World Food Programme

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# Rainwater harvesting and management technologies for arid and semi-arid lands of Kenya

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## Acronyms

**ADCL** – Appropriate Development Consults Ltd

**ALRMP** - Arid Lands Resource Management Project

**ASAL** - Arid and Semi-arid Land

**C** – Catchment Area

**CA** - Cultivated Area

**FAO** – Food and Agriculture Organization

**FFA** – Food for Asset

**HI** – Horizontal Interval

**NGO** – Non Governmental Organization

**PET** - Potential Evapotranspiration

**RHM** - Rainwater Harvesting and Management

**VI** – Vertical Interval

**WC** - Water Conservation

**WH** - Water Harvesting

## 1. Introduction

A large population of people and livestock live in the arid and semi-arid areas (ASAL) of Kenya. In these parts of the country reduced rainfall or prolonged dry spells challenge livestock and crop production activities. Much of the response by government and NGOs to alleviating water shortage in ASAL areas has been on developing fuel-driven boreholes (deep and shallow) that are usually expensive to implement and to maintain (Gomes, 2006). Moreover walls of the dug wells often collapse and pumps fail to function due to lack of maintenance and increased running costs. The lowering of water levels in most of the boreholes has challenged sustainability of borehole interventions. Information show that the proliferation of boreholes and water abstraction hasn't been implemented concurrently with implementation of *in situ* moisture conservation activities that contribute to recharging of the groundwater table.

Several invasive species (e.g. Prosopis sp.) have restricted access to pasture and rapidly destroyed the quality of the same in many ASAL districts. As a result, a vast area of "pastureland" remains barren the whole year round. Even rainfall storms of low intensity causes a high magnitude of overland flow volume and velocity which in turn creates rill and gully erosion problems reducing soil fertility and productivity. This phenomenon could obviously diminish soil infiltration and the recharging of groundwater table.

One answer to this problem could be promotion of in situ moisture conservation and harvesting of surface runoff. Limited amount of rainwater harvesting technologies have been implemented and harvested water for domestic purposes (for humans and animals) and small scale irrigation. However, most of these structures faced severe siltation problem and heavy interferences from livestock and people. Consequently, the structures often sustained and served the intended purpose for only short period of time. For example out of several water pans that have been constructed by different organization only few of them had an adequate capacity and served the communities during the extended dry periods. Some of the pans were small in size and poorly protected and managed. Out of the few exemplary pans that provided good service over long duration, the one at Wayu Duka site, Tana District need to be mentioned. The construction of this pan was commissioned by the Arid Lands Resource Management Project (ALRMP).

The other limitation of the past rainwater harvesting activities has been the short sights for exploiting the water for productivity improvement and income generation of the households. Thus it is a high time to think of an effective design of rainwater harvesting and management (RHM) schemes for productive uses. It is also imperative to explore indigenous RHM technologies which can be implemented through involving communities. Future approach to sustainable RHM activities should be such that they are effective, productive and acceptable to the communities at the same time. They cannot be considered as an independent activity but as an integrated component of the broad soil, water, crop and livestock management systems. This may call for a participatory integrated RHM project preparation and implementation so as to achieve improved crop-livestock production. However information shows that experience and knowhow on RHM are still limited particularly in the pastoral and other semi-arid areas of the country.

FFA activities will focus on assisting pastoral and semi-pastoral communities in the ASAL districts (85 % of the country) harvest the rainwater and use it to grow pasture, browse, drought tolerant crops, and for human and livestock consumption. Project implementation will require close supervision to ensure good quality activities are implemented and useful knowledge is transferred. In general the activities are expected to improve food security in the ASAL by having the following impacts:

a. Improved pasture and browse production,
b. Increased crop production (diversification of sources of food),
c. Improved access to water for both human and livestock use, and
d. Reduced environmental degradation.

One of the major strategies of FFA is to transfer appropriate RHM technologies to partners and technical offices in different districts that will in turn transfer it to communities. This document is, therefore, prepared to be used as a technical manual on RHM technologies mainly for those staff who have been working on rainwater harvesting without taking adequate technical training on RHM as well as for those who have undertaken a technical training in RHM but need to get their knowledge refreshed. The trainees are expected to prepare an integrated RHM plans and technically support during the project implementation.

To assist in the right choice of RHM technology and make an adequate planning technology options are given and standard specification made for each technology. According to this guideline a minimum technical standard is defined as the minimum dimensions, size, spacing, etc., for each RHM technology. The measures are described adequately and considered sufficient to provide the required information. For additional information, experts should refer to other textbooks and training documents from different sources.

For most of the technologies, an estimate worknorm is recommended and worknorm elements listed. Worknorm elements refer to the main different operations necessary to accomplish a given output. Many of the minimum technical standards indicated for various activities do not mean that the standard design indicated is the only one possible. Within those standards and worknorm conditions, modifications are possible and even recommended to accommodate different requirements.

## 2. Why rainwater harvesting?

Water harvesting technologies have been defined as the process of collecting and concentrating water from runoff into a run-on area where the collected water is either directly applied to the cropping area or stored in the soil profile for immediate use by the crop. Distinction should be made between water conservation and water harvesting. Water conservation (WC) refers to the conservation of precipitation where it falls (*in situ*), for plant growth, through increasing water infiltration and diminishing evaporation loses. Activities like level fanya juu, tie-ridges, check dams, mulching, etc. are included here. On the other hand, water harvesting (WH) refers to the concentration of rainfall runoff from a bigger area (catchment) into a smaller area for crop growth, animal and human consumption. The storage of water in pan, dam,

stern or storage tank, roadside flood harvesting, etc. are some of the major WH activities. However, experiences have shown that WC and WH activities have been implemented either in combination or solitarily in the various moisture deficit areas.
Before deciding implementing rainwater harvesting technologies one should know whether or not the targeted area receives sufficient amount of rainfall to support the crop or livestock production activities of the communities. When the total amount of soil water used for transpiration by the plants and evaporation from the surrounding, i.e. evapotranspiration, is greater than the amount of rainfall it indicates that some kind of rainwater harvesting is required. Evapotranspiration represents the amount of water utilized by the plant and its environment.

Water harvesting is not new to ASAL. It has been in place since time immemorial. The existence of *Elas* (Borana) and *Berkads* (Somalia) are testimony to a long history of harnessing rainwater for domestic and livestock uses. The movement of people along with animals during the dry season, in search of water and fodder for their animals, shows that the practice of ASAL communities in water management has been there for long time.

ASAL receives low rainfall and very high temperatures, hence high evaporation from surface reservoirs. This means that large tracks of land are required as catchment areas to generate adequate runoff for ponds or dams. We use the monthly average rainfall data of Isiolo meteorological station to explain this situation. Isiolo receives about 650 mm of rainfall annually (Figure 1). This water is unevenly distributed in time. Annual potential evapotranspiration (PET) in Isiolo is very high (average is 1230 mm) exceeding rainfall in most months. Monthly PET is higher than the mean monthly rainfall except for the months of April and November. This shows that, except for the months of April and November, additional water is required to sustain a good crop and pasture growth.

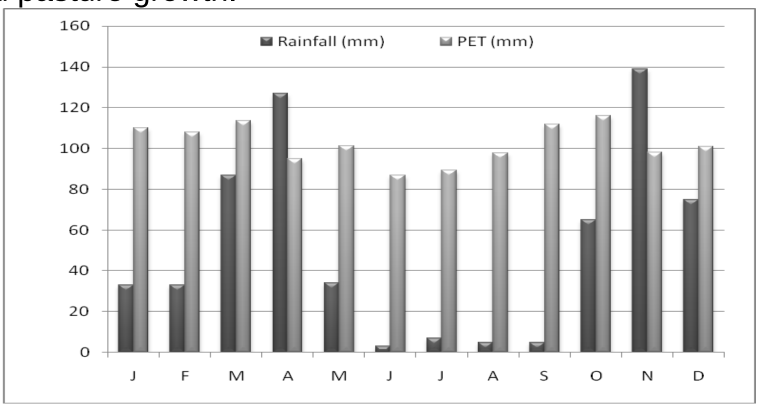


Figure 1. Monthly average rainfall and potential evapotransipiration rate of Isiolo, Kenya. *Source:* Data generated from the New Local Climate Estimator V1.06, FAO.

On the other hand, rainfall data obtained from the Kenyan Meteorological Department (71 years data) show that the annual average rainfall amount of Isiolo town was 650 mm, but it showed some variation over the period of analysis (1938–2008) (Figure 2). This average rainfall is quite high compared to other ASAL of Kenya. Annual rainfall ranged from 327 mm in 1950 to 1293 mm in 1961. We assumed a range of 300 mm around the average (500–800 mm) as being normal fluctuations. Years with rainfall above or below this range were considered abnormally wet or dry, respectively. Accordingly, years 1951, 1962, 1969, 1990, 1997 and 2006 were abnormally wet. Several dry years have been experienced since 1938. A general decline in annual rainfall can be observed in recent years including the years 2005, 2007 and 2008.

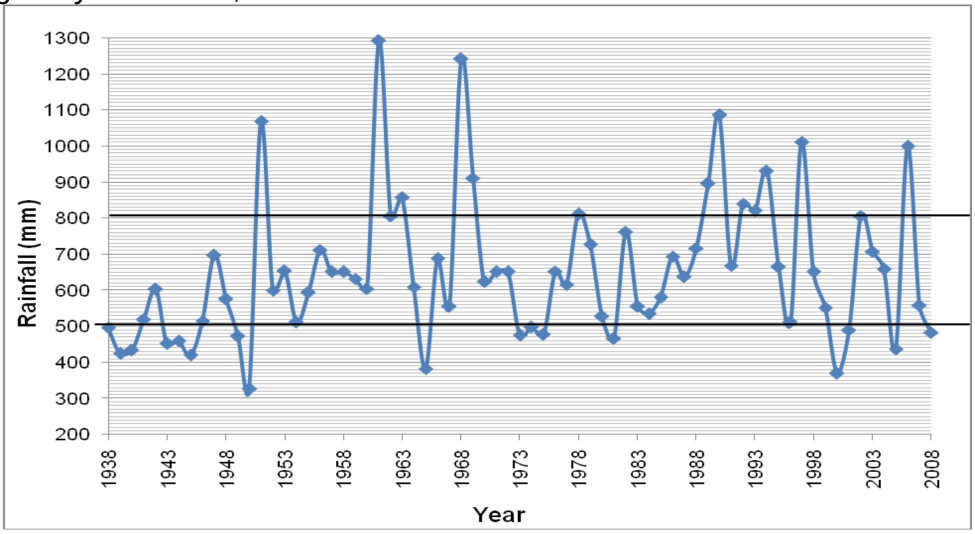


Figure 2. Annual average rainfall amount of Isiolo town.

Rainfall distribution in Isiolo is bimodal; short and long rainfall seasons. Short rainfall season is between March and April during which 33% of the total annual average rainfall being received. But long rainfall season is between October and December during which 48% of the total annual average rainfall occurs. Figure 3 shows how the rainfall values of the long rainfall season flactuate during 71 years of observation. As compared to the earlier seasons there has been no any significant shortage of rainfall noted in recent years. Like in the other dry years, rainfall amounts of long rainfall season are were low in 2005, 2007 and 2008. This will have negative implication on the availability of pasture and water for livestock production and domestic uses. But this value was high for the year 2006.Though crop production is less important in this area compared to livestock production, the current low amount of rainfall will lead to the failure of the alraedy poor crop productivity. Therefore, this rainfall deficit should be agumeted by implimeting the *in situ* and *ex situ* RHM technologies. It can be hypothesised that RHM initiatives could yield better impact in areas like Isiolo compared to areas with exteremely low amount of rainfall.

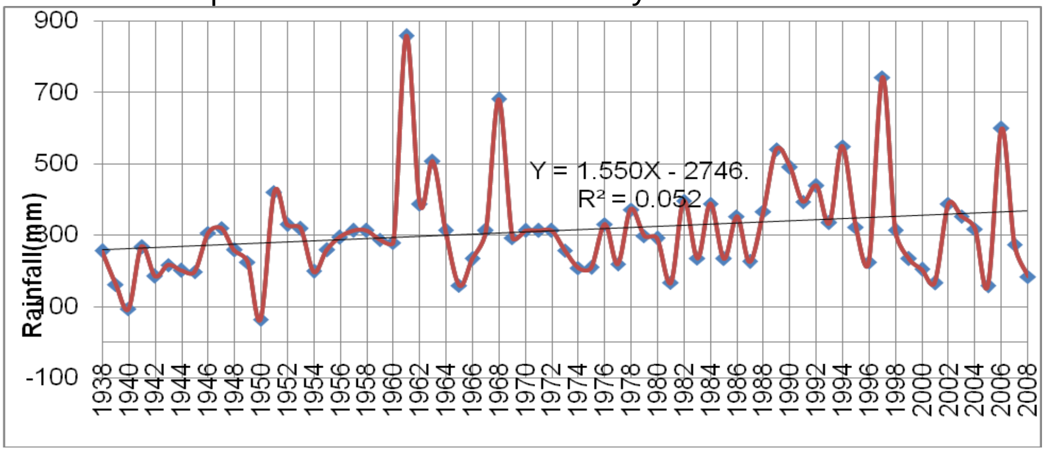


Figure 3. Rainfall amount of the long rainfall season (October to December) in Isiolo.

Air temperature and wind speed are important especially in designing open RHM reservoirs or tanks, particularly when considering losses due to evaporation. The mean air temperatures in ASAL are generally high all the year round. December and March are the hottest months but July and August are the coolest months. High wind speed increases evaporation losses from open surface reservoirs. Thus losses due to evaporation are enhanced with increased temperatures and further accelerated with higher wind speeds. Where possible for open water bodies, the losses due to evaporation can be reduced by planting wind-breaking trees on the windward direction.

In summary, there are multiple advantages of RHM locally as well as regionally. Some of these are:

- RHM creates opportunities to coping with droughts, thus enabling communities to invest in livelihood activities,
- RHM boosts agricultural productivity and thus food security,
- RHM complements other water sources,
- RHM mitigates against the devastating effects of climate change (as soil infiltration enhanced, water stored at different points, etc).

## 3. Water and soil requirement for rainwater harvesting and management

In this Chapter general information about water and soil requirement for RHM technology options are outlined as follows:

### 3.1 Crop, animal and domestic water requirements

The water requirement for crop and livestock production should be known prior to the choice and design of RHM system. Crops differ in their response to moisture deficit. When crop water requirements are not met, crops with high drought sensitivity (e.g. maize and beans) suffer greater reductions in yields than crops with low sensitivity (e.g. groundnuts, sorghum). The highest crop and livestock water needs are thus found in areas which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind.

The basic formula for the calculation of crop water requirement is presented below.

**ETcrop = Kc x Eto**

where:

**ETcrop** = the water requirement of a given crop in mm per unit of time e.g. mm/day, mm/month or mm/season.

Kc = the "crop factor“. It is related to the percent of ground covered by the crop canopy and varies depending on the crop growth stage (see Table 1).

**ETo** = the "reference crop evapotranspiration" in mm per unit of time e.g. mm/day, mm/month or mm/season. The reference crop evapotranspiration ETo (sometimes called potential evapotranspiration, PET) is defined as the rate of evapotranspiration from a large area covered by green grass which grows actively, completely shades the ground and which is not short of water. The rate of water which evapotranspirates depends on the climate. The highest value of ETo is found in hot, dry, windy and sunny areas but the lowest values are observed in areas where it is cool, humid and cloudy with little or no wind.

Table 1. Crop factor (Kc) at different crop growth stages.

| Canopy cover | Crop factor (Kc) |
|---|---|
| **Bare ground** | 0.3 |
| **¼ canopy** | 0.4 |
| **½ canopy** | 0.6 |
| **¾ canopy** | 0.7 |
| **Full canopy** | 0.85 |
| **Maturing crop** | 0.65 |

Water requirements of different crops, trees and animals depend on the kind of crop, tree and animal and the climate of the place where the same is grown. In this manual we shall not deal with the calculation of crop water requirement because of lack of detailed input data in most of rainwater harvesting areas. Instead we present approximate water requirement values for some seasonal crops (Table 2), multipurpose trees (Table 3) and animals (Table 4). Anybody interested in the calculation of crop water requirements using the above formula can read any irrigation textbooks and apply it.

Table 2 - Approximate values of seasonal crop water needs

| Crop | Crop water need (mm/total growing period) | Total growing period (days) | Crop | Crop water need (mm/total growing period) | Total growing period (days) |
|---|---|---|---|---|---|
| Beans (dry) | 300 – 500 | 70-95 | Melon | 400-600 | 135-180 |
| Cabbage | 350-500 | 90-150 | Onion | 350-550 | 70-95 |
| Groundnut | 500 – 700 | 130-140 | Peanut | 500-700 | 130-140 |
| Maize | 500 – 800 | 95-120 | Pea | 350-500 | 90-100 |
| Sorghum | 450 – 650 | 105-140 | Pepper | 600-900 | 120-210 |
| Millet | 450 – 650 | 135-180 | Potato | 500-700 | 105-145 |
| Soybean | 450 – 700 | 135-150 | Tomato | 400-800 | 135-180 |

There is little information available about the water requirements of multipurpose trees planted under RHM systems in ASALs. Generally, trees are relatively sensitive to moisture stress during the establishment stage but their ability to withstand drought improves once their root systems are fully developed. Therefore, the critical stage for most trees is in the first two years of growth stages. Table 2 presents some basic data of multipurpose trees often planted in ASAL based on the ICRAF Publication "Agroforestry in Dryland Africa", Rocheleau et al. (1988).

Table 3 - Naturally preferred climatic zones of multipurpose trees.

| Plant species | Semi-arid/marginal 500-900 mm rain | Arid/semi-arid 150-500 mm rain | Tolerance to temporary waterlogging |
|---|---|---|---|
| Acacia albida; A. nilotica | Yes | Yes | Yes |
| A. saligna; A. senegal | No | Yes | Yes |
| A. seyal; A. tortilis | Yes | Yes | Yes |
| Albizia lebbeck | Yes | No | No |
| Azadirachta indica | Yes | No | Some |
| Balanites aegyptiaca | Yes | Yes | Yes |
| Cassia siamea | Yes | No | No |
| Casuarina equisetifolia | Yes | No | Some |
| Colophospermum mopane | Yes | Yes | Yes |
| Cordeauxia edulis | No | Yes | ? |
| Cordia sinensis | No | Yes | ? |
| Delonix elata | Yes | No | ? |
| Eucalyptus camaldulensis | Yes | Yes | Yes |
| Prosopis chilensis | Yes | Yes | Some |
| Prosopis cineraria | Yes | Yes | Yes |
| Prosopis juliflora | Yes | Yes | Yes |
| Ziziphus mauritiana | Yes | Yes | Yes |

To determine the water requirement for any particular household, or community, information on the number of people need to be gathered. For example the daily water use of a typical ASAL can be assumed as 14 litres per person per day for a household of eight for 180 days per year (Nissen-Petersen, 2006). In this case 6 months out of 12 months per year are assumed to be dry and some kind of water harvesting is required for those months. Thus the total domestic water requirement for a family size of 8 people is then 20,160 litres. This approach could be followed to estimate the domestic water requirement of households that the project aim to address.

Livestock water requirement depends on climatic condition and type and number of animals to utilize the harvested water (Table 4).

Table 4. Livestock dry season water requirement

| Animal | Water intake (lit/day) |
|---|---|
| Zebu cow | 27 |
| Milk cow | 50 |
| Camel | 60 |
| Sheep | 5 |
| Goat | 5 |

*Source:* Rain Catchment and Water Supply in Rural Africa, Nissen-Petersen, E. 1982 & Finkel and Segerros 1995 (RELMA Technical Handbook No. 22).

## 3.2 Soil requirement

The physical, chemical and biological properties of the soil affect the yield response of plants to extra moisture harvested. Generally the soil characteristics for water harvesting should be the same as those for irrigation. Ideally the soil in the catchment area should have a high runoff coefficient while the soil in the cultivated area should be a deep, fertile loam. Where the conditions for the cultivated and catchment areas conflict the requirements of the cultivated area should always take precedence. Soil texture, structure, depth, fertility, salinity/sodicity and infiltration rate are important aspects of soils that determine crop choices as explained below.

**Texture:** Soil texture refers to its composition in terms of mineral particles. The texture of a soil has an influence on several important soil characteristics including infiltration rate and available water capacity. The medium textured soils, the loams, are best suited to WH system since these are ideally suited for plant growth in terms of nutrient supply, biological activity and nutrient and water holding capacities.

**Structure:** Soil structure refers to the grouping of soil particles into aggregates, and the arrangement of these aggregates. A good soil structure is usually associated with loamy soil and a relatively high content of organic matter. Inevitably, under hot climatic conditions, organic matter levels are often low, due to the rapid rates of decomposition. The application of organic materials such as crop residues and animal manure is helpful in improving the structure.

**Depth:** The depth of soil is particularly important where WH systems are proposed. Deep soils have the capacity to store the harvested runoff as well as providing a greater amount of total nutrients for plant growth. Soils of less than 1 m deep are poorly suited to WH but 2 m depth or more is ideal.

**Fertility:** In areas where WH systems may be introduced, lack of moisture and low soil fertility are the major constraints to plant growth. Nitrogen and phosphorus are usually the elements most deficient in these soils. While it is often not possible to avoid poor soils in areas under WH system development, attention should be given to the maintenance of fertility levels.

**Salinity/sodicity:** Sodic soils, which have a high exchangeable sodium percentage, and saline soil which have excess soluble salts, should be avoided for WH systems. These soils can reduce moisture availability directly, or indirectly, as well as exerting direct harmful influence on plant growth.

**Infiltration rate:** The infiltration rate of a soil depends primarily on its texture. Typical comparative figures of infiltration are 50, 25, 12.5 and 7.5 mm/hour for sandy soil, sandy loam, loam and clay loam, respectively. A very low infiltration rate can be detrimental to WH systems because of the possibility of waterlogging in the cultivated area. On the other hand, a low infiltration rate leads to high runoff, which is desirable for the catchment area. The soils of the cropped area however should be sufficiently permeable to allow adequate moisture to the crop root zone without causing waterlogging problems. Therefore, the requirements of the cultivated area should always take precedence. Crust formation is a special problem of ASAL, leading to high runoff and low infiltration rates. Soil compaction as a result of heavy traffic from grazing animals could also result in lower infiltration rates.

## 4. Rainfall probability, design rainfall, runoff coefficient and efficiency factor

### 4.1 Rainfall probability analysis and design rainfall

Runoff is generated by rainstorms, and its occurrence and quantity are dependent on the characteristics of rainfall event. The amount, timing and variability of rain, which occurs during a season or year are the key factors that must be evaluated in designing a water harvesting system. The following steps can be followed to make rainfall probability analysis:

*Step 1:* obtain a long-term annual rainfall totals (min 10 years) for the **cropping season** from the area of concern. But in this example we use the annual rainfall values (instead of seasonal rainfall values) of Isiolo station because length of cropping season may differ from crop to crop. An analysis of less than 10 years of observations is inadequate as these values may belong to a particularly dry or wet period and hence may not be representative for the long-term rainfall pattern. In locations where rainfall records don't exist, figures from stations nearby may be used with caution. In the following example, a mean annual rainfall data from Isiolo meteorological station were used for analysis (Table 5). Readers should know that there is no especial reason for using rainfall data form Isiolo except that the current RHM training is being planned here.

*Step 2:* Rank the annual totals with m = 1 for the largest and m = 71 for the lowest value and rearrange the data in descending order. The probability of occurrence P (%) for each of the ranked observation can be calculated using the equation:

$$P(\%) = \frac{m - 0.375}{N + 0.25} \times 100$$

where:

P = probability in % of the observation of the rank m

m = the rank of the observation

N = total number of observations used

Table 5. Unranked and ranked rainfall (R = mm), probability of occurrence (P = %) and return period (T = Years), for Isiolo meteorological station, Kenya.

| Year | Unranked rainfall (mm) | Ranked Rainfall (mm) | m | P (%) | T | Year | Unranked rainfall (mm) | Ranked Rainfall (mm) | M | P (%) | T |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1938 | 495 | 1293 | 1 | 0.9 | 114.0 | 1974 | 498 | 616 | 37 | 51.4 | 1.9 |
| 1939 | 425 | 1243 | 2 | 2.3 | 43.8 | 1975 | 478 | 610 | 38 | 52.8 | 1.9 |
| 1940 | 434 | 1087 | 3 | 3.7 | 27.1 | 1976 | 652 | 604 | 39 | 54.2 | 1.8 |
| 1941 | 519 | 1068 | 4 | 5.1 | 19.7 | 1977 | 616 | 603 | 40 | 55.6 | 1.8 |
| 1942 | 603 | 1012 | 5 | 6.5 | 15.4 | 1978 | 812 | 600 | 41 | 57.0 | 1.8 |
| 1943 | 452 | 1000 | 6 | 7.9 | 12.7 | 1979 | 726 | 594 | 42 | 58.4 | 1.7 |
| 1944 | 459 | 931 | 7 | 9.3 | 10.8 | 1980 | 528 | 581 | 43 | 59.8 | 1.7 |
| 1945 | 420 | 911 | 8 | 10.7 | 9.3 | 1981 | 467 | 575 | 44 | 61.2 | 1.6 |
| 1946 | 515 | 897 | 9 | 12.1 | 8.3 | 1982 | 763 | 559 | 45 | 62.6 | 1.6 |
| 1947 | 697 | 859 | 10 | 13.5 | 7.4 | 1983 | 555 | 555 | 46 | 64.0 | 1.6 |
| 1948 | 575 | 841 | 11 | 14.9 | 6.7 | 1984 | 535 | 555 | 47 | 65.4 | 1.5 |
| 1949 | 473 | 821 | 12 | 16.3 | 6.1 | 1985 | 581 | 552 | 48 | 66.8 | 1.5 |
| 1950 | 327 | 812 | 13 | 17.7 | 5.6 | 1986 | 694 | 535 | 49 | 68.2 | 1.5 |
| 1951 | 1068 | 806 | 14 | 19.1 | 5.2 | 1987 | 638 | 528 | 50 | 69.6 | 1.4 |
| 1952 | 600 | 806 | 15 | 20.5 | 4.9 | 1988 | 717 | 519 | 51 | 71.1 | 1.4 |
| 1953 | 654 | 763 | 16 | 21.9 | 4.6 | 1989 | 897 | 515 | 52 | 72.5 | 1.4 |
| 1954 | 512 | 726 | 17 | 23.3 | 4.3 | 1990 | 1087 | 512 | 53 | 73.9 | 1.4 |
| 1955 | 594 | 717 | 18 | 24.7 | 4.0 | 1991 | 669 | 512 | 54 | 75.3 | 1.3 |
| 1956 | 712 | 712 | 19 | 26.1 | 3.8 | 1992 | 841 | 498 | 55 | 76.7 | 1.3 |
| 1957 | 651 | 707 | 20 | 27.5 | 3.6 | 1993 | 821 | 495 | 56 | 78.1 | 1.3 |
| 1958 | 651 | 697 | 21 | 28.9 | 3.5 | 1994 | 931 | 490 | 57 | 79.5 | 1.3 |
| 1959 | 632 | 694 | 22 | 30.4 | 3.3 | 1995 | 666 | 484 | 58 | 80.9 | 1.2 |
| 1960 | 604 | 689 | 23 | 31.8 | 3.1 | 1996 | 512 | 478 | 59 | 82.3 | 1.2 |
| 1961 | 1293 | 669 | 24 | 33.2 | 3.0 | 1997 | 1012 | 475 | 60 | 83.7 | 1.2 |
| 1962 | 806 | 666 | 25 | 34.6 | 2.9 | 1998 | 651 | 473 | 61 | 85.1 | 1.2 |
| 1963 | 859 | 658 | 26 | 36.0 | 2.8 | 1999 | 552 | 467 | 62 | 86.5 | 1.2 |
| 1964 | 610 | 654 | 27 | 37.4 | 2.7 | 2000 | 370 | 459 | 63 | 87.9 | 1.1 |
| 1965 | 383 | 652 | 28 | 38.8 | 2.6 | 2001 | 490 | 452 | 64 | 89.3 | 1.1 |
| 1966 | 689 | 651 | 29 | 40.2 | 2.5 | 2002 | 806 | 437 | 65 | 90.7 | 1.1 |
| 1967 | 555 | 651 | 30 | 41.6 | 2.4 | 2003 | 707 | 434 | 66 | 92.1 | 1.1 |
| 1968 | 1243 | 651 | 31 | 43.0 | 2.3 | 2004 | 658 | 425 | 67 | 93.5 | 1.1 |
| 1969 | 911 | 651 | 32 | 44.4 | 2.3 | 2005 | 437 | 420 | 68 | 94.9 | 1.1 |
| 1970 | 624 | 651 | 33 | 45.8 | 2.2 | 2006 | 1000 | 383 | 69 | 96.3 | 1.0 |
| 1971 | 651 | 638 | 34 | 47.2 | 2.1 | 2007 | 559 | 370 | 70 | 97.7 | 1.0 |
| 1972 | 651 | 632 | 35 | 48.6 | 2.1 | 2008 | 484 | 327 | 71 | 99.1 | 1.0 |
| 1973 | 475 | 624 | 36 | 50.0 | 2.0 | | | | | | |

*Step 3:* Calculate and plot the ranked observations against the corresponding probabilities. Finally, a curve is fitted to the plotted observations in such a way that the distance of observations above or below the curve should be as close as possible to the curve (Figure 4). From this curve (which is in fact a straight line) it is

now possible to obtain the probability of occurrence or exceedance of a rainfall value of a specific magnitude. For example it precisely predicts a rainfall value of 552 mm at probability of 67%. But the model predicts slightly higher value of rainfall (than observed data of 669 mm) at probability of occurrence or exceedence of 33%. This poor performance of the model at this probability level could be attributed to exceptionally high rainfall amounts of the years 1938 and 1939 which have significant role in increasing the slope of the line. The model also helps to obtain the magnitude of the rain corresponding to a given probability.

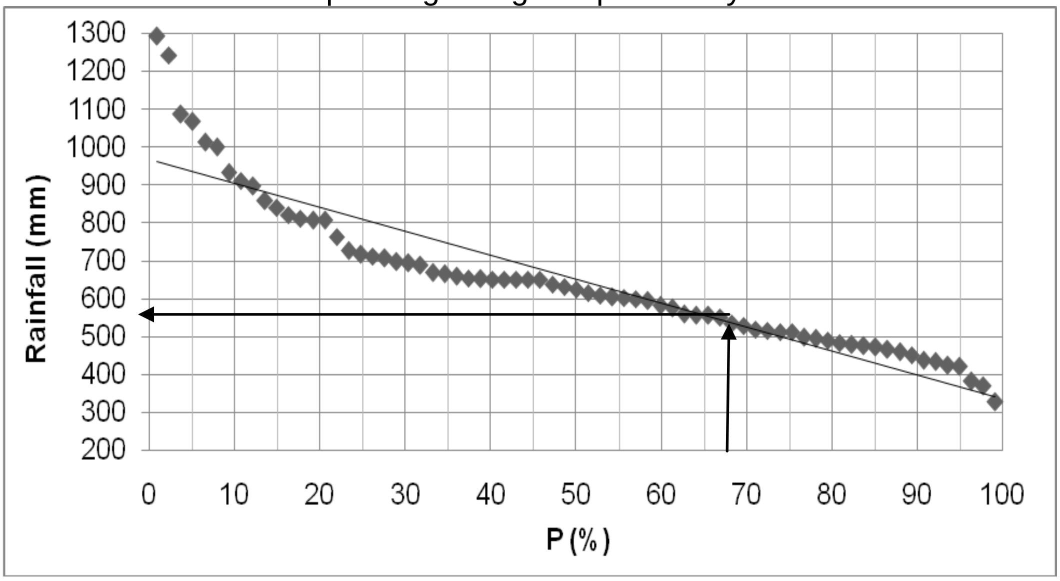


Figure 4**.** Observed rainfall data against probability of occurrence.

