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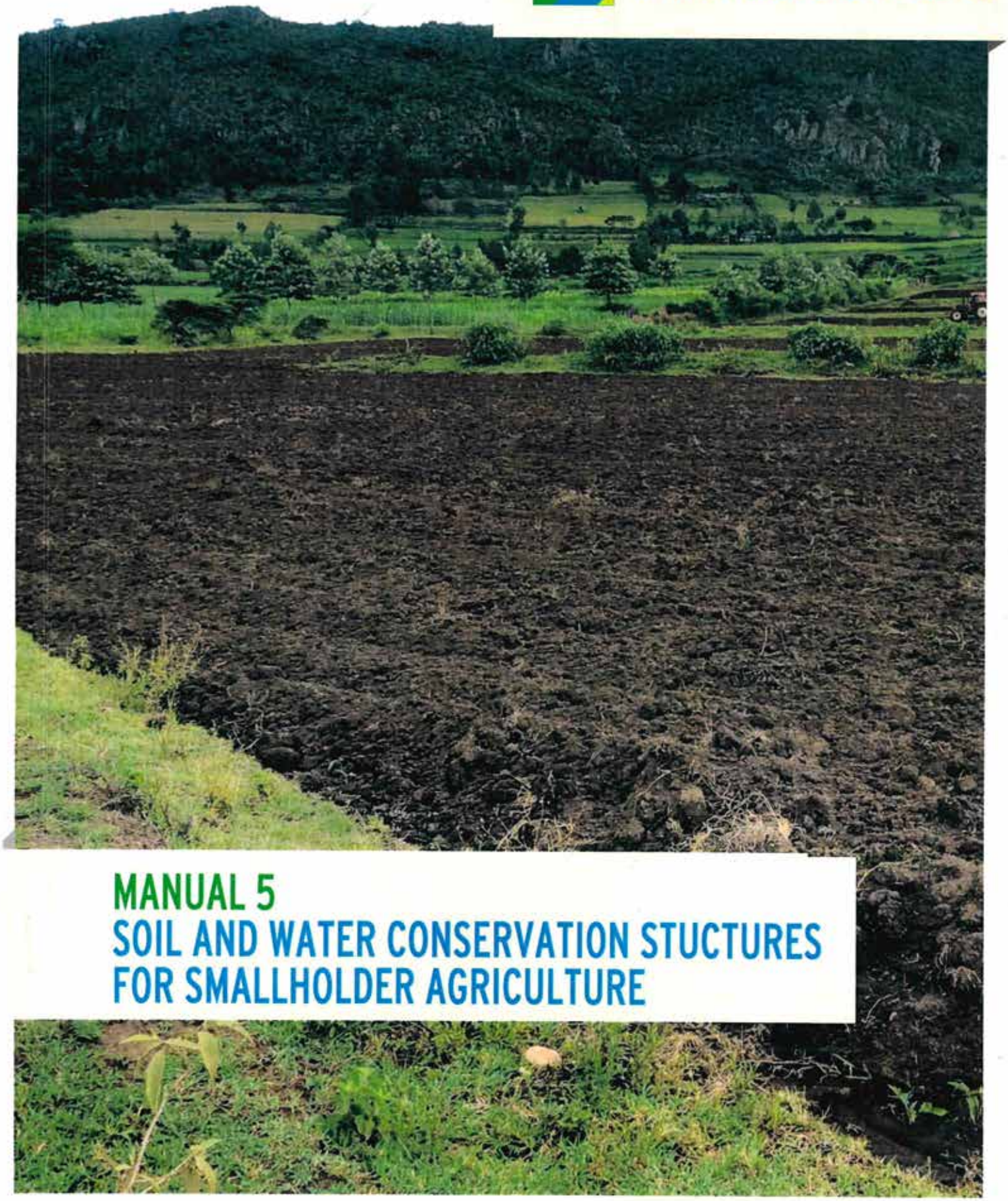

MANUAL 5
SOIL AND WATER CONSERVATION STUCTURES FOR SMALLHOLDER AGRICULTURE

NELSAP-CU

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NELSAP
REGIONAL AGRICULTURE & TRADE PROJECT (RATP)

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The Nile Basin Initiative (NBI) is an Intergovernmental partnership of ten Nile Riparian countries that is seeking to manage and develop the common Nile Water resources in acooperative manner and promote regional peace and security.

The Nile Equatorial Lakes Subsidiary Action Program (NELSAP) is one of the investment arm of the NBI and is mandated to facilitate identification, preparation, and resource mobilization and implementation supervision of "Cooperative and Consultative Nile Projects" and builds subregional capacity for country implementation of transboundary investment projects in the Nile Equatorial Lakes (NEL) region.

Nile Equatorial Lakes Subsidiary Action Program Coordination Unit (NELSAP CU)
Kigali City Towers, 5th floor, KN 81 Street
P.O. Box 6759, Kigali, Rwanda
Tel: +250 788 307 334
Fax: +250 025 588 0100
Email: nelsapcu@nilebasin.org

Author (2012): Bancy M. Mati (bancym@gmail.com)
Reviewer (2017): Dr. Collins Handa (handacollins@gmail.com)
Graphic Designer (2017): Munene M. Muverethi & Harelimana Pascal

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TRAINING MANUAL No. 5

Soil and Water Conservation Structures for Smallholder Agriculture

This publication was produced in 2012 for review by the Nile Equatorial Lakes Subsidiary Action Program (NELSAP) Regional Agriculture and Trade Project (RATP) with the support of Canadian International Development Agency (CIDA) through the Nile Basin Trust Fund (NBTF), and published in 2018 with the support of Cooperation for International Waters in Africa (CIWA) Trust Fund Nile Cooperation for Results (NCORE) Project

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Illustrations and diagrams drawn by: Munene M. Muverethi

Nile Equatorial Lakes Subsidiary Action Program
(NELSAP) Regional Agricultura land Trade Programme
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DISCLAIMER

About this Training Manual

The Nile Basin Initiative (NBI) is a partnership of the riparian states (Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda, Eritrea is participating actively in the NBI as an observer) that seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security through its shared vision of "sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources". NBI's *Strategic Action Program* is made up of the *Shared Vision Program (SVP) and Subsidiary Action Programs (SAPs)*. The SAPs are mandated to initiate concrete investments and action on the ground in the *Eastern Nile (ENSAP) and Nile Equatorial Lakes' sub-basins (NELSAP)*.

NELSAP through its sub basin programs implements pre-investment programs in the areas of power, trade and development and natural resources management. As part of its pre-investment framework, the Regional Agricultural Trade and productivity Project (RATP), in concert with the NELSAP, intends to promote and disseminate best practices on water harvesting and small scale irrigation development as a contribution towards agricultural development in the NEL Countries. NELSAP has previously implemented and completed a project called Efficient Water Use for Agriculture Project (EWUAP). One of the recommendations of EWUAP was the need to develop Training/Dissemination materials on "*adoption of low cost technologies for water storage, conveyance, distribution, treatment and use for agriculture that can be adapted by communities and households of the rural and peri-urban poor*". This Training Manual is the initiative of NELSAP, for that purpose.

This Training Manual summarizes the major components of irrigation planning, design, development and management and the requisite factors considered. It is meant to improve the skills of engineers, technicians, extension workers, managers and practitioners of irrigated agriculture, especially those working in smallholder irrigation in Africa. More specifically, the manual equips the reader with knowledge on how to (i) identify the appropriate irrigation system for a given area or circumstances, and (ii) plan and design of irrigation systems. It is meant to inform, educate, enhance knowledge and practice targeting smallholder irrigation in the NEL region. The information contained here may not be exhaustive and thus, readers are encouraged to seek further information from references cited in this publication and elsewhere.

Acknowledgement

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Definition of key terms

Term	Definition/Brief description
Arid	Very dry climate with less than 300 mm average annual rainfall, where cropping is possible only with support of either water harvesting or irrigation.
Available water holding capacity	The amount of water a soil profile can hold for plant uptake. It depends on soil depth, texture, structure and organic matter content.
Bulk density	The apparent density of a soil, measured by determining the oven-dry mass of soil per unit volume
Contour (line)	An imaginary line joining all points of the same elevation on a land surface.
Fanya juu	Swahili name meaning "throwing soil up" slope from a ditch to form a bund along a contour.
Deep percolation	Downward movement of water below the root zone under the force of gravity, eventually arriving at the water table.
Depression storage	Temporary retention of rainfall in hollows and surface depressions
Diversion ditch	A channel made across the slope to protect cultivated land from external runoff, normally with a gradient of 0.25-0.5%, also called cut-off drain
Grassed waterway	A broad, shallow channel running down the predominant slope and usually planted with short, closely growing grass. It is used for the disposal of concentrated flows at safe velocities. Also called artificial waterway.

Term	Definition/Brief description
Gully	A deep channel created as a result of severe soil erosion, usually caused by running water.
Horizontal interval	The horizontal distance between two structures
Hydraulic conductivity	The rate at which water can pass through a soil material, usually measured under saturated conditions.
Infiltration	Absorption and downward movement of rainfall into the soil
Infiltration capacity	Limiting rate at which falling rain can be absorbed by a soil surface in the process of infiltration.
Infiltration rate	The rate at which water enters the soil profile. Infiltration rate can be relatively fast, especially as water enters into pores and cracks of dry soil. As the soil wets up and becomes saturated, the infiltration rate slows to the point where surface runoff occurs.
Interception	Catching and holding of rainfall above the ground surface by leaves, stems and residues of plants
Interflow	Movement of soil water through a permeable layer in a downslope direction parallel with the ground surface, also called through flow
Liquid Limit	The moisture content at which a soil begins to flow and behave like a liquid.
Nitrogen-fixing	The ability of certain small organisms (bacteria, algae) to convert atmospheric nitrogen (a plant nutrient) into a form which can be used by plants. These organisms live near the roots of legumes
Overland flow	Water flowing over a sloping ground surface to join a stream flow: a form of runoff

Term	Definition/Brief description
Overtopping	Water flowing over the top of a bund or ridge, leading to erosion.
Perennial (crop)	A plant that lives for three or more years and which normally flowers and fruits at least in its second and subsequent years.
Plastic limit	The moisture content at which a soil changes from a semi-solid to a plastic state
Rainfed agriculture	Agricultural systems whereby natural rainfall is the predominant source of water for growing crops, trees or pasture on that field. It also includes crops grown with flood flows harvested from excess rainfall runoff.
Retention ditch	A relatively large, deep channel that runs across the slope to catch and retain all incoming runoff for infiltration into the soil. It also called an infiltration ditch, or cutoff ditch
saline soils	Soils having high concentration of soluble salts
Saturation	The moisture content at which all soil pores are completely water-filled.
Semi-arid	Fairly dry climate with average annual rainfall of about 300-700 mm, with high variability in rainfall.
Slope gradient	The angle of inclination of a slope, which may be expressed in degrees or as a percentage.
Soil and water conservation (SWC)	Activities that maintain or enhance the productive capacity of land in areas affected by or prone to soil erosion.
Soil erosion	The movement of soil from one part of the land to another through the action of wind or water.

Term	Definition/Brief description
Soil fertility	The capacity of a soil to produce crops by supplying nutrients (macro and micro) in correct proportion and in adequate amounts over a long time.
Soil moisture	Water held in the soil and available to plants through their root system, also called soil water.
Soil moisture profile	The depth to which water infiltrates into the soil, also called infiltration boundary
Soil porosity	The percentage of a given volume of soil that is made up of pore spaces. Soils are oven-dried to measure bulk density, so porosity is a measure of air-filled pore space
Spillway	An outlet created in a retaining structure for allowing overflow of excess runoff
Sub-humid	A humid climate with average annual rainfall of roughly 700-1000 mm.
Surface runoff	Excess rainfall which runs off the surface of the land, it includes both overland flow and stream-flow
Surface sealing	When soil forms a sort of clay cement after rain, because the finest grains clog the soil pores, preventing water infiltration. Also called clogging up
Sustainable Land Management (SLM)	The use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions.
Terrace	A piece of land whose slope steepness and/or length has been reduced by either construction works, or by creating barriers across

Term	Definition/Brief description
	the slope, so as to absorb and/or reduce surface runoff
Tillage	preparation of the land for planting, or all the operations undertaken to prepare a seed bed in agriculture
Time of concentration	The storm duration which corresponds with the maximum rate of runoff in a watershed. Also described as the time duration when the watershed contributes peak discharge rate.
Transpiration	Water that is taken up by plants from the soil and then lost to the air through small openings in the leaves of plants.
Vertical distance	Spacing between two structures determined on the basis of the difference in ground elevation, also referred to as vertical interval.
Vertisol	A type of montimorillonitic clay (also called black cotton soil) with high clay content, which cracks when dry and is difficult to till when wet
Water conservation	The control, protection, storage, management and utilization of water resources in such a way as to optimize productivity
Water harvesting	Activities where water from rainfall and/or surface runoff is collected, diverted, stored and utilized.
Water logging	State of land where the water table is located at or near the surface resulting in poorly drained soils, adversely affecting crop production
Water storage capacity	Maximum capacity of soil to hold water against the pull of gravity, also called field capacity
Water table	Upper limit of ground water (or the saturated zone under the soil profile).

INTRODUCTION

1.1 What is soil and water conservation?

Soil and Water Conservation (SWC) are activities that maintain or enhance the productive capacity of land in areas affected by or prone to soil erosion. ***Soil erosion,*** on the other hand, is the movement of soil from one part of the land to another through the action of wind or water (Figure 1.1). Thus, soil erosion by water is caused by raindrop impact surface sealing, and crust formation leading to high runoff rate and amount, high runoff velocity on long and undulating slopes, and low soil strength of structurally weak soils with high moisture content due to frequent rains. Soil erosion by wind is caused by lack of vegetation cover, dry pulverized soils, strong wind speeds, and poor land management practices such as continuous tillage and over-grazing.

Figure 1.1 (a) Long, steep slopes that require soil conservation structures (photos by B. Mati)

(b) Badly gullied semi-arid land that requires multi-faceted rehabilitation measures.

Therefore, SWC includes the prevention, reduction and control of soil erosion alongside proper management of the land and water resources. Effective erosion management involves:

(i) Reduction of the amounts and velocity of surface runoff,

(ii) Maintaining good soil cover through mulching and canopy cover

(iii) Conservation and retention of soil moisture,

(iv) Prevention or minimizing the effects of raindrop impact on the soil

(v) Maintaining favorable soil structure for reducing crusting

(vi) Re-shaping the slope to reduce its steepness and slope length so as to minimize runoff flows

(vii) Maintenance or improvement of soil fertility, and

(viii) Removal of unwanted excessive runoff safely through protected waterways and graded channels.

Based on these principles, erosion control measures are grouped into two broad categories:

(i) Preventive techniques, and

(ii) Control measures.

The erosion preventative measures mainly comprise the ***agronomic soil and water conservation*** practices that improve land productivity without construction of structures (see Training Manual 4 in these series). The erosion control measures involve the ***construction of various structures*** for the control, diversion or conservation of runoff, which is the focus of this Training Manual (Figure 1.2). For improved agricultural productivity, both the agronomic and structural measures of soil and conservation are necessary, especially on steeply sloping lands, where water conservation or drainage of excessive water are required.

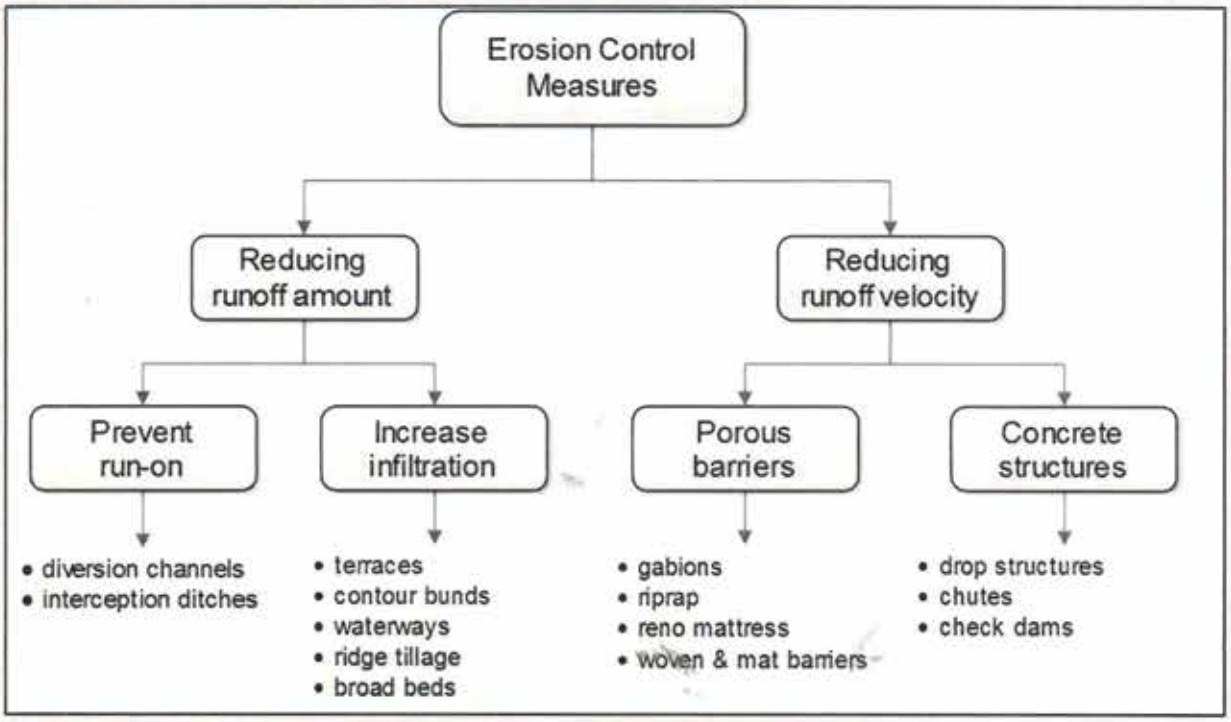

Figure 1.2 *Flow chart depicting various methods of erosion control measures*

1.2 What are soil and water conservation structures?

Soil and water conservation structures include all mechanical or structural measures that control the velocity of surface runoff and thus minimize soil erosion and retain water where it is needed. They usually consist of engineering works involving physical structures, made of earth, stones, masonry, brushwood or other material for the construction of earthworks such as terraces, check dams, and water diversions, which reduce the effects of slope length and angle. SWC structures can be designed to either conserve water or to safely discharge it away. They supplement agronomic or vegetative measures but do not substitute for them. Suitability of SWC structure depends on:

(i) Climate and the need to retain or discharge the runoff.

(ii) Farm sizes.

(iii) Soil characteristics (texture, drainage, and depth).

(iv) Availability of an outlet or waterway.

(v) Labor availability and cost.

(vi) The adequacy of existing agronomic or vegetative conservation measures.

1.3 Determining amounts of runoff for design of SWC structures

1.3.1 Characteristics of surface runoff

Surface runoff (or simply runoff) is the portion of precipitation that makes its way towards the stream channels, lakes or oceans as surface or subsurface flows. Runoff occurs when precipitation rate exceeds infiltration rate, and is the most destructive component of rainfall. In the design of SWC structures, the most important factors used are

(i) peak runoff rates,

(ii) runoff volume, and

(iii) temporal distribution of runoff rates and volumes.

Factors affecting runoff

These include both catchment factors and rainfall factors.

1.3.2 Catchment factors

Runoff is influenced by catchment factors such as topography, vegetation, infiltration rates, soil storage capacity and drainage pattern. In addition, the size of the catchment, its shape, orientation, geology and surface culture also affect runoff. The larger a catchment, the more runoff it will generate. Slope steepness is particularly important as soil erosion is more prone on steeper slopes. Surface culture includes the soil tilth, whether there is vegetative cover or not, and other land management activities, e.g. cultivation that would increase erosion.

1.3.3 Rainfall factors

Rainfall factors associated with surface runoff and erosion include; rainfall amounts, storm duration, intensity and distribution, as well as seasonal patterns, e.g. Dry areas are more prone to erosion than wet areas because prolonged dry spells destroy vegetation cover, and rain storms tend to be of high intensity and thus erosive. The most significant component of rainfall is its intensity, which is a function of the energy the raindrops impact on the soil. The intensity-duration relationship of rainfall gives an indication of expected runoff. For example:

$$I = a/(t+b)$$

Where: I = Rainfall intensity

T = Duration of rainfall (min)

a & b are constants

For any given duration, the graph or equation will indicate the highest average intensity which is probable for a storm of that duration. This is calculated as:

$$I = kT^x/t^n$$

Where,

T = is the return period in years

T = is the duration in minutes

k, x, and **n** are all constants

Calculations involving rainfall probability must relate to a chosen return period, e.g. for conservation works on small farms, about 10 years.

Time of Concentration (Tc)

The storm duration which corresponds with the maximum rate of runoff is known as the time of concentration (Tc). It is assumed that during the time of concentration, all parts of the watershed are contributing simultaneously to the discharge at the outlet. Tc is also described as the longest time for water to travel by overland flow from any point in the catchment to the outlet. It is equivalent to the time it takes water to flow from the furthest corner of the catchment to the outlet.

Design storm

A design storm, is a storm of known return period. It is used as a basis for designing structures. For example, a 10-year, 1-hour rainfall is the maximum rainfall amount expected in a 1-hour period with a 10-year return period.

Design runoff rates

The capacity to be provided in a structure that must carry runoff may be termed as the design runoff rate. Structures and channels are designed to carry runoff that occurs within a specified return period (T_R). E.g. 10 years for vegetative waterways, and 100 years for permanent channels.

1.3.4 Estimation of surface runoff

It is important to know the quantities of water to be handled. If the objective is to impound water e.g. dams, peak volumes are used, if the purpose is to convey water e.g. channels/waterways, peak runoff rates are used. It is necessary to estimate runoff or design of conservation and also conveyance structures, to avoid failure due to overtopping. Estimates of the rates of surface runoff therefore depend on two processes:

(i) estimating the rate of rainfall, and

(ii) estimating how much of the rainfall becomes runoff.

The runoff rate is more crucial and is determined using various methods or equations as described below:

a) The Runoff Coefficient

The simplest method is to use a single coefficient which represents the ratio of rainfall loss.

If half of the rainfall is "lost" by infiltration, the other half appears as runoff, then the coefficient, C is 0.5.

Examples of runoff coefficients:

Woodland on flat sandy loam, C=0.10

Woodland, flat tight clay C = 0.40

Cultivated, hilly clay soil, C = 0.60

Urban, rolling, 50% built up, C = 0.65.

b) Catchment Characteristics or Cook's method

The method consists of summing numbers each of which represents the extent to which runoff from the catchment will influence a particular characteristic. The effect of four features is considered in Cook's method, which are

(i) the relief,

(ii) soil infiltration,

(iii) vegetal cover, and

(iv) soil surface storage.

Each of these is considered in turn and the condition of the watershed compared with four descriptions, i.e. extreme, high, normal, and low. Each description/feature has a number. For example, an arithmetic total (e.g. 30+10+15+10=65) is the watershed characteristic and will lie between the extreme values of 100 and 25. The main problem of this method which estimates by addition is that the errors are propagated.

c) Runoff Curve Numbers

This is an extension of Cook's method, which allows for variations in the physical conditions of a catchment and also the land use. Like in Cook's method, four variables are considered and in each case, a selection has to be made from a list of options. Ten categories of land use or cover are offered (row crops, pasture, woods, fallow, and farmstead among others) with a choice of soil conservation practices such as contouring and terracing. The hydrologic condition of the catchment is graded good, fair or poor and a subjective assessment of this factor is designated one of four major hydrologic soil groups described earlier. The method relies on subjective non-measurable assessment.

d) The Rational Formula

$$Q = 0.0028CIA$$

Where:

Q = The design peak runoff rate in m3/s

C = Runoff coefficient (a function of catchment vegetation, slope, surface culture)

A = Area of the watershed in hectares

I = Rainfall intensity in mm/hr for the design return period and for a duration equal to the time of concentration of the watershed.

The Rational method predicts runoff through this equation:

The Rational method is developed on the assumption that (i) rainfall occurs at uniform intensity for a duration equivalent to the time of concentration, and (ii) rainfall occurs at a uniform intensity over the entire area of the catchment.

1.4 General principles for the design of SWC structures

The design of SWC structures considers severity and extent of erosion damage or risks, the factors causing erosion, as well as the suitability of land to the identified intervention. SWC control measures are directed at protecting the soil from raindrop impact and hydraulic forces of runoff. The process involves three areas of attention:

(i) Reduction of raindrop impacts on soil;

(ii) Reduction of overland flows;

(iii) Increase infiltration rate, and

(iv) Slowing runoff velocities.

1.4.1 Factors considered

Soil and water conservation structures are usually made by hand labor or machinery although some terraces develop naturally from vegetative barriers. They are particularly important on steep slopes where annual crops are grown and in marginal rainfall areas where there is a need to conserve rainfall in situ. The selection and design of structure depend on many factors such as:

(i) Climate and the need to retain or discharge runoff.

(ii) Farm size and system (large or small-scale, mechanized or non-mechanized).

(iii) Cropping pattern (perennial or annual, with or without rotations).slope steepness.

(iv) Soil characteristics (erodibility, texture, drainage, depth, stoniness and risk of mass movement).

(v) The availability of an outlet or waterway for safe discharge of runoff away from cropland.

(vi) Labor availability and cost

(vii) The availability of material e.g. stone

(viii) The adequacy of existing agronomic or vegetative conservation measures.

1.4.2 Structures for retention or discharge of runoff

Structure can be designed either to retain or discharge runoff. They can also be designed so that part of the runoff is retained but the excess, during heavy storms, is discharged. In the higher rainfall areas(e.g. over 1,250 mm per annum), where crops are rarely short of water, or where there is a risk of water logging at certain times, it is usually to design structures to discharge runoff if there is no suitable outlet such as a natural waterway, artificial waterway or grassed slope. Discharging water onto a footpath, road or existing gully would aggravate soil erosion. On large-scale farms it is usually possible to set land for waterways. In densely settled area this is much more difficult.

In the drier areas (e.g. less than 750 mm per annum) it is usually desirable to keep rainwater *in situ* and to prevent runoff. Other factors that must be considered in reaching a decision, besides the availability of a discharge area or waterway, include the soil type, soil depth land slope and the risk, if any, of retaining water *in situ*. Soils in higher rainfall areas that are prone to water logging because they are shallow or because of the clay content, such as the grey soil (planosols) or black cotton soils (vertisols) in other areas, normally require structures that will drain water. Some soil on steep slopes, such as the areas with andosols, it is better to drain water. Also, areas prone to landslides become unstable if they very wet, and conservation structures should be designed to drain the water away.

When there is a need to discharge water but no suitable space for a waterway, there are two options. One is to change the land use to a permanent crop or fodder grass that does not require conservation structure. The other is to use contour barriers designed to conserve all the runoff.

1.4.3 Size of conservation structure

The design of any structure to retain or discharge runoff should be based on a reasonable estimate of the volume of runoff (m^3) to be retained or the peak rate of runoff (m^3/s) to be discharged. A retention structure can rarely be made big enough to capture all runoff during exceptionally wet period, unless the catchment area is very small. One alternative with retention structures is to incorporate a spillway to take the overflow.

Similarly the design of a structure to discharge runoff can rarely be based on the heaviest storm possible. Usually it is based on the heaviest storm that can be expected in a given period (e.g. 10 years) with the knowledge that a heavier storm, of a magnitude that occurs once in twenty, fifty or a hundred years, could take place (the frequency in years with which a storm of a given amount is likely to occur is known as the return period).

1.4.4 Risks

The risk of damage due to an exceptional storm should be considered when designing structures. If the risk cannot be eliminated, it must be minimized by ensuring that the structures are stable when they are made and carefully maintained afterwards. Failure to pay attention to this point can lead to damage during heavy storms and greater erosion than erosion than if the structures had not been installed in the first place. Where there are a series of structures on a hills slope there is a risk if a structure is breached near the top, then those downhill would also get damaged.

1.5 Types of conservation structures

The main SWC structural measures used on croplands comprise diversion ditches (cut-off) drains), retention (infiltration) ditches, terraces and waterways. Supportive cultural measures such as grass or vegetative material for stabilizing the structures are also required for selection of proper species. The identification of appropriate types of SWC structures should take into account the need to retain runoff in areas where water is short or discharge runoff where it is in excess. The design of structures to discharge runoff, such as diversion ditches and waterways, should be based on an estimate of the peak rate of runoff. Structures which are intended to discharge runoff should not be installed unless there is safe place for disposal of water e.g. a natural or artificial waterway or permanent vegetation.

In higher rainfall areas e.g. areas receiving more than 1000mm of rain per annum, and where crops rarely lack water, or where there is a risk of water it is usually necessary to design structures to discharge runoff. However, it would be erroneous to design a structure to discharge runoff if there is no suitable outlet such as a natural waterway, artificial waterway or grassed slope. Discharging water onto a footpath, road or existing

gully will aggravate the problem of erosion. In the drier area (less than 750 mm per annum), it is usually desirable to keep rainwater *in situ* and prevent runoff.

1.6 Benefits of conservation structures

Soil and water conservation bears benefits over a longer time span after construction. However, some benefits such as increased crop yields can be attained within the first year. In general, the benefits of SWC can be summarized as follows:-

(i) Increased agricultural productivity (higher yields, fodder for livestock livestock)

(ii) Conservation of potentially productive land i.e. SWC supports sustainable agriculture

(iii) Reduced nutrient loss from the soil, and thus less fertilizer requirements

(iv) Environmental conservation, by storing more water within the soil profile and thus improved catchment hydrology

(v) Soil drainage benefit in areas prone to floods or waterlogging,

(vi) SWC benefits irrigation and drinking water supplies, by protecting reservoirs from sedimentation

(vii) SWC protects infrastructure such as roads from erosion damage, e.g. gullies.

1.7 Limitations

The planning and construction of SWC structures on smallholder farms can be complicated by the small sizes of plots on given slope. This is because farm boundaries are not necessarily aligned to the contour or following a natural feature such as a crest line or drainage line. Thus, it is difficult to get appropriate site and space for an artificial waterway. Sometimes, the best site for a waterway may already be occupied by a footpath or a gully. Attempting to plan one farm in isolation from the others is likely to cause failure. A catchment plan is needed but there are social implications which must first be resolved.

SWC structures can be expensive to install. In particular, gully control structures can be very expensive. There is also a lot of labor needed to excavate terraces, especially bench terraces. SWC requires some level of engineering design, and thus technical know-hoe can be a limitation. SWC structures function by retaining water in-situ, thus denying runoff to downstream areas. This can be a potential source of conflict which should be addressed.

1.8 Management and maintenance

SWC structures require regular maintenance and repairs if they get damaged. Grazing in cultivated lands treated with SWC structures should not be allowed as the animals can damage the structures. Instead, fodder should be cut and taken to animals preferably under cut and carry systems. Replanting vegetative materials and lining out of construction and channels should be done at least every season.

2 DIVERSION DITCHES

2.1 What is a diversion ditch?

A diversion ditch (also known as cut-off drain or storm-water drain) is an open channel, made across the slope, with the ridge of the downhill side (Figure 2.1). Diversion ditches are usually constructed above cropped land to protect cultivated land from excessive flooding coming in from home compounds, roads, gullies and other surfaces. It is the first line of defiance and is vital to the protection of the entire farm since all the structures lower down are designed on the assumption that all the run-off from outside the arable land is well controlled. If the diversion ditch fails the runoff ensuing would certainly breach the lower conservation works.

Figure 2.1: A newly excavated diversion ditch (Photo by B. Mati)

There are various types of diversion ditches, called variously storm water drain, storm water channel, diversion terrace, cutoff ditch, cutoff drain, diversion ditch, or other combinations of these terms. However, the major distinguishing feature is whether the structure is meant to drain away excess flows – in which case it is called a "drain" or for water conservation – then the term "ditch" applies. Diversion ditch will be the term used in this manual.

2.2 Functions of diversion ditches

(i) The primary purpose of a diversion ditch is to protect intercept surface runoff which flows down from higher ground and convey the water safely to an outlet such as a waterway.

(ii) A diversion ditch protects other SWC structures downhill behind it from erosion damage

(iii) In dry land areas, diversion ditches can be used for water harvesting by directing water coming from the upper catchments into farmlands.

(iv) In places where there is relatively high rainfall, and in areas with Vertisols, diversion ditches are used as drainage ways to let out water from the farmland to the natural or artificial waterway.

(v) Diversions structures may also be used to control gully erosion, and dissipating excess flows from roads, home compounds and hilly areas.

(vi) They are used for water conservation or as water retention structures and tree crops grow inside the ditch, especially in dry areas.

(vii) Diversion ditches can pond runoff which can be used to raise the soil moisture of adjacent farmlands through seepage.

2.3 Design of diversion ditches

The design of diversion ditches should be based on the outlet conditions, topography, land use and soil type. As diversion ditches are made to protect cultivated land, they should be designed to carry the peak runoff from the contributing catchment during the worst that can be expected in a 10 year period. The location of a diversion ditch is usually determined after checking the outlet conditions, topography, land use, soil type and length of slope. To achieve effective protection of farmland, the diversion ditch or cut-off drain, should be constructed between uncultivated and cultivated land.

2.3.1 Allowable Velocity

The dimensions of a diversion ditch are determined using the manning equations with permissible velocities shown below.

$$Q = (AR^{2/3}S^{1/2})/n$$

Where, Q = flow rate, m^3/s

A = area of flow, m^2;

V = mean velocity, m/s

R = hydraulic radius, m, (R= A/P; where P is the wetted perimeter)

S = bed slope, m/m

n = Manning roughness coefficient = 0.03 for drains

The channel shape and cross-sectional area are related. But since most diversion ditches are designed with a trapezoidal cross-sectional area, then the values of A and P are calculated as follows:

$$A = bd + Zd^2; \quad \text{and} \quad P = b + 2d\,(1+Z^2)^{1/2}$$

Where,

Z = side slope of a trapezoidal channel. Z should be less than the angle of repose of the saturated material. In any case Z should not be steeper than 1.5: 1 (Horizontal: Vertical).

b = bottom width of the drain,

d = depth of water

2.3.2 Channel shape and dimensions

The channel cross-section can be made rectangular, parabolic, semi-circular or trapezoidal. Manually excavated ditches are usually rectangular or trapezoidal, while those made using machinery the shape can be trapezoidal, parabolic or semi-circular. The trapezoidal shape is preferred because it accords larger capacities than either rectangular or parabolic shapes. The channel width and depth must be appropriate to the cross-sectional area calculated from equation given above.

For an average smallholder farm, the channel dimensions range about 0.6 to 1.4 m bottom width, with a top width ranging 1.2 to 2.8 m.

- The depth of diversion ditches can be about 0.3-0.7m.
- On larger mechanized farms, the side slope of the channel should be 4:1,
- but in small-scale farming a steeper gradient of up to 1:1 is recommended to save land.

Channel dimensions depend on the gradient of the ditch. For gentle slopes, wider, shallow channels are used while on steep slopes, narrow, deep channels are more appropriate. In any given situation there are usually several possible dimension which are related to the bed gradient as shown in Table 2.1. Generally, the channel cross-section should have a wide shallow cross section to minimize the risk of erosion and allow easy crossing by people and livestock.

Table 2.1: Allowable discharge rates for various channel dimensions and gradients of diversion ditches

Ditch dimensions				Gradient of ditch		
Bottom Width	**Depth**	**Top width**	**Cross-sectional area**	**0.1%**	**0.2 %**	**0.5%**
(m)	**(m)**	**(m)**	**(m^2)**	**(m^3/s)**	**(m^3/s)**	**(m^3/s)**
0.6	0.3	1.2	0.27	0.14	0.20	0.31

0.8	0.4	1.6	0.48	0.30	0.42	0.67
1.0	0.5	2-0	0.75	0.54	0.77	1.21
1.2	0.6	2.4	1.08	0.88	1.25	1.25
1.4	0.7	2.8	1.47	1.34	1.88	1.88

Note: These values assume earth lining and 1:1 side slopes.

Source Thomas, 1997

2.3.3 Channel gradient

The channel gradient of a diversion ditch depends on the topography of the area and should vary between 0.1% and 1% with 0.5% as the optimum. For light sub-soils, (sandy silt and sandy loam) channel gradient is 0.1%-0.2% and for heavy sub-soils (clay and clay loam) it is 0.4%-0.5%. For small discharges about 1% gradient can be used. In order to minimize the risks of sedimentation and over-topping, the diversion ditch should not be long.

2.3.4 Channel Length

Generally, the length of a diversion ditch is commensurate with the width of the farm. But for very small farms it may be necessary to excavate one continuous channel across farm boundaries with one outlet, rather than several small ditches with respective waterways. This has social implications as neighboring farmers should all be agreeable. To minimize the risks of sedimentation and overtopping, a diversion ditch should not be too long, preferably not exceeding 250 m for areas with highly erodible soil. On more stable soil, e.g. red clay loams, the length should not be more 500 m. In exceptional cases, a longer ditch could be made if it is the only way to reach a safe outlet or waterway.

2.3.5 Free Board

A Free board is an additional capacity added to the design depth of channel. The design is based on the peak discharge, which will occur at the outlet of the ditch. For earthen channels, extra depth equivalent to a 10% increase in the design depth is used. A freeboard is necessary to take care of unexpectedly high flows, and to act as a safety net in case of sedimentation of the channel or settlement of the embankment.

To reduce unnecessary earth excavations, depth can be less at the upper end of the channel so that the water will move at a slower velocity but the channel will fill to about the same capacity. In practice, it is usually easier to make the same dimensions throughout. If a large is estimated, the catchment area should be sub-divided and several diversion ditches made so that none is carrying an excessive amount of water.

2.3.6 Channel lining and stability

A grass lined channel is more stable than an earth lined channel. Crass resists scouring but it slows down the flow of water and encourages deposition. If it grows tall it can block the channel. Broad shallow channels are usually lined with creeping grasses whereas narrow and deep channels are more likely to be earth lined. In areas of small-scale farming, the channels are usually narrow and dug into the subsoil so that condition ate not suitable for a grass lining and the design should be based on the assumption that the lining is of earth.

2.4 Layout and construction

Diversion ditches can be laid out with a line level or quickset level. The layout should start from the outlet end and stakes placed along the proposed diversion. In smallholder farms, the diversion ditch sometimes crosses several farm holdings and it is to survey the alignment across a number of fields wherever possible. The design and layout should conform to the principles of catchment planning and the farmers should be involved at all stages.

The diversion ditch should be constructed before the land downhill is terraced. Construction should start from the outlet end. The time taken to excavate a given volume of earth for a diversion ditch depends on the type of soil, soil moisture content and size of cross-sectional area of the ditch. It is more difficult and expensive to dig clayey soil than sandy soil. Generally, it would take an active person about 8 hours of hard work to excavate 3 to 4 m^3 of soil. The embankment is usually compacted and stabilized with grass planting.

The excavated soil from the ditch is placed on the downhill side to form the embankment. The embankment helps to further increase the capacity of the diversion ditch. A berm measuring about 15-30 cm (strip or ledge) is left between the embankment and the channel in order to prevent sliding of the soil. A good grass cover is then established on the embankment, and a strip of grass, alloy, and sisal planted along the upper edge to prevent the inflow of sediment.

2.5 Retention Ditches

Retention ditches, also called infiltration ditches, are larger ditches designed to catch and retain all incoming runoff for infiltration into the soil. They operate like contour furrows, increasing the supply of water made available to crops planted in and adjacent the ditch, while also reducing soil erosion. However, they handle much more water. Retention ditches are in essence water harvesting and conservation structures. They are commonly used as an alternative to diversion ditches if there is no places to discharge runoff or if there is a need , as in semi –arid areas , to harvest water , e.g. for bananas. The ditch should have all the impounded water infiltrated within 48 hours to avoid any water logging of the surrounding areas

Retention ditches are normally constructed on relatively flat areas with closed ends and wide and deep enough to hold all the runoff expected. They are often found on steep slopes in humid area under small scale farming where there is no opportunity to discharge runoff to a waterway. Retentions ditches can be useful where soils are permeable, deep and stable. However, retention ditches are not recommended for areas with shallow soil, those prone to land slides or where soil salinity is a possibility.

Retention ditches should be sited very close to the contributing catchment area. When used on sloping cropland in humid areas to stop runoff, the spacing can be based on the usual terrace spacing formula. However, retention ditches in dry areas are often made for harvesting water from roads or tracks and the location of such ditches will be specific to the site. In this situation, the areas of the catchment should be estimated and the volume of runoff calculated.

When constructing the ditches, the soil is thrown to the lower side to form an embankment that prevents soil from falling back in. This structure can be stabilized further by planting grass on it. On soils with lower infiltration rate, or on slopes, the ends can be left open to allow excess water to drain out. Retention ditches are commonly used in semi-arid areas for growing crops that have high water requirements, such as bananas. They should be used on lighter, free draining soils that are deep, stable and not prone to landslides.

2.6 Management and maintenance

Diversion ditches and retention ditches should be well managed and kept on best working conditions. The agronomic and land husbandry activities on the farm is also necessary to stabilize the embankment with grass and to plant a strip of grass along the upper side of the ditch in order to reduce sedimentation. Retention ditches may be necessary but they are no substitute for good land husbandry.

3. TERRACES

3.1 What is a terrace?

A terrace is a broad term to include all types of structures made across a slope for the purpose of soil and water conservation. However, there are many definitions by various authors as to what constitutes a terrace. One simple definition describes a terrace as "a more or less change in slope profile with a reduction in gradient of the planted zone". Thus, reducing slope steepness and/or length is also referred to as terracing (Figure 3.1). A more elaborate definition describes a terrace as "a unit consisting of a relatively steeply faced structure across the slope (referred to as a riser, bank, dyke, ridge, wall or embankment), that supports above it a relatively flat terrace bed (which may be either flat, or sloping backwards or forwards and may slope laterally)". In general, all structures, whether constructed or implemented as agronomic practices, but which alter land steepness constitute a form of terracing. Techniques like construction of ditches, earth and some stone bunds, and vegetative barriers are normally defined as soil and water conservation (SWC) structures and are primarily promoted to reduce soil erosion. But terraces are made for various purposes such as for erecting buildings on sloping land, developing public areas like stadiums, in landscaping, and even a simple staircase is a terrace. Thus, for agricultural purposes, a terrace can be described as "a piece of land whose slope steepness and/or length has been reduced by either construction works or by creating barriers across the slope, so as to absorb and/or reduce surface runoff".

Figure 3.1 Terraces reduce slope steepness and slope length(Photo by J. Gassasira)

3.1.1 Functions of a terrace

The word terrace is sometimes used to refer to the structure itself, sometimes to the land between the structures and sometimes to both together. The change in slope of the cropped area may be minor, as with a *fanya juu* terrace, or major as with bench terraces. A common feature of all terraces is that they involve a more or less permanent change in slope profile. Terraces normally have a ridge or embankment of earth or stone which may or may not be combined with a channel. Thus, the functions of a terrace include:

(i) On sloping lands, terracing reduces overland flow rates thereby reducing soil erosion.

(ii) Terraces increase the infiltration of water and thus conserve moisture.

(iii) They help to retain nutrients of the land thus boosting soil fertility –less fertilizer use

(iv) Terraces can be used to drain away excess floods safely

(v) They re-shape the slope profile to make other agronomic activities, e.g. mechanized agriculture possible

(vi) Although terraces are normally to be used on cultivated lands, they can be on grasslands if the land is badly eroded.

(vii) Terraces are of value on practically all soils except those that are too stony, sandy or shallow to permit practical and economic construction and maintenance.

(viii) In drier areas the construction of terraces even in gentle sloping lands would be essential to enable water retention.

(ix) The grass grown on terrace banks is used as animal feed

(x) Terraces increase the overall productivity of agricultural lands.

3.12 Limitations of terraces

(i) Construction of terraces can be labor intensive, and even expensive.

(ii) Terracing may increase the risk of landslides in high rainfall areas

(iii) Sometimes, lack of a suitable outlet may lead to erosion of areas adjacent terraces

(iv) They require technical expertise to plan and construct.

(v) Terraces result in increased infiltration which can cause high water pressure in the soil pore and collapse of terrace embankments on unstable soils.

(vi) Terraces is not advisable to terrace lands with very gentle slopes (except where water retentions is required) also on very steep slopes or where the topography is very irregular.

3.2 Design of terraces

Terraces are usually designed to re-shape the slope profile, by reducing the slope steepness and/r length. This requires the calculation of the most opportune terraces spacing. The right terrace spacing should enable effective functioning as in reducing soil erosion to a minimum. If the spacing is too wide, soil erosion continues to occur, and if too close, the construction is unnecessarily expensive.

3.2.1 Criteria for good terrace location

Terracing is achieved when long slopes are broken with earthworks installed across the steepest slope to intercept the surface runoff. Terrace earthworks consist mainly of two parts:

(i) an excavated channel, and

(ii) a bank or ridge on the one side (either uphill or downhill) formed with the spoil from the excavation. Sometimes the spoil is spread over the land to create a level or nearly level steeped terrace as in bench terracing.

The planning of a terrace system should be coordinated with the water management system for the entire farm, giving adequate consideration for proper land use. Wherever possible, adjacent farms having fields in the same drainage area may consider joint terracing system. The following factors are considered for selecting terrace location:

(i) Farm orientation in relation to agricultural operations, cropping patterns and ease of farming operations

(ii) Identify location of terraces where there would be minimum maintenance requirement

(iii) Reasonable investment cost

(iv) Adequate control of erosion

(v) Availability of outlet for discharging excess flows, especially in the case of graded terraces

(vi) Better alignment of terrace can usually be obtained by placing the terrace ridge just above eroded areas such as gullies and abrupt change in slope

(vii) Location of roads, fences and other infrastructure in relation to the terraces

(viii) Top terrace should be laid out first, starting from the outlet end

(ix) Top terrace should be properly located so that it will not overtop and cause failure of the other terraces below.

Terraces are more effective when used in combination with other practices, such as proper agronomic and vegetative practices. Contouring and strip cropping are the best techniques to be used with terracing.

3.2.2 Determining terrace spacing

The amount of runoff carried by a terrace is calculated through any of the methods discussed in Chapter 1. The capacity of channels in terraces can be calculated using Manning's Equation also in Chapter 1. For simple terraces such as fanya juu terraces, the general formula for terrace spacing is determined as follows:

$$V1 = \frac{(\%\ slope+2)}{4} * 0.3$$

Where:

VI = Vertical interval between terraces in meters

The vertical interval can be converted to the horizontal interval using the formula

$$HI = \frac{VI \times 100}{\%\ slope}$$

Where:

HI =horizontal interval between consecutive terraces in meters.

Terrace spacing can be adjusted and made wider where agronomic practices are well practiced. For instance, the spacing of narrow-based and broad channel terraces can be increased by 25% or even 50% if there are high standards of soil and crop management. Also, a farmer who practices conservation tillage could space terraces further apart. However terraces will help to protect the land during periods of exceptionally heavy rainfall and their importance as a safety measure should not be underestimated. Spacing them too widely can lead to failure.

3.3 Types of terraces

Terraces can be directly constructed or developed over the long term through natural sedimentation. Some of the more common terracing technologies used by smallholder farmers include contour bunds, *fanya juu* terraces, bench terraces, stone lines, trash lines and vegetative barriers. The vegetative and agronomic methods of developing terraces have been covered in Training Manual 4 of these series. For the purpose of this manual, the terraces described are grouped into four main categories:

(i) Channel terraces,

(ii) Progressive terracing,

(iii) Excavated bench terraces, and

(iv) Intermittent terracing.

The types of terraces under each of these categories are further described here below.

3.4. Channel terraces

This is a broad category of terrace types involving earth bunding, whereby a channel is created on the upslope while the embankment/bund is on the downslope. Most channel terraces are made for discharge of excessive runoff, and are thus graded. They are suited to high rainfall areas, and are preferred for gentle slopes. The main advantage of channel terraces is their function to dispose water. However, soil erosion may continue within the terrace to be deposited in the channel, thereby losing soil nutrients from the land. For this reason, he intra-terrace slope should be very low, and not exceeding 3% slope. Also, another limitation is that channel terraces do not facilitate formation of a bench terrace.

3.4.1 Contour Bunds

Contour bunds (or contour ridge terraces) are soil conservation structures that involve construction of an earthen bund by excavating a channel and creating a small ridge on the downhill side. The difference with contour earthen bunds used in water harvesting (see Training Manual 1) is in the fact that contour bunds for SWC are used for draining excess runoff from steep cultivated slopes. Thus contour bunds resemble narrow channel terraces, which in Kenya are referred to as "*fanya chini*" terraces - meaning "do it downwards". Contour bunds are used for prevention of flooding and erosion control. They are popular in the high rainfall plateau areas prone to seasonal waterlogging during the rainy season, or where drainage of excess runoff is a priority. Contour bunds are

usually designed with a standard 1 m vertical interval. They are constructed manually but sometimes, tractor or animal drawn bunding equipment are used.

3.4.2 Broad-based channel terrace

A broad-based channel terrace is one made with the excavated channel being upslope and the spoil used to create the bund downslope. The main distinguishing feature is that a broad-based channel terrace has a wider and shallower channel, and a broader and flatter embankment on the downhill side. It is meant to drain away excess runoff from cultivated lands. Channel terraces is constructed by machinery and is suited to mechanized farms on land having very gentle slope, particularly growing small grain crops like wheat and barley. Thus, it is designed to be crossed by machinery. It is suited to high rainfall areas having low intensity storms. The embankments of broad-based terraces may be worn down during cultivation and should be rebuilt on a regular basis. Cultivation should fallow the alignment of the terraces.

3.4.3 Narrow-based channel terrace

A narrow-based contour terrace is also graded channel terraces but having a steep-sided bank, often constructed by machinery such as a road grader. Thus, it cannot be crossed by tractors and implements, and is sited on relatively steeper slopes. This type is commonly used when protection is only required for short periods. It is a variation of a contour bund, in which the soil is thrown downhill, and is sometimes called "fanya chini" (Figure 3.2). The embankments of narrow-based terraces should be planted with grass and the species recommended for grass strips can be used. The channel should normally be cultivated and planted along with the rest of the field to avoid wastage of land but on some large farms both the channel and the embankment are left in grass.

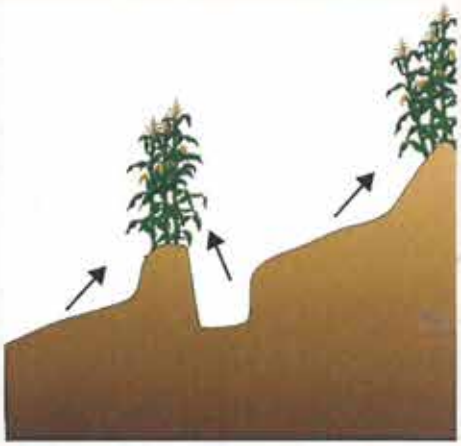

Figure 3.2 (a) Sketch of a "fanya chini" terrace *(b) A "fanya chini" terrace with grass on embankment (Photo courtesy of Faith Muthoni)*

3.4.4 Ridge terrace

A ridge terrace (also called Mangum terrace) is a variation of channel terrace in which the earthen embankment is built up from both sides, thus creating a ridge. The soil excavated from the uphill side and used for building the ridge serves a double purpose- the channel is excavated and the embankment is raised. The soil from the lower side simply helps to raise the bank. Broad- based contour ridges have a wide, low bank and a shallow channel with gently sloping sides. They are intended to be easily crossed by tractors and implements, so that row crops continue over them without interruption.

3.5 Progressive terracing

Progressive terracing involves of construction of barriers at intervals across the slope without the physical re-shaping of the land. The barriers block runoff flows to facilitate bench formation through natural processes of intra-terrace erosion and sedimentation. Such structures or bunds are created using earthen bunds, stones, crop residues, grass strip or vegetative buffers. The idea is to end up with bench terraces developed over time without having to move large volume of soil. Thus, progressive terraces function by slowing down runoff to allow sediments eroded from the intra-terrace area to be deposited uphill of the barrier. That way, no soil is lost within the intra-terrace space, but instead it builds up through the natural processes of erosion and deposition eventually becoming a bench terrace (Figure 3.3).

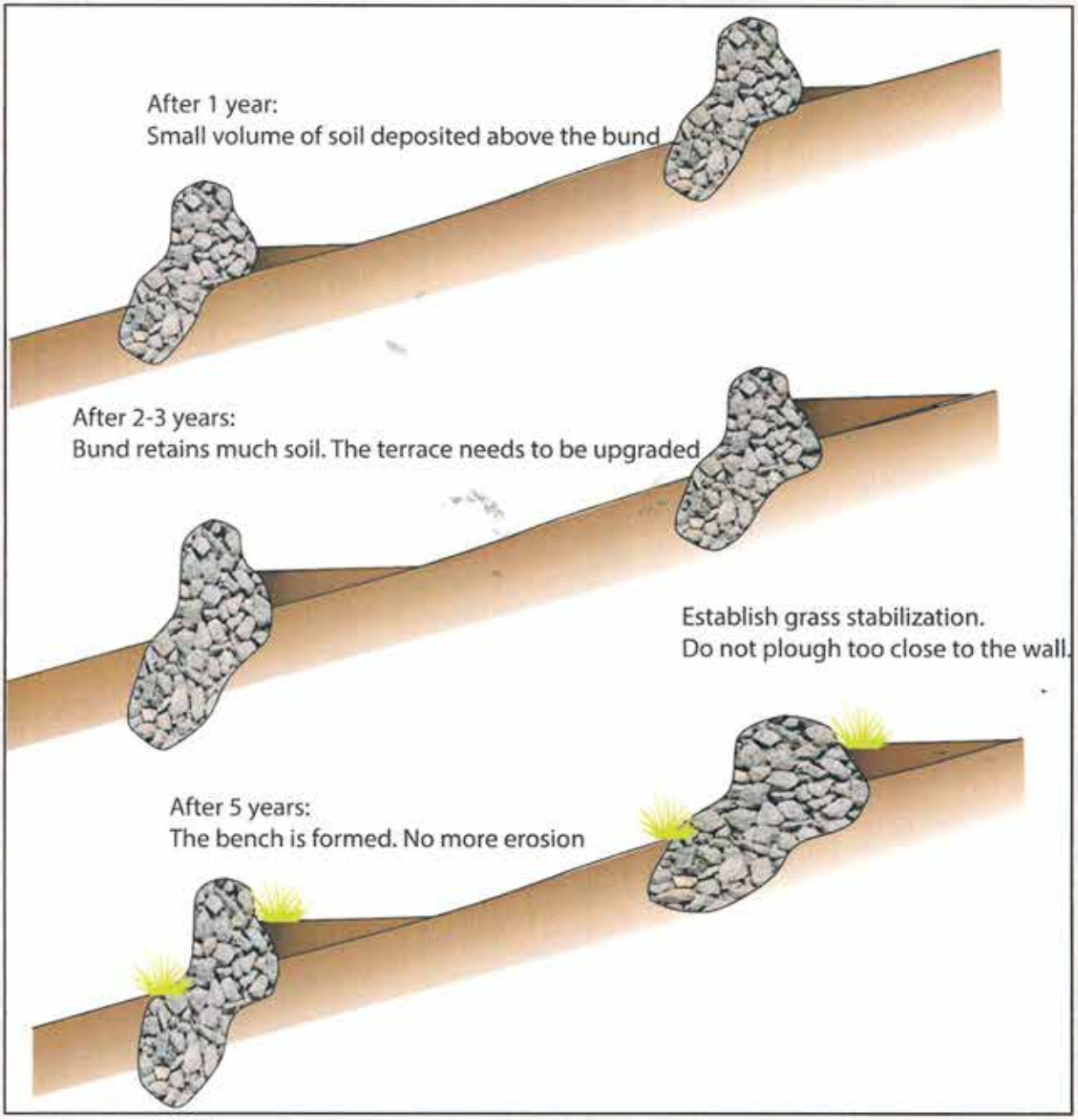

Figure 3.3. Illustration of the development of progressive terraces from stone terraces

Progressive terraces can be made on the contour and closed at the ends to allow conservation of all water *in-situ*. In areas requiring drainage of excessive rainfall, the terraces can be graded to allow excess runoff to leave at non-erosive velocities. Whether graded or on the contour, all soil material should be conserved and not allowed to leave the terrace. The methods of progressive terracing with vegetative material (trash lines,

grass strips, vegetative buffers) has already been discussed elsewhere (see Training Manual 4 of these series) and will not be repeated here. Therefore, only the structural methods of progressive terracing are discussed here.

3.5.1. Fanya Juu Terraces

Fanya juu terraces (sometimes called *converse terraces*), are earthen bunds created by (Figure 3.4), are made by digging a trench about 60 cm wide along the contour, and throwing the soil upslope to form an embankment. This effectively reduces slope-length, and hence soil erosion from steep croplands. In some cases, enlarged embankments are made to allow ponding of harvested runoff and, therefore, the structure can be used in water harvesting systems having external catchments. The soil bund retains water and thereby, safeguards yields even during droughts.

The cross-sectional profile of a fanya juu terrace comprises an embankment to impound water, soil and nutrients, a storage area above the embankment to prevent overtopping by runoff and a berm or ledge to prevent the embankment soil from sliding bank into the trench. The trench below the embankment may or be retained. A Fanya juu terrace is often the first stage in the development of a bench terrace.

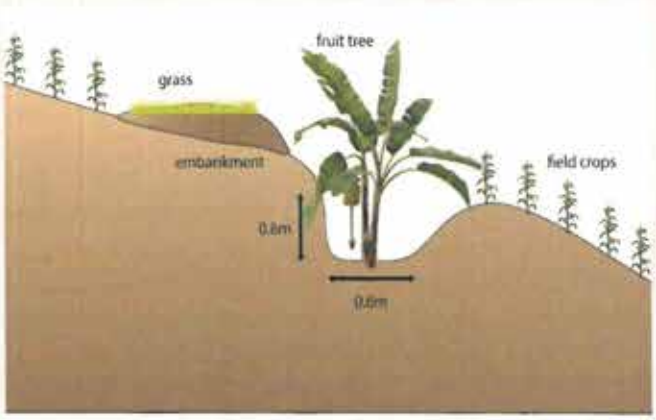

Figure 3.4 (a) Sketch of a fanya juu terrace

(b) Fanya juu terrace with banana in channel (Photo by B. Mati)

Fanya juu terraces are suitable on slopes with annual rainfall of 500-1,000 mm. Planting grass, trees and bushes along the terrace banks stabilizes the bunds, while contributing to productivity and biodiversity such as fodder, fuel and fruits. The bunds gradually become enlarged as soil is transported downwards and deposited upon them. Within a few years, a terrace is developed through natural processes of erosion and deposition.

Some farmers prefer to enlarge the trench from which the soil has been dug and use it as a retention ditch for planting tree crops such as bananas. This channel, which should be left to disappear but sometimes, it is used to runoff harvesting by diverting surfaces flows from roads and other surfaces directly into the channel. Sometimes, the soil used to build up the fanya juu bund is obtained from a shallower but wider area, and the ground leveled so that the whole area between the terraces can be cropped in the same way.

Fanya juu terraces are popular in smallholder farms particularly in semi-arid areas where they are quite effective in conserving moisture and nutrients. They are applicable in areas where soils are too shallow for level bench terracing and on moderately steep slopes (e.g. below 20%) They are not suitable for stony soil. They normally develop into out ward sloping bench terraces after a few years depending on the amount of soil which moves down slope and lodges above the embankment.

Design of Fanya juu terraces

Fanya juu terraces are made with the intention that they should gradually develop into bench terraces. The spacing i is designed as discussed in Section 3.3. The terrace can be graded at 0.04 % to discharge runoff but where have proved most useful, in the semi-humid and semi-arid areas; they are normally made with zero gradients, i.e. level from end to end. The general requirements for terraces spacing, trench excavation and labor requirements are provided in Table 3.1.

Table 3.1 Fanya juu terrace: Typical dimensions and labor required for different situations

Land slope (%)	Terrace Spacing VI (m)	HD (m)	Trench excavated to build terrace Width (m)	depth (m)	Trench Area (m^2)	Shoulder bund height (upper side) to retain runoff when infiltration is Low	medium	high	labor . Days per 100m	labor Days per ha
5	1.00	20	0.50		0.25	32cm	29cm	26 cm	8.3	42
	1.35	14	0.50							
10					0.28	37cm	34cm	30 cm	9.3	66
	1.73	12	0.55							
15			0.55		0.33	41 cm		38cm	11.0	91

20	1.80	9	0.60	0.36	33cm		12.0	133
			0.55					
					41cm	37cm		
			0.60		33cm			
			0.60					

Note. *The figures for terrace spacing are based on the terrace spacing with a VI of ```1.8 m which allows the terraces to develop into level benches in time. The dimensions of the trench are typical but can be varied to suit local conditions. The labor required is based on an assumption that one person can dig 3 m³ per day (Source Thomas, 1997).*

Construction and maintenance of fanya juu terraces

The construction of fanya juu terraces is labor intensive and involves digging a trench a trench on the contour and throwing the soil upslope to form an embankment. Construction is carried out after laying out pegs on the contour, or at a gradient, as required. A berm of 15cm to 30 cm is left to prevent the embankment soil up slope to form an embankment, which should be stabilized with grass. The excavated trench should be as narrow as possible to reduce wastage of cultivated land. Where the trench can be used for planting tree crops such as bananas, it should be wide enough to accommodate the crop. The embankment should be planted with perennial grass to stabilize it.

3.5.2. Stone Lines

In areas where stones are plentiful, stone bunding is a simple and cost effective terracing technique, used for both soil conservation or for runoff harvesting. Stones are arranged in lines across the slope to form a small bund (Figure 3.5). As stone lines are strong and permeable, they slow down runoff rate, filter it, allowing eroded sediments to settle above the bund. Excess runoff slowly filters through to spread over the field, thus enhancing water infiltration and reducing soil erosion. Stone lines are suitable on all slopes but are particularly and rainfall regimes, but are more popular in areas receiving 200-750 mm of annual rainfall. In design, they are usually spaced according to the general principles of determining terrace spacing as described in Chapter 1. However, on steep slopes, stone lines can be spaced about 15-30 m apart, and reinforced with earth or crop residues to make them more stable

The lines are constructed by making a shallow foundation trench along the contour. Larger stones are then put on the down slope side of the trench. Smaller stones are used to build the rest of the bund. When it rains, soil builds up on the upslope side of the line, and over time a natural terrace is formed. Like other methods of progressive terracing,

stone lines can convert sloping land into level bench terraces through the natural process of erosion and deposition.

Figure 3.5 Stone lines laid on the contour to create terraces (Photo by B. Mati)

Stone lines are often used to rehabilitate eroded or abandoned land by trapping silt and are popular in dry stony areas. However, they may provide a refuge for rodents, snakes, scorpions and other vermin. Even then, stone lines are a more sustainable method of terracing than many of the earth moving techniques. The stone bund must be regularly maintained to prevent runoff creating channels between the stones.

3.5.3 Stonewall terracing

Stonewall terracing involves using large stones and rocks to erect a stone wall across a slope, thus creating a terrace (Figure 3.6). Ideally, the stone wall should not be air-tight, albeit in certain instance a concrete wall is built. This is so that the structure allows excess water to flow through while retaining the sediments in the upslope side. Thus, the slope of a cultivated hill, valley or streambed is gradually transformed into a chain of level bench terraces. Stone wall terraces can also be used as runon areas (receiving area) in water harvesting system and spate irrigation systems. The method is suitable for conservation of soil in unstable slopes, e.g. those prone to landslides or very steep hillsides. The method can be quite expensive. The main advantage is that the structure can be quite resilient and effective even with excessive floods and such as typhoons.

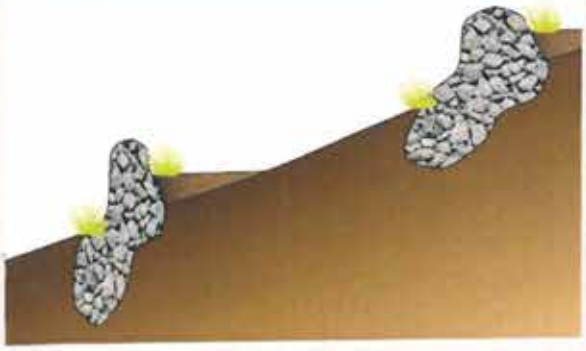

Figure 3.6 (a) Cross-sectional view of a stone wall terrace *(b) Stone wall terrace with sorghum crop (photo by B. Mati)*

3.6 Excavated Bench Terraces

Bench terraces (or *hillside terraces)* are made by re-shaping a steep slope to create a series of flat or nearly flat ledges or beds, separated by vertical or nearly vertical walls between the ledges (Figure 3.7). Bench terracing therefore achieves the desired slope gradient immediately on construction. They are made on very steep slopes where other methods, such as progressive terracing, would be inadequate to control runoff or reduce erosion. Sometimes bench terraces are also made to achieve optimum water conservation in dry areas. Due to the high labor demand, bench terraces are usually made for high-value crops such as irrigated vegetables and coffee.

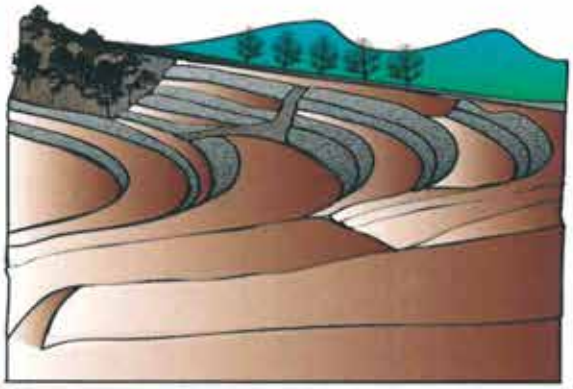

Figure 3.7 (a) Sketch of excavated bench terraces *(b) Excavated bench terraces with vertical riser(Photo courtesy of J.J. Muhinda)*

Like with all terraces, the embankment of a bench terrace should be stabilized, usually by planting a close-growing grass or grass sods. But in certain cases, the terrace riser

may be stabilized with stones, or infrequently with brick, masonry or timber. Bench terrace risers usually have a uniform slope which varies with the soil type and the method of stabilization, e.g. whether grass or stones. Risers of 1 m height can be quite stable on clay loams can where they can be made nearly vertical but if they are 2 m high an angle of 70-80° would be advisable. Sandy soils make terrace risers unstable, so the embankment should carry an angle of 50-60° inclination. These ratios may be adjusted depending on soil stability and method of stabilizing the riser (e.g. grass or stones).

Bench terraces may be constructed on the contour, to minimize run-off or with a slight gradient to allow for drainage of excess flows. The main problem is how to discharge any surface run-off down the steep slope without causing erosion damage. Grassed waterways may be used where feasible. When bench terraces are used for cultivated crops, each bench should be as wide as possible. Bench terraces can be used on slopes of up to 30° (55%) provided that the soil are deep enough and stable enough.

Due to the high cost of construction, excavated bench terraces are recommended where

(i) The crop to be grown has a high cash return

(ii) The effective depth of soil is at least 1.5 m

(iii) It is essential to cultivate steep slopes, and

(iv) Other physical soil measure is not adequate to protect the crop.

Construction of excavated bench terraces

Bench terraces are usually constructed with hand tools. The terrace spacing are first laid out using a line level or quickset level. The layout should be done in a sequence starting from the top of the field. In order to avoid a drop in fertility, which can occur if topsoil gets buried and subsoil is brought to the surface, the first step is to isolate the topsoil to the center line between the terraces. Then the subsoil is excavated and levelled. Finally, finally the topsoil is returned to the surface. Also, when constructing the terrace risers, they should be compacted with the back of the shovel. The risers should be stabilized with grass planting or packed stones.

Bench terraces can be sub-divided into level bench terraces, reverse (inward) sloping bench terraces and forward (outward) slopping bench terraces (Figure2). Level and reverse sloping bench terraces are very effective in controlling erosion on steep lands as compared to forward sloping bench terraces. They can be used on slopes up to 50% provided that the soils are deep and stable enough.

3.6.1 Level bench terraces

Level bench terraces are those made with a flat or 0% slope gradient within the ledges, albeit he risers can be vertical or nearly vertical (Figure 3.8). They are the ultimate way to conserve soil and water on a steep slope. To achieve the flat level on the bench requires a lot of earth moving and labour. Level benches are made for almost all crop types and rainfall patterns. If the benches are wide enough, they can be cultivated using machinery. The terrace spacing for level bench terrace is calculated based on slope steepness to achieve the required vertical interval.

The level bench terraces are used in the areas which receive medium rainfall and have highly permeable soils. Since the soils are highly permeable, therefore it is expected that most of the flowing surface passing through these terraces are absorbed by the soil.

Figure 3.8 (a) Sketch of a level bench terrace

(b)Level bench terraces on a very steep slope (Photo courtesy of J.J. Muhinda)

3.6.2 Step Bench terraces

Step terraces are narrow bench terraces made on very steep slopes, e.g. 40%, designed to fit one or two rows of tree crops. The idea is to create a bench for each tree row, thereby achieving a closer spacing, which makes them look like "steps". The height of rise is about 1m and they are spaced horizontally about 5-10 m apart depending on the expected size of the trees or a few crop rows (Figure 3.9).Step terraces are sometimes easier to build since less volumes of earth are moved. Step terraces are used for fruit trees, tea, coffee, grape vines and other horticultural crops.

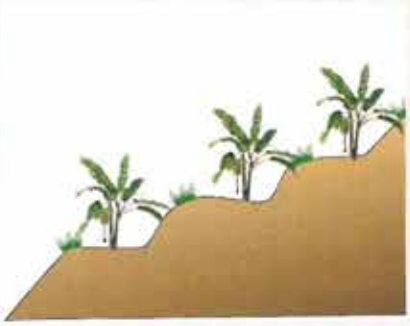

Figure 3.9 (a) Sketch of step terraces with tree crop *(b) Step terraces with bean crop and grassed banks(Photo courtesy of J.J. Muhinda)*

3.6.3 Forward-sloping bench terraces

Forward-sloping bench terraces are bench terraces but constructed with the intra-terrace space still having a slight slope in the same direction as the predominant slope (Figure 3.10). They are made this way to reduce the slope steepness, while using less labor required in excavation of benches. They may also be made where soils are too shallow for proper level bench construction. Thus, they function like progressive terraces, since some erosion could still occur within the terrace space. The main advantage is the reduced labor during construction. The main limitation is likelihood of continued soil erosion. Otherwise the banks of forward sloping bench terraces should be stabilized with grass and maintained, to encourage the formation of a level bench in the long run.

Figure 3.10 (a) Sketch of forward sloping bench terrace *(b) Forward sloping bench terrace on a hillside (Photo by B. Mati)*

3.6.4 Reverse-slope bench terraces

Reverse-slope terrace (sometimes referred to as *radical terracing)*, is a bench terrace that has an intra-bench slope of about 2-3 percent on the bed in the opposite direction. It is made for water conservation as any excess runoff flows back upslope towards the riser within the bench (Figure 3.11). It also has a raised riser that can be up to 2 m high. The terrace is designed that way for optimum retention of rainfall. It is suited to dry areas, where the need for water conservation may mean that farmers have to "overdo" bench terracing so that they acquire a reverse-slope bench. Such a bench terrace is sometimes combined with water harvesting from an external catchment, e.g., a road, to optimize the increased storage space. The larger capacity and, the fact, that water is ponded on the upper side ensure stability of the structure. Despite the high labor demand, reverse-bench terracing in the dry areