment.

Burkina Faso - earth or stone bunds, 50 cm high with VI of 40 - 60 cm.
Short-term Storage Systems

a. Contour Ridges

This technique is described from Baringo District Kenya where it is used for row crops and trees (see Figure I). Its particular advantages are the high runoff coefficients of the micro-catchment strips, even plant growth and the ability to hold runoff from heavy storms without damage. It is suited to both small scale manual, and large scale mechanized schemes.

Where applicable: Limited to the relatively more favorable semi-arid areas because of small sized catchments (e.g. AEZ 5 in Kenya). Slopes should be less than 2%.

Construction/Dimensions:

- Ridges dug by hand for crop production: 20 cm high (with furrow uphill) and minimum 1.5 m apart.
- Ridges made by machine for tree planting: 40 cm high (furrow uphill) and approximately 10 meters apart, tied at 10 meter intervals.
- Labor required: Approximately 50 man/days per hectare for crop system.
- Cutoff drain or diversion to present inflow sometimes necessary.
- Catchment:cultivated area ratios up to 3:1.

b. Tree Micro-catchments ("Negarim")

Classical diamond shaped micro-catchments were reported from Turkana, Kenya and Lesotho (see Figure 13) for establishment of fodder and fruit trees respectively. "V" shaped catchments can be used for individual trees.

Where applicable: Wherever moisture limits seedling establishment. Slopes should be below 5%; above this terracing more suitable.

Construction: By hand. Difficult to mechanize.

Dimensions: Usually in blocks of diamond or square shaped catchments. Individual catchment size, up to 250 m² in Turkana, 36 m² in Lesotho.
c. **Semi-Circular Hoops**

Similar shaped structures were described from Baringo, Kenya (for range rehabilitation: Figure 3), Turkana, Kenya (for fodder banks: Figure 6), and Burkina Faso (for tree establishment). The Turkana structures, however, are very much larger than the others.

Where applicable: In semi-arid areas for establishment of grass, fodder or trees. Slopes should be below 2%.

**Construction:**

By hand, difficult to mechanize.

**Labor Required:**

0.1 man/days per unit, (approximately 10 days per hectare covered)  
25 man/days per unit, Turkana

**Dimensions:**

Baringo - radius 6 m (20 cms ridge)  
Turkana - radius 15 m (large bund)  
Burkina Faso - radius 5 m  
Tips surveyed on contour for overflow.

**Catchment:** Cultivated area ratio-minimum 2:1  
Baringo: up to 20:1 Turkana

d. **Trapezoidal Bunds**

Although given different names and with varied dimensions, the basic term "Trapezoidal Bund" fits several systems described from various countries. Runoff is impounded in front of the main bund, which is usually sited on the contour, and the structure completed by side bunds, or wing walls. Excess runoff passes around the tips of the wing walls which are surveyed on the contour. This is usually preferable to allowing overflow to pass through spillways in the bottom bund.

Trapezoidal bunds, of one type or another, are the most common and appropriate technique for impounding runoff from catchments external to the plot.

In all the cases cited these systems are used for crop production.

Where applicable: In most situations where it is required to harvest runoff from an external catchment. Cultivated area usually limited to slopes 2% or less (above which flooding is too uneven).
Construction: Can be hand built (e.g., Turkana, Kenya) or bunds formed by heavy machinery (Somalia)

Labor Required: 380 man/days per unit in Turkana.

Dimensions: Turkana - "Trapezoidal Bund" (Figure 7) bottom bund straight and standard length of 40 meters. 120 m between tips of wing walls. Maximum water depth (on 1% slope) of 40 cm. Catchment: Cultivated Area ratio (C:CA) up to 20:1

Somalia (NWADEP) - "Bunding" (Figure 10) - Series of contour bunds, one meter in height. Vertical interval (VI) of 60 cm. Wing walls to 30 cm VI above contour bunds. C:CA ratio up to 2:1

Burkina Faso - "Lowland development" (Figure 9) - Series of contour bunds, 50 cm high in valley bottoms. Vertical interval of 15 cm. Wing walls allow overflow through flumes. C:CA ratio unspecified.

Sudan - "Terraces" (Figure 12) - Bottom bund approximately on contour. Wing walls to vertical interval of (approximately) 50 cm above bund. Smaller trapezoidal structures within main one. C:CA ratio approximately 3:1.

Long Term Storage Systems

a. Rock Catchments

This technique is common in Kitui (Kenya) where rock outcrops provide a source of relatively clean runoff and the basis for the storage structure. There is potential for similar structures in Lesotho.

Where applicable: In areas where there are outcrops of hard, unfissured rock.
Construction: Masonry or concrete structures impounding water in natural depressions on the rock. Occasionally storage is in excavated ponds below the rock.

Dimensions: Site specific.

b. **Ground Catchments**

Ground catchments are utilized for harvesting runoff for tanks, ponds, hafirs and reservoirs. Examples have been cited from most of the countries, with specific details of livestock reservoirs from Somalia and tanks for irrigation of vegetables from Lesotho.

Where applicable: In areas where water is limited for livestock or human supplies or for irrigation of high value crops.

Construction: Small structures may be excavated or constructed by hand. Large structures built by machine.

Dimensions: A wide range. Example of Reservoir cited from Somalia has a capacity of 22,000 m³ and a catchment area of 5 - 6 km². Storage tank in Lesotho has a capacity of 100 m³ and a catchment area of 600 m².
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