For a water harvesting planner, the most important task is to select the appropriate design rainfall according to which the ration of catchment to cultivated area will be determined. The **design rainfall** is defined as the total amount of rain during the season at which or above which, the catchment area will provide sufficient runoff to satisfy the crop water requirements (or the storage requirements of the water pan). If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may damage the structures, unless otherwise regulated. Note that a conservative design would be based on a higher probability (which means a lower design rainfall), in order to make the system more "reliable" and thus to meet the crop water requirements more frequently. However, the associated risk of flooding of the system would be more frequent in years where rainfall exceeds the design rainfall.

The design rainfall is usually assigned to a certain probability of occurrence or exceedance and determined by means of a statistical probability analysis. In the above example, the annual rainfall with a probability level of 67% of exceedance is 552 mm. In the other words in 67% of time (2 years out of 3) annual rain of 552 mm would be equalled or exceeded. If, for example, the design rainfall with a 67% probability of exceedance is selected, this means that on average this value will be reached or exceeded in two years out of three and therefore the crop water requirements would also be met in two years out of three.

In other words, if rainfall of 552 mm were a seasonal rainfall amount of Isiolo for October to December or March to May during which specific crop type (e.g. maize) is to be grown then this amount is considered to be design rainfall for this crop type. This design rainfall is then compared with the approximate values of a seasonal crop water requirement value of this crop (500-800 mm, see Table 2). This shows that Figure 4 should have been sketched based on the seasonal rainfall values of Isiolo or any other station of interest when WH system is to be designed for seasonal crop production. But this is not usually done; very often people analyse an annual average rainfall amount and select design rainfall at a probability level of 67% of occurrence or exceedance.

The return period T (in years) can easily be derived once the exceedance probability P (%) is known from the equations.

$$T = \frac{100}{P} (\text{years})$$

From the above examples the return period for the 67% and the 33% exceedance probability events would thus be:

$$T_{67\%} = \frac{100}{67} = 1.5 (\text{years})$$

i.e. on average an annual rainfall of 552 mm or higher can be expected in 2 years out of 3;

$$T_{33\%} = \frac{100}{33} = 3 (\text{years})$$

respectively i.e. on average an annual rainfall of 669 mm or more can only be expected in 1 year out of 3.

### 4.2 Runoff Coefficient

This is the proportion of rainfall which flows along the ground as surface runoff. It depends amongst other factors on the degree of slope, soil type, vegetation cover, antecedent soil moisture, rainfall intensity and duration.

**Soil type and antecedent soil moisture:** The infiltration capacity is among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have considerable smaller infiltration capacities. The infiltration capacity depends furthermore on the moisture content prevailing in a soil at the onset of a rainstorm.

In a high intensity storm the kinetic energy of raindrops causes a breakdown of the soil aggregate as well as soil dispersion with the consequence of driving fine soil particles into the pore spaces and hence results in clogging of the pores. This effect is often referred to as capping, crusting or sealing and causes increased rate of surface runoff even when the rainfall duration is short and the rainfall depth is comparatively small. Soils with a high clay or loam content are the most sensitive for forming a cap with subsequently lower infiltration capacities. On coarse, sandy soils the capping effect is comparatively small.

**Vegetation:** An area densely covered with vegetation, yields less runoff than bare ground. The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. A dense vegetation cover shields the soil from the raindrop impact and reduces the crusting effect as described earlier. In addition, the root system and organic matter in the soil increase the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving the water more time to infiltrate and to evaporate.

**Slope and catchment size:** Steep slope plots yield more runoff than those with gentle slopes. However, the quantity of runoff generally decreases with increasing slope length. This is mainly due to lower flow velocities and subsequently a longer time of concentration. This means that the water is exposed for a longer duration to infiltration and evaporation before it reaches the catchment outlet.

Apart from the above-mentioned site-specific factors which strongly influence the rainfall-runoff process, it should also be considered that the physical conditions of a catchment area are not homogenous. Even at the micro level there are a variety of different slopes, soil types, vegetation covers, etc. Each catchment has therefore its own runoff response and will respond differently to different rainstorm events. For this reason the use of runoff coefficients which have been derived for catchments in other geographical locations should be avoided for the design of a water harvesting scheme. Also runoff coefficients for large catchments should not be applied to small catchment areas.

Therefore, the **runoff coefficient** from an individual rainstorm is defined as runoff divided by the corresponding rainfall both expressed as depth over catchment area (mm):

$$K = \frac{\text{Runoff [mm]}}{\text{Rainfall [mm]}}$$

For larger construction programme (such as dam) actual measurements should be carried out until a representative range is obtained, usually at least 2 years. A much better relationship would be obtained if in addition to rainfall depth the corresponding rainstorm intensity, the rainstorm duration and the antecedent soil moisture were also measured. This would allow rainstorm events to be grouped according to their average intensity and their antecedent soil moisture and to plot the runoff coefficients against the relevant rainfall durations separately for different intensities. Rainfall intensities can be accurately measured by means autographic rain gauge. It is also possible to time the length of individual rainstorms and to calculate the average intensities by dividing the measured rainfall depths by the corresponding duration of the storms.

Estimating the value of the runoff coefficient presents one of the greatest difficulties and is a major source of uncertainty in many water resources projects. In any water resources design, the values of the runoff coefficient are taken from tables of possible values depending on the description of the area. The main concern in selecting these values is that they are chosen rather subjectively in a vague manner and largely reflect personal judgement rather than hard data. Yet, field technicians are advised to make their own judgement and experience and select runoff coefficient values as presented in Table 6.

Table 6. Runoff coefficient values at a given topography (or slope steepness), land use (or vegetation cover) and soil texture.

| Topography & vegetation | | Soil texture | | |
|---|---|---|---|---|
| | | Sandy loam | Clay & silt loam | Tight clay |
| Woodland | Flat (<5% slope) | 0.10 | 0.30 | 0.40 |
| | Rolling (5-10% slope) | 0.25 | 0.35 | 0.50 |
| | Hilly (10-30% slope) | 0.30 | 0.50 | 0.60 |
| Pasture | Flat (<5% slope) | 0.10 | 0.3 | 0.40 |
| | Rolling (5-10% slope) | 0.16 | 0.36 | 0.55 |
| | Hilly (10-30% slope) | 0.22 | 0.42 | 0.60 |
| Cultivated | Flat (<5% slope) | 0.30 | 0.50 | 0.60 |
| | Rolling (5-10% slope) | 0.4 | 0.60 | 0.70 |
| | Hilly (10-30% slope) | 0.52 | 0.72 | 0.82 |
| Urban areas | | 30% of area impervious | 50% of area impervious | 70% of area impervious |
| | Flat (<5% slope) | 0.40 | 0.55 | 0.65 |
| | Rolling (5-10% slope) | 0.50 | 0.65 | 0.80 |

### 4.3 Efficiency factor

The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment, i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency. This factor takes into account the inefficiency of uneven distribution of the water within the field as well as losses due to evaporation and deep percolation. Where the cultivated area is levelled and smooth the efficiency is higher. Micro-catchment systems have higher efficiencies as water is usually less deeply ponded. Selection of the factor is left to the discretion of the designer based on his experience and of the actual technique selected. Normally the factor ranges between 0.5 and 0.75.

## 5. Design model for catchment: cultivated area ratio

Water harvesting is based on the utilisation of surface runoff; therefore it requires runoff producing and runoff receiving areas. In most cases, with the exception of floodwater harvesting from far away catchments, water harvesting utilizes the rainfall from the same location or region.

Water harvesting projects are generally local and small scale projects. Each WH system consists of a catchment (collection) and a cultivated (concentration) area. The relationship between the two, in terms of size, determines by what factor the rainfall will be "multiplied". For an appropriate design of a system, it is recommended to determine the ratio between catchment (C) and cultivated area (CA). Many successful water harvesting systems have been established by merely estimating the ratio between C and CA. This may indeed be the only possible approach where basic data such as rainfall, runoff and crop water requirements are not known. It should be noted that calculations are always based on parameters with high variability. Rainfall and runoff are characteristically erratic in regions where WH is practised. It is, therefore, sometimes necessary to modify an original design in the light of experience, and often it will be useful to incorporate safety measures, such as cut-off drains or diversion ditches, to avoid damage in years when rainfall exceeds the design rainfall. The calculation of C:CA ratio is useful for WH systems where crops and trees are intended to be grown.

The calculation of the catchment: cultivated area ratio is based on the concept that the design must comply with the rule: **Water harvested = Extra water required**

The amount of water harvested from the catchment area is a function of the amount of runoff created by the rainfall on the area. This runoff, for a defined time scale, is calculated by multiplying a "design" rainfall with a runoff coefficient. As not all runoff can be efficiently utilized (because of deep percolation losses, etc.) it must be additionally multiplied with an efficiency factor.

**Water harvested = catchment area x design rainfall x runoff coefficient x efficiency factor**

The amount of water required is obtained by multiplying the size of the cultivated area with the net crop water requirements which is the total water requirement less the assumed "design" rainfall.

**Extra water required = Cultivated area x (Crop water requirement - Design rainfall)**

By substitution in our original equation: **Water harvested = Extra water required**
We obtain:

**Catchment area x design rainfall x runoff coefficient x efficiency factor = cultivated area x (crop water requirement - design rainfall)**

If this formula is rearranged we finally obtain:

$$\frac{C}{CA} = \frac{CWA - P}{P * Cr * Ef}$$

Where: C/CA = Catchment to cultivated area ratio (dimensionless)
CWA = Crop water requirement (mm)
P = Design rainfall (in mm at Probability of 67%)
Cr = Runoff coefficient (assumed at 0.25 for long catchment with low slopes when data on slope , soil type, vegetation cover, antecedent moisture, design rainfall and duration are lacking)
Ef = Efficiency factor (taken as 0.5 for long slopes)

## 5.1 Examples on how to calculate the ratio C: Ca

### 5.1.1 System for crops

**Example 1.**

- Climate: Arid
  RWH System: External Catchment (e.g. trapezoidal bunds)
- Crop Millet:

- Crop Water Requirement for Millet (total growing season) = 475 mm (low because rapid maturity)
- Design Rainfall (growing season) = 250 mm (at a probability level of P = 67%)
- Runoff Coefficient (seasonal) = 0.25 (low due to relatively long catchment and low slope)
- Efficiency Factor = 0.5 (general estimate for long slope technique)

$$\frac{C}{CA} = \frac{475 - 250}{250 \times 0.25 \times 0.5} = 7.2$$

i.e.: The catchment area must be 7.2 times larger than the cultivated area (in other words, the catchment: cultivated area ratio is 7.2:1)
Comment: The ratio is high, but the system is designed for a dry area with a low runoff coefficient assumed.

**Example 2.**

- Climate: Semi-Arid
  RWH System: External Catchment (e.g. trapezoidal bunds)
- Crop: 110 day Sorghum
- Crop Water Requirement = 525 mm
- Design Rainfall = 375 mm (P = 67%)
- Runoff Coefficient = 0.25
- Efficiency Factor = 0.5

$$\frac{C}{CA} = \frac{525 - 375}{375 \times 0.25 \times 0.5} = 3.2$$

i.e: The catchment area must be 3.2 times larger than the cultivated area. In other words, the catchment: cultivated area ratio is 3.2:1.
Comment: A ratio of approximately 3:1 is common and widely appropriate.

**Example 3.**

- Climate: Semi-Arid
  RWH System: Micro-catchment (e.g. contour ridges)
- Crop: 110 day Sorghum
- Crop Water Requirement = 525 mm
- Design Rainfall = 310 mm (set at a probability level of P = 75% to give more reliability)
- Runoff Coefficient = 0.5 (reflecting the high proportion of runoff from very short catchments)
- Efficiency Factor = 0.75 (reflecting the greater efficiency of short slope catchments)

$$\frac{C}{CA} = \frac{525 - 310}{310 \times 0.75 \times 0.5} = 1.85$$

i.e. The catchment area must be approximately twice as large as the cultivated area.

Comment: Ratios are always lower for micro-catchment systems due to a higher efficiency of water use and a higher runoff coefficient. Using a design rainfall of 67% probability (i.e. a less reliable system) would have even reduced the ratio to 1:1.

### 5.1.2 Systems for trees

The ratio between catchment and cultivated area is difficult to determine for systems where trees are intended to be grown. Hence, only rough estimates are available for the water requirements of the tree species commonly planted in WH systems. Furthermore, trees are almost exclusively grown in micro-catchment systems where it is difficult to determine which proportion of the total area is actually exploited by the root zone bearing in mind the different stages of root development over the years before a seedling has grown into a mature tree (Figure 5, a and b).

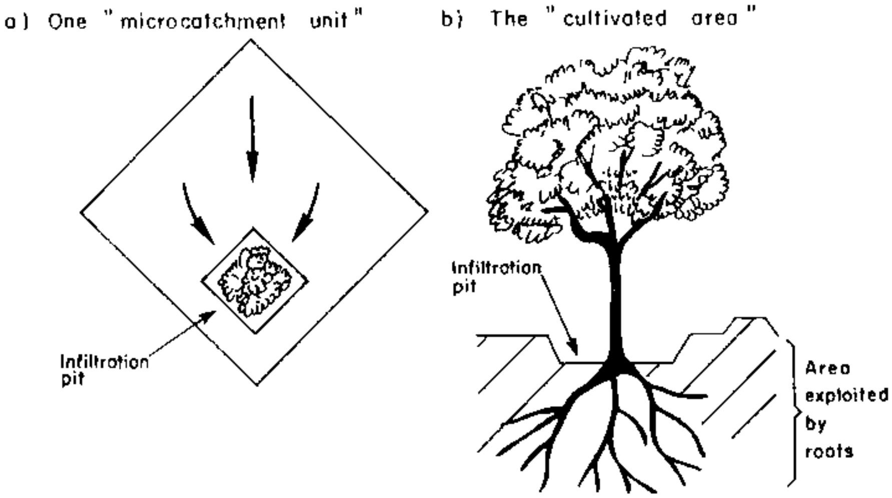


Figure 5. Micro-catchment system (*Negarim* micro-catchment) for trees.

In view of the above, it is therefore considered sufficient to estimate only the total size of the micro-catchment (MC), that is the catchment and cultivated area (infiltration pit) together, for which the following formula can be used:

$$MC = RA * \frac{WR - DR}{DR * K * EFF}$$

Where: MC = total size of micro-catchment ($m^2$)
RA = area exploited by root system ($m^2$)
WR = water requirement (annual) (mm)
DR = design rainfall (annual) (mm)
K = runoff coefficient (annual)
EFF = efficiency factor

As a rule of thumb, it can be assumed that the area to be exploited by the root system is equal to the area of the canopy of the tree.

**Example:**

- Semi-arid area, fruit tree grown in *Negarim* micro-catchment
- Annual water requirement (WR) = 1000 mm
- Annual design rainfall (DR) = 350 mm
- Canopy of mature tree (RA) = 10 $m^2$
- Runoff coefficient (K) = 0.5
- Efficiency factor (EFF) = 0.5

Total size of micro-catchment (MC) $= 10 * \frac{1000-350}{350 * 0.5 * 0.5}$ = **74 $m^2$**

As a rule of thumb, for multipurpose trees in the arid/semi-arid areas, the size of the micro-catchment per tree (catchment and cultivated area together) should range between 10 and 100 m$^2$, depending on the aridity of the area and the species grown. Flexibility can be introduced by planting more than one tree seedling within the system and removing surplus seedlings at a later stage if necessary.

## 6. Categories of rainwater harvesting technologies

Rainwater harvesting technologies can be categorised in to 3 groups based on their function and catchment length. They can also be grouped in to 3 classes based utilization systems. Both scenarios are briefly presented as follows:

### 6.1 RHM technologies based on function and catchment length

**a) Micro-catchments rainwater harvesting** sometimes referred to as "within-field catchment system"

**Main characteristics:**

- overland flow harvested from short catchment length
- catchment length usually between 1 and 30 metres
- runoff stored in soil profile
- ratio catchment: cultivated area usually 1:1 to 3:1
- normally no provision for overflow
- plant growth is even.

**Example:** *Negarim* and contour bunds (both for trees), contour ridges (for crops) and semi-circular bunds (for range and fodder)

**b) External catchment systems rainwater harvesting -** long slope catchment technique

**Main characteristics:**

- overland flow or rill flow harvested
- runoff stored in soil profile
- catchment usually 30 - 200 metres in length
- ratio catchment: cultivated area usually 2:1 to 10:1
- provision for overflow of excess water
- uneven plant growth unless land levelled.

**Typical examples:** trapezoidal bunds and contour stone bunds (both for crops)

**c) Floodwater farming (floodwater harvesting)** often referred to as "water spreading" and sometimes "spate irrigation"

**Main characteristics:**

- turbulent channel flow harvested either (a) by diversion or (b) by spreading within channel bed/valley floor
- runoff stored in soil profile
- catchment long (may be several kilometres)
- ratio catchment: cultivated area above 10:1
- provision for overflow of excess water

**Example:** permeable rock dams and water spreading bunds (both for crops).

### 6.2 RHM technologies based on utilization type

**Crop production systems:** These are either water harvesting or water conservation systems that capture runoff water that is stored in reservoirs for later use, or direct rainfall for *in situ* soil moisture conservation. Technologies that benefit from direct runoff and that are either used for supplementary or full irrigation include earth dams, pans, trapezoidal bunds, semi-circular bunds, etc.

**Livestock production systems:** These are systems that make use of runoff or underground water for livestock production. Runoff water is collected and stored in natural depressions or man-made reservoirs such as pans and dams. Quite often, the stored water is shared for crop production and domestic use. Areas with shallow groundwater also abstract water for animal use.

**Domestic water harvesting and conservation systems:** Domestic water harvesting and conservation systems harness either direct rainwater or ground water. From roof or rock catchments rainwater is collected and later stored in concrete water tanks. Rainwater is also conserved in sandy river beds in areas with sufficient rainfall also conserve rainwater. Water for domestic use can also be drawn from shallow wells and springs.

## 7. Rainwater harvesting and management technologies

A wide variety of water harvesting techniques for many different applications are known. But we chose the ones we believe are suitable to ASAL condition and describe them in detail and recommend standard specification. Lists of worknorm elements and approximate (interim) values are also given for some technologies. Moreover, worknorms developed for different activities (irrigation, soil and water conservation, reforestation, etc) in Kenya are given in Appendix 2.

### 7.1 Semi-circular bunds

Semi-circular bunds are earth embankments in the shape of a semi-circle with the tips of the bunds on the contour. They are used in varying dimensions for mainly rangeland rehabilitation or fodder production and growing trees and shrubs. In some cases they have been used for growing crops. The characteristics of the catchment area for them were medium slopes; permeable soils covered with stones; and low bush vegetation. Depending on the location, and the chosen catchment: cultivated area ratio, it may be a short slope or long slope catchment technique. Semi-circular bunds are recommended as a quick and easy method of improving rangelands in ASAL. They are more efficient in terms of impounded area to bund volume than other equivalent structures - such as trapezoidal bunds for example.

Semi-circular bunds for rangeland improvement and fodder production can be used under the following conditions:

- Rainfall: 200 -750 mm: from arid to semi-arid areas.
- Soils: all soils which are not too shallow or saline.
- Slopes: up to 2%, but with modified bund designs up to 5%.
- Topography: even topography required.

Even though semi-circular bunds can be designed to a variety of dimensions (e.g. small structures closely spaced or larger structures wider spaced), one specific design (larger structures wider spaced) is explained in this Chapter because it is more suitable for drier areas, and does not need such even topography.

**Overall configuration:** The large and wide spaced bund has bunds with radii of 20 m and can accommodate limited runoff from external source. Bunds are constructed in staggered lines with runoff producing catchments between structures (Figure 6).

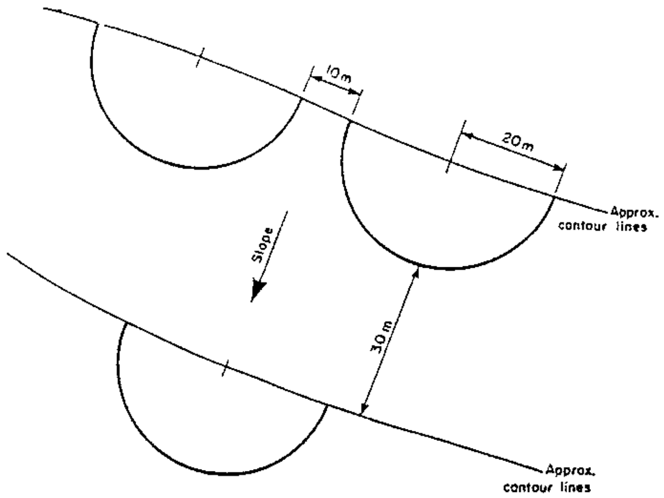


Figure 6: Field layout of 20 m radius semi-circular bund.

**Catchment: Cultivated area** (C:CA) ratios of up to 3:1 are generally recommended. A detailed calculation is not required. The reasons for applying low ratios are that already adapted rangeland and fodder plants in ASAL need only a small amount of extra moisture to respond significantly with higher yields. Larger ratios would require bigger and more expensive structures, with a higher risk of breaching.

This structure can have a C:CA ratio of 3:1 to 5:1 and  be implemented on slope up to 2%. For higher slopes, smaller radii are required. For example, on a slope of 4%, the radius should be reduced to 10 m and the distance between two adjacent rows from 15 m to 30 m while the tips of two adjacent structures should be 5 m apart instead of 10 m. The number of structures required for one hectare would thus increase to 16 which maintains the C:CA ratio of 3:1.

The cross-section of the bund changes over its length. At the wing tip, the bund is only 10 cm high, but the height increases towards the middle of the base to 50 cm with side slopes of 3:1 (horizontal: vertical), and a top width of 10 cm. Corresponding base widths are 70 cm and 3.10 m, respectively. Due to the larger dimensions of the bunds there are only 4 structures required per hectare. The distance between the tips of two adjacent structures in one row is 10 m while 30 m are recommended between the base of the upper structure and the tips of the lower one (Figure 7).

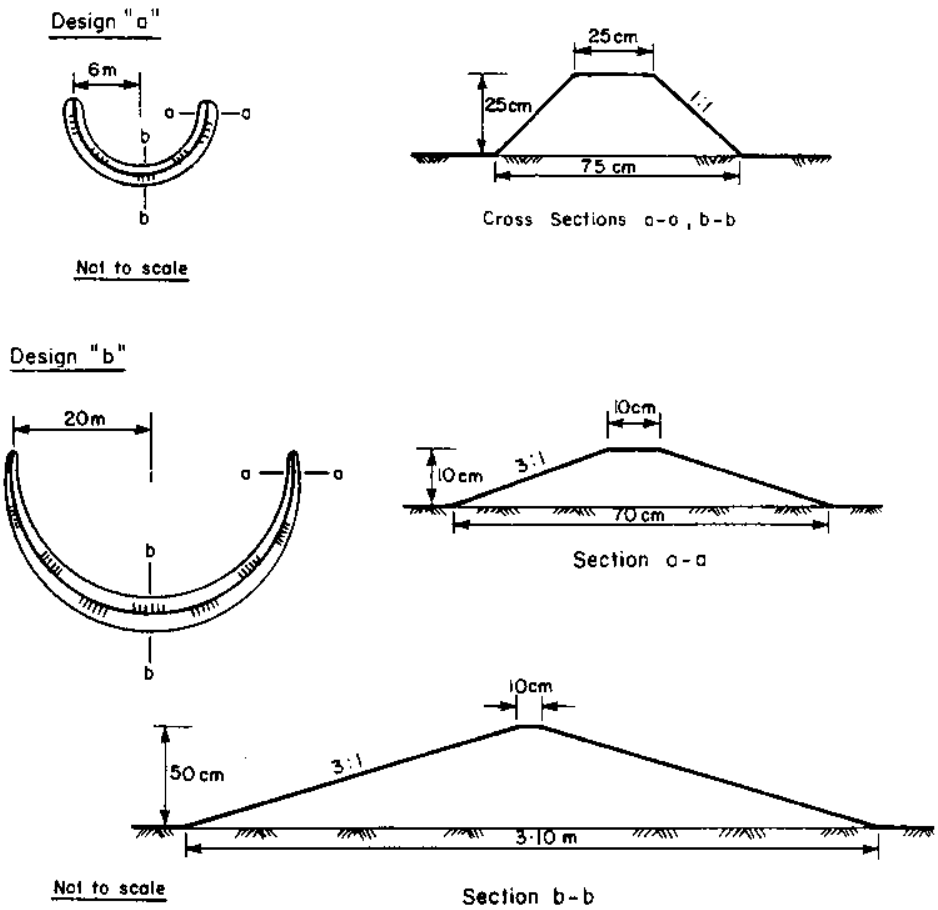


Figure 7. Semi-circular bund dimensions.

**Quantities of earthworks:** Table 7 gives quantities of earthworks required for different layouts. Semi-circular bunds can be constructed in a variety of sizes, with a range of both radii and bund dimensions. Small radii are common when semi-circular bunds are used for tree growing and production of crops. A recommended radius for these smaller structures is 2 to 3 m, with bunds of about 25 cm in height.

Table 7. Quantities of earthworks for semi-circular bunds

| Land slope (%) | Radius (m) | Length of bund (m) | Impounded area per bund ($m^2$) | Earthworks per bund ($m^3$) | Bunds per ha | *Earthworks per ha ($m^3$)* |
|---|---|---|---|---|---|---|
| ≤ 2 | 20 | 63 | 630 | 26.4 | 4 | *105* |
| 3-4 | 10 | 31 | 160 | 13.2 | 16 | *210* |

**Layout & construction:** Layout for both designs is similar, only dimensions differ.

*Step 1:* The first contour, at the top of the scheme, is staked out using a simple surveying instrument (e.g. line level) as described in Appendix 1. This line need not be smooth.

*Step 2:* A tape measure is now used to mark the tips of the semi-circular bunds on the contour. The tips are 40 m apart and the distance to the next structure is 10 m.

*Step 3:* The centre point between the tips of each semi-circular unit is marked. A piece of string as long as the selected radius is now fixed at the centre point by means of a peg. Holding the string tight at the other end, the alignment of the semi-circle is defined by swinging the end of the string from one tip to the other. The alignment can be marked by pegs or small stones (see Figure 8).

*Step 4:* Staking out and construction of the semi-circular bunds in the second and all following rows will be carried out in the same way. It is important that the structures in each row are staggered in relation to structures in the row above. The centre points of the bunds, for example, in the second row should coincide with the middle of the gaps between bunds in the first row and so forth. It must be ensured that the space between bunds from one row to another is according to the chosen distance, in this case 30 m.

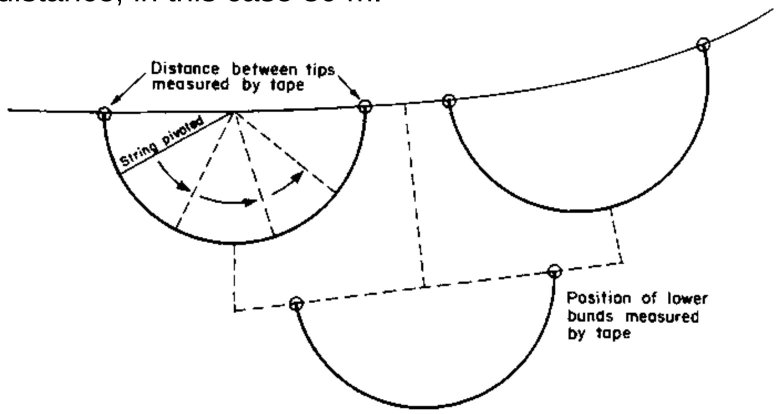


Figure 8. Layout technique

*Step 5:* After setting out, bund construction is started with excavation of a small trench inside the bund. Further excavation should always be from inside the bund, as evenly as possible. This will increase the storage capacity of the semi-circular bund. The bund should be constructed in layers of 10-15 cm with each layer being compacted and wetted first if possible.

*Step 6:* The bund tips are protected with a layer of stones, as shown in Figure 9. This will ensure that the bund tips are more resistant to erosion when excess water discharges around them. A diversion ditch above the first row of structures may be necessary to protect the first row of bunds against runoff coming from the catchment area above. In that case diversion ditches should be 1.0-1.5 m wide and 50 cm deep, with a gradient of 0.25%.

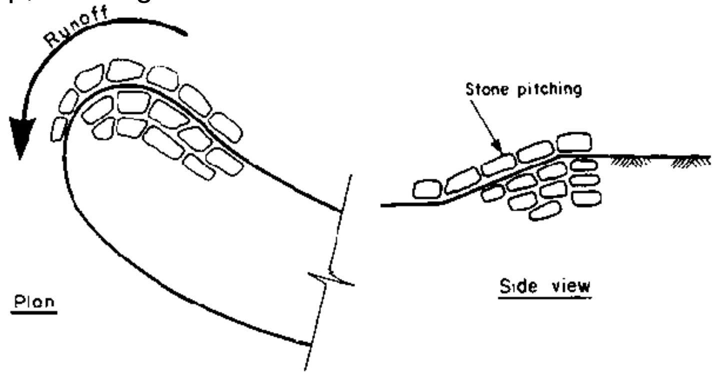


Figure 9. Protection of wingtips.

**Husbandry:** It may be possible to allow the already existing vegetation to develop - provided it consists of desirable species or perennial rootstocks. In some cases, however, it will be more appropriate to re-seed with seed from outside. Local collection of perennial grass seed from useful species can be appropriate provided the seed is taken from "virgin land". Together with grass, trees and shrub seedlings may be planted within the bunds. Note that it may be difficult to motivate the population to invest voluntarily, in the time and effort required for implementing and maintaining such a water harvesting system. Even when this is possible, it is important to introduce an appropriate and acceptable range management programme to avoid over-grazing and subsequent degradation of the range. Controlled grazing is also essential to maintain good quality rangeland, and the bunded area must be rested periodically for it to regenerate, so that natural reseeding can take place.

**Maintenance:** As with all earthen structures, the most critical period for semi-circular bunds is when rainstorms occur just after construction, since at this time the bunds are not yet fully consolidated. Any breakages must be repaired immediately. If damage occurs, it is recommended that a diversion ditch is provided if not already constructed. Structures that are used for fodder production normally need repairs of initial breaches only. This is because in the course of time, a dense network of the perennial grasses will protect the bunds against erosion and damage. The situation is different if animals have access into the bunded area and are allowed to graze. In this case, regular inspections and repair will be necessary.

WFP has subcontracted Appropriate Development Consults Ltd (ADCL) to demonstrate semi-circular bunds for forage production in Chumvi Yare, Isiolo district beginning of 2009. The runoff factor for the field was estimated to be 0.3. The C:CA ratio for annual grass requiring 350 mm per annum was 4:1. Based on this calculation the cultivated area used for grass production was 160 $m^2$ and catchment area also called runoff area was estimated at 600 $m^2$. The length of catchment area feeding into a 20 m diameter semi-circular hoop was 30 m (Figure 10). The distance from tip of one semi-circular bund to the next was 10 m. There wasn’t any diversion ditch constructed to protect the first row of bunds against runoff coming from the catchment area above. The performance of the structure was not possible report due to poor rainfall distribution in the area following construction of the structure.

Figure 10. Semi-circular bund constructed in Chumvi Yare, Isiolo district of Kenya.

## 7.2 Trapezoidal bunds

Trapezoidal bunds are used to enclose larger areas (up to 1 ha) and to impound larger quantities of runoff which is harvested from an external or "long slope" catchment. The name is derived from the layout of the structure which has the form of a trapezoid - a base bund connected to two side bunds or wingwalls which extend upslope at an angle of usually 135 degrees. Crops are planted within the enclosed area. Overflow discharges around the tips of the wingwalls.

The general layout, consisting of a base bund connected to wingwalls is a common traditional technique. The three sides of a plot are enclosed by bunds while the fourth (upslope) side is left open to allow runoff to enter the field. The simplicity of design and construction and the minimum maintenance required are the main advantages of this technique. The design and layout of a typical trapezoidal bund is presented as follows:

Trapezoidal bunds can be used for growing crops, trees and grass. Their most common application is for crop production under the following site conditions:

- Rainfall: 250-500 mm; arid to semi-arid areas.
- Soils: agricultural soils with good constructional properties i.e. significant (non-cracking) clay content.
- Slopes: from 0.25% - 1.5%, but most suitable below 0.5%.
- Topography: area within bunds should be even. Construction of trapezoidal bunds on slopes steeper than 1.5% is technically feasible, but involves large quantities of earthwork.

**Overall configuration:** Each unit of trapezoidal bunds consists of a base bund connected to two wingwalls which extend upslope at an angle of 135 degrees. The size of the enclosed area depends on the slope and can vary from 0.1 to 1 ha. Trapezoidal bunds may be constructed as single unit, or in sets. When several trapezoidal bunds are built in a set, they are arranged in a staggered configuration; units in lower lines intersect overflow from the bunds above. A common distance between the tips of adjacent bunds within one row is 20 m with 30 m spacing between the tips of the lower row and the base bunds of the upper row (see Figure 11). The planner is of course free to select other layouts to best fit into the site conditions. The staggered configuration as shown in Figure 11 should always be followed. It is not recommended to build more than two rows of trapezoidal bunds since those in a third or fourth row receive significantly less runoff.

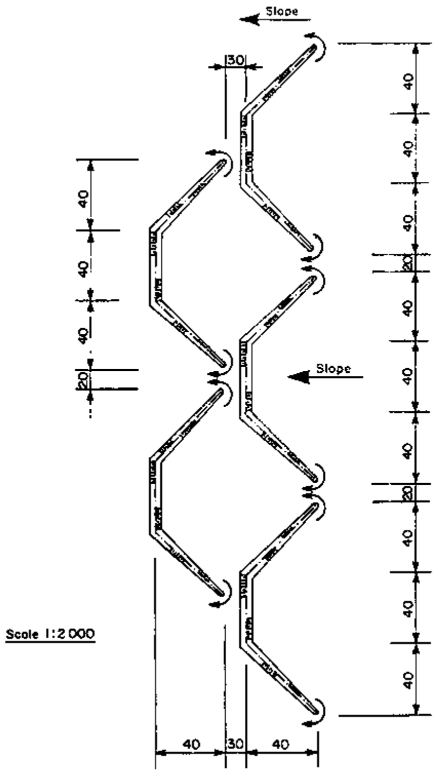


Figure 11. Trapezoidal bunds: field layout for 1% ground slope.

**Catchment: cultivated area (C:CA) ratio**: The basic methodology of determining C:CA ratio is given in Chapter 5, for the case where it is necessary to determine the necessary catchment size for a required cultivated area. It is sometimes more appropriate to approach the problem the other way round, and determine the area and number of bunds which can be cultivated from an existing catchment.

**Example:** Calculate the number of trapezoidal bunds needed to utilize the runoff from a catchment area of 20 ha under the following conditions:

| | |
|---|---|
| Slope: | 1% |
| Crop water requirement | 475 mm per season |
| Design rainfall | 250 mm per season |
| Runoff coefficient | 0.25 |
| Efficiency factor | 0.50 |

From Chapter 5: $\frac{C}{CA} = \frac{475 - 250}{250 \times 0.5 \times 0.25} = \frac{225}{31.25} = 7.2$

But C = 20 ha, Thus $CA = \frac{20}{7.2} = 2.8\text{ha}$

From Table 8 the area available for cultivation within one trapezoidal bund on a 1% slope is 3200 $m^2$ = 0.32 ha. Therefore, number of bunds required: N = 2.8/0.32 = 8

In common with all water harvesting techniques which rely on external catchments, the C:CA ratio is based on seasonal rainfall reliability in a year of relatively low rainfall. In years of high rainfall, and particularly under storm conditions resulting in excessive inflow, damage can be caused to crops and to the bunds themselves. This is particularly the case for bunds on steeper slopes and for those with high C:CA ratios. This results in recommendation of a maximum C:CA ratio of 10:1, although ratios of up to 30:1 are sometimes used.

Where the use of a large catchment is unavoidable a temporary diversion ditch of 1.0-1.5 m wide and 50 cm deep, with a gradient of 0.25% is advisable to prevent excessive inflow of runoff. Conversely, in situations where the catchment is not of adequate size, interception ditches can be excavated to lead runoff from adjacent catchments to the bunds. The configuration of the bunds is dependent upon the land slope, and is determined by the designed maximum flooded depth of 45 cm at the base bund. Consequently as the gradient becomes steeper the wingwalls extend less far upslope as is illustrated in Figure 12. The greater the slope above 0.5%, the less efficient the model becomes because of increasing earthwork requirements per cultivated hectare. Bund cross-sections are based on a 1 m crest width and 4:1 (horizontal: vertical) side slopes.

The dimensions and earthworks quantities for different slopes as practiced in the Turkana area are given in Table 8. Considerable variations are possible dependent on climatic, physical and socio-economic conditions. The optimum design for an individual set of circumstances can only be achieved by a process of trial and error.

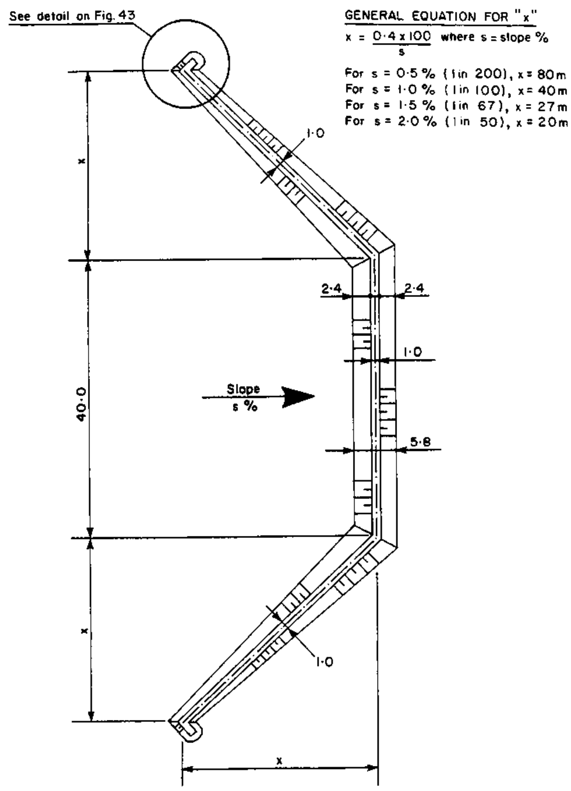


Figure 12. Trapezoidal bund dimensions**.**

Table 8. Quantities of earthworks on different slope for trapezoidal bund.

| Slope (%) | Length of base bund (m) | Length of wingwall (m) | Distance between tips (m) | Earthworks per bund ($m^3$) | Cultivated area per bund ($m^2$) | Earthworks per ha cultivated ($m^3$) |
|---|---|---|---|---|---|---|
| 0.5 | 40 | 114 | 200 | 355 | 9600 | 370 |
| 1.0 | 40 | 57 | 120 | 220 | 3200 | 670 |
| 1.5 | 40 | 38 | 94 | 175 | 1800 | 970 |

*Note:* Where diversion ditches or collection arms are required these add 62.5 $m^3$ for each 100 m length.

**Layout and construction:**

*Step 1.* When the site for the bund has been decided, the first thing to do is to establish the land slope using a line level or an Abney level. Dimensions for bunds on different slopes are given in Table 8. Having established the ground slope, the tips of the wingwalls will be determined (Figure 13). Starting at the top of the field a peg is placed which will be the tip of one of the wingwalls (point 1). The second wingwall tip (point 2) is at the same ground level at the distance obtained from Table 8. This is set out using a line level and a tape and is marked by a peg.

*Step 2.* The dimensions for staking out the four main points of the bund are shown on Figure 13. Point "a" can be established by measuring the distance "x" from Point 1 along the line joining points 1 and 2. Values for "x" (for different slopes) can be obtained from Figure 12. Similarly, Point "b" is established by measuring the distance "x" from Point 2 along the line joining points 1 and 2. Points 3 and 4, which are the points of intersection of the base bund and the wingwalls, lie a distance x downslope from points "a" and "b" respectively, measured at right angles to the line joining Point 1 and Point 2. The right angle can most easily be found by using a wooden right angle triangular template (sides: 100 cm, 60 cm and 80 cm). Points 3 and 4 are then pegged.

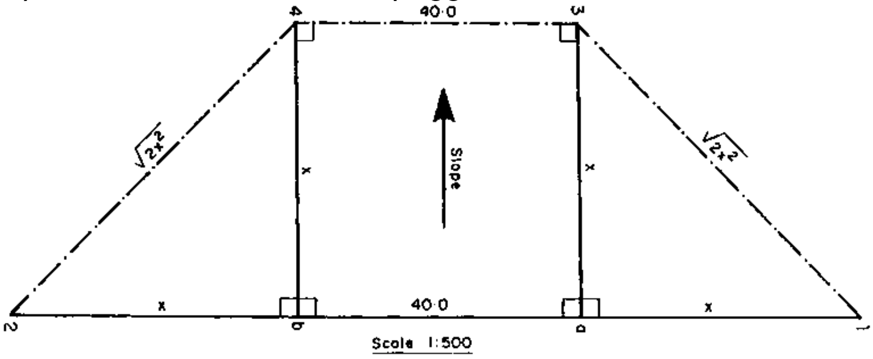


Figure 13. Trapezoidal bund: staking out of main points.

*Step 3.* The accuracy of the setting out can be checked by measuring the distances between Point 3 and Point 4, Point 3 and Point 1, and Point 2 and Point 4 which should be: Point 3 - Point 4 = 40 m; Point 1 - Point 3 = Point 2 - Point 4.

If, on checking, there is an error greater than 0.5 m in any of these three dimensions, the setting out procedure should be repeated.

*Step 4.* Having set the main points of the bunds it is necessary then to set out pegs or stones to mark the earthworks limits. Along the base bund this is done by marking parallel lines at a distance of 2.9 m from Line 3-4. For the wingbunds, the demarcation of the earthworks limits is slightly more complicated. At point 1 (2) perpendicular distances of 1.30 m either side of the wingbund centreline are measured and marked. At point 3 (4) distances of 2.90 m either side and perpendicular to the wingbunds centreline (line 1-3, 2-4) are measured and marked. It is then possible to peg out earthwork limits on both sides of the wingbunds centreline. Where more than one bund is required, the other bunds should be pegged out accordingly.

*Step 5.* Construction of a set of trapezoidal bunds must start with the row furthest upslope. Before commencing construction the soil within the foundation area of the bunds should be loosened to ensure good "mating" with the fill. The bund is constructed in two layers, each having a maximum thickness of 0.30 m. The thickness of the first layer will gradually taper off to zero as filling proceeds upslope along the wingbunds. Similarly, the thickness of the second layer will taper to 0.20 m at the tips. Each layer should be thoroughly compacted by rolling, ramming or stamping, and should be watered prior to compaction, where this is possible. Excavation to provide the necessary fill should be taken from within the bunded area, where possible, to assist in levelling the area within the bund to promote even depth of flooding. Material for fill should not be excavated adjacent to the bunds on their downslope side, as this promotes gullying and bund failure.

*Step 6.* The tips of the bunds are only 20 cm high, and excess runoff drains around them. To prevent erosion of the tips they should be shaped with a small extension or "lip" to lead water away. This lip should be pitched with stones for extra resistance to erosion. Suggested dimensions are shown in Figure 14.

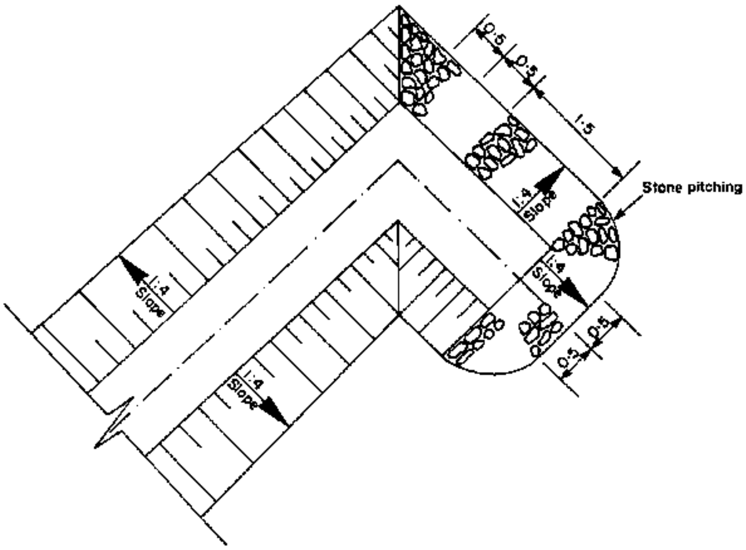


Figure 14. Trapezoidal bund: detail of tip

*Step 7.* Where the catchment is large in relation to the bunded area, it is advisable to construct a diversion ditch to prevent excessive inflow to the bunds. This ditch is usually 50 cm deep and of 1.0 to 1.5 meters width, and is usually graded at 0.25%. Soil excavated from the ditch is used to construct an embankment on the downslope side, which also assists in diverting runoff from the bunds. During the early part of the season breaches can be made in this embankment at approximately 10 meter intervals and the material used to temporarily plug the ditch, thus permitting runoff to enter the trapezoidal bunds. As shown on Figure 15, it is necessary to continue excavation of the diversion ditch some distance downslope, to allow its bed level to reach ground level. Over this length the bed width of the ditch should be gradually increased to 3 m.

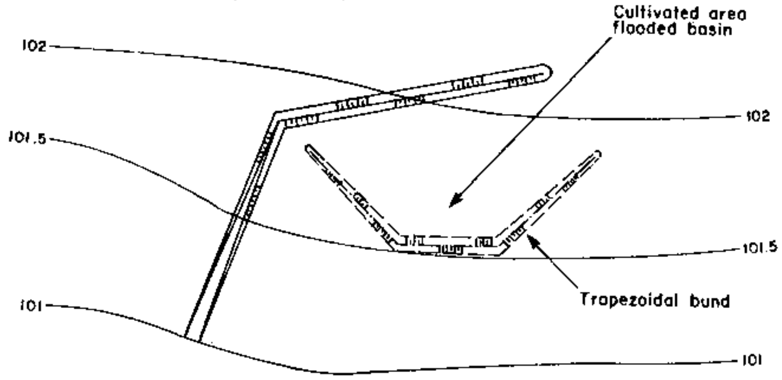


Figure 15. Trapezoidal bund: diversion ditch

*Step 8.* In situations where the catchment is not of adequate size, interception ditches can be made to lead runoff from adjacent catchments to the bunds. These are opposite in effect to diversion ditches but have similar sizes and design criteria. An example is shown in Figure 16.

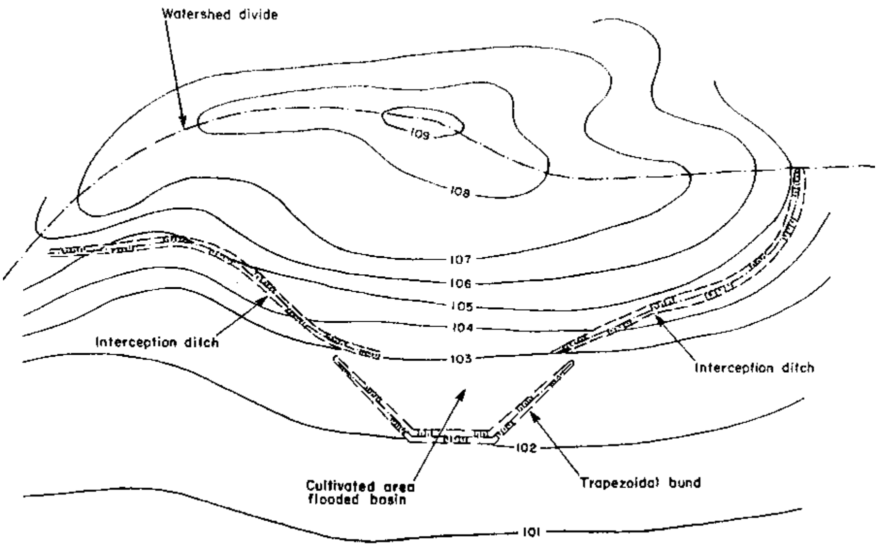

Figure 16. Interception ditch.

**Husbandry:** Trapezoidal bunds are normally used for production of annual crops such as sorghum and millet. Sorghum is particularly appropriate for such systems because it is both drought tolerant and withstands temporary waterlogging. In the trapezoidal bund, water tends to be unevenly distributed because of the slope, and ponding often occurs near the base bund. However, cowpeas, greengrams, chickpeas, watermelon and pigeon can also be grown using this structure. Planting is carried out in the normal way, after ordinary cultivation of the soil within the bund. It is usual to plough parallel to the base bund, so that the small furrows formed by ploughing will locally accumulate some water. In the driest areas planting is sometimes delayed until a runoff event has saturated the soil within the bund, and germination is guaranteed. Watermelons can be planted on the bottom bund if water ponds deeply.

**Maintenance:** The bunds should be compacted through when soils are moist. If there are breaches in the bund, these must be repaired immediately, and the earth compacted thoroughly. Breaches are often caused by poor construction, or because the catchment area is producing damaging amounts of runoff or both. Holes burrowed by rodents can be another cause of breaching. These should be filled in whenever spotted. Allowing natural vegetation to grow on the bunds leads to improved consolidation by the plant roots. Repairs to the wing tips will frequently be needed when overflow has occurred. These should be built up, and extra stone pitching provided if required.

WFP Kenya and its partners have implemented trapezoidal bunds in Isiolo, Dadaab and Tana districts end of 2008 and beginning 2009. Chumvi Yare, Wayu Boro and Wayu Duka are target areas for this activity. The criteria and dimensions used in the design of bunds in Chumvi Yare (Isiolo district) are given in Table 9 and Figure 17, respectively. Trapezoidal bunds which were implemented in 2008 at Wayu Boro have improved crop production; farmers are impressed about the result. Dadaab is expanding implementation of trapezoidal bunds based on the request from the communities.

Recommendation was given to plant sorghum and millet at downstream part of cultivated area because these crops tolerate drought and withstand temporary waterlogging problems. In the upstream part of the crop area crops such as cowpea and chickpea were planted because these crops are more susceptible temporary waterlogging problems compared to sorghum and millet (see Figure 18). Watermelons and pumpkins were planted on the bottom bunds.

Table 9. Criteria used in the design of bunds in Chumvi Yare, Isiolo district.

| | |
|---|---|
| Land slope | 1.8 degrees |
| Maximum depth of water | 0.45 m |
| Length of base bund | 25 m |
| Angle between base and side bunds | 135° |
| Maximum bund height: | 0.75 m |
| Minimum bund height (at tips): | 0.30 m |
| Base width at centre | 7.0 m |
| Base width at tip | 3.4 m |
| Earthwork | 200 person days |

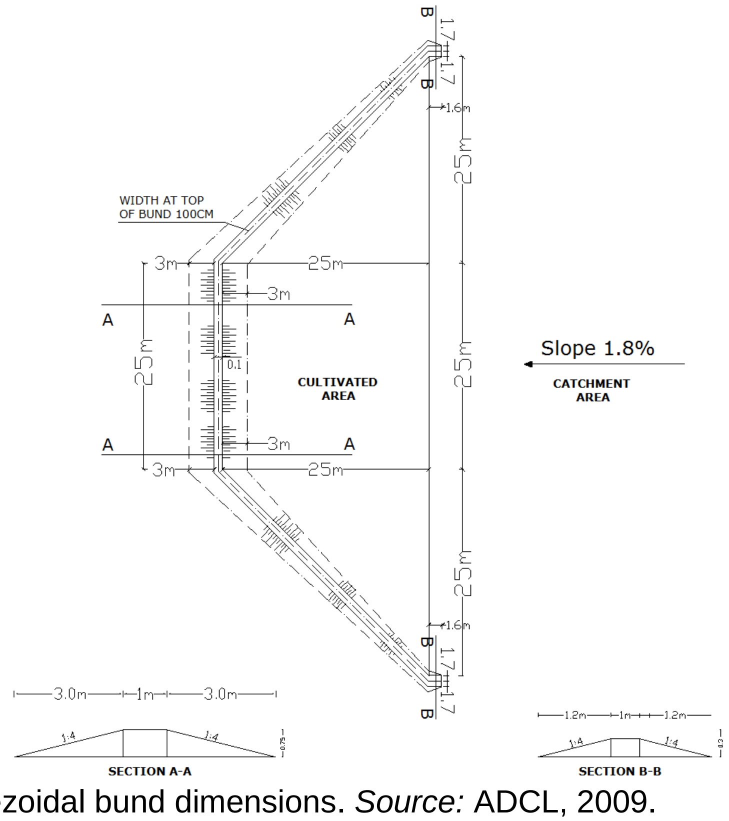


Figure 17. Trapezoidal bund dimensions. *Source:* ADCL, 2009.

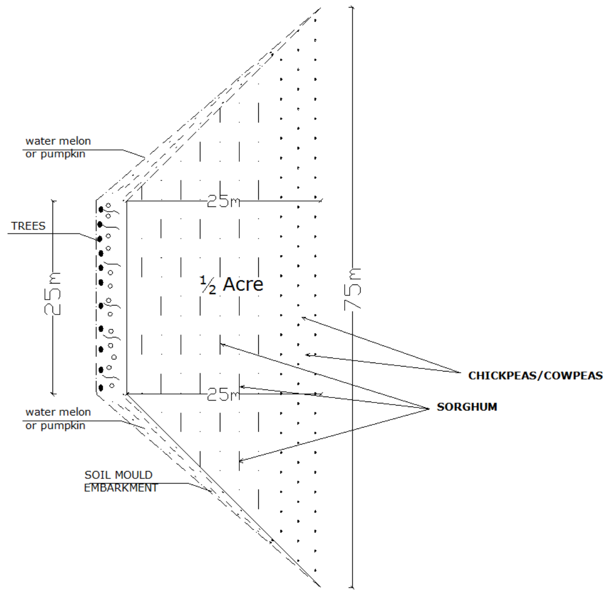


Figure 18: Farm plan for cultivated area in trapezoidal bund. Source: ADCL (2009)

Technically there is no any significant problem related to the design and construction of this structure. But soil fertility management initiative requires improvement. For example, in most of the cases fresh manure (livestock dropping) has been spread over the surface of the crop area (without being covered by soils). Basically, this manure should have been decomposed first, before being used for crop production and be incorporated into the soil. Nutrients from the fresh manure can be available for plant growth when the manure is decomposed. By covering the manure nutrient/nitrogen loss to the environment can be reduced.

### 7.3 *Negarim* micro-catchment

*Negarim* micro-catchments are diamond-shaped basins surrounded by small earth bunds with an infiltration pit in the lowest corner of each (Figure 19). Runoff is collected from within the basin and stored in the infiltration pit. Micro-catchments are used for growing trees (including fruits) or bushes and conserves soil. This technique is appropriate for small-scale tree planting in any area with moisture deficit. *Negarim* micro-catchments are precise and relatively easy to construct.

*Negarim* is not a cheap technique, bearing in mind that one person-day is required to build (on average) two units, and costs per unit rise considerably as the micro-catchment size increases. It is essential that the costs are balanced against the potential benefits. In the case of multipurpose trees in ASAL areas, for several years the main benefit will be the soil conservation effect and grass for fodder until the trees become productive.

The area of each unit is determined on the basis of a calculation of the plant (tree) water requirement. Factors to consider when establishing *negarims* are soil depth, slope steepness and rainfall amount. Soils should be deep enough (about 2 m to allow storage of harvested runoff water), optimum slope should be 1-5% and average annual rainfall be 300-700mm.

**Tools needed:**

- Spirit level and cotton string

- Measuring tape
- Pegs
- Simple hand tools: jembe, shovel, panga, hammer.

**Layout and construction methods:** Protect the field from excessive external runoff with a cut-off drain or a retention ditch. Clear vegetation from the site only where it is appropriate.

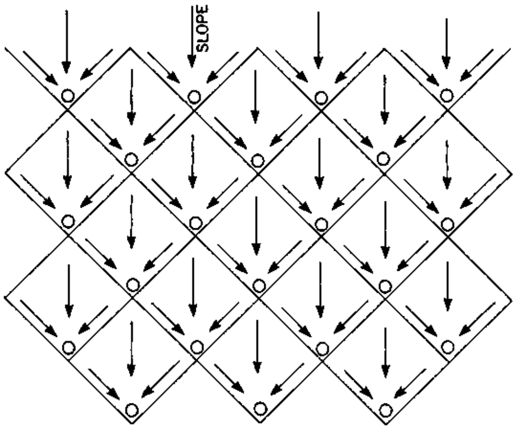


Figure 19. *Negarim* micro-catchments - field layout.

Size of micro-catchments normally range between 10 $m^2$ and 100 $m^2$ depending on the species of tree to be planted but larger sizes are also feasible, particularly when more than one tree will be grown within one unit.
**Design of bunds:** The bund height is primarily dependent on the prevailing ground slope and the selected size of the micro-catchment. It is recommended to construct bunds with a height of at least 25 cm in order to avoid the risk of over-topping and subsequent damage. Where the ground slope exceeds 2%, the bund height near the infiltration pit must be increased. Table 10 gives recommended figures for different sizes and ground slopes. The top of the bund should be at least 25 cm wide and side slopes should be at least in the range of 1:1 in order to reduce soil erosion during rainstorms. Whenever possible, the bunds should be provided with a grass cover since this is the best protection against erosion.

Table 10. Bund heights (cm) on higher ground slope.

| Micro-catchment size ($m^2$) | Ground slope (%) | | | |
|---|---|---|---|---|
| | 2 | 3 | 4 | 5 |
| 3x3 | even bund height | | | |
| 4x4 | of 25 cm | | | 30 |
| 5X5 | | | 30 | 35 |
| 6X6 | | | 35 | 45 |
| 8X8 | | 35 | 45 | 55 |
| 10X12 | 30 | 45 | 55 | |
| 12X12 | 35 | 50 | not recommended | |
| 15 X 15 | 45 | | | |

*Note:* These heights define the maximum height of the bund (below the pit). Total bund excavation volume remain constant for a given micro-catchment size.

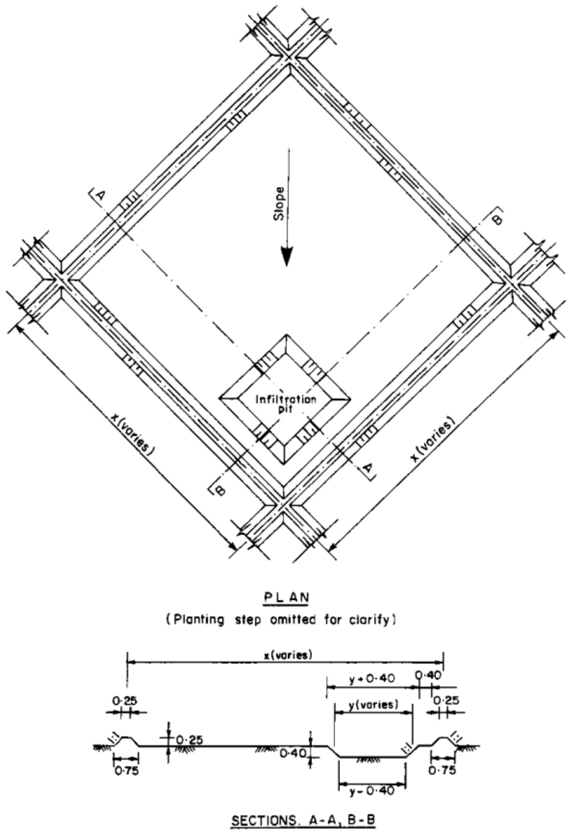


Figure 20. *Negarim* micro-catchment: details for 0.25 m bund size (for dimensions x and y see Table 11)

**Size of infiltration pit:** A maximum depth of 40 cm should not be exceeded in order to avoid water losses through deep percolation and to reduce the workload for excavation. Excavated soil from the pit should be used for construction of the bunds.

**Quantities of earthworks:** Quantities per unit include only the infiltration pit and two sides of the catchment, while the other two bunds are included in the micro-catchment above. When a diversion ditch is required additional earthworks of 62.5 $m^3$ per 100 m length of ditch will be needed.

Table 11. Quantities of earthworks for *Negarim* micro-catchments.

| Micro-catchment size ($m^2$) | Size Infiltration Pit (m) | Ground Slopes Suitable for 25 cm Bund | Volume Earthwork Per Unit** | No. Units Per ha | Earthworks m³/ha |
|---|---|---|---|---|---|
| Sides (x) Area | Sides,(y) Depth | Height* | ($m^2$) | | |
| 3 m x 3 m = 9 $m^2$ | 1.4 x 1.4 x 0.4 | up to 5% | 0.75 | 1110 | 835 |
| 4 m x 4 m = 16 $m^2$ | 1.6 x 1.6 x 0.4 | up to 4% | 1.00 | 625 | 625 |
| 5 m x 5 m = 25 $m^2$ | 1.8 x 1.8 x 0.4 | up to 3% | 1.25 | 400 | 500 |
| 6 m x 6 m = 36 $m^2$ | 1.9 x 1.9 x 0.4 | up to 3% | 1.50 | 275 | 415 |
| 8 m x 8 m = 64 $m^2$ | 2.2 x 2.2 x 0.4 | up to 2% | 2.00 | 155 | 310 |
| 10 m x 10 m = 100 $m^2$ | 2.5 x 2.5 x 0.4 | up to 1% | 2.50 | 100 | 250 |
| 12 m x 12 m = 144 $m^2$ | 2.8 x 2.8 x 0.4 | up to 1% | 3.25 | 70 | 230 |
| 15 m x 15 m = 225 $m^2$ | 3.0 x 3.0 x 0.4 | up to 1% | 3.50 | 45 | 160 |

* These ground slopes allow construction of a bund of 25 cm height throughout its length. Above these gradients the bund should be constructed relatively <u>higher</u> at the bottom (below the pit) and <u>lower</u> upslope.
** Calculation of earthworks per unit includes only two of the sides around the catchment: the other two sides are included in the micro-catchment above doesn't include earthworks required for diversion ditch (which is 62.5 $m^3$ for each 100 m length).

**Layout and construction procedure:**

*Step 1:* The first step is to find a contour line which is also called control contour. This can be done by using a line level. Since natural contours are often not smooth, it will be necessary to even out the contours so that finally a straight line is obtained. The first line, at the top of the block is marked (see Figure 21). If the topography is very uneven, separate smaller blocks of micro-catchments should be considered.

*Step 2:* By means of a tape measure, the tips of the bunds are now marked along the "straightened contour". The first line will be open-ended. The distance between the tips (a-b) depends on the selected catchment size. Table 12 gives the corresponding distance between a-b for different catchment sizes.

*Step 3:* A piece of string as long as the side length of the catchment (5 m for a 5 m x 5 m micro-catchment) is held at one tip (a) and a second string of the same length at the other tip (b). They will exactly meet at the apex (c). The apex is now marked with a peg and the catchment sides (a-c) and (b-c) marked on the ground alongside the strings with a hoe. This procedure will be repeated until all bund alignments in the first row have been determined.

Table 12. Distance between blinds in relation to catchment size.

| **Micro-catchment dimension (m)** | **Distance a – b (m)** |
|---|---|
| 3x3 | 4.2 |
| 4x4 | 5.7 |
| 5x5 | 7.1 |
| 6x6 | 8.5 |
| 8x8 | 11.3 |
| 10x10 | 14.1 |

*Step 4:* The next row of micro-catchments can now be staked out. The apexes of the bunds of the upper row will be the tips for the second row and the corresponding apexed will be found according to Step 3. When the second row of micro-catchments has been marked, repeat the same procedure for the third row, etc. The final result will be a block of diamond-shaped micro-catchments, with a first row which is open at the upslope end.

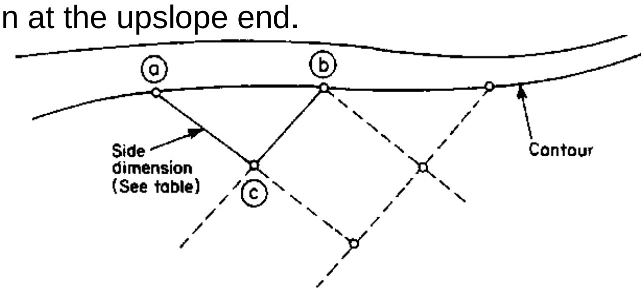


Figure 21. *Negarim* micro-catchment: layout technique

*Step 5:* The size of the infiltration put (dimension to be taken from Table 10) is staked out and the pit is excavated - leaving a small step towards the back on which the seedling will be planted (see Figure 22).

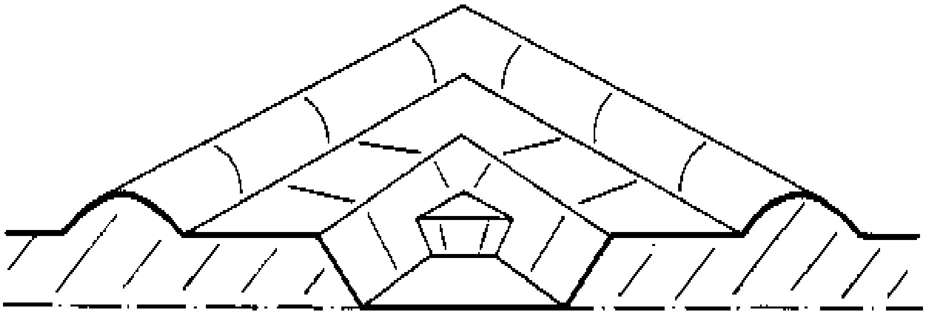

Figure 22. Infiltration pit with planting step.

*Step 6:* Before constructing the bunds, the area within the micro-catchments should be cleared of all vegetation. The bunds should then be constructed in two layers. The excavated material from the pit is used to form the bund. The bunds should be compacted during construction. Before compaction, the soil should be wetted wherever possible. Compaction may be done by foot or with a barrel filled with sand or water. To ensure a uniform height of the bund, a string should be fixed at the beginning and the end of each bund alignment and be adjusted above ground according to the selected bund height.

*Step 7:* A diversion ditch should be provided above the block of micro-catchments if there is a risk of damage by runoff from upslope of the block. The diversion ditch should be aligned in a 0.25% slope and in most cases a depth of 50 cm and a width of 1.0-1.5 m will be sufficient (Figure 23). The soil is deposited downslope. The diversion ditch should be constructed first to prevent damage in case a rainstorm occurs during construction of the micro-catchments.

*Step 8:* Dig planting hole of required size, apply manure and plant (fruit) tree during the rains. Tree seedlings of at least 30 cm height should be planted immediately after the first rain of the season. It is recommended that two seedlings are planted in each micro-catchment - one in the bottom of the pit (which would survive even in a dry year) and one on a step at the back of the pit (Figure 24). If both plants survive, the weaker can be removed after the beginning of the second season. For some species, seeds can be planted directly. This eliminates the cost of a nursery. Manure or compost should be applied to the planting pit to improve fertility and water-holding capacity. If grasses and herbs are allowed to develop in the catchment area, the runoff will be reduced to some extent, however, the fodder obtained gives a rapid return to the investment in construction. Regular weeding is necessary in the vicinity of the planting pit.

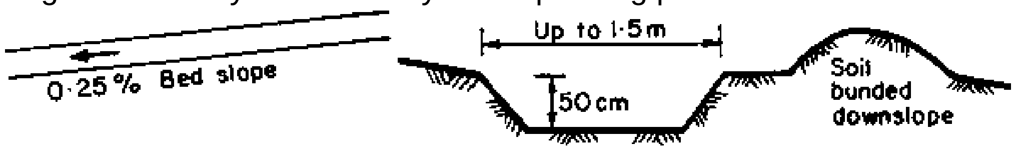


Figure 23. Diversion ditch

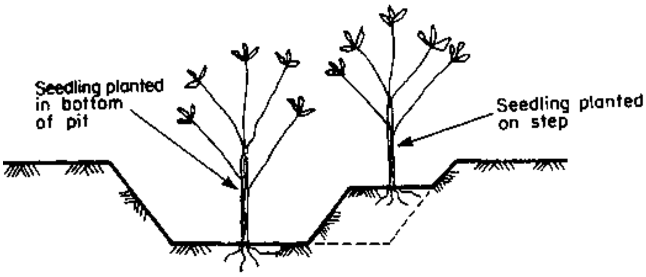


Figure 24. Planting site for seedling.

**Maintenance:** Repair broken embankments and keep the bund height at the recommended 25 cm by topping with soil, keep (fruit) trees well manured, desilt the cut-off drain or retention ditch regularly and repair embankments.

## 7.4 *Zai* (planting) pits

One promising option is *zai*, a traditional land rehabilitation technology that has been invented by farmers in Burkina Faso. Small pits 20-30 cm in diameter and 10-20 cm deep are dug into degraded soils, often hardpans. Pits are dug in the dry season. At the bottom of the pits farmers place about two handfuls of organic material (animal dung or crop residues) (Figure 25). Millet or sorghum seeds are planted in these pits as soon as the rainfall starts. In the dry season the pits trap litter and fine sand deposited by the wind. The pits are often filled with manure mixed with earth. This attracts termites, which dig tunnels in the soil, transporting nutrients from deeper layers to the top and improving the infiltration capacity of the soil. In addition, the *zai* pits collect and concentrate water at the plant. This reduces the risk of water stress in a region of low and erratic rainfall. *Zai* therefore combines water and nutrient management. Its design needs little external assistance and its construction is inexpensive.

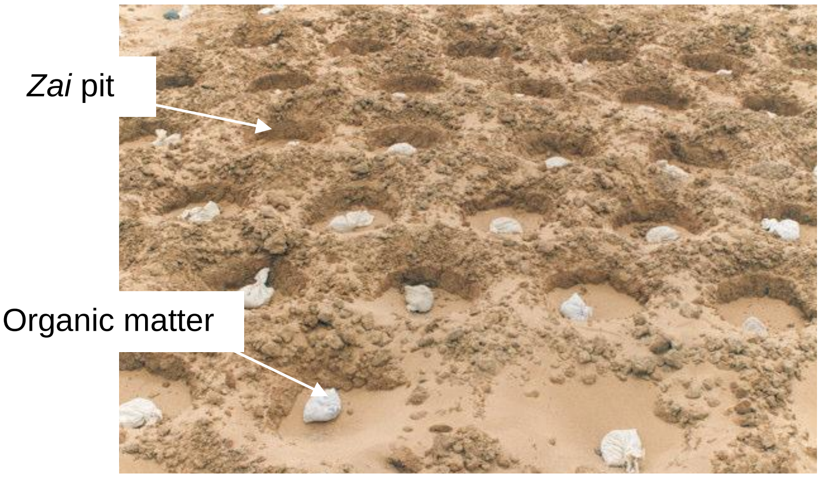


Figure 25. *Zai* pit and organic matter placed at bottom of the pit.

Conditions for choosing, procedures for laying out, pit preparation and crop management are given below:

**Conditions:**

- *Rainfall* - 200-750 mm.
- *Soil* - Planting pits are particularly successful for rehabilitating barren, crusted soils and clay slopes where infiltration is limited and tillage is difficult. The soil does not need to be very deep. Where soils are already shallow farmers should

not plant in the pit, but rather on top of the ridge of excavated soil in order to maximise rooting depth.

- *Slope* - below 2%.
- *Topography* - Does not have to be even. Suitable technique to rehabilitate uneven, broken terrain.

**C:CA ratio:** Usually the C:CA ratio is estimated. But it varies from1:1 to 1:3. The larger the planting pits, and the wider the spacing, the more water can be harvested from the uncultivated area between the pits.

**Laying out:**

- Select a part of the farm that is not too steep (1-2% in slope) and neither on very flat ground. If land is on a steep slope, terraces should first be made. It is important that the pits are dug at alternate positions behind each other to allow enough catchment area for sufficient runoff to be generated,
- It is not necessary to follow the contour line. Starting at one end of the field, use a tape measure or a marked string, to fix pegs 150 cm apart on the first row,
- Measure a row spacing of 75 cm downhill,
- On the second row, place the first peg 75 cm from the line of the first peg,
- Continue to place pegs 150 cm apart as with row 1, so that all the pegs in row-2 are at alternate positions behind row-1,
- Continue measuring and pegging in this way until you have a network of pegs at alternate positions.

**Pit preparation:** At each peg position, prepare a planting pit measuring 60 cm deep x 60 cm diameter as follows:

- Dig a hole 60 cm diameter, placing topsoil (about 20 cm depth) on the uphill side,
- Dig the soil, to a depth of 60 cm and place the subsoil on the downhill side,
- Reshape this subsoil to resemble a semi-circular bund or micro-basin to enable better water storage,
- Mix the topsoil with one medium size bucket of well-composed manure and return to hole. Ensure that the hole is not refilled to the top so that some space remains to collect and store runoff water,
- Plant several seeds (about 5 seeds) of maize or sorghum or millet in one hole. The number of seeds per hole depends on crop type, its variety and climate. If you plant seeds in pairs, remember to thin to single plants later.

**Ridge design:** designing the ridge of a *zai* pit is very simple. The ridge is formed by placing excavated earth from the planting pit immediately downslope of the pit.

**Crop management:** Once the crop is growing in the planting pit, the following management practices are needed:

- Keep the field clear of weeds. Outside the pits (catchment), do not dig with a jembe, clear the weeds with a panga to leave a firm compacted catchment. Inside the pits, you can weed normally to encourage infiltration,
- Protection of the crop from pests and diseases.

**Advantages of planting pits**

- Once prepared, planting pits can be re-used for up to four crop seasons or two seasons without the need to add more manure,
- Increased crop yield and better crop survival in time of drought. Planting pits can make a difference between getting a harvest or nothing at all in a low rainfall season,
- Weed control is easier,
- Water Conservation in the pit, thus reducing soil erosion on other parts of the farm,
- Improved soil fertility and environmental conservation.

**Limitations**

- The main limitation with planting pits is the heavy labour demanded in preparing the pits for the first time.
- Also, they may not work well in water logging soils.

***Zai* pits (planting pits) in Kenya:** while *zai* pits in western Africa have circular cross-section, in Kenya they are boxlike structure in cross-section. Planting pits have been implemented in districts such as Kilifi, Kinango and Turkana and increased crop yields. The standard layout is 0.6 m by 0.6 m – both row and inter-row spacing and dimensions of 0.6 m length x 0.6 m width x 0.6 m depth for 5 plants (crops). To enhance soil fertility and improve structure, organic matter (dry grass) is laid on the bottom of the pit and top soil mix with manure (1:1 ratio) place on top. About 2,222 planting pits can be fitted in one acre of land and each pit can produce 2-3 kg of maize. Larger planting pits of 0.9 m length x 0.9 m width x 0.6 m depth were also introduced for 9 plants. But farmers opted for the standard planting pits due to labour consideration. Although planting pits are labour intensive, once constructed they can be used for 3-4 years.

### 7.5 Water spreading bunds

Water spreading bunds are often applied in situations where trapezoidal bunds are not suitable, usually where runoff discharges are high and would damage trapezoidal bunds or where the crops to be grown are susceptible to the temporary waterlogging, which is a characteristic of trapezoidal bunds. The major characteristic of water spreading bunds is that, as their name implies, they are intended to spread water, and not to impound it (Figure 26). They are usually used to spread floodwater which has either been diverted from a watercourse or has naturally spilled onto the floodplain. The bunds, which are usually made of earth, slow down the flow of floodwater and spread it over the land to be cultivated, thus allowing it to infiltrate. This technology has been practiced in few ASAL districts of Kenya (example, Turkana and Tana River) and used for sorghum and maize production.

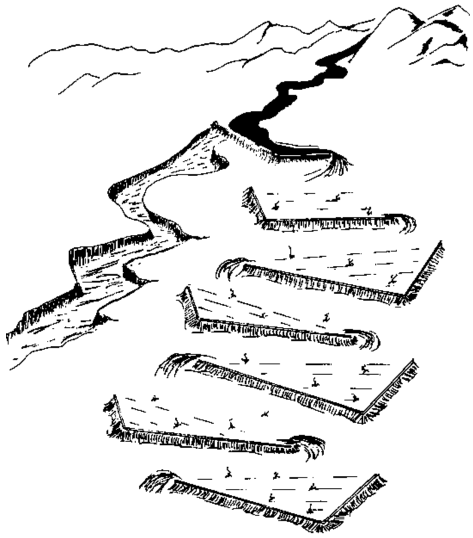

Figure 26. Flow diversion system with water spreading bunds in Pakistan (Source: Nas 1980).

**Technical Details -** Water spreading bunds can be used under the following conditions:

- Rainfall: 100 mm - 350 mm; normally hyper-arid/arid areas only.
- Soils: alluvial fans or floodplains with deep fertile soils.
- Slopes: most suitable for slopes of 1% or below.
- Topography: even.

The technique of floodwater farming using water spreading bunds is very site-specific. The land must be sited close to watercourse, usually on a floodplain with alluvial soils and low slopes. This technique is most appropriate for arid areas where floodwater is the only realistic choice for crop or fodder production.

**Catchment: cultivated area ratio -** The precise calculation of a catchment: cultivated area ratio is not practicable or necessary in the design of most water spreading bunds. The reasons are that the floodwater to be spread is not impounded - much continues to flow through the system, and furthermore often only part of the wadi flow is diverted to the productive area. Thus the quantity of water actually utilized cannot be easily predicted from the catchment size.

**Bund design** - Two methods of design can be followed:
**a. Slopes of less than 0.5% -** Where slopes are less than 0.5%, straight bunds are used to spread water (Figure 27). Both ends are left open to allow floodwater to pass around the bunds, which are sited at 50 metres apart. Bunds should overlap - so that the overflow around one should be intercepted by that below it. The uniform cross section of the bunds is recommended to be 60 cm high, 4.1 metres base width, and a top width of 50 cm (Figure 28). This gives stable side slopes of 3:1. A maximum bund length of 100 metres is recommended.
**b. Slopes of 0.5% to 1.0% -** In this slope range, graded bunds can be used (Figure 29). Bunds, of constant cross-section, are graded along a ground slope of 0.25%. Each successive bund in the series downslope is graded from different ends. A short wingwall is constructed at 135° to the upper end of each bund to allow interception of the flow around the bund above. This has the effect of further checking the flow. The

spacing between bunds depends on the slope of the land. The bund cross section is the same as that recommended for contour bunds on lower slopes. The maximum length of a base bund is recommended to be 100 metres.

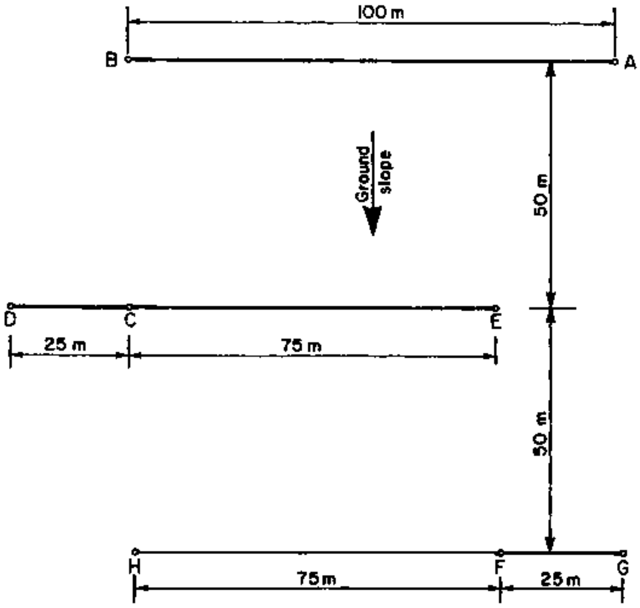


Figure 27. Setting out of level bunds: groundslope < 0.5%.

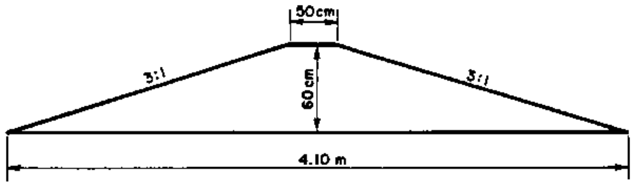


Figure 28. Bund dimensions

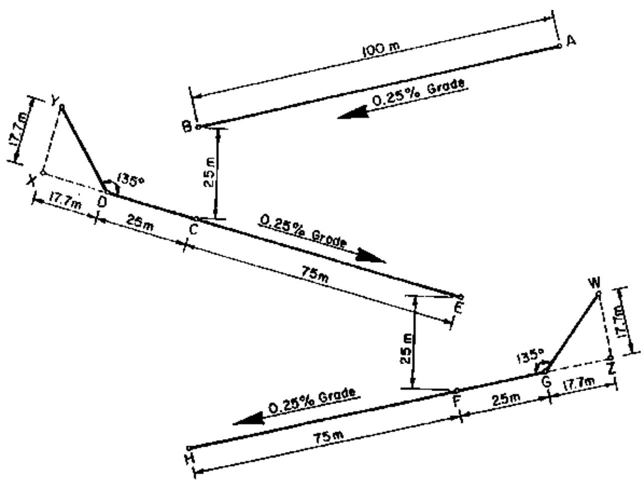


Figure 29. Setting out of graded bunds: groundslope > 0.5%.

**Quantities and labour** - Table 13 gives details of the quantities and labour involved in construction of water spreading bunds for different slope classes. A bund cross section of 1.38 $m^2$ is assumed. Labour requirements are relatively high because of the large sized structures requiring soil to be carried.

Table 13. Quantities of earthworks for water spreading bunds

| Slope class / technique | No. of bunds per ha | Total bund length (m) | Earthworks ($m^3$/ha) |
|---|---|---|---|
| **Level bunds** | | | |
| < 0.5% | 2 | 200 | 275 |
| **Graded bunds** | | | |
| 0.5% | 2 | 220 | 305 |
| 1.0% | 3 | 330 | 455 |

**Design variations -** There are many different designs for water spreading bunds possible, and that given in this manual is merely one example. Much depends on the quantity of water to be spread, the slope of the land, the type of soil and the labour available. Existing systems are always worth studying before designing new systems (Figure 30).

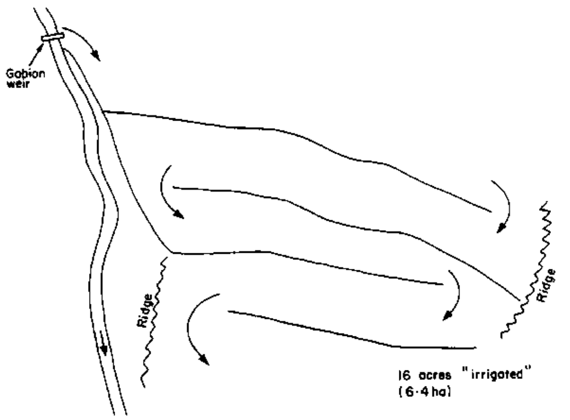


Figure 30. Impala Pilot Water Spreading Scheme, Turkana, Kenya (Source: Fallon 1963)

**Layout and construction:**

*Step 1.* The first step is to measure the slope of the land, in order to select the appropriate bunding system. This can be done most simply with an Abney level, or with a line level.

*Step 2.* Straight bunds are used for ground slopes of less than 0.5% and are spaced at 50 m intervals. The bunds should, however, be staggered as shown on Figure 27, which also illustrates the setting out procedure. Having selected the starting point at the upslope end of the bund system point A is marked with a peg. Using a line or water level and, if necessary, a tape, point B is pegged on the contour 100 m away from A. Line AB is then the centreline of the first bund and should be marked with pegs or stones. Point C is 50 m downslope from point B and can be established by marking of a right angle perpendicular to AB, using a wooden triangular right angle frame (sides: 100 cm, 60 cm, 80 cm) and a tape. Point D is then established with level and tape at the same ground level as C, at a distance of 25 m from C to allow overlap with AB. Point D is then pegged. Point E is also on the same ground level as point C, but 75 m distant in the opposite direction to point D. The line DE is the centreline of the second bund and should be marked with pegs or stones. Point F is 50 m downslope of point E and is established in a similar manner as point C. Point G is then established on the same ground level as point F but 25 m distant to allow overlap with DE. Similarly point H is at the same ground level as point F but 75 m distant, in the opposite direction to point G. This process can be repeated down the slope to lay out the field of bunds.

*Step 3.* For ground slopes above 0.5% bunds aligned with a 0.25% gradient are used and are termed "graded bunds". Having selected the starting point (A) at the upslope end of the bund system, it is marked with a peg. Using a line, or water level, and a tape, the line AB is set out on a 0.25% gradient. As the distance AB is 100 m, the ground level at B is 25 cm below that at A. Point B is then marked with a peg and the line AB, forming the centreline of the first bund, is marked with pegs or stones. Point C, on the centre line of the second bund, is at a distance of 25 m immediately downslope of point B. It is most easily found by using the line or water level to establish the maximum field gradient between B and C, and by measuring from B through that point a distance of 25 m. Having established C the 0.25% slope line is again established and point D located along that line 25 m from C. Note that point D will be at a slightly higher ground level than point C and should provide overlap with the line AB, as shown in Figure 29. The other end of the bund centreline, point E, is 75 m on the opposite side of C along the 0.25% slope line. The points D and E should be pegged and mark the centreline of the second bund. The wing bund always starts from the overlapping end of the base bund, in this case point D. The wing bund is 25 m long and at an angle of 135° to the base bund. It is most easily found by extending the line ED a distance of 17.7 m from D to give point X. Point Y is then a distance of 17.7 m upslope from point X, and at a right angle to the line XDE. It can be located using a tape and right angle template as described above. The first point on the next bund line, point F, is located in a similar manner to point E and the bend centreline HFG can be set out as above. The end of the wing bund, W, can be located in a similar manner as Y. This process is continued down the field.

*Step 4.* Having marked out the centrelines of the bunds, the limits of fill can be marked by stakes or stones placed at a distance of 2.05 m on either side of the centrelines.

*Step 5.* Construction begins at the top of the field as in all water harvesting systems. Earth should be excavated from both sides to form the bunds, and in the shallow trenches formed, earth ties should be foreseen at frequent intervals to prevent scouring. The earth beneath the bunds should be loosened to ensure a good mating with the bund. The bunds are constructed in two layers of 30 cm each, and compaction by trampling is recommended on the first course and again when the bund is complete.

*Step 6.* At the ends of the contour bunds, and at the tip of the wingwalls of the graded bunds, stone pitching should be placed - if loose stone is available - to reduce potential damage from flow around the bunds.

**Maintenance -** As is the case in all water harvesting systems based on earth bunds, breaches are possible in the early stages of the first season, before consolidation has taken place. Thus there must be planning for repair work where necessary and careful inspection after all runoff events. In subsequent seasons the risk of breaching is diminished, when the bunds have consolidated and been allowed to develop vegetation - which helps bind the soil together, and reduces direct rainfall damage to the structures. Nevertheless with systems which depend on floodwater, damaging floods will inevitably occur from time to time, and repairs may be needed at any stage.

**Husbandry** - Water spreading bunds are traditionally used for annual crops, and particularly cereals. Sorghum and millet are the most common. One particular feature of this system, when used in arid areas with erratic rainfall, is that sowing of the crop should be undertaken in response to flooding. The direct contribution by rainfall to growth is often very little. Seeds should be sown into residual moisture after a flood, which gives assurance of germination and early establishment. Further floods will bring the crop to maturity. However if the crop fails from lack of subsequent flooding - or if it is buried by silt or sand (as sometimes happens) - the cultivator should be prepared to replant. Because water spreading usually takes place on alluvial soils, soil fertility is rarely a constraint to crop production. Weed growth however tends to be more vigorous due to the favourable growing conditions, and thus early weeding is particularly important.

**Socio-economic factors -** As the implementation of water spreading systems is a relatively large-scale exercise, consideration has to be given to community organization. One particular problem is that the site of the activity may be distant from the widely scattered homes of the beneficiaries. Food for work can be used to support the labour intensive activities. This incentive should not be considered as a job opportunity and make people lose interest in the scheme once the incentives have come to an end.

### 7.6 Permeable rock dams

Permeable rock dams are a floodwater farming technique where runoff waters are spread in valley bottoms for improved crop production. Developing gullies are healed at the same time. The structures are typically long, low dam walls across valleys. This technique is particularly popular where villagers have experienced the gullying of previously productive valley bottoms, resulting in floodwater no longer spreading naturally. The activity involve large amount of work and needs a group approach, as well as some assistance with transport of stone. The main limitation of permeable rock dams is that they are particularly site-specific, and require considerable quantities of loose stone as well as the provision of transport.

**Technical Details** - Permeable rock dams for crop production can be used under the following conditions:

- Rainfall: 200-750 mm; from arid to semi-arid areas
- Soils: all agricultural soils - poorer soils will be improved by treatment
- Slopes: best below 2% for most effective water spreading
- Topography: wide, shallow valley beds.

A permeable rock dam is a long, low structure, made from loose stone (occasionally some gabion baskets may be used) across a valley floor. The central part of the dam is perpendicular to the watercourse, while the extensions of the wall to either side curve back down the valleys approximately following the contour (Figure 31). The idea is that the runoff which concentrates in the centre of the valley, creating a gully, will be spread across the whole valley floor, thus making conditions more favourable for plant growth. Excess water filters through the dam, or overtops during peak flows. Gradually the dam silts up with fertile deposits. Usually a series of dams is built along the same valley floor, giving stability to the valley system as a whole.

**Catchment: cultivated area (C:CA) ratio:** This is not necessary as the catchment area and the extent of the cultivated land are predetermined. However, the catchment characteristics will influence the size of structure and whether a spillway is required or not.

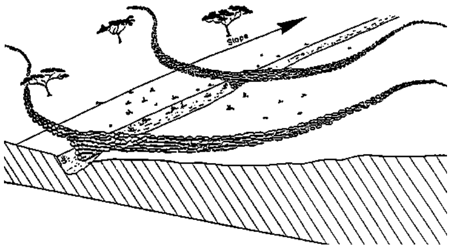

Figure 31. Permeable rock dams: general layout (Source: Critchley and Reij 1989).

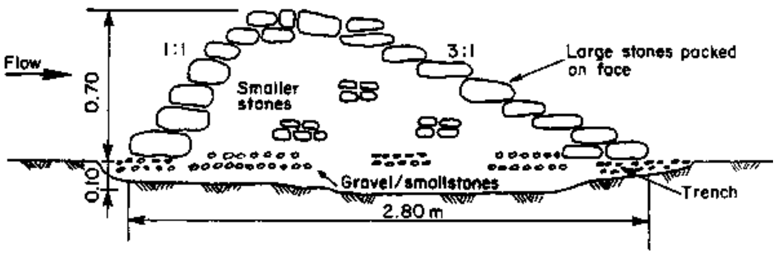


Figure 32. Dam dimensions.

Table 13. Quantities for permeable rock dams

| Land slope (%) | Spacing between dams* (m) | Volume of stone per ha cultivated ($m^3$) |
|---|---|---|
| 0.5 | 140 | 70 |
| 1.0 | 70 | 140 |
| 1.5 | 47 | 208 |
| 2.0 | 35 | 280 |

* vertical intervals between adjacent dams = 0.7 m

**Dam design:** The design specifications given below are derived from a number of permeable rock dam projects in West Africa. Each project varies in detail, but the majority conform to the basic pattern described here.

The main part of the dam wall is usually about 70 cm high although some are as low as 50 cm (Figure 32 and Table 13). However, the central portion of the dam including the spillway (if required) may reach a maximum height of 2 m above the gully floor. The dam wall or "spreader" can extend up to 1000 m across the widest valley beds, but the lengths normally range from 50 to 300 m. The amount of stone used in the largest structures can be up to 2000 tons.

The dam wall is made from loose stone, carefully positioned, with larger boulders forming the "framework" and smaller stones packed in the middle like a "sandwich". The side slopes are usually 3:1 or 2:1 (hor: ver) on the downstream side and 1:1 or 1:2 on the upstream side. With shallower side slopes, the structure is more stable, but more expensive. For all soil types it is recommended to set the dam wall in an excavated trench of about 10 cm depth to prevent undermining by runoff waters. In erodible soils, it is advisable to place a layer of gravel, or at least smaller stones, in the trench.

**Quantities and labour:** The quantity of stone, and the labour requirement for collection, transportation and construction depends on a number of factors and vary widely. Table 13 gives the quantity of stone required per cultivated hectare for a series of typical permeable rock dams under different land gradients. The figures were calculated for a rock dam with an average cross-section of 0.98 $m^2$ (70 cm high, base width of 280 cm) and a length of 100 m. The vertical interval between dams is assumed to be 0.7 m, which defines the necessary spacing between adjacent dams (see Figure 32).

Transport of stones by lorries from the collection site to the fields in the valley is the normal method. Considerable labour may be required to collect, and sometimes break, stone. Labour requirements, based on field estimates, are in the range of 0.5 $m^3$ of stone per person per day - excluding transport.

**Design variations:** Where permeable rock dams are constructed in wide, relatively flat valley floors, they are sometimes made straight across - in contrast to the usual design where the spreader bunds arch back from the centre to follow the contour. With straight dams, the height of the wall decreases from the centre towards the sides of the valley to maintain a level crest.

**Layout and construction:**

*Step 1:* Site selection depends both on the beneficiaries and the technicians. It is best to start at the top of the valley. After site identification it is necessary to determine whether the structure needs a defined spillway: as a rule of thumb no spillway is required if the gully is less than 1 m deep. For greater depths, a spillway is recommended. Gullies of over 2 m depth pose special problems and should be only tackled with caution. It is important not to build a permeable rock dam immediately above a gully head, as there is the risk that the dam will fall into the gully if continued erosion causes the gully head to cut back.

*Step 2:* Where a spillway is required, this should be built first. Gabions are best for spillways, as loose stone is easily destabilized by heavy floods. The following should be noted:

- A foundation of small stones, set in a trench, is required.
- An apron of large rocks is needed to break the erosive force of the overflow (Figure 33).
- The downstream banks of the watercourse should be protected by stone pitching to prevent enlargement of the gully.

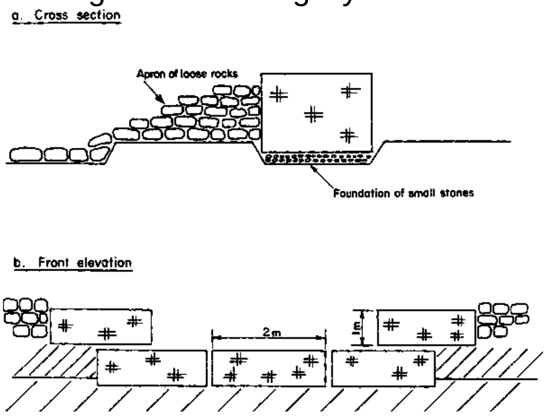


Figure 33. Gabion spillway

*Step 3:* The alignment of the main dam walls can be marked out, starting at the centre of the valley (where there may/may not be a spillway). This alignment is ideally along the contour, or as close to the contour as possible. Thus the extension arms sweep backwards in an arc like the contours of a valley on a map. The arms end when they turn parallel to the watercourse. The contour can be laid out simply using a line level.

*Step 4:* A typical cross-section (taken from the design of the PATECORE project in Burkina Faso) is recommended for general use. This is of 280 cm base width, 70 cm height and side slopes of 1:1 upstream and 3:1 downstream. Larger cross-sections may be required dependent on catchment characteristics. The first action after aligning the extension arms of the dam is to dig a trench at least 10 cm deep and 280 cm wide (according to the base width of the bund). The earth should be deposited upslope and the trench filled with gravel or small stones.

*Step 5:* The skill of construction is in the use of large stones (preferably of 30 cm diameter or more) for the casing of the wall. This should be built up gradually following the required sideslope, and the centre packed with smaller stones. The whole length of the bund should be built simultaneously, in layers. This layered approach reduces the risk of damage by floods during construction. Earth should not be mixed with the stone because it may be washed out and thus destabilize the structure. It is particularly important to pack the small stones well at the lower levels to increase the rate of siltation. The structure is finished off with a cap of large stones. It should be possible to walk on the structure without any stones falling off. The dam wall should be level throughout its length, which can be checked by the use of a line level.

*Step 6:* If a series of permeable rock dams is to be built, an appropriate vertical interval (VI) should be selected. It is correct to:

- start at the top of the valley and work down;
- use a VI equal to the height of the structure - so that the top of one structure is at the same level as the base of the one above it (see Figure 34).

Therefore, for dams of 70 cm height, the VI should theoretically be 70 cm. However in practice this may not be practicable due to the amount of stone and labour involved. As a compromise, a VI of 100 cm might be more realistic. Even wider spacing could be adopted, and the "missing" structures "filled in" afterwards. The vertical interval can be determined most easily by the use of a line level. The horizontal spacing between adjacent dams can be determined from the selected VI and the prevailing land slope according to the formula:

$$HI = \frac{VI}{Slope}$$

where:
HI = horizontal interval (m)
VI = vertical interval (m)
Slope = land gradient expressed as m/m.

For example, for a VI of 0.7 m and a 1% land slope,
HI = 0.7 /0.01 = 70 metres

For a VI of 0.7 m and a 2% land slope,
HI = 0.7/0.02 = 35 metres.

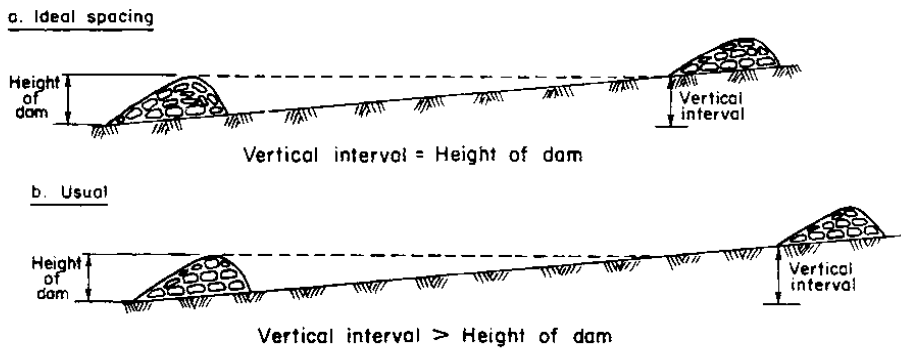

Figure 34. Spacing of rock dams (Source: Berton, 1989)

**Husbandry:** Permeable rock dams improve conditions for plant growth by spreading water, where moisture availability is a limiting factor. In addition, sediment, which will build up behind the bund over the seasons, is rich in nutrients, and this will further improve the crop growth. This technique is used exclusively for annual crops. In the sandier soils, which do not retain moisture for long, the most common crops are millet and groundnuts. As the soils become heavier, the crops change to sorghum and maize. Where soils are heavy and impermeable, waterlogging would affect most crops, and therefore rice is grown in these zones. Within one series of permeable rock dams, several species of crop may be grown, reflecting the variations in soil and drainage conditions.

**Maintenance**: The design given above, with its low side slopes and wide base should not require any significant maintenance work provided the described construction method is carefully observed. It will tolerate some overtopping in heavy floods. Nevertheless there may be some stones washed off, which will require replacing, or tunneling of water beneath the bund which will need packing with small stones.

### 7.7 Rock catchment

If there are large rocky hills where you live, you will know that when it rains, a lot of water pours off the rocks. This runoff water can be harvested and stored for domestic and livestock uses. Solid rock, better if unfractured, offers good opportunities to construct rock catchments systems for rainwater harvesting depending on a number of factors such as the size of the reservoir, the shape of the site where the masonry wall is being constructed. Thus rock catchment is an area defined by a rock outcrop which has the capacity of catching and concentrating rainwater runoff into a storage structure for productive use. The concentration and conveyance is done by stone gutters constructed around the rock with rough stones/hardcore, joined with mortar, with access to the storage facility (Figure 35).

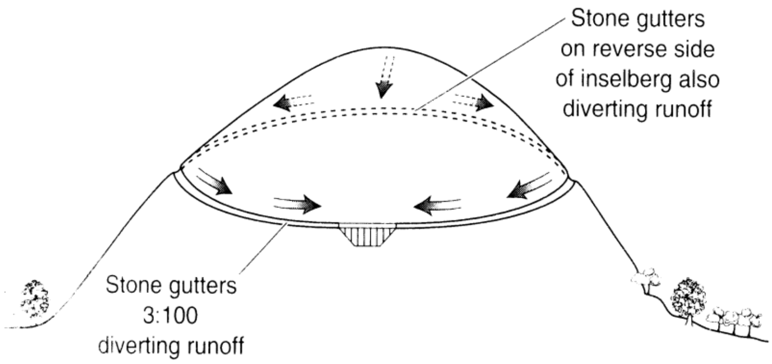

Figure 35. Rock catchment and stone gutter.

A masonry gravity dam was built in 1957 to harvest surface runoff from rocky catchment in Mwingi district and since then it serves for domestic use and livestock consumption throughout year (Figure 36). Water abstraction points for people and animals were installed at downstream dam site. Suction pipes convey water downstream for people and livestock to abstraction points. Soil erosion problem is minimal in the catchment and hence the water is less turbid.


Figure 36. Omenrock catchment Mwingi district.

**Design considerations** – In effect, there is no standard design for the rock catchment as such. However, the size of the reservoir is ultimately determined by the size of the catchment, the water requirement, the rainfall regime, the number of users and by other local factors. When site selection, design and construction are made the following issues need to be considered:

**a) Rock catchment siting factors**

- Dams should be built at sites that can produce a relatively high depth to surface area ratio so as to minimize evaporation losses (Figure 37)
- Rock surfaces should not be fractured or cracked, which may cause the water to leak away to deeper zones or underneath the dam
- Dam foundations must be of solid impermeable rock with no fracture lines
- The dam should be in a convenient location for user groups
- There should be no severe soil erosion in the catchment area or be easily controlled by simple soil conservation methods.

As the rock surface dips come in a variety of slopes and sizes, the shape of the dam wall varies too. For instance, for a V shaped small valley in the rock surface, a single wall dam will be appropriate. For a funnel shaped depression, a more adequate wall dam will have a V shape. Finally, for a continuous slope where the dip is down slope, a U shaped wall dam is required.

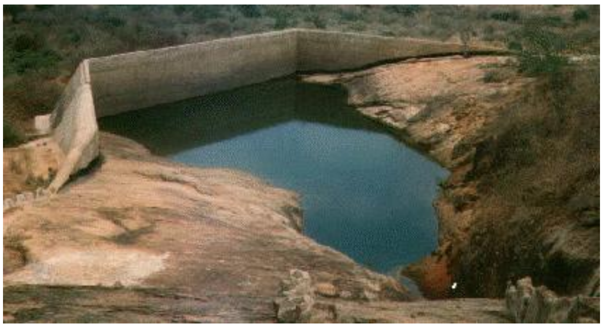

Figure 37. Vertical wall around the outer edge of a depression in a rocky surface to harvest water.

**b) Design and construction of a rock catchment dam**

- Clear and clean the site off vegetation
- Mark out the effective catchment area of the rock surface where you plan to collect the rainwater from. This area will be enclosed with gutters of 0.3 m height and 0.25% gradient
- Estimate the amount of runoff volume ($m^3$) anticipated. Runoff volume (m3) = rainfall (m) x catchment area ($m^2$) x runoff coefficient (0.5-0.9 for rock surfaces depending on rock structure). This volume will guide the design of the rainwater storage structure
- Site the water storage structure or masonry gravity dam on the outer edge of a hollow or depression on the rock surface. The shape of the reservoir created by the dam should minimize evaporation losses
- Estimate the material requirements for both the rock catchment and the water storage structure or dam. Local construction materials should be used as much as possible
- An out-take, gravity pipe and water tap point should be constructed to abstract water downstream from the dam
- The downstream side of the dam should be protected against erosion in case the dam overflows. The catchment area should be protected against sedimentation or pollution.
- Organise the team and start to build, during the dry season!

The volume of rainfall falling on a sloping surface is less per square meter, than an horizontal surface, the following conversion is necessary:

- 90 degrees gradient receives 100% less rainfall than a horizontal catchment,
- 80 degrees - 86%,
- 70 degrees - 68%,
- 60 degrees - 47%,
- 50 degrees - 38%,
- 40 degrees - 23%,
- 30degrees - 13%,
- 20 degrees - 5%,
- 10 degrees - 2%.

These factors assist in estimating run off response of the catchment which leads to the volume of harvestable water. As a rule of thumb, the storage volume of a reservoir is further reduced by 20% to cater for evaporation and consumption during the rainy season.

**Operation and maintenance** - the following issues should be considered:

- Controlling access and demand management
- Choose suitable water abstraction devices
- Revenue collection - the community or dam committee should establish by-laws to govern the sale of water and set tariffs for different water uses.
- Regular catchment and reservoir protection and maintenance. Fencing the catchment area and reservoir is crucial.
- Built pit latrine to reduce hygiene problem,
- Plant wind breaks.

*Note:* For additional information on the design and construction of rock catchment Erik Nissen-Petersen (2006) can be read. It is available at:
www.timfoster.org/2008%2010%20WASH%20Kenya/Participant%20CD/files/Book_1_%20Water_from_rock_outcrops.pdf

## 7.8 Sand dams

A sand storage dam (or sand dam) is a small dam build on and into the riverbed of a seasonal river or ephemeral stream (Figure 38). Sand dams effectively increase the volume of groundwater available for abstraction as well as prolonging the period in which groundwater is available. Since a large quantity of the water is additionally stored in the riverbanks the volume of water available for abstraction is considerably larger than just the volume present in the riverbed sands. Water is captured through a scope hole, hand-dug well or tube well, supplying water to nearby villagers in the dry season (Figure 39).

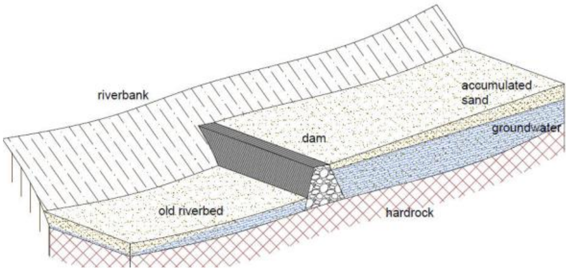


Figure 38. Schematic cross section of a typical sand storage dam (Borst & de Haas, 2006).

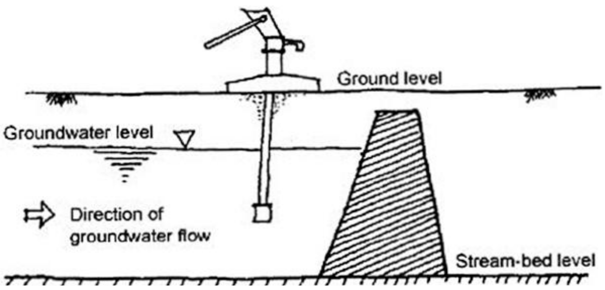


Figure 39. Water abstraction from sand dams.

**Applying conditions:**

- Intermittent rivers in regions with semi-arid climates and erratic but intensive rainfall,
- Sandy riverbeds experiencing high sediment loads after heavy rain storms,
- River valleys with gradients between 1% and 2%,
- The dam location should be chosen carefully to ensure the highest storage capacity and implemented at minimum cost.

**Advantages:**

- Clean, good quality water due to the filtering effect of sand,
- Underground storage means limited evaporation, less chance of pollution and no breeding of surface-water disease vectors,
- During a period of serious drought, some dams still provide water,
- Water is also stored in the riverbanks. Through the increased base flow from the banks, the riverbed can be recharged during the dry season,
- Low maintenance (costs) and long life.

**Considerations:**

- Expert input is required to determine the best site. Problems primarily relate to aspects of dam locations and construction,
- Risk of erosion and contamination during the rainy season,
- Accurate estimation of the groundwater reserves is difficult,
- Dams made of concrete, stone-masonry and brickwork require skilled labour for construction, but are stronger and have a longer lifespan,
- The construction of sand dams in cascades improves total storage and efficiency and minimises seepage losses,
- The effects of sand dams on downstream river discharge are generally small (< 10% of runoff),
- Regular checks and repairs are required after floods.

**<u>Practical steps within a sand dam project</u>**

The following sep-wise approaches should be followed in implementing a sand dam project:

i. Site selection
ii. Water use assessment
iii. Design
iv. Excavation and construction
v. Water extraction
vi. Maintenance & management.

### i. Site selection

Site selection is the first and most important step in constructing a sand dam. Accuracy in site selection will determine the success of the dam. A construction site should be appropriate on both physical and social grounds. Site selection includes selecting potential catchments, riverbeds and riverbed sections and the sand dam location(s). These issues are explained as follows:

a) Suitable riverbeds must have **two high riverbanks**, to enable the wing walls to keep over-flowing flood water within the spillway, and not flowing over the riverbanks. If flood water is allowed to flow over the wing walls and riverbanks, it will erode the riverbanks and cause the river to change its course, thereby leaving the sand dam (Figure 40),

Figure 40. River has changed its original course.

b) Dam walls should **never be built on fractured rocks or large boulders** because such walls cannot be made water-tight. Water will always seep out between the boulders,
c) Dam walls should therefore always be built either on a solid bedrock base, or keyed 1 m into solid and impermeable soil. If dam walls are keyed less than 1 m into solid and impermeable soil, water will find its way out under the dam wall, and cause the wall to hang in its wing walls over the riverbed,
d) Riverbeds with fine-textured sand originating from flat land, are also unsuitable for sand dams, because less than 5% of the water stored in the voids between the sand particles can be extracted,
e) Wide riverbeds, > 25 m width, are also unsuitable for sand dams, because the reinforcement required for the long dam walls is expensive. Riverbeds exceeding 25 m in width are suitable for subsurface dams built of soil, because that material is pliable (flexible) and does not crack like concrete,
f) Sometimes whitish stones known as *calcrete* can be available along riverbed. If animals (livestock as well as wild animals) lick this stones that means that they contain salt and other minerals. If *calcrete* is situated in the riverbank upstream of a dam, then the water will be saline and therefore only useful for livestock,
g) Vegetation that indicate the presence of water, should be growing on the banks where the reservoir will be located, as proof of the riverbed capacity to store water. Ficus species, Acacia seyal, etc. are known as water-indicating vegetations,
h) Waterholes, even temporary ones, should preferably be located where dam reservoirs are to be constructed to prove that the riverbed has no leakages draining water into the ground below,
i) As mentioned earlier, the walls of sand dams, weirs and subsurface dams should always be constructed on natural underground dykes, to benefit from storage of water while also reducing construction costs.

### ii. Water demand assessment

The water demand of the local community has to be investigated before starting a water project, to understand the most important needs of a community. Next to this the community has to be aware of the possibilities and limitations of a sand dam. The water needs of a community is the amount of water currently used by people for domestic purposes as drinking, cooking and cleaning, as well as for irrigation or for animals. This information gives insight into water demand, future aspirations and water quality problems. The water demand assessment has to be executed by the implementing organisation before selecting the locations of the sand dams. The information which should be gathered includes:
- the number of households within a community,
- their current water needs for each water requiring activity,
- their aspirations / expectations for future water needs.

### iii. Design

After determining the water demand and estimating the water yield at the selected sand dam location, the following four main parts of sand dam can be designed:
- the dam
- spillway
- the wing walls and
- the stilling basin

**Dam height:** To determine the dam and spillway height at a specific location, it is very important that the water level and the maximum flood level will remain below the riverbanks after construction of the dam (Figure 41). The dam and spill way height are therefore determined by the maximum discharge and maximum flood height.

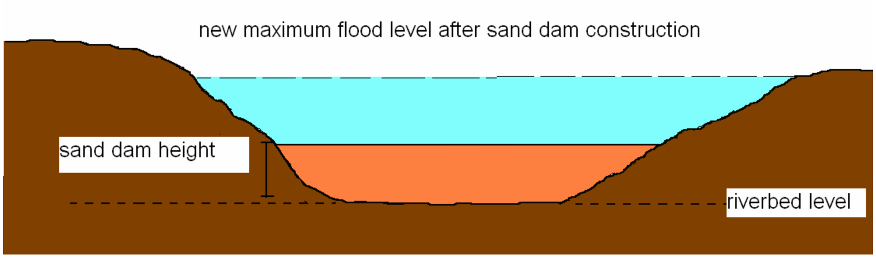


Figure 41. Examples of sand dam heights.

The most practical way of calculating maximum discharge is by getting information in the field and from the selected beneficiaries on flood levels. However, maximum discharge can be calculated in 2 different ways:

- Calculating the maximum discharge by the highest flood level (known by flood marks on the banks or information from local community's);
- Calculating the discharge at the selected location by using a certain return period (for example: a rain event with a return period of 50 years) by using a rainfall-runoff model or a mathematical formula for rainfall runoff.

In Figure 42 you see a cross-section at a dam location, with the different parameters that have to be measured to calculate the maximum discharge.

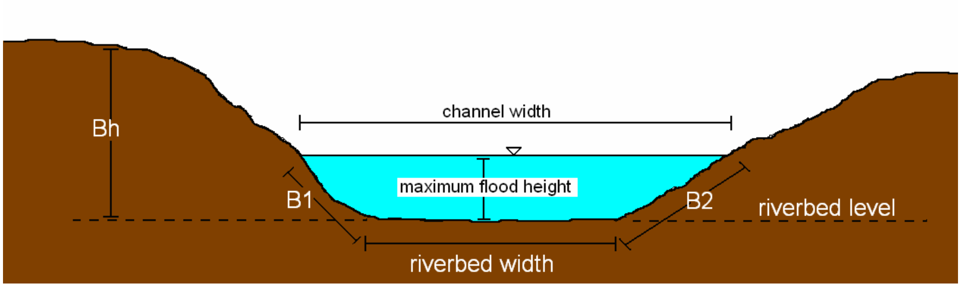


Figure 42. Cross-section with max flood height to determine max discharge.

**Maximum discharge in riverbed section:**

$$Q = 1/n * A * R^{2/3} * S^{1/2}$$

Q = maximum discharge in riverbed section ($m^3$/s)
n = Manning's roughness of riverbed
A = wetted cross-sectional area ($m^2$), by: ½*(channel width + riverbed width)* flood height
P = wetted perimeter (m), by: B1 + riverbed width + B2
R = hydraulic radius (m), by: A/P
S = slope of riverbed (m/m).

**Spillway, wing walls and stilling basin dimensions:** The maximum discharge (as determined using the above equation) is used to determine the spillway dimensions, for which the formula is given below:

$$\mathbf{Q = c * Ls * H^{3/2}}$$

Q = maximum discharge in riverbed section ($m^3/s$)
$L_s$ = length of spillway (m)
c = 1.9 (constant depending on spillway shape, here: broad crested weir)
H = height of spillway (m)

**Cross-sectional width dimension of a sand dam** (Figure 43):
$G_f$ = gross freeboard (m)
$L_w$ = length wing wall (m)
$H_f$ = height freeboard (m)
$L_{we}$ = length wing wall extension (m)
$H_d$ = total height of dam (m)
$L_s$ = length spillway (m)
$H_s$ = total height of spillway (m).

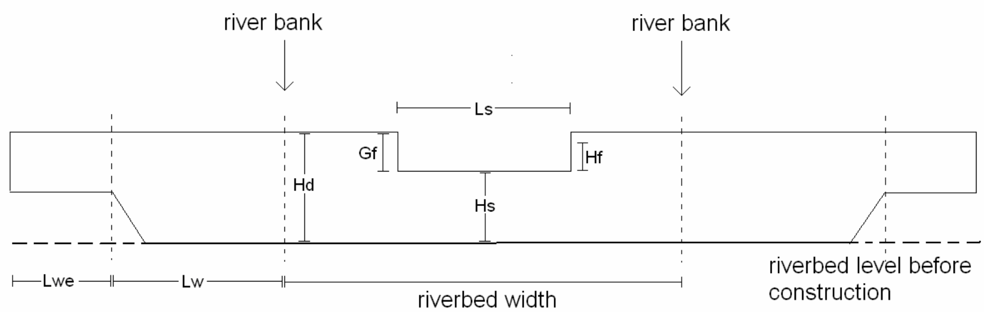


Figure 43. Cross-section of sand dam body and its dimensions. *Source:* RAIN, 2007.

When determining the distance the wing walls go into the banks, bank characteristics have to be taken into account (Munyao et al, 2004):

- in loose riverbanks: approximately 7 m into the riverbanks;
- in hard soils: approximately 5 m into the riverbanks;
- in hard and impermeable soil: approximately 0-1 m into riverbanks;
- in rock formation: no need of constructing in riverbanks.

The length of the wing wall ($L_w$) should be approximately 2 m into the riverbanks. The length of the wing wall extension ($L_{we}$) should be approximately 5 m. This is an example of wing wall dimensions in loose riverbanks.

**Stilling basin dimensions** (Figure 44):

$$\mathbf{S_L = c * L^{1/3} * H_2}^{1/2}$$

$S_L$ = length of stilling basin (m)
c = 0.96 (constant)
$H_2$ = height of freefall (m): height of water level upstream – height of water level downstream

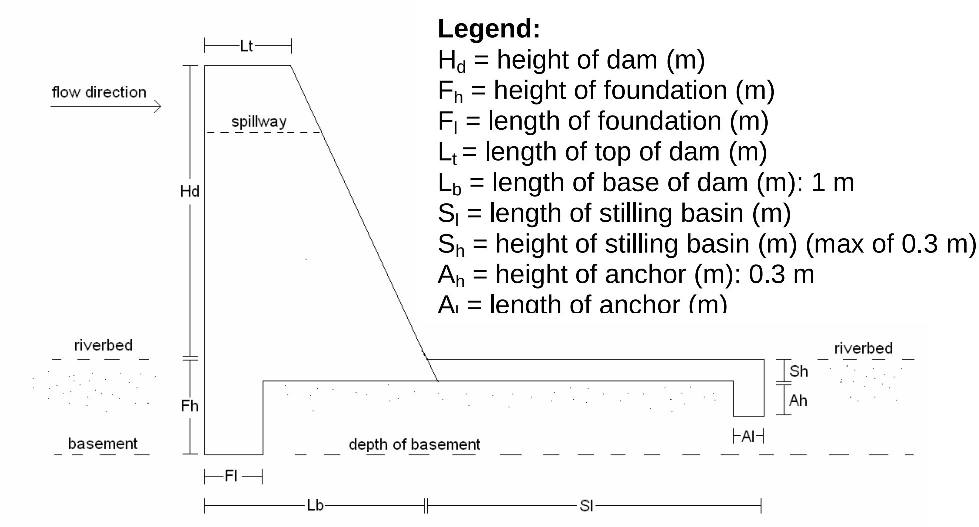


Figure 44. Legend of cross-sectional profile of a sand dam body and its dimensions. *Source:* RAIN, 2007.

### iv. Excavation and construction

The types of materials needed to construct a sand dam depend on the type of dam we select. This depends on physical properties of the catchment and on the materials available on the market as well as within the area of the selected sand dam location. If materials like stones and sand are locally available, this will reduce costs of materials and transport. In general 3 types of sand dams can be considered; Stone-masonry dam, reinforced concrete dam and earth dam.

a) **Stone-masonry dam** - A dam built of concrete blocks or stones (Figure 45). This type of dam can be easily constructed by local artisan. A stone-masonry dam is also durable and suitable for any dam height. The dam is cheap when construction materials are available within the dam area.

Figure 45: Stone-masonry sand dam after one runoff event in Borana, Ethiopia (Ethiopian Rainwater Harvesting association (ERHA), 2008).

b) **Reinforced concrete dam** - A dam consisting of a thin wall made of reinforced concrete (Figure 46). It is a durable structure, relatively expensive but suitable for any dam height.

Figure 46: Reinforced concrete dam in Mwingi, Kenya.

**c) Earth dam -** A dam consisting of impermeable soil material (mostly clay or clayey soils, or black soils). This type of dam is relatively expensive to construct and it requires special skill for its design and construction. An earth dam can easily be damaged and even destroyed by underground flow. Earth dams are not popular and are seldom used (only for minor works).

**The bill of quantity for stone-masonry dams:**

**Stilling basin:**
- 1:3 mortar
- Large boulders

**Dam:**
- 1:4 mortar with well interlocked stones, ratio cement:sand:hardcore = 1:4:9-12
- Upstream wall and top of dam plastered with 1:3 mortar (30 mm)

**Foundation:**
- 1:3 mortar foundation (100 mm)
- 1:4 mortar with well interlocked stones, ratio cement:sand:hardcore = 1:4:9-12
- (reinforcement bars of barbed wire (400 mm spacing)- for reinforced concrete dam

*Note:* Guideline in the calculation of the quantity of the materials derived from the dimensions of the dam is presented in Appendix 3.

**Labour:** The number of masons needed and days required to construct the sand dam depend largely on the size and location of the dam.

**The trench:** The size and position of the dam should be marked taking in to account the size of the wing walls and working space during construction (Figure 47). To estimate the size of the trench, the following should be taken into account:
- Measure the appropriate distance from one of the riverbanks depending on bank characteristics and fix a peg.
- Fix another peg across the river perpendicular to the river course at the appropriate distance.
- Use a plumb bob and line mark several points from the building line and fix pegs.

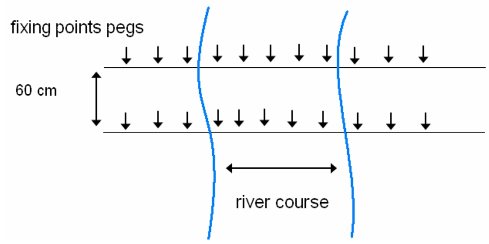


Figure 42. Example of setting a trench with pegs.

**Excavating the trench:** The marked trench is dug guided by the building line (Figure 47). The depth of the trench is determined by the depth of impermeable layer in the ground which will obstruct seepage below the sand storage dam. The dug out soil should be placed downstream of the building location to avoid it filling the aquifer. If the dam is build into bedrock material, a trench should be cut into the rock to ensure secure jointing of the rock and mortar. Care should be taken to make sure no fractures or weathering zones are present in the basement rock. If suspected, this can be tested by poring water on the suspected weathered zones. If the water leakes away, the rock surface should be cleaned from the weathered rock or fractured rock. If clay forms the impermeable layer, the trench should be dug in for about 0.5 m to avoid seepage.

**Construction of the dam:** Construction starts with putting in place the reinforcement columns vertically in the trench followed by the construction of the foundation blinding slab. Reinforcement is only required if a high dam is constructed. After this the second horizontal reinforcement layer is placed, followed by the second foundation blinding slab and then the actual masonry structure (of hard core and mortar) starts. In Appendix 4 you will find a detailed guideline for construction of a sand dam. Intensive technical supervision and monitoring is the major activity that should be attained during the construction process of a sand dam.

**v. Water extraction**

The most common way to abstract water from a sand storage dam is by means of a hand dug scoop hole in the riverbed. Water is scooped out at first, and the water that refills the scoop hole is abstracted. The method is susceptible for pollution, especially by animals. Therefore, animals and humans should use different scoop holes. The human scoop holes should be located close to the sand dam, on the upstream side. The animal waterhole should be at the downstream side of the sand storage dam.

A well is the better alternative for a scoop hole. It will protect the water quality because animals and river water can not enter. Many different types of wells exist. A well need to be covered and a hand pump should be used to extract water. If a well is located in the riverbank, the profile should be checked on permeable layers and their connection to the riverbed by making a test drill.

**Construction of wells:** A well for a sand dam is constructed similarly as a shallow hand dug well, usually constructed for exploration of shallow ground water. It is important that the well abstracts the water from the deepest parts of the river sands. The deepest sands will produce the safe water. The lining of the well should preferably have no openings at shallow depths. It could even be considered just to have an open well-floor, covered by gravel. If a well is constructed at the centre of a river, it is extremely important to protect it from high flood damages. The well has to be a ‘hydrodynamic’ type to withstand the forces of a flood and must be protected from siltation by keeping its height about 0.5-1 m above the surface of the riverbed. The top must be covered with a concrete slab (facing downstream to prevent entry of floodwater) to prevent contamination and mosquito breeding. The detailed construction process for a well and wellhead is given in Appendix 5.

**vi. Maintenance & management**

**Training of local community:** Facilitating community trainings on implementation, operation, management and maintenance are advised to be addressed during a community based sand dam project. Community trainings have the following objectives for the community:

- Full participation in the process of the project planning and implementation
- Enhanced awareness on project management
- Ensured technical and management skills after project completion
- Enhanced awareness on management of the water quality and risks involved.

**Technical training on operation, management and maintenance:** The water committee is responsible for proper operation, management and maintenance of the sand dam, which includes:

- Regular monitoring of the functioning and utilization of the sand dam
- Establishing a demand driven payment scheme
- Effective management of the water reservoir as far as possible.

Technical knowledge and skills to execute maintenance and repair works is hereby ensured. The trained community members can become potential artisans for the construction of future sand dams within the area. They will become the caretakers of the sand dam, wells and surrounding area.

**Management of a sand dam:** Since the water committee and care takers have been trained and have coordinated community mobilization during implementation, the responsibility of the sand dam will be fully assigned to the water committee and care takers after completion of the construction of the sand dam. The water committee will be responsible for the management of the sand dam as well as the payment scheme and the caretakers will be responsible for the daily monitoring, operation and maintenance of the sand dam, wells and surrounding area. The water committee, with support and assistance of the concerned local government departments and the implementing partner, will monitor all activities to ensure sustainability of the project.

**Maintenance:** If a sand dam is properly constructed, it only requires little or no major maintenance. The following issues have to be properly addressed:

- Good workmanship during the construction of the sand dam
- Full involvement of the community to ensure operation, management and maintenance once construction of the sand dams has been completed
- Presence of a trained mason near to the dam project to ensure adequate repairs
- Proper linkage between the local community, local administration and governmental.

## 7.9 Water pan for runoff water harvesting

A lot of water is lost in ASAL as surface runoff. Harvesting of this runoff and storage of the same into water pans makes it available for domestic/livestock use and supplementary irrigation. Pans can be square, rectangular or round in cross section and impound and retain surface runoff from uncultivated grounds, roads or *laga* (in Borana) and should be located in slopes not higher than 3%. Pans may require rehabilitation activities to make sure that adequate amount of water is ponded at every rainy season. Depending on mode of construction pans can be either excavated or impounded reservoir.

### 7.9.1 Excavated pan

A Pan also called pond as an excavated earth reservoir is easy to construct in relatively flat terrain and harvest runoff for livestock utilization and small-scale irrigation. Pans are preferably located in the topographically low area where runoff from infrastructures such as roads can easily be harvested and where impervious soils prevail to reduce seepage losses. Evaporation loss can be minimised by reducing amount of surface area in proportion to its volume. The capacity is variable and depends on site conditions and how much one wants to invest. Common ones are 1500 $m^3$ to 5000 $m^3$ but the capacity can be increased with time to hold more water. Site selection is essentially determined by the nature of the soils and the hydrological conditions.

a) **Nature of soil:** An adequate depth of impervious soil which can be easily excavated is essential. If there is any doubt as to the nature of the soil, numerous test auger holes should be bored over the proposed reservoir area to determine the suitability of the soil and particularly the permeability of the sub-soil strata. Sites with porous soils or with underlying strata of sand, gravel, fissured limestone and other porous materials should not be selected unless such strata are not of sufficient magnitude to cause trouble. Actually the easiest way for identifying possible sites for an excavated reservoir with the best probability of success is to select an area where water naturally accumulates or has accumulated and where clayey deposits cover a large area. In any case the thickness of the clayey layer has to be checked. However, it is possible to select a site even in case of insufficient clay thickness provided that during the construction work, the clay is carefully put aside and then spread again and compacted over the bottom of the reservoir after excavation. If hard rock is found costs of excavation will increase greatly. The fact that a reservoir may lose considerable water immediately after excavation does not necessarily mean that it will be unsatisfactory: performance will increase when bed and embankments become sealed in several months or even year(s).

Make sure that an adequate amount of runoff can be generated from the upstream catchment and be safely directed to the pond. The runoff from road side drains, (bare) hillsides and waterways can be targeted. If farmlands in upstream of pan have been treated using level fanya juu or soil bund it is hardly possible to obtain adequate amount of overland flow to fill up the pond.

**Hydrological conditions:** Before undertaking the excavation work, it is necessary to estimate the probability of filling the reservoir by runoff water. The hydrological investigations which can yield reliable information are usually lengthy and difficult to achieve. This is likely to happen only in the case of large reservoirs such as dam construction which may justify preliminary hydrological studies. In most cases the preliminary investigations will be limited to an enquiry with the local inhabitants and, in the case of already existing pans, to a careful survey of the trails of mud which give evidence of the water extension during the wet season. Where possible the drainage area should be chosen to minimize sediment runoff into the pan and the drainage area should be relatively small. Water normally enters into a pan through a well stabilised inlet. Water inlet should have silt trap(s) along the inlet channel to filter excess sediment load. Failure to have this, however, leads to an excessive influx of sediment load which undermines the live storage of the pond.

**Shape and depth:** Although pans can be built to almost any shape desired (rectangle, circular or trapezoidal) the rectangular shape is popular because it is simple to build and can be adapted to different kinds of excavating equipment. But embankments of trapezoidal and circular shapes are preferred for easy access of the livestock and stability of the walls. The side slopes should be as flat as possible using gradients of 2:1 or 3:1 depending on soil stability. Depth should be at least 4 m. Compaction of the embankment fill with barrels filled with soil, with a roller, lining the bed and walls with clay soil or polythene sheet on soils and planting of trees such as euphorbia around the water pan can increase the stability of the structure.

If pans are wide in surface area (e.g. 40 m by 60 m) but shallow in depth (e.g. 1 to 1.5 m) the effectiveness of pans can be poor due to excessive evaporation and seepage losses. Therefore go for deeper pans (up to 4 m deep) by reducing the surface area.

Surplus/excess water can be disposed of using a spillway that must be constructed for this purpose. In some cases water inlets are used as spillway; there is no problem in using inlet channel as a spillway.

**Building the pan:** The reservoir area should first be cleared of vegetation. The next step is to mark the outside limits of the proposed excavation with stakes indicating the depth of cut from the ground to the pan bottom. Normal tractors equipped with a bulldozer blade or simple bulldozers are generally used. But if the excavated material has to be transported far away from the excavation, additional equipment (power shovel and trucks) may be needed. For small reservoirs located in areas where manpower is not a constraint, hand operation can be envisaged for the digging work and transport of the excavated material. If the thickness of the impervious upper layer is insufficient when compared to the planned depth of the pond, the topsoil should be temporarily stockpiled for later use as sealing layer over the bottom of the pond. In that case, the clayey material should be properly compacted after it has been spread and moistened. Construct silt trap(s) along the inlet channel to filter excess sediment load.

Excavated soil from the reservoir section should be used to build the embankment wall, with side slopes of 1:2.5 for shallow pans to 1:3 for deep pans. When pans are dug the excavated material should be put in a designated place (at around the pan), levelled and compacted. This important issue is sometimes overlooked and the excavated material is just through away.

**Stock watering and protection of the pan:** Complete fencing of the reservoir is recommended to avoid damaging by trampling and water pollution by livestock. When the pan is fenced a watering system (usually cattle trough) has to be installed outside the fenced area. It is also possible to install a suction pipe that runs below the bank of the pan and feed water to water utilization point. The water inlet inside the reservoir should be protected against clogging by a strainer made of a piece of screen. The pipe itself may be of small diameter, 2 inches for example, arid made of steel or plastic. Note that it is extremely difficult in hot climates to prevent livestock (and sometimes herders) from destroying fences which they consider as an unjustified obstacle to reach water when they are thirsty.

**Minimum technical standards and worknorm elements:**
For easy understanding we present typical rectangular pan constructed by the Arid Lands Resource Management Project (ALRMP) in Tana River (Wayu Duka) (Figure 33, left) and circular pan constructed using WFP's food assistance for vegetable production in Ethiopia (Figure 48, right). This circular pan (Figure 48, right) has stairs or steps making water abstraction easy for the communities. For plan and cross-sectional views of a typical trapezoidal pan see Figure 49.


Figure 48. Rectangular pan (left) and circular pan (right).

Construction and water abstraction:

- Reservoir capacity can vary between 1500 m³ and 5000 m³ and depth 4 meter. Cross-section can be either circular or trapezoidal,
- Clear the reservoir area of vegetation
- Mark the outside limits of the proposed excavation with stakes indicating the depth of cut from the ground to the pan bottom (Figure 49)
- Dig and put the excavated material at a designated place (at around the pan)
- Build a trapezoidal embankment using the excavated material with side slopes of 1:2 for shallow pans to 1:3 for deep pans
- Level and compact the embankment as building progresses
- Lining the bed and walls with clay soil or polythene sheet reduces seepage
- The level of the collection channel should be 50 cm below maximum water level
- Surplus water can be disposed of using a spillway designed with free board height 0.5-0.75 m, and width based upon watershed area, runoff coefficient and max rainfall intensity. Spillway must be paved and side protected. In some cases water inlets are used as spillway. To reduce head cut and scouring problems drop structure + apron are needed

- **Silt trap** (min. 2-4 m x 2-4 m width x 1.0-1.5 m depth) constructed minimum 10 m between end of interception drain and pond area
- Construct stairs or steps against pan wall for domestic use up to 0.5 meter from bottom of pan (Figure 48, right)
- Install suction pipe that runs below the bank of the pan and convey water to water utilization point. The pipe diameter can be 2 inches made of steel or PVC. The water inlet inside the reservoir should be protected against clogging by a strainer made of a piece of screen
- Animals should not be allowed to enter pans; Dry fencing + vegetative fencing is required for better protection.

**Worknorm elements:**

- Removal of grasses and shallow trench construction on place for embankment,
- Excavation,
- Transport of soil, embankment raising and compaction,
- Spillway construction,
- Cattle trough construction,
- Access path for water collection construction,
- Collection drain construction,
- Silt trap construction,
- Dry fencing with thorny bushes (vegetative fencing has its own work norm).

**Worknorm: 1 m$^3$ per person day.** Digging and scooping of the top soil will be easy in general. But as depth increases digging and scooping require more energy.

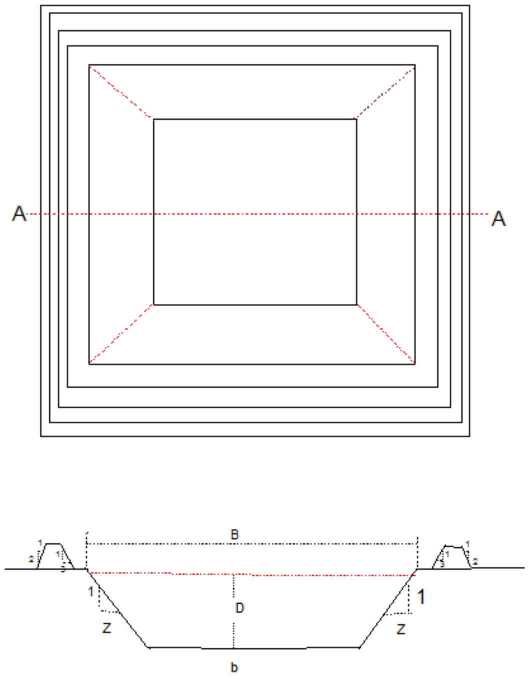


Figure 49. Plan and cross-sectional views of typical trapezoidal water pan.

### 7.9.2 Impounded pan

An impounded reservoir (embankment pan), is made by building an embankment or earth fill across a narrow valley. While excavated reservoirs usually consist of improving an existing situation (natural pans), the impounded reservoirs create a completely new surface water storage structure. In short impounded reservoirs are intended to intercept runoff from open catchments. The volume of runoff water is often bigger than the capacity of the reservoir itself so that it is usually necessary to provide a spillway to bypass surface runoff after the pan is filled. The implementation of impounded reservoirs requires a more accurate estimate of the surface runoff than for excavated reservoirs since both the embankment and the spillway have to be designed accordingly.

**Site selection:** Selecting a suitable site for the impounded reservoirs is important and preliminary surveys are needed before final design and construction (please read other texts for understanding survey techniques). Site selection is determined by multiple factors that include: morphological characteristics, adequacy of the drainage area, nature of soils in the ponded area, foundation conditions, spillway requirement and design of the dam.

a) **Morphological characteristics:** A good site is where a dam can be built across a narrow section of a valley, the side slopes are steep and the slope of the valley floor permits a large area to be flooded. Sites where water may expand over large areas under shallow depth should be avoided since they would expose a large surface of shallow water to high evaporation.
b) **Adequacy of the drainage area:** The contributing drainage area should be large enough to fill the reservoir at least 8 years out of 10. However the drainage area should not be so large than expensive overflow structures (spillways) are needed to bypass excess runoff during storms. Where rainfall is not too variable the drainage area can often be chosen to have a minimum cost overflow. In semi-arid areas this is not the case and irregular, high intensity storms of short duration may cause extensive damage if proper spillways are not constructed. The amount of runoff that can be expected from a given watershed depends on so many interrelated factors that no set rule can be given for its determination. The physical characteristics that directly affect the yield of water are relief, soil infiltration, evaporation rate, plant cover and surface storage.
c) **Nature of soils in the ponded area:** Suitability of a pond site depends on the ability of the soils in the reservoir area to hold water. The soil should contain a layer of material that is impervious and thick enough to prevent excessive seepage. However, the presence of a surface layer of sand or other permeable material does not necessarily mean that the proposed sites should be abandoned; these pervious layers may just be an alluvial deposit covering an impervious bedrock. In most cases detailed investigations including auger holes should be carried out.
d) **Foundation conditions:** Particular attention should be paid to the nature of the soils at the proposed dam location in order to ascertain that the foundation would ensure stable support for the structure, and provide the necessary resistance to the passage of water. Good foundation materials, those that provide both stability and imperviousness, are a mixture of coarse and fine textured soils like gravel-sand-clay or sand-silt-clay mixtures. When the soil beneath the dam location is

able to ensure the stability but not the imperviousness, a cut-off core of impervious material must be installed under the dam.

e) **Fill material:** The availability of suitable material for building a dam is a determining factor in selecting a pond site. Enough suitable material should be located close to the site so that placement costs are not excessive. Materials selected must have enough strength for the dam to remain stable and be tight enough when properly compacted, to prevent excessive or harmful percolation of water through the dam. The best material for an earthfill dam contains particles ranging from small gravel to fine sand and clay in the desired proportions. The material should contain about 20% by weight of clay particles. As for the foundations, if the material selected for the earthfill is pervious, a core of clay material has to be placed in the centre of the fill.

f) **Spillway requirements:** The function of a spillway is to pass excess storm runoff around the dam so that water in the pond does not rise high enough to damage the dam by overtopping. Emergency spillways for small dams in semi-arid countries should have the minimum capacity to discharge the peak flow expected from a storm of a frequency of 1 year in 10 and duration of 24 hours. As a very rough estimate it is possible to use the following formula corresponding approximately to the most usual situation in semi-arid countries. This formula can be applied for a small drainage area with moderate slope over the drainage area and with moderately permeable soils,

$$D = 1.84 \times A^{0.675}$$

in which D is the peak discharge in litres per second per millimetre of maximum daily rainfall with a frequency of 1 year in 10 and A is the drainage area in hectares.

In arid climate an artificial spillway has to be excavated beside the dam and then lined with stones or concrete.

g) **Design of the dam:** The detailed design of a dam, even if it is small, cannot be treated here in the framework of this manual. The main points which have to be taken into consideration are:
   a) water supply pipe through the dam is needed for the stock water troughs;
   b) cut-offs through the foundation and the dam itself may be needed in order to ensure tightness;
   c) the top of the dam should be wide enough to ensure the stability;
   d) side slopes upstream and downstream should be low enough to prevent collapse.

### 7.9.3 Pan maintenance

A pan, no matter how well planned and built, must be maintained in order to preserve its storage capacity as well as a proper functioning of the watering facilities, if any, throughout its expected life. When fenced, a pan needs a permanent maintenance in order to ensure the integrity of the fence during the whole period of presence of water in the reservoir, but this constraint is so costly that watching and maintenance are not sufficient and the fences disappear a few weeks after the pan has come into operation. Pan maintenance activities should be accomplished before each rainfall season kicks off to make sure that the necessary amount of water is ponded. The following specific activities should be done:

- Desilting and deepening

- Application of clay blankets for seepage control
- Construction of embankments protecting wells (water deflection)
- Rehabilitation of silt traps
- Fencing of pan area.

### 7.10 Homestead (*manyatta*) intensification & diversification

Water harvesting should support productivity improvement and income generation of the households in ASAL. The water stored in different reservoirs (micro-dams and farm ponds can be used for growing fruits, vegetables and other high value crops. Manyatta areas are suitable for these kinds of activities. Nonetheless, this very important venture has rarely been recognized and effectively utilized. This situation might have contributed to the poor advances and wide application of the RHM technologies in ASAL.

Intensification and diversification of agricultural production activities and income can be feasible way of attaining food security at household level by subsistent communities. Manyatta intensification activities will have the advantage of reducing hardship, improve income generation and saving, direct control and easier management of rehabilitated areas, high potential of technology dissemination to other areas, empowers women, etc. However, one should be aware that an integrated approach among different professions and/or organizations is required which is not always easy to achieve in arid areas. Moreover, inter and intra household dynamics need to be addressed and considerable follow up of the activities is required at initial stage.

In Manyatta areas, runoff and rainfall water can be concentrated from a bigger area (catchment) into a smaller area to be used for vegetable, fruit and fodder growing. Besides *in-situ* moisture conservation efforts can be enhanced to improve infiltration and retention capacity of soils. These efforts (*ex-situ* and *in-situ*) can be better reinforced and implemented at *manyatta* areas by individual households or group of households for income generation because:

- Livestock manure is plenty here but poorly unutilized
- Manyattas can be easily fenced (green or dry) to control interferences of any sort
- Family members (especially women) can be sensitized to take up the initiatives
- Distance travelled to do farm management activities can be less compared to that for areas situated faraway from manyatta areas.

The following packages of activities can be implemented:

- Tie-ridges, trenches, Zai pits for growing of fruit trees, fodder, medicinal (Neem, Arthemisia, etc) and shade trees
- Dry land forestry (including fruit trees, dyes and gums trees and cash crops)
- Fodder plantation (backyard plantations)
- Multi-storey agro-forestry system
- Composting and manure application techniques.
- Alley cropping, strip cropping, mulching in tie ridges for home gardens
- Enclosures, reseeding and semi-circular hoops for improved supply of grass
- Fuel saving stoves enterprises.

With harvested water the availability of grass and fodder can be improved in close proximity to the manyatta. Since, in some cases, the area has already been divided into enclosures for individual stock keepers it becomes relatively easier to manage. Soil fertility management is one of the key methods for soil conservation and improvement of productivity. Composting and manuring are among such techniques, which have proven to be effective for sustainable fertility management and erosion control at the same time. They are extremely important for increasing production and cutting down of spending on chemical fertilizers. To realize this aspiration, the villagers or individual households should maximize biomass production from various vegetation species: grasses, legumes and shrubs/trees on hillsides, in gullies, around fences, on farm boundaries, etc. The biomass production from weeds and other vegetation during rainy season should be carefully collected and used for compost making. The activities can be managed by individual household or group of households (mainly women groups). A manyatta development plan can use the approach as in Figure 50. Live fence can be established around manyatta houses to reduce trampling of activities by people and animals. Another live fence can be established at an intensification exterior boundary for the same reason as with an interior intensification boundary. The size of the land to be developed can be decided based on specific situations (e.g. land availability, commitment of the community and technical support) in the area.

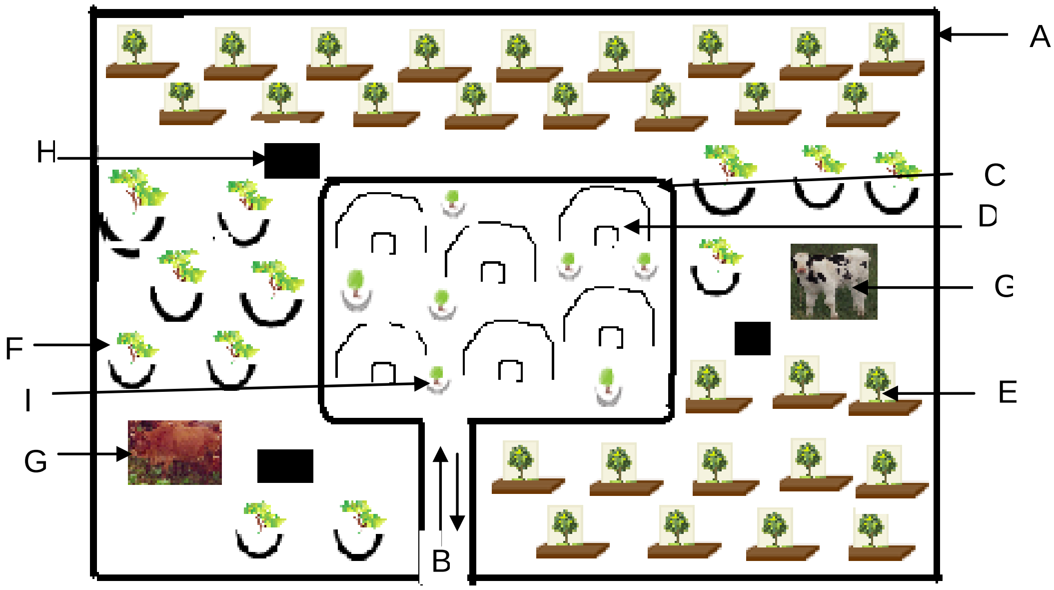


Figure 50. Manyatta intensification plan.

***Note:*** A = An exterior boundary (live fence); B = Gate; C = An interior boundary (live fence); D = Manyatta home; E = Micro-catchment planted with fruit or fodder tree; F = Semi-circular bund planted with fodder plant; G = Stall fed animal; H = Manuring/Composting, I = Microbasin planted with shade tree.

### 7.11 Nursery establishment and seedling production

Fuel wood is the most common source of household energy for both rural and urban households in ASAL. Moreover charcoal production as an economic activity is nowadays widely practiced. Charcoal production activity which targets the big trees that have been growing for the last 20 to 30 years is expanding these days. This could reduce the vegetation cover of the already fragile ecosystem. Yet there is no

any meaningful plantation going on to replace those trees cut for different purposes including charcoal making.
Conservation (protection) of natural vegetation and plantation activities can simultaneously be implemented in ASAL. Conservation of exiting trees and shrubs could be achieved through awareness raising and creating and enforcing community bylaws. It was indicated earlier that planting of trees by communities is not common in ASAL probably due to community's pastoral way of life; there has been no any meaningful support provided either. However, with the introduction of water harvesting technologies (*negarims*, micro-basins, trapezoidal bunds, etc) trees can be planted at manyatta areas and along (ephemeral) rivers and gullies. Combining rainwater harvesting technologies and tree planting will enhance seedling survival rates especially during the dry period.

Thus developing nursery sites for the production of drought tolerant multipurpose plant species is very important activity. This activity will increase income generating opportunities and contribute to resilience building and environmental protection. Besides other factors the availability of water is a precondition for establishing nursery sites. The activities in these nurseries can be managed by group of people mainly women groups and should be linked to homestead and riverin development initiatives. These development sites should be fenced (dry or green fencing) with locally available materials to reduce livestock interferences. Seeds can either be collected locally by using food for work or purchased from elsewhere. Training should be done on nursery management (tools and seeds handling, seedling transplanting, watering, weeding, grafting, pruning, seeds scarification, soaking, compost making, etc.). Table 14 Gives names and uses of some tree, shrub and grass species suitable for ASAL condition. Seeds can either be collected locally or purchased.

Table 14. Suitable trees and shrubs suitable under ASAL condition.

| **Botanical name** | **Uses** |
|---|---|
| Acacia tortilis | Fodder (pods), fuel wood, charcoal |
| Acacia Senegal (Gum Arabic) | Gum |
| Acacia melifera | Edible gum, fuel wood, charcoal |
| Acacia reficiens | Edible gum, fibre |
| Balanites aegyptiaca | Fodder (fruit), medicinal |
| Cordia sinensis | Fodder (fruit), construction, furniture |
| Maerua crassifolia | Camel browse, medicinal |
| Grewia villosa | Edible fruit, fodder, charcoal, walking sticks |
| Tamarindus indica | Edible fruit, fodder, charcoal, walking sticks |
| Ziziphus mauritiana | Edible fruit, medicinal, tool handles |
| Acacia albida | Fodder (pods), tannin |
| Acacia seyal | Medicinal, pods for fodder |
| Leucaena spp, Sesbania spp | Fodder, soil fertility |
| Senna siamea | Fuel wood |
| Azaridachta indica (Neem) | Medicinal, fuel wood |
| Terminalia brownie | Construction |
| Melia volkensii | Construction and timber |
| Melia azridach | Construction and timber |
| Cassia siamea | Legume, timber and hedgerow |
| Parkinsonia aculeate | Windbreak |

**Site selection -** Success or failure of a tree nursery depends on the suitability of the selected site. Factors to consider are plot area, water, soil, topography and access:

a) **Area required** - Depends on the number of seedlings to be raised and the production system. For Chiefs Nursery/School Nursery aimed at producing 50,000 plants per season require 25 m x 25 m (625 $m^2$) area. More specifically to raise 1000 forest/fodder trees only 4.5 $m^2$ land is required. But to raise 1000 fruit trees just 8.5 $m^2$ is sufficient. Above is minimum area required in starting a nursery but additional space for foot paths, store, working area, etc are required.

**b) Water availability**

- Seedlings have to be watered once or twice daily.
- Quality of water is important; it should not be saline and should be of neutral PH.
- Distance between the water source and nursery is important.
- Water requirements for nursery stock will vary with location of the nursery, time of the year, stage of seedlings and production method.
- Thumb rule - potted stock requires about 5 to 10 mm per day.
- Equivalent to 5 to 15 liters of water per $m^2$ of nursery bed per day

**c) Soils**

- Soil is the growing medium for all plants
- Good soil must be available within the nursery or close at hand.
- Soil requirement: for 10,000 seedlings in 4x6 inches tubes is about 5 $m^3$ of soil; for 2000 fruit seedlings 5x9 inches bags – 3 $m^3$
- The soil used, must be light and freely drained and must as well have capacity to retain moisture.
- Bare-root seedlings utilize the soil already in the nursery.

**d) Slope**

- Best site should be 3 -5% slope to allow ease of drainage of excess water without causing erosion. If the site is flat there is risk of flooding and appropriate drainage must be put in place.
- Site – steeper slope must be terraced.

**e) Access and fencing**

- A nursery must be close to the area where the seedlings are to be planted and suitable for evacuating seedlings.

**Fencing and windbreaks**

Once the nursery site is established fencing is done using live fence or wire mesh but be advised to plant hedge around the nursery. The species include Leucaena, griliricidia, camiphora, etc.

A well designed windbreak will protect the nursery from strong winds and reduces evaporation losses. It provides a favourable micro climate to the seedlings and protects young seedlings from damage and promotes better growth. Windbreak also creates good working environment for the people working in the nursery. Windbreak should aim at reducing wind speed by 50%. Prosopis species, Azadirachta indica (Neem), Acacia scorpioides, Leucaena leucocephala, Parkinsonia aculeate, etc. can be used for windbreaks in ASAL.

**Seedbed**

- Soil in the seedbed should be freely drained, light clay and contains good amount of sand
- Width of bed should be 1 m to 1.2 m but can be length of any length
- In clay soils - drainage must be improved by digging a 0.4-0.5 m deep formulation a layer of stone laid (0.20-0.25 m) and filled up with sand
- Seedbed surrounded by blocks of stones or timber to support the soil
- Polytubes planted with seedlings are arranged in a proper order
- Root pruning of young seedling is a laborious but necessary job
- A sheet of black polythene is usually laid on the ground to prevent roots from growing into the soil beneath the tubes or bags
- A layer of 1-2 cm coarse sand above the polythene sheet will retain moisture while protecting roots from fungi attacks
- Drainage system should be put in place, which can be opened and closed
- In dry areas, beds should be laid below ground level (sunken bed). Sunken beds should not go below 5 -10 cm below ground level
- But raised bed can be used where floods occur to avoid water digging
- In both raised and sunken beds the walls should be stabilized with stones or cut of timber.

**Access and paths:** Access should be planned for during the initial layout. Paths between nursery beds should be between 60 and 80 cm wide to ensure ease of mobility.

**Shade:** Young Nursery stock requires shade during the establishing period. Shade could be provided by a large trees or simply thatched house. The shade could be permanent or semi permanent. A permanent shade is structure where potted nursery stock is placed during first few weeks after transplanting and is at least 2 m high. A permanent shade covers several beds. A semi-permanent shade covers a single bed and is placed about 60-90 cm above the seedlings. Structure for semi-permanent shade is made by wooden sticks and covered by grass or branches. When no longer needed, the shade is removed.

**Sowing the seeds and weeding:** Care should be taken when packing the seedlings and delivery to planting site. Generally seeds should be planted in a fine seedbed at depth of 1 to 2 times its diameter. After germination regulate seed density to maintain vigor and appropriate size of the seedlings. Care of seedlings in the seedbed should ensure that good healthy seedlings are planted. Weeding should be done regularly.

**Water supply:** Water can be applied using either watering cans or irrigation canal. Irrigation canals lead water to the nursery and nursery beds by gravity. Water demand can be determined as follows: for seedbeds (seeds not yet germinated) water application rate can be as low as 5 mm per day. This means that 5 liters of water is required to irrigate 1 $m^2$ of seedbed. But for nursery beds (after germination) one application per day of 10 mm (10 litres per $m^2$ of nursery bed) is recommended. Quantity of water required can fluctuate, depending on local climatic conditions, stage or the seedlings, the species and other factors.

A wide variation of worknorms are expected if computed based upon type of trees to raise, access to water, etc. However, a realistic average should be found. Different organizations allocate individual worknorms for each element of seedling production activities which is relevant at nursery site for monitoring of day-to-day activities by a nursery foreman (see Annex 2). For example one can approach in such a way that 1 person fills 100 poly pots per day. However, for planning purpose at national and provincial levels a computed (sum) worknorm is required. For example in Burundi 20 person days are required for producing about 1000 seedlings.

### 7.12 Pitting: digging holes for seedling planting

Pitting is exclusively allowed for area closure enrichment, road side plantation and other plantations which are mainly conservation based (including large community woodlots combined with conservation structures). Pitting should be done prior to plantation date, usually one month before plantation date. One person can dig 15 to 20 pits per day. Pitting for individual and interested groups plantations is not considered because they should be done on self-help basis.

**Minimum technical standards:**

- Diameter: 30 cm
- Depth: 30-50 cm
- Staggering of subsequent line of pits (preferable)

**Work norm elements:**

- Layout (staggered between consecutive rows)
- Excavation of soil
- Removal of large stones from soil (if any)

**Worknorm: 1 person day per 15 planting pits.**

### 7.13 Tree seedling planting

Seedling planting is an activity that as much as possible should be conducted on a self-help basis. This should be compulsory for individual or groups woodlots and homestead plantations. However, there are cases where conservation sites need particular attention and need certain kind of incentive. For instance plantation of degraded sites such as area closures and gully sections need incentive.

**Minimum technical standards and work norm elements:**

- Preparation of running nursery or resting place,
- Watering of seedlings before plantation,
- Transportation to planting site (carrying, loading and unloading),
- Removal and disposal of polythene tubes (if any),
- Plantation and filling and compaction of soil around seedling.

**Worknorm: 1 person day per 50 seedlings.**

### 7.14 Alley cropping

When shrubs or trees are planted in a series of rows across the slope (on the contour) and crops are planted between them, it is called alley cropping. The shrub or tree rows are called hedgerows and the space between where the crops are grown are called alleys (Figure 51). When nitrogen-fixing shrubs are grown, leaves and shoots from hedgerows can be used as green manure for fertilizing crops and orchards, and as fodder for livestock.

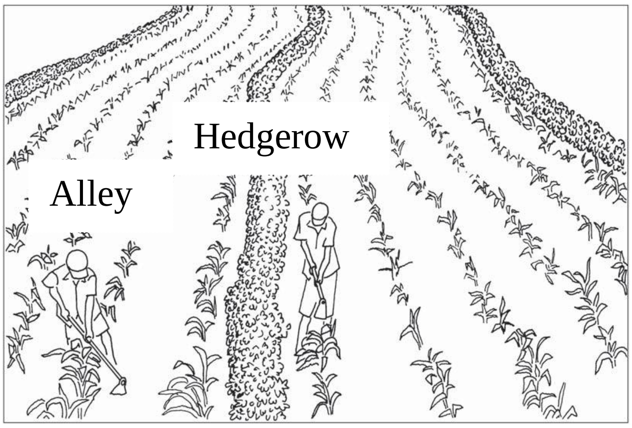


Figure 51. Lay out of hedgerow and alleys.

Some of the major advantages of alley cropping are:

- Provide nutrient rich green manure and mulch to fertilize crops and orchards,
- Produce fodder for animals,
- Protect and improve topsoil. Hedgerows slow down rainwater, filter out soil particles, add organic matter, and let more water soak into the ground,
- Reduce erosion,
- Provide shade and food (if trees are planted).

Some hedgerow shrubs and trees are pigeon pea, sesbania, calliandra, Leucaena leucocephala, Cassia siamea, Senna spectabilis and Gliricidia sepium can be used for hedgerow planting in ASAL Kenya. To get good results:

- Pick hedgerow plants that will not compete too much with crops for water and fertilizer,
- Let hedgerow trees or shrubs grow for at least 12 months before pruning them back to the desired height,
- Manage hedgerow plants so they won't shade crops,
- Don't use hedgerow plants that will attract insects and diseases to crops,
- Don't use hedgerow plants that can escape from the farm and become problem weeds in natural areas or forests.

Plant level and across the slope, without any low spots where water can channel and break through. Alley cropping hedgerows should be flat across the slope, no steeper than 1-2% grade. It is important to take time to lay out contour lines to guide you in the field. This is done with simple instruments such as a line level or A-frame. Extension workers can help show farmers how to layout contour lines.

The spacing between the shrubs in the hedgerows can be determined based on the recommendation given in Table 15. The steeper the slope of the land, the closer together the hedgerows should be. On very steep slopes, plant hedgerows with at least two rows of trees spaced closely together.

Table 15. Suggested spacing for alley cropping hedgerows.

| % Slope | Field spacing (meter) |
|---|---|
| 3-10 | 18.0 |
| 10-20 | 9.0 |
| 20-30 | 6.0 |
| 30-40 | 4.5 |
| 40-50 | 4.0 |

*Source:* USDA NRCS Vegetative Barriers.

**Minimum technical standards:**

- A great range of designs and spacing are possible,
- Double row is considered effective,
- Maximum spacing between alleys is 4-18 meters,
- Plant density within row: 20-50 cm,
- Plant spacing between two rows of each alley**:** vary based on species e.g. 30-40 cm
- Tree and shrub seedlings are planted in shallow furrows on ploughed fields.

**Work norm elements:**

The work norm includes furrowing, planting and compaction of soil around plants.
As much as possible this activity should be part of self-help work and be considered for food payments only as demonstration or in exceptional cases. Management of alleys (pruning, etc.) should be part of self-help effort.
Achievements are reported in kilometre.
Interim **work norm: 20 person** days per kilometre of alley.

### 7.15 Grass strip planting

Grass strips along the contour serve as barriers which capture soil particles that have been detached and are transported with runoff from the cultivated land. The strips are usually about 0.5 to 1 m wide and spaced at normal terrace spacing. It is an effective soil conservation measure on soils with good infiltration and slopes up to 30%. Grasses could be used for animal feed. Grass strips should have a very dense growth near the soil surface to effectively slow down runoff and retain eroded soil material (Figure 52). As runoff is usually only a few centimetres deep, it is most important that the grass strip is dense at the ground level and without gaps. Grass strips lead to the formation of terraces, mainly because of deposition on the upper portion of the strip and are one of cost effective soil conservation measures.

The following are grasses commonly used for making grass strips: Elagrostis (Maasai grass), Cenchruscilliaris (African foxtail), Cynodom dactylon (star grass), *Pennisetum purpureum*, (Bana grass), *Panicum maximum* (Guinea grass), *Chloris gayana* (Rhodes grass), *Vetiveria Zizanioides* (vetiver grass), etc. One has to choose which grass species is suitable to which agro-climatic condition and implement accordingly.

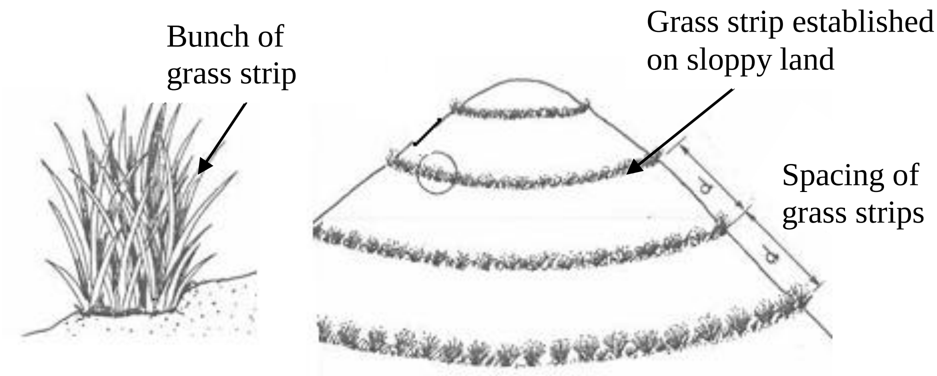


Figure 52. Grass strips established on sloppy land along contour lines.

Grass strips can be established by either direct seeding or through planting of splits or tillers along single, double or triple rows depending on the width of the strip and plant species. When multiple rows are done planting should be staggered to maximise soil infiltration and filtering of soil particles (Figure 53). Direct grazing of grass strips reduces their effectiveness and should thus be avoided as much as possible. Instead the grasses can be utilised using cut and transport method.

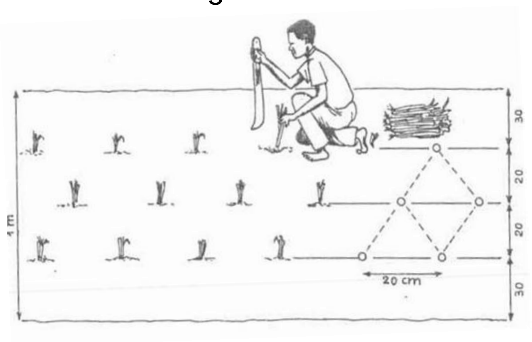


Figure 53. Planting technique of 1 m grass strips; triple rows 0.2 m space between plants and rows; splits or tillers are used.

**Minimum technical standards:**

- A 0.5 -1.0 m **standard width single or multiple rows of strip** is considered. When 3 rows are required 2 outer rows of grasses and one middle row of legume is recommended. Other options are also considered when particular grasses are planted such as Vetiver (one tight row of vetiver and one of legume shrubs),
- The activity includes fine seedbed preparation (fine ploughing, removal of weeds), shallow furrows, planting of grass splits and seedlings close apart (10 cm) within row and light compaction around plants.
- When legumes are planted in a middle row, by direct seeding not deeper than 1.5 cm.

**Work norm elements:** Work norm includes precise layout, seedbed preparation and sowing and planting, and compaction.

**Achievements** are reported in kilometre.

**Interim work norm:** 30 person days per kilometre.

## 7.16 Soil bund 'fanya chini'

Soil bund also called *fanya chini* in Swahili is channel terrace structure constructed across the sloping arable land surface to intercept surface runoff. These structures break up a long slope into a series of short ones, each channel collecting the runoff from a definite area of the slope above it. Depending on the soil type, amount and intensity of rainfall, soil bund can be graded or level. In areas of low rainfall, if the slope is gentle and the permeability of the soil is good, absorption or level bunds are used. Level bunds are formed along the contour with the intention of holding runoff water so that it gradually infiltrates into the soil. On the other land, at steeper slopes, in wet and moist regions and where the permeability of the soil is low, graded bunds are formed on a gradient with the intention of draining off the runoff from the arable land at a non-erosive velocity to a place where it can be safely discharged. In general, level structures are appropriate conservation measures for drier areas where the rainfall is less than 700 mm.

*Fanya chini* are constructed by digging ditches and throwing the soil downhill to form a downside embankment. It is suitable and economical for slopes between 8 and 15%, soils about 1 meter deep and medium rainfall areas. Herbs and grasses should be established on the bund to stabilise the structure and the plants can be used for different purposes such as fodder, food and soil fertility enhancing.

Layout of bunds can be easily done by using a line level or A-frame. When a line level is used, two poles of each about two meters height graduated at every 5 cm and nylon string of about 11 m are required. Three persons are also needed, a technician and two farmers. The technician guides the alignment by putting/hanging the line level in the middle of the string while the two farmers hold the poles far apart (see Appendix 1). Laying out of level bunds by using line level does not require special skill.

*Fanya chini* can have either a rectangular or trapezoidal cross-section (Figure 54). It is easy for farmers to make rectangular sections but trapezoidal bunds are more stable. The volume of the ditches or basins (depth, width and length) varies with the amount of runoff, which in turn varies with spacing, the peak rainfall, surface conditions and infiltration rate of soils. As a rule, they should be designed and constructed wide and deep enough to hold the peak runoff water expected from each specific sub-watershed or strips of land until it infiltrates. A 15-20 cm Berm (strip or ledge) is left between the embankment and the channel in order to prevent sliding of the soil into the channel. The embankment should be placed properly in a designated space, compacted and levelled when it is wet by people walking on it or rollers. A good grass cover should be established on the embankment, and a strip of grass should be planted along the upper edge to prevent the inflow of sediment.
Spacing between two soil bunds is estimated using this formula:

$$VI = 0.3 \left(\frac{S}{4} + 2\right); \qquad HI = \frac{VI * 100}{\%slope}$$

*VI* = vertical interval between successive bunds (m)
HI= horizontal interval (m)
S= land slope (%)

**Note:** in this formula only land slope is taken into consideration (other factors such as soil infiltration, permeability and rainfall are not considered).

**Minimum technical standards:**
A range of fixed values for dimension of soil bund are given based on the following schematic representation of a trapezoidal cross-section:

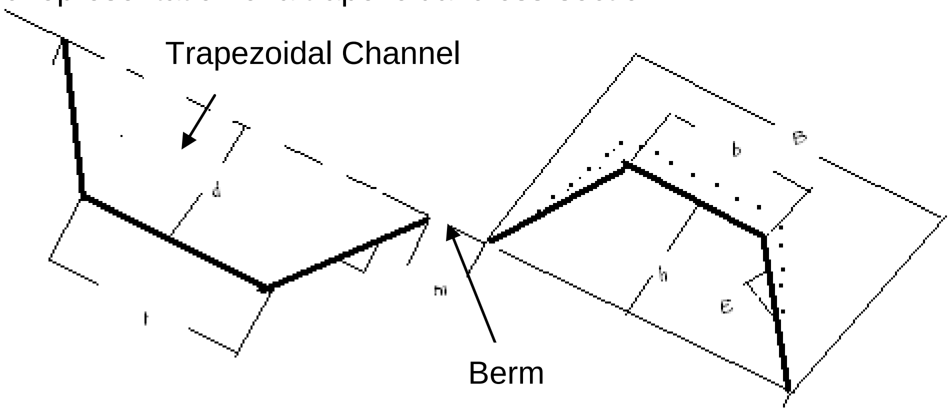


Figure 54. Cross-section of trapezoidal soil bund.

T= Top width of burrow trench (80 cm)
t = Bottom width (40 cm)
d= Depth of burrow trench (50 cm)
E= Embankment gradient 1 (horiz.): 2 (vert.)
B = Width of bund at base (90 cm)
m = Berm (15 - 20 cm)
b = Top width (30 cm)
h= Height after compaction (5 15-20 cm Berm

*Note:* **Channel:** shape, depth and width vary with soil, climate and farming system,
**Ties (if appropriate):** tie width with dimension as required, placed every 3-6 m interval along channel (only level bunds),
**Gradient (for graded bunds):** minimum 0.2% - maximum 0.6%

**Work norm elements:**

- Precise layout along contours (level) or gradient (graded),
- Scratching or removal of grasses from where embankment is constructed for better merging and stability,
- Excavation of trench or channel,
- Ties along channel (if necessary),
- Embankment building, shaping and compaction,
- Levelling of top of bund with an A-frame (level bunds)
- Checking gradient of graded channel (graded bunds)
- Stabilization of bund outlet (graded bund) and link to waterway

**Work norm: 150 person days per kilometre.**

## 7.17 Fanya juu bund

Fanya juu bund is similar to soil bund in many aspects. However, fanya juu bund is constructed by throwing the soil uphill to form an upside embankment and can easily develop to bench terraces as compared to level bunds. Fanya juu construction requires higher labour than soil bunds because of uplifting of soil material. It is suitable for slopes between 15 and 30 %, soils deeper than 1 meter and medium rainfall areas. Fanya juu can be either a rectangular or trapezoidal in cross-section. It is easy for farmers to make rectangular one but trapezoidal fanya juu is more stable.

Furthermore, fixed values for dimension of fanya juu are given based on the following schematic representation of a trapezoidal cross-section (Figure 55):

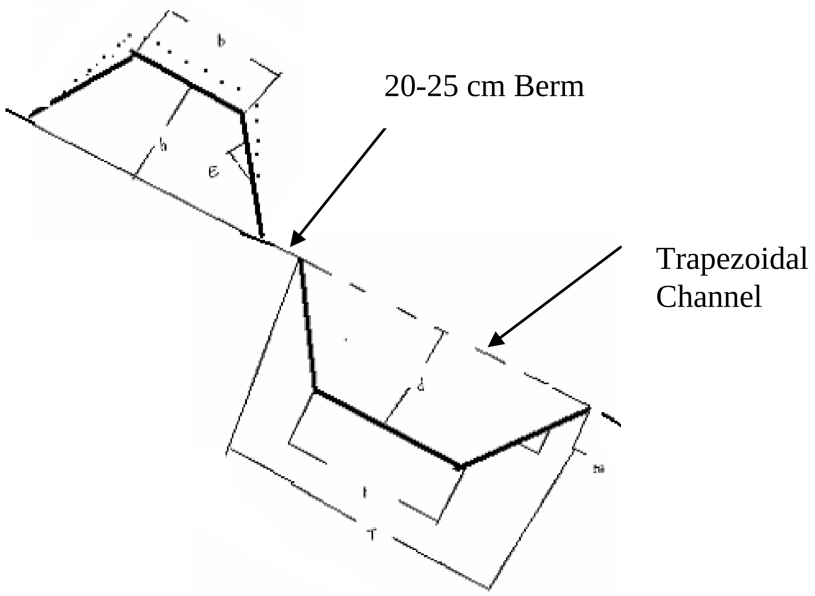


Figure 55. Cross-section of trapezoidal fanya juu.

A 20-25 cm Berm is required between the embankment and the channel in order to prevent sliding of the soil into the channel. However, a fanya juu bund portrayed in Figure 56 is without a Berm. In this case there is a high risk for the embankment to slide into the channel. Moreover, the excavated soil should be placed in proper space, levelled and compacted when it is moist by people walking on it or using locally available material.

A good grass cover should be established on the embankment, and a strip of grass should be planted along the upper edge to prevent the inflow of sediment and reduce land lost too crop production due to the structure. The plants can be used for different purposes such as fodder, food, soil fertility enhancing (composting) and mulching. Some farmers plant bananas in the channel beds of Fanya juu bund. This is practiced for two reasons. Firstly, to economise space reduced for crop production due to construction of this structure. Secondly, to effectively use moisture stored in the channel.


Figure 56. Fanya juu bund without Berm, FFA Kitui District, Kenya.

**Work norm elements:** Same as for soil bunds except that a Berm in this case should be slightly greater than that of soil bund.

**Work Norm: 200 person days per kilometre.**

### 7.18 Stone bund

Stone bunds are constructed on steep farmlands where the soil is shallow and large stones are available. The bund, which should be about 0.5 m wide and 0.70 to 1.0 m high, is made of stones laid along the contour (Figure 57). The vertical interval between consecutive terraces is determined using the same method used for soil bund and fanya juu. The bund could be used for enhancing soil infiltration and reducing soil erosion problem. If well maintained, terraces will gradually be formed due to the accumulation of soil above the stone bund.

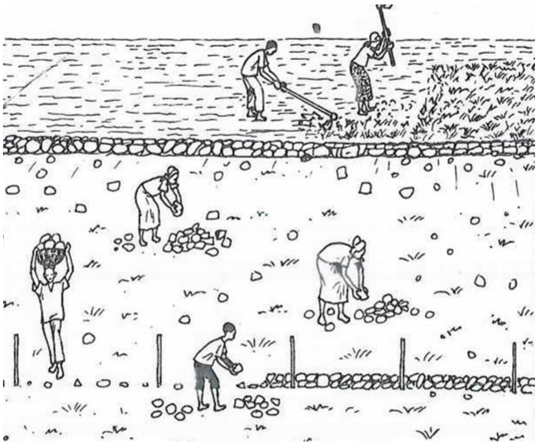

Figure 57. People collecting stone, lay outing and constructing stone bund.

**Minimum technical standards:**

- Height: 70 -100 cm (lower side)
- Total base width: (height/2) + (0.3 to 0.5 m)
- Top width: 30-40 cm
- Foundation: 0.3 m width x 0.3 m depth
- Grade of stone face downside: 1 horizontal : 3 vertical
- Grade of stone face upper side: 1 horizontal : 4 vertical
- Grade of soil bank (seal) on upper side: 1 horizontal:1.5-2.0 vertical

**Work norm elements:**

- Precise layout,
- Collection of stones from working site, light shaping (if necessary) of side of some stones with sledgehammer for better stability and merging,
- Excavation of foundation,
- Placement and building of stone walls,
- Filling of voids between walls with smaller stones,
- Small stone ties every 5 m (optional),
- Levelling of top of bund with an A-frame.

**Work norm: 250 person days per kilometre**

### 7.19 Planting on bund

A good grass cover should be established on the embankment, and a strip of grass should be planted along the upper edge of soil bund and fanya juu to prevent the inflow of sediment. In addition to graded or level bunds and fanya juus, planting on bunds is also referring to the stabilization of cut-off drains and other structures with soil embankment. Planting on bunds should be regarded more as an intensification and productive use of the structure rather than a stabilization activity *per se*. Ultimately, planting of trees and shrubs plays also a great role in stabilization but more in the medium and long term.

Pigeon peas, Sesbania, Leaucaena, Calliandra, Treelucerne, Setaria, Tripsacum/ Bana grass, Pennisetum, Elephant grass, etc can be planted on bunds. Planting on bund can be done during rainfall season mainly between September and February. This increases chances for the plants to survive and become effective. Weeding and cultivation should be done to enhance plant growth and improve biomass production. Livestock should be kept away during all time. Cut and carry system could be used to feed the animals on the fodder.

Farmers should be encouraged to render productive various structures and control free movement of animals in conserved and productive areas. One of the methods to encourage them is by offering a better worknorm. For example while it is possible to stabilize 1 kilometre of bund or fanya juu by employing about 10 person days rising this rate to 16 person days per 1 kilometre can motivate farmers to widely apply this technique.

**Minimum technical standards:**

- Bund stabilization with productive shrub seedlings assumes a minimum standard spacing between plants of 0.2 m in a single row placed on one side of bund (side of Berm) or at its top.
- Taking into account the standard minimum spacing indicated above, **double row** is also possible as well as closer spacing within row (0.15 m).

**Work norm elements:**

- Preparation of niches or small pits for planting,
- Handling and transporting of seedlings from grass multiplication area,
- Plantation and soil compaction around seedlings.

**Work norm:** 16 person days per kilometre

### 7.20 Gully reclamation

Gully erosion is caused when run-off concentrates and flows at a velocity sufficient to detach and transport soil particles. A waterfall may form, with run-off picking up energy as it plunges over the gully head. Splashback at the base of the gully head erodes the subsoil and the gully eats its way up the slope. Gullies may develop in watercourses or other places where run-off concentrates. In cultivation or pastures, advanced rill erosion can develop into gully erosion if no protective measures are taken. Cattle pads can be a starting point for a small rill that can develop into a large gully.

Widening of the gully sides may occur by slumping and mass movement especially on the outside curve of meanders. Scouring of the toe slope can lead to mass failure of the side of the gully under gravity. This soil is then washed away by subsequent flows. Gully depth is often limited by the depth to the underlying rock which means that gullies are normally less than 2 m deep. However on deep alluvial and colluvial soils gullies may reach depths of 10 to 15 m. Generally gullies make land unproductive, damage roads and other infrastructures, cause siltation in the ponds and reservoirs, interfere with tillage operations and lower groundwater table (Figure 58).

Figure 58. Gully erosion problem in Isiolo District of Kenya.

As gully control is an expensive undertaking, it should be remembered that prevention is always better than cure. The approach for controlling gullies should be based on an understanding of the process of gully erosion, i.e. whether the gully is in an active stage or healing stage. Gullies are considered to be active when they grow rapidly in depth, width and length and the sides are bare of vegetation, and considered inactive when they have stabilized sizes (depth, width and length) and started growing vegetation.

Before starting a gully control programme, one should first study whether the gully is in an active stage of erosion or in healing stage. When the gully is in healing stage, much of the soil has already gone away and the gully bottom and embankment would have reached none erodible stage. In such cases, the best solution is to put a fence or hedge around it to protect it from grazing and rely on natural regeneration. If natural regeneration is slow, it can be encouraged by planting with grasses, legumes, shrubs, trees, etc. On the other hand, where a gully is active and grows in depth, length and width, controlling measures should be applied at least to halt the progress of gulling to productive bordering land.

Gully control measure involves use of appropriate structural & vegetative measures in the head, floor & sides of the gully. Reduce erosion in a drainage channel by restricting the velocity of flow and filtering sediment, allowing the channel to stabilize. Two categories of measures: structural and vegetative

### 7.20.1 Structural measure: check dam

Structural measures are check dams that include loose rock, gabion and pole/brushwood constructed across the floor of the gully to reduce the channel gradient and then to slow runoff and to trap sediment. They are mainly used to facilitate the establishment of vegetation in the gully, which will eventually stabilize the gully and protect it from further erosion. If properly used and the runoff flowing to the gully is diverted, check dams can also be used to gradually build up the floor of the gully to its original ground level, or to rehabilitate the gully. Check dams can be made of any material available locally, such as stones, branches of trees, gabions, etc.

Where stones are available loose stone check-dams appropriate; durable and have an advantage to hold in contact with the bottom of the gully because of the weight of stones (Figure 59). Several short (low) check dams are more useful to slow the flow and control erosion in a gully than few large dams. Short check dams are less likely to fail and the over-fall water cuts away less soil in the lower side of the check dam.

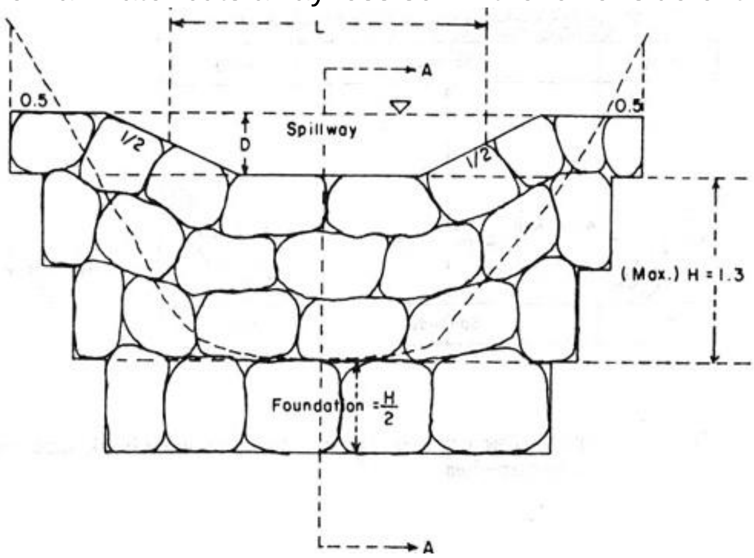


Figure 59. View of loose rock check dam.

The quality, shape and size distribution of the stones used in the construction of a check-dam affect the success and life span of the structure. Stones that disintegrate easily when continuously exposed to water will have short structural life. Furthermore, if only small stones are used in the construction of the check-dames, they can be easily moved by the impact of the first large water flow and the dam can be quickly destroyed. On the other hand, a check-dam constructed of only large stones that will leave large voids in the structure can offer resistance to the flow, but may create water jets through the voids. Such water jets can be highly destructive if directed towards unprotected part of the gully. The following points should be considered in designing and constructing loose rock check dams:

- Low check dams are less likely to fail than high dams. High dams will impound much water and pressure may lead to cause seepage and undermine the structures,
- A check dam should have a spillway in the centre to discharge excess water and shoulders on either side to prevent water from cutting around,
- A check-dam should have a properly constructed apron on the downstream side to protect the dam from undercutting. The apron should have a length of 1.5 times the height of the check-dam. For gullies with bed slopes more than 15% the apron length should be 1.8 times the height of the dam,
- For check-dams to be effective they must be spaced at a distance that takes into consideration the gradient of the gully and the expected height of the dam as explained below (see Figure 60),
- Check-dams should be properly keyed to the floor as well as to the sides of the gully to improve its stability. This involves excavation of a foundation of about 0.5 m deep and wide across the gully floor and 0.5 m into the gully sides for constructing masonry, concrete or stone check-dams.

*Spacing*: The spacing of check-dams should be such that the spillway crest of one check-dam is level with the base of the next check-dam upstream. This is meant that the steeper the slope of the gully floor and the shorter the check dams the closer should they be.

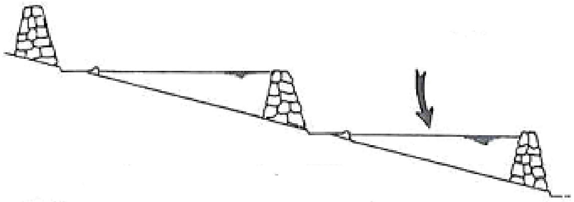

Figure 60. Spacing of check dam.

Check-dams spacing can also be determined using the following empirical formula:

$$D = \frac{1.7\ H}{G}$$

where:
D = spacing or slope length (m) between two consecutives check-dams,
H = effective height (height of spillway) of the check-dam, (m),
G = gradient of the gully floor (%).

**Example.** Effective height of a stone check-dam is expected to be 50 cm and slope of the gully floor is measured to be 25% on average. How far apart should the check-dams be constructed?

$$D = \frac{1.7 \times H}{G} = \frac{1.7 \times 0.5}{0.25} = \underline{3.4\ m}$$

The check –dams should be spaced 3.4 metre apart.

**Minimum technical standards – Loose rock check dam:**

- **Spacing** estimated on the safe side using S (spacing) m = Height (m) x 1.2
- Gradient (in decimals)
- **Side key**: 0.0 -1.0 m inside gully sides,
- **Bottom key and foundation**: 0.5 m depth x width of check-dam.

- **Height**: min 1m and max 1.2 excluding foundation.
- **Base width**: minimum 1 m and maximum 3 m.
- **Stone face 1:3/1:4** for increased stability,
- Spillway (trapezoidal) with 0.5 m **free board** and 0.25-0.3 m **permissible depth**, width min 0.75 m and max 1.2 m (based on small watersheds)
- **Drop structures** on steep slopes (above 15%) before the apron (ladder placed stones up to half the height between apron and spillway level).
- **Apron** at least 50 cm wider on both sides of spillway fall (total width 1.5-2 m) and length towards water flow of minimum 1 m, with stones placed vertically.

**Work norm elements:**

- Layout and spacing,
- Collection & transport of stones from working site, light shaping (if necessary) of side of some stones with sledgehammer for better stability & merging,
- Excavation of side and bottom keys,
- Stone walls and risers,
- Spillway construction,
- Drop structure (if necessary),
- Apron construction,
- Up-slope stone + soil sealing.

**Work Norm: 0.5 $m^3$ per person day.**

**Wooden poles check dam:** Check dams can also be constructed by using wooden poles and twigs across gully sections (see Figures 61 and 62). Posts (e.g. Commiphora) are inserted into the gully beds and twigs are interwoven with the posts to filter out the fine soil materials carried by flowing water in the gully. They are effective for small gully heads, no deeper than 1 m but should not be used to treat ongoing problems such as concentrated run-off from roads or cultivated fields. These structures are less costly and can be as effective as loose rock check dams. Similar procedures can be followed in determining spacing and height.

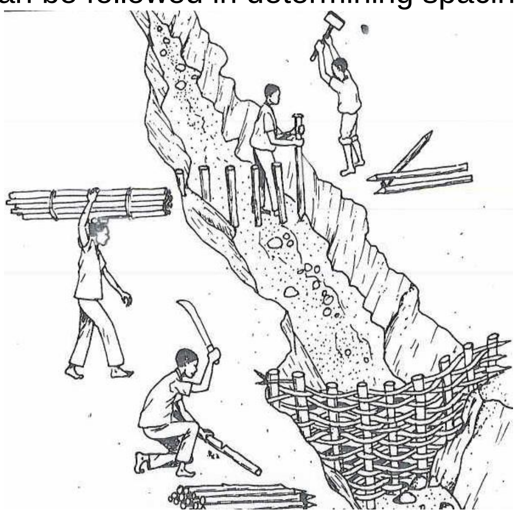

Figure 61. Check dam constructing using wooden pole webbed with twigs.

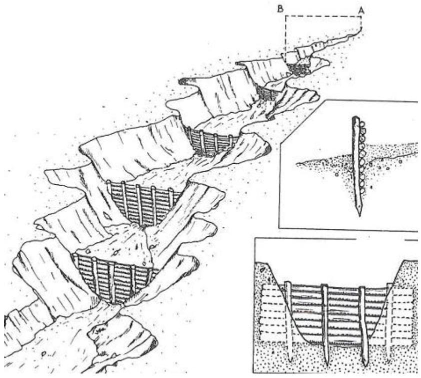


Figure 62. Check dam constructed using wooden pole.

### 7.20.2 Vegetative measure

Vegetative measures include the planting of shrubs and grasses along the gully profile. In dry areas, succulents such as sisal and finger Euphorbia could be used. Moreover star grass, Vetiver grass, Napier grass, etc. are well known planting materials for gully treatment. On slopping bank the use of splits or seedlings give better results than direct seeding. Sacks filled with (fertile) soils could be embedded in gully floor for planting grasses in holes formed in the sacks with soils.

**Check dam maintenance:** Check dam construction following proper quality standards should not require any or little maintenance, which can be undertaken on a voluntary basis. Provided the design of check dam follows the criteria indicated above, there is no need to increase the height of check dams, because the sediment contained by one extends to the toe of the next upper one. In this regard, check dam maintenance should be considered as a consolidation activity rather than maintenance. However, check dam maintenance relates to:

- inserting drop structures and aprons,
- increasing size and stability of spillway and side wall (extension of apron on gully sides) for side protection, specially, in case of V-shaped gullies.

**Minimum technical standards:**

- **Increasing spillway size:** by min 0.2 cm on all sides,
- **Insertion of a drop structure:** ladder shaped placed stones (better large and flat stones) from spillway level down to the bottom of the spillway chute. The width of the apron should be 25 cm larger than spillway width on both sides,
- **Apron:** 0.5 m width on both sides of spillway fall x 1 meter downstream (vertical shaped stones buried 20 cm deep into the soil,
- **Side walls (optional):** side walls protect the downstream part of the check dam from water that may fall from the gully sides and from strong overflow from spillway, which may side erode the gully and ultimately provoke the collapse of the structure.
- **Side walls** for small check dams usually extend 50 cm from the base of the check dam along the apron and raise up to spillway level.

**Work norm elements:**

- Collection of stones (from working site), light shaping (if necessary) of side of some stones with sledgehammer for better stability and merging,
- Replacement of dislodged stones,

- Reinforcement of side keys,
- Construction of drop structure,
- Construction of apron,
- Construction of side walls (optional).

**Work Norm:** 1 $m^3$ per person day

### 7.21 Microbasin (eyebrow terrace)

By microbasin (half-moon or eyebrow) it is intended a small circular and stone faced (occasionally sodded) structure for tree planting. They are suitable for medium and slightly low rainfall areas, stony areas and shallow soil depth (50-100 cm) on sites with modest slopes (5-20%). They can also be used to complement hillside terraces in areas where there are gaps in the natural vegetation, or on hillsides where no terraces are to be constructed but where there are some gaps in the vegetation where physical measures are needed. The size and layout of half-moon-shaped microbasins vary according to local conditions. But the standard diameter of a microbasin can be 3 m, and it is usually reinforced by paving stones on the lower and steeper side. This type of microbasin is constructed in order to create suitable conditions for tree and shrub seedlings on degraded sites. When used for planting of trees or shrubs, the primary purpose is to harvest and retain enough water for the seedling to survive the long dry season. Rainwater harvesting also improves the growth and survival of naturally occurring young trees and shrubs. It is often preferable and easier to encourage natural re-growth of the local vegetation than to make new plantings. Based upon experience they are not very effective in low rainfall areas where other better water harvesting activities should be implemented.

Construction of microbasins is done following the contour line, and the spacing between two consecutive contour lines is either 2.5 m or multiples of 2.5 m. The microbasins should be constructed using a staggered layout (see Figure 63). The number of microbasins per hectare will be approximately 700 if the horizontal interval between the contour lines is 2.5 m and the distance between the centre points of the microbasins is 6 m. With a horizontal interval of 5 m, the number of microbasins per hectare will be half as many. The outer side of the microbasins should be consolidated with stones whenever stones are locally available.

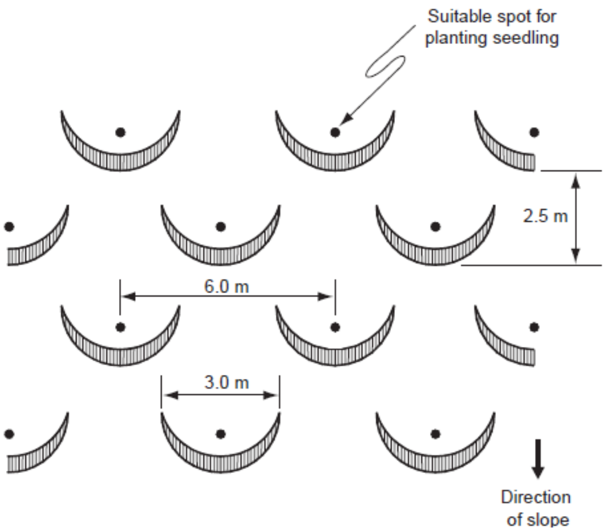


Figure 63. Layout of microbasins.

**Minimum technical standards:**

- Diameter: Min 1 m and max 1.5 m.
- Small stone riser: 0.2 m foundation and height 0.2-0.4 cm above ground based on slopes,
- Plantation pit: 30 cm diameter x 50 cm depth,
- Soil sealing: sealed with soil from cut area,
- They are constructed in staggered position between rows and in rather close spacing within row in case of 1 m diameter basins (some overlapping required between rows).

**Work norm elements:**

- Layout in staggered position,
- Foundation,
- Placement of stone raiser,
- Cut and fill and seal,
- Plantation pit construction.

**Work Norm: 1 person day per 5 microbasins.**

### 7.22 Composting

The decomposition of organic material is a natural, important process that returns valuable nutrients to the soil for plants to use. Composting means storing and mixing crop residues, cow dung and other animal waste, kitchen household waste and other organic matter for quick decomposition. The decomposed organic matter is known as compost. Its unique physical and chemical properties provide a number of benefits to soil, including:

- Improved soil fertility
- Improved soil structure
- Improved water-holding capacity
- Reduced erosion
- Reduced levels of plant pathogens, insects, and weeds
- Help supplement chemical fertilizers.

There are two methods of preparing compost, namely the **pile method** (Figure 64) and the **pit method** (Figure 65). The pile method is mostly used in areas with relatively higher rainfall while the pit method can be recommended for the low rainfall part of the country. Pit method for compost making is suitable for dry zones and cold areas (frost prone). In dry zones pits conserve moisture longer (and need less watering). In frost prone areas they reduce the risk that microbial activity may be hampered or slowed down by low temperatures (resulting in poor breakdown of compost elements). The pit method of compost making is rather labour intensive, both for excavating the pits and for turning & mixing the compost.

Compost should be prepared in an area that is protected from wind, rain, sun and runoff. When the compost is well decomposed, it can be applied at the rate of up to 20 tonnes per hectare, but practically only smaller amounts will be available for the small-scale farmer. Compost is a valuable product and should first of all be used for high-value crops and crops that require a good soil. Since compost is heavy, composting should be done near the field where it is supposed to be used. Compost and manure should be covered with soil immediately after they are applied. Exposure to the hot sun results in loss of nitrogen and thus reduction of the value of the compost as a source of plant nutrients.

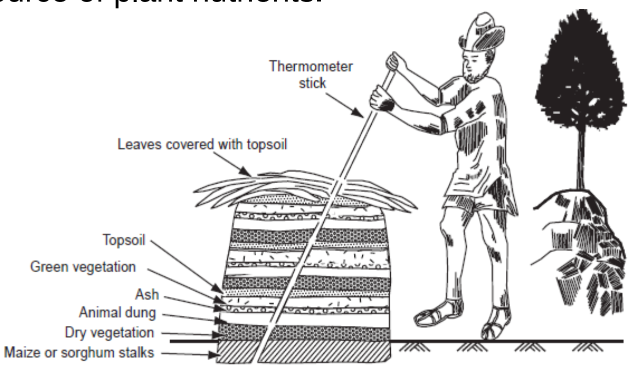


Figure 64. The pile method of compost making.

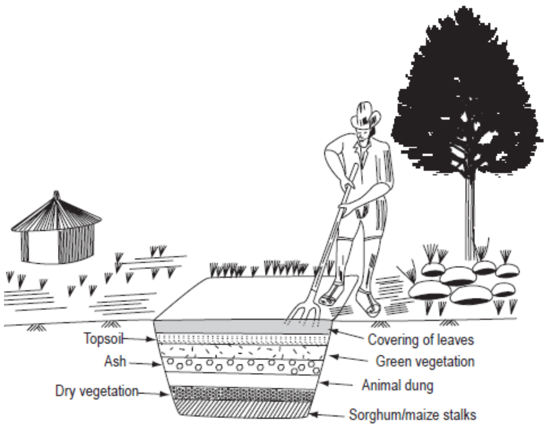


Figure 65. The pit method of compost making.

**The following steps are recommended for the pile method:**

a) Dig a shallow trench for the placement of the heap or pile (0.15 m deep x 1.5 m wide x as long as materials allow). Put the soil on one side of the pit.
b) Put rough and chopped plant residue in the pit as a bottom layer about 30 cm thick.
c) Add a second layer of grass or dry vegetation about 15 cm thick. Sprinkle water on each layer to make it moist.
d) Put in a third layer of animal manure and spread some ash on this layer.
e) Make the next layer of green vegetation about 15-20 cm thick, and sprinkle on a little of the topsoil.
f) Repeat this process until the pile is the desired size.
g) Cover the pile with leaves and about 10 cm topsoil, then sprinkle water about every 3 days depending on the weather. If it is raining, there is no need to water.
h) Push a pole several times into the pile to make aeration holes that will allow air to penetrate the lower layers of the compost.
i) Take a long, sharp-pointed stick and drive it into the pile at an angle so it passes through the pile from top to bottom. This stick will act as a *thermometer* to allow you to check the condition of the compost. After three days, decomposition will have started in the pile, and the stick will be warm when you pull it out. Pull the stick out once a week or so to check progress in decomposition. You can tell from the stick how dry or wet the pile is: it should be moist but not wet. If the stick

becomes covered with a white fluffy fungal growth, then the pile is too dry and should be watered.

j) After 2-3 weeks the pile should be turned over, and again after another 2-3 weeks.
k) This is done by shifting the compost to another pile so that the material from the top of the first pile is placed at the bottom of the second pile. Do not add any fresh material except water. You must turn the pile if the *thermometer* is cold when you pull it out or if a white fluffy substance on it shows that the decomposition has stopped.
l) The compost should be ready to be used after 4-8 weeks.

- Achievements are reported in the quantity ($m^3$) of compost prepared.
- Interim work norm is 1 person day per 1.5 $m^3$ of pit dug.
- Compost making should be done on self-help basis by targeted farm household.

**The following steps are recommended for the pit method:**

a. Dig three rectangular pits side-by-side about 1 m deep, 1.5 m wide and 1.5 m long (or as long as materials allow).
b. Build a pile in the pit, using the same method of layering the materials as in the pile method.
c. Add water when necessary.
d. Push a pole into the pit to make aeration holes that allow air to penetrate the lower layers of the compost.
e. Check the condition of the compost with a long, sharp, pointed stick. Use the same method as for the pile method.
f. Turn over the compost every 2 weeks. The compost should be ready for use after 4-8 weeks.
    - Achievements are reported in the quantity ($m^3$) of compost prepared.
    - Interim worknorm is 1 person day per 1.5 $m^3$ of pit dug.
    - Compost making should be done on self-help basis.

### 7.23 Agronomic aspects of water harvesting

Once the availability of water is assured through implementing *in situ* moisture conservation or other rainwater harvesting technologies farmers should choose suitable crop species (annuals as well as perennials) and apply appropriate farming systems and crop husbandry techniques. These issues are briefly explained as follows:

**a) Suitable crops and crop husbandry**

Farming is done in small pockets of land in ASAL; the total arable land being about 1%. Crops commonly grown are maize, sorghum, millet, cowpeas, beans, pigeon peas, green grams, dolichos lablab and water melon. Provided that water is made available, these crops can perform well under the altitude and the soil temperatures of ASAL. Crops such as sorghum and millet have the capacity to grow under conditions of flooding for a number of days followed by weeks with no additional moisture. Seedling transplanting would be recommended for sorghum and millet. Green grams, cow peas, dolicchos lab and pigeon peas can withstand limited amount of flooding. Due to its vegetative growth rate dolicchos lab would contribute to improving the organic matter of the soil while increasing the total nitrogen content. Crops such as chick-peas, beans, cowpeas, pigeon peas and green grams are generally early maturing crops that may do well under the practice of conservation agriculture.

A good source of seeds appropriate for the area must be identified and a mechanism put in place to ensure that they are accessible on time to avoid late planting. Agronomist with ASAL experience should be consulted to determine spacing between plants and rows. Moreover care should be taken during the choice of the crop seeds to avoid having hybrids that will force farmers to buy new seeds every year. Composites should be preferred.

Early weeding is needed, followed by 1–2 weeding rounds, at mid-season and before the weeds set seed. Proper mulching suppresses weeds. Maximising fertilisation and infiltration *only* in planting lines, thereby assures that weeds (between rows) suffer from lack of sufficient water and nutrients hence delays their growth.

**b) Soil fertility management**

Most soils in ASAL are generally sandy in nature and excessively drained. However, there are pockets of areas such as in Isiolo District, where clay soils with very good water holding capacities are found. ASAL soils also display very low organic matter content which is crucial in maintaining soil structure, increasing effectiveness of water conservation and crop yield. One should be aware about the fact that ASAL soils are alkaline in nature but this could be rectified by applying livestock droppings (manure). Moreover application of acidifying fertilizers like DAP or Sulphate of Ammonia (SA) for a limited period of time during the cropping season would bring down the alkalinity making the soils favourable for optimal crop growth. Over all most of the soils in ASAL are suitable for crop production, however, the limiting factor is water. Employment of suitable water harvesting technologies would help supplement the additional moisture required for sustaining crops.

Soil fertility management should be one of the key activities for improvement of crop productivity in ASAL. Composting and manuring are among such techniques, which have proven to be effective for sustainable fertility management and erosion control at the same time. In several *manyatta* areas manure is piled and unutilised for crop production. This manure can be decomposed and applied in sufficient amount to improve soil fertility level. Moreover the villagers or individual households should be advised and encouraged to increase their biomass production from various vegetation species: grasses, legumes and shrubs/trees on hillsides, in gullies, around fences, on farm boundaries, etc. This biomass should be used for compost making (see Chapter 7.22 for composting techniques).

Mulching of dead plant material (such as dry grass, straw, maize stalks, dry leaves, etc.) helps to reduce soil temperature and hence conserve soil moisture. But crop residues are used as livestock feed or firewood. It is essential that the mulches are free from seeds, diseases and pests. It also important to ensure that mulches used do not regenerate.

**c) Farming system; conservation tillage**

Most of the lands in pastoral communities are virgin in a sense that they have not been used for crop production. Consequently the fertility level of such land is generally higher than the one under crop production. On the other hand a vast area of pastureland has been subjected to overstocking and overgrazing problems. Even if this land use type has not been used for crop production purposes its virgin soil quality level would be low. The fertility level drops when virgin lands put under cultivation or overstocked and overgrazed; because, agricultural potential reduces through degradation of the soil structure unless protected with appropriate cultivation practices. Conservation tillage could be an important component of this process. Hoe, ripper/ridger, subsoiler, etc. are tools commonly used for conservation tillage.

Conservation tillage is, hence, defined as any tillage system with the objective of minimising the loss of soil and water, and having an operational threshold whereby at least 30% mulch or crop residue cover is left on the surface throughout the year. The basic aim of conservation tillage is to apply tillage practices, which ensure maintenance of the virgin soil quality. In brief, it involves minimum destructive tillage, which leaves the crop residue on the surface, thus enhancing good rainwater infiltration and crop root development, and manages the organic matter content, fertility and soil structure well.

Often, conservation tillage is associated with zero tillage or minimum tillage because zero tillage is the ultimate goal of any conservation tillage strategy. Successful zero tillage implies that the soil structure has returned so closely to the virgin soil state, that soil crusting, structural compaction and weed infestation pose very few problems.

### 7.24 Rural road

**General:** A rural road is an identifiable route, way or path between places. It is typically smoothed, paved, or otherwise prepared to allow easy travel. Rural road construction requires the creation of a continuous right-of-way, overcoming geographic obstacles and having grades low enough (<10% slope) to permit vehicle or foot travel. The process is often begun with the removal of earth and rock by digging, construction of embankments, removal of vegetation and followed by the laying of pavement material. Alignment of the road is set out by a surveyor and gradient are designed and staked out to best suit the natural ground levels and minimize the amount of cut and fill.

Storm drainage and environmental considerations are a major concern. Erosion and sediment controls are constructed to prevent detrimental effects. Drainage lines are laid with runoff coefficients and characteristics adequate for safe disposal of excess water and without causing erosion problem on croplands and settlements in downstream areas of the road. In other words drainage systems must be capable of carrying the ultimate design flow from the upstream watersheds.

Processes during earthwork include excavation, filling, compacting and construction. The topsoil is usually stripped and stockpiled nearby for rehabilitation of newly constructed embankments along the road. Stumps and roots are removed and holes filled as required before the earthwork begins. General fill material should be free of organics and have a low plasticity index. Select fill should be composed of gravel, decomposed rock or broken rock below a specified Particle size and be free of large lumps of clay. Sand clay fill may also be used. The completed road way is finished by paving or left with a gravel or other natural surface.

Road construction standards should be improved by improving skills in layout, construction and supplementary measures (drain, ford crossing structure, retention walls, scour checks, etc.). In this regard, the work norm should be developed and then applied only when the minimum technical standards indicated below are fulfilled.

**a) Unpaved road**

In areas where adequate amount of stones are not available unpaved (non-surfaced) roads can be constructed. Minimum technical standards and work norm elements were presented as follows:

**Minimum technical standards:**

- In case of areas without stones, layout of roads should not exceed 10% slope (occasionally up to 15% if those portions are surfaced),
- Minimum width of road is 5 m (excluding drain),
- The road should be camber towards drainage ditch (or on both sides – two drains) and stabilized with scour checks (brushwood),
- Fords crossing: In absence of stones for proper stone paved crossing gradier, fords should be crossed on tightly bound wood beams (framed by side posts) contributed by the community,
- Downside of sloping curves reinforced with stone walls (if stones available) or wood posts inter-woven with branches (+fill with soil),
- Every 10 cm of soil layer from cut and fill should be strongly compacted with manual compactors. Wetting is recommended for compaction.

**Work norm elements:**

- Precise layout,
- Cut and fill,
- Shaping (camber)
- Compaction,
- Excavation of drain (s),
- Fords crossing,
- Reinforcement of outer side of sloping curves (walls),
- Brushwood or stones (if available) small checks every 5-10 meters based on slope.

**Work norm: 3000** person days per kilometre.

**b) Paved road**

This type of road is paved (surfaced) with gravel. Pebbles or gravel should be available from distances not far from site or carried by cart from a nearby site or quarry. In this case separate work norm could be applied for stone collection and transporting activities. This type of road can be combined with the unpaved one, particularly for portions likely to suffer from erosion, steeper slopes and poorly drained areas. In practice this work norm is used to supplement the none-surfaced road type for those portions of the road hard to construct (stony areas) or that needs specific reinforcements (along curves, steeper portions, etc.).

**Minimum technical standards:**

- The road standard should have a 5-6 m width, can be constructed in steeper slopes (up to 15-20%) provided the shape of road (camber) and side drainage is very well constructed, as well as reinforcements (stone walls) are placed along entire curving Sections. Stone side walls are also needed in all small depressions,
- Road surface: 4 meters wide with slopes 1.5-2.5 towards side drains,
- Width of shoulders: 1 meter with 3% slope towards drain,
- Surface gravel should be about 10 cm thick and compacted,
- Roll or compact split stone (2-5 mm) into the layers of gravel,
- Other recommendations are similar to none surfaced road (compaction, drainage checks, etc.)

**Work norm elements:**

- Same as none-surfaced road +
- Excavation, collection and transport of gravel (sometimes, gravel is mixed with some soil),
- Spreading of gravel, shaping and compaction,
- Achievements are reported in kilometre.

**Interim work norm** is 4000 person days per kilometre.

**c) Rural road maintenance**

Like all structures, roads deteriorate over time. Deterioration is primarily due to accumulated damage (from traffic, erosion, etc.) or due to poor layout and construction. Virtually such roads require some form of maintenance before they fail to serve their intended purposes. Thus road maintenance is an activity which should consider roads constructed in the past without the supplementary measures indicated above (reinforcements, drains, ford crossing and checks) and not only in terms of filling of eroded portions or rills. In this regard, **road maintenance is rather a road improvement work**, which would then eventually require only light maintenance on a yearly basis or so by community contribution. The work norm proposed is also sufficient for construction of roads on terrain with <5% slope and stable sub-surface as well as limited runoff from nearby watershed areas.

**Minimum technical standards and work norm elements:**

- Road maintenance includes reinforcement of outer side sloping curves (walls by stones or wood posts, etc.),
- Re-shaping of road (cut and fill) for camber shape and strong compaction,
- Excavation and stabilization of side drains (+ small stone and wood checks),
- Stable structures for crossing fords (stones, wood).

**Work norm:** 500 person days per kilometre.

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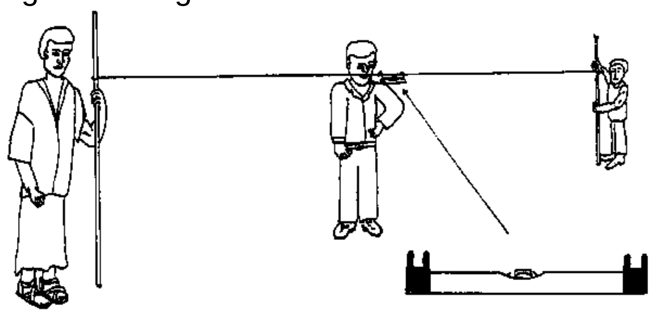
## Appendix 1: Use of the line level for surveying

**Introduction:** The line level is a simple surveying instrument which can be used to lay out contours and gradients, and also to measure the slope of land. It is simple to operate and is easier to transport than other similar surveying tools such as the A-frame. It is especially quick and very accurate when used properly. However a line level does require three people to operate it. It consists of two poles, between which a length of string is suspended. A spirit level is hung on the string. The level is the type used by builders, but has small hooks at either end.

The poles should be of even height (1.5 to 2.0 m) and the string (about 2 mm in diameter) and precisely 11 metres in length. A notch is made in each pole at exactly the same height (say 1.4 m above ground level) and the ends of the string tied around these notches. The centre of the string (5 m from each end) is marked and the level itself is suspended there.

**Laying out a contour:** The poles are held apart by operators with the string extended and the spirit level positioned exactly in the middle of the string. When the bubble in the level is between the two marks this means that the poles are positioned on level points on the land - in other words on the contour. The poles must be held vertically.

To lay out a contour across a slope, the team begin at the edge of the field. The operator holding the pole at the field's edge (operator A) remains stationary while the operator holding the other pole (operator B) moves up and down the slope until the third operator is satisfied that the bubble is centred. Points A and B are then marked (with stones or pegs). Operator A then moves to B and operator B moves onwards and the process is repeated. This continues until the contour line reaches the far end of the field. Care should be taken that small obstacles, such as minor high spots, or rills, are avoided by skipping forward a pace or two. This avoids sharp irregularities in the contour. When the contour has been laid out, the curves can be smoothed by eye according to the guidelines given for stone or earth bunds.



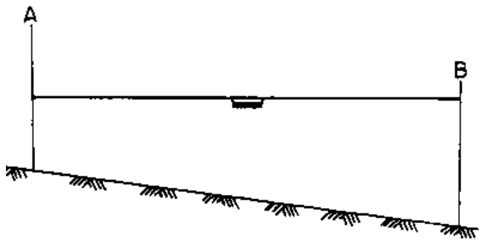
**Laying out a graded contour:**

- A graded contour deviates slightly from the true contour and is normally used to align a channel, such as a diversion ditch, or to stake out a graded earth bund.
- In order to lay out a graded contour, further notches must be made on one of the poles. These notches are made below the original notch at intervals of 2 cm.
- The usual gradient for a structure such as a diversion ditch is 0.25%. The string of the near side operator (A) should be affixed to the second notch down his pole (2 cm below the original) and the far operator (B) retains his string at the original notch. When the bubble in the level is between the two marks, this now implies

that A is 2 cm above B, which is equivalent to a 0.25% slope over the distance of 10 metres. For a slope of 0.5%, Operator A fixes his string to the third notch down his pole (4 cm below the top notch) and, when Operator B finds a position where the level reads dead centre, he is at a ground level 4 cm below that of Operator A. Over a distance of 10 metres the slope is then 0.5%.

- The operation now proceeds as before, operator A moving forward to the spot occupied by B, and B moving onwards - slightly downslope. Once again minor irregularities should be avoided and the curve smoothed.
- If a diversion ditch must follow a precise field boundary it can be excavated so that the bottom of the ditch is given a suitable gradient. Surveying will therefore take place during excavation.

**Measuring the slope of the land:**
It is simple to use the line level to measure the slope of the land. Operator A stands exactly upslope of Operator B and adjusts the string to the notch which gives a level reading. For example if this notch is the 3rd (i.e. 4 cm below the top notch) the gradient is 0.5%, if the notch is the eleventh (i.e. 20 cm below the top notch) the gradient is 2.5%, etc.




Up to 21 notches should be marked on pole A and the following table shows the percentage slope indicated by each.

| **Notch on Pole A** | **% slope** |
|---|---|
| **Top** | **0 (level)** |
| 2nd (2 cm below top) | 0.25 |
| 3rd (4 cm below top) | 0.50 |
| 4th (6 cm below top) | 0.75 |
| 5th (8 cm below top) | 1.00 |
| 7th (12 cm below top) | 1.50 |
| 11th (20 cm below top) | 2.50 |
| 21st (40 cm below top) | 5.00 |

**Important points to remember:**

- Always check the spirit level - by placing it on a horizontal surface and noting the position of the bubble which should be between the two marks.
- Check the centre point of the string each day and its length also,
- Remember that when laying out a gradient that operator (A) is upslope.
- Make sure poles are held vertically.
- Avoid placing the poles in depressions or on top of minor high spots in the field.

## Appendix 2. Worknorms

Indicative worknorms/task rates for WFP FFA project implementation in Kenya, Nairobi, March 15, 2001

Site clearing norms (average $m^2$ cleared per Work Day)

| | |
|---|---|
| Dense bush | 100 |
| Medium bush | 200 |
| Light bush | 300 |
| Grubbing | 175 |

De-stumping: To be decided by experience and the size of stumps

Excavation norms (average $m^3$ excavated per Work Day)

| | |
|---|---|
| Soft soil | 3.1 |
| Medium soil | 2.2 |
| Hard soil | 1.9 |
| Very hard soil | 1.3 |
| Rock | 0.5 |
| Mitre drain | 2.2 |

Wheelbarrow haulage norms (average by haul distance $m^3$ per Work Day)

| | |
|---|---|
| 0 - 20 m | 8.5 |
| 20 - 40 m | 7.5 |
| 40 - 60 m | 6.5 |
| 60 - 80 m | 5.5 |
| 80 - 100 m | 5.0 |
| 100 - 150 m | 4.5 |

Loading, and unloading norms (average productivity rates $m^3$)

| | |
|---|---|
| Loading | 8.5 |
| Unloading | 10.0 |

Manual compaction norms ($m^2$ per worker day)

| | |
|---|---|
| Manual compaction | 18 |
| Spreading | 18 |

Culvert laying norms

| | |
|---|---|
| Culvert installation (m per worker day) | 0.3 |
| Concrete ($m^3$ per worker day) | 1.0 |
| Masonry ($m^3$ per worker day) | 1.5 |

**Work norms/task rates based on past FFA projects in Kenya,** Project KEN4616 Support to Forestry Activities in Kenya:

Forest Management

| | |
|---|---|
| Land Clearing | 20wd/ha |
| Staking our | 7wd/ha |
| Pitting | 23wd/ha |
| Planting | 250 seedlings/wd |
| Weeding | 12wd/ha |
| Pruning | 3wd/ha |
| Thinning | 14wd/ha |
| Creeper cutting | 7wd/ha |
| Firebreak clearing | 20wd/km |

| | |
|---|---|
| Boundary clearing | 17wd/km |

**Forestry Extension**

| | |
|---|---|
| Rehabilitation of Communal Silvipasture lands | 135wd/ha |
| Plantation of hilltops on trust lands | 135wd/ha |
| Plantation of hilltops on private lands | 135wd/ha |

Project KEN3935 Food Aid to Core Activities in ASAL Areas

| | |
|---|---|
| Maintenance/Control of gullies | 20m/wd |
| Rehabilitation of irrigation schemes | 90wd/ha |
| Water catchment area rehabilitation | 200wd/ha |
| Tree nursery maintenance | 1000seedlings/wd |
| Filling tubes | 500-800/wd |

Project KEN2669/1 Arid Lands FFW

| | |
|---|---|
| Making blocks Nos. | 50/wd |
| Making tiles Nos. | 50/wd |
| Making poles Nos. | 4pieces/wd |
| Fetching water | 120liters/km/wd |
| Carrying/collecting materials | 120kg/km/wd |
| Check dams Nos. | 5/wd |
| Terracing | 4 m/wd |
| Fencing with shrubs | 6m/wd |
| Clearing garden | 200m$^2$/wd |
| Digging/tilling garden | 100m$^2$/wd |
| Fencing garden | 5m/wd |
| Making Maendeleo stoves Nos | 2/wd |
| Animal transport/haul | 4Mt/km/wd |
| Quarrying | 2.5 m/wd |
| Molding Jiko Liners | 8 pieces |
| Weeding- lightly infested | 400m$^2$ |
| Weeding heavily infested | 200m$^2$ |
| Planting vegetables | 200m$^2$ |
| Pit reinforcement | 2.4 m$^2$ |
| Slab making | 3 people/slab |

From other Projects: Terracing (1M Width *0.7 M deep) for soil and water conservation and Irrigation canals

| | |
|---|---|
| Soft soil | 5M |
| Medium Soil | 4 M |
| Hard Soil | 3 M |

**Explanation and guidelines**

- All the data collected have essentially an indicative meaning and local conditions (nature of the work soil, as well as social habits) should be taken in account. Specific work norms for the project should be discussed and we are recommending the following guidelines:
- The work norms fixed in a project proposal should not exceed 25 % differences with the data above.
- Any wider difference should be precisely explained within the project proposal (cf. Technical issues) and agreed upon by relevant stakeholders.

*Source:* Adapted from ILO, Productivity Norms for Roads Labor-based Construction, ASIST Information Service, Technical Brief No 2, Nairobi 1998, and pp.-19 - 26.

## Appendix 3: Calculating the quantities of material required for sand dam construction

I. **Concrete**
Mix Ratio – 1:a:b
Where: 1 = cement proportion: a = sand proportion: b = coarse aggregate proportion
If the amount of concrete needed is C, then:
Cement Quantity (kg) = 1 * C * 1400 * 1.3 * 1.05/(1+a+b)
Sand Quantity ($m^3$) = a * C* 1.3 * 1.15/(1+a+b)
Gravel Quantity ($m^3$) = b * C * 1.3 * 1.15/(1+a+b)

**II. Stone Masonry**
For water tight structures usually 65% of masonry body is proposed to be stone and 35% cement mortar. So, if the volume of stone masonry work is S, then
Volume of Stone ($m^3$) = 0.65 * S * 1.3
Volume of Mortar, M ($m^3$) = 0.35 * S
If mix ratio of mortar is 1: C,
Cement Quantity (kg) = 1 * M * 1400 * 1.2 * 1.05/(1+C)
Sand Quantity ($m^3$) = C * M * 1.2 * 1.15/(1+C)

**III. Plastering**
Follow the same formula used for mortar ingredients of stone masonry.

**IV. Pointing**
Pointing area is taken as 1/3 of plastering area and then follows the same way used for plastering.

**V. Water**
Water required for mixing, curing, washing dirty construction faces, workers construction and food preparation is roughly calculated from the total cement requirement of the site.
If Z Quintals of cement is required to complete the construction work,
Total volume of water = 280 * Z.

## Appendix 4: Guideline for sand dam construction

*Step 1:* Placing reinforcements. These are placed vertically across the entire length of the dam at an interval of 2.5m. They are round bars with a diameter of 12.5 mm and the length depending on the complete height of the dam. The amount necessary can be determined as follows:

No of columns = $\frac{Ld}{2}-1$

With $Ld$ : length of the dam in metres.

For example: if Ld =10, Then number of columns = (10/2)-1 = 4.

Mark the positions of the columns along the building line, then measure the vertical depths to the bottom of the trench and record them as follows.

No 1 = 2.53 m, No 2=2.27 m, No 3 = 3.05 m, No 4 = 1.97 m

The round bars of the columns are firmly grouted into holes on 5 cm deep that have been cut into the foundation at the requested depth (depending on the bedrock material or soil type).

*Step 2:* Making the foundation blinding slab. A layer of cement mortar (1:3) is prepared on the foundation to the depth of 5cm. When there is no foundation rock the vertical iron bars are placed in the mortar layer.

*Step 3:* Constructing the first horizontal reinforcement layer. After the mortar layer 12 strands of barbed wire are evenly divided over the building slab along the dam.

*Step 4:* Constructing the second foundation blinding slab. The barbed wire is covered by 5cm of foundation blinding slab.

*Step 5:* Masonry comprising hardcore and mortar substructure. After the foundation blinding slab sets and holds the columns firmly, the foundation trench is filled with masonry comprising clean hardcore and mortar (1:4). Mortar for filling should have more water. The joints between the rocks are filled 25mm of this mortar. The rocks should be tapped well to settle completely into all voids. When the filling reaches the level of the back flow, the construction of the backflow should be done along side that of the wall as shown. Masonry comprising is extended to the wind wells.

*Step 6:* Installation of templates above the sand level. The two templates made of timber are erected at the ends of the spillway for giving the outline of the dam wall, spillway and wing wall. Nylon strings have to be drawn tightly from the inner corners of the 36 templates to pegs hammered into the soil next to the upper end of the wing walls. In this way, the position of the outer sides of the masonry wall can be determined.

*Step 7:* Constructing Masonry hardcore and mortar substructure within two templates
Flat stones have to set in cement mortar 1:4 along the inner lines of the strings. The next day, the space between the flat stones has to be filled with mortar, 1:4, into which round rubble stones were compacted. After that the flat stones were mortared onto the wing walls so that they could be filled with mortar and stones the following day.

*Step 8:* Preparation and construction of the stilling basin structure along with the dam body. The base of the dam wall, the spill-over apron and the spillway, (the latter being situated between the two templates), were only raised to 30 cm above the original sand level in the riverbed. A small flooding deposited a 20 cm layer of coarse sand that reached the first stage of the spillway. The spillway was therefore raised another 100 cm above the sand level, for the next stage of the spillway. The wing walls construction is executed at a time while extending each stage of the dam height construction.

*Step 9:* Stilling basin construction with the stone pavement for flood protection at the bank of the river. Large boulders were concreted into the spill-over apron, to reduce the velocity (speed) and speed of surplus water falling over the spillway and wing walls. Stone pavement were placed as a unit part of the stilling basin and extended at either side of the riverbank to down stream of the flood flow.

*Step 10*: Construction for the dam wall. The next flooding deposited coarse sand up to the level of the spillway. The spillway was raised another 30 cm above the new sand level. The process of raising a spillway in stages of 30 cm height, may be completed in one rainy season provided the required number flooding occurs and builders are ready for their work without delay.

*Step 11*: Plastering and pointing works. Exposed dam section at the upstream side, top surface of the entire dam and wing wall section are plastered with cement mortar of ration 1:3. The up stream section of the dam well plastered to be watertight. Down stream-exposed section of the dam wall and the stone pavements extended from the stilling basin were pointed with cement mortar mix ratio of 1:3.

## Appendix 5: Guideline for well construction

This calculation is based on Nissen-Petersen E, 2006.

*Step 1:* Excavation.

- Select the site and clear the area for excavation
- Mark out a circle of 1-metre radius.
- Dig the well using skilled man power as the well should be excavated straight for the diameter of 2 metres.
- Excavation of well continues until a depth at which sufficient water from the lowest water level of the sand storage can be extracted. Well digging is normally carried out in the dry season when the water table is lowest.
- While the digging process is on going, local construction materials such as sand, stones and preparation of crashed stone will be executed simultaneously.

*Step 2:* Construction of concrete ring and blocks.

- Preparation of concrete ring. This ring will have an outside radius of 75 cm and inside radius of 55 cm.
- The width of the ring is 20 cm and the thickness is 25 cm. The ring is made in a circular trench carefully dug to the correct dimensions. A concrete of mix of cement, sand and crashed stone (1:3:4) is used and six round of 3 mm galvanized wire are used to provide reinforcement of the ring.
- Additionally, 16 vertical pieces of wire 60cm long are attached to the reinforcing for fixing rope when lowering the ring in to the shaft. The ring is kept wet for seven days to cure the concrete.
- The concrete blocks are made in specially fabricated mould with curved sides. The block is 15cm high, 10cm wide and 50 cm long. The concrete mix is the same as for the ring. The blocks are placed on a plastic sheet and kept wet for seven days for curing.

*Step 3:* Construction of the well cover.

- The well's cover is made with a diameter of 150 cm and thickness of 10 cm; it has a hole of 60 cm in diameter in the middle. This will be used for drawing water. An additional smaller hole, 10cm in diameter, is made to one side as outlet hole to allow an exchange of fresh air. The cover is cast in an excavation in the ground. The same concrete mix is used as before together with 8 rounds wire connected by 31 shorter pieces of reinforcement.
- The well lid to cover the centre hole is made in a similar manner with barbed wire reinforcement of 50 mm thickness. Two handles of round bars should be made for lifting.

*Step 4:* Construction of the well shaft.

- The well ring is lowered using ropes if sufficient depth of the well has been reached.
- The con is lowered using ropes with the help of at least 15 men because of the weight. The concrete blocks are lowered one by one in a bucket. A cement and sand mortar mix (1-3) is used for the vertical joints and between the ring and the first course.
- In the horizontal joints between the first and second course and the second and third course, no matter is used so that water can gain entry. One round 3-mm galvanized wire is used with mortar between the third and fourth course and a step made from a round iron bar is installed. The same sequence continues until there are six horizontal joints without mortar through which water can enter.
- All subsequent joints are mortared. Steps are installed every three courses. After every six courses, the surrounding space in the well shaft is filled with coarse sand to act as a filter.
- The shaft is built till 60 cm above ground level to prevent surface runoff from entering the well. Barbed wire is left sticking out to joint with the reinforcement in the apron that will be constructed around the well shaft to keep the area clean and prevent contamination.
- The apron extends around the well shaft and slopes outward to a distance of 1.2 metres. This area is first excavated and then back-filled with hardcore to a depth of 30cm, to which is added a 5-cm layer of ballast. A 5-cm layer of concrete (1:3:4, cement:sand:ballast) is laid on the surface, and barbed wire is placed concentrically and radially for reinforcing. A further 5 cm of concrete covers the reinforcing.
- The apron is surrounded by al low wall with a gap to allow spilt water to drain away. Building two steps complete the work, each 30 cm high, to the well cover, plastering as necessary and placing the lid in position.
- Before the well can be used, the community must remove all the water and clean the bottom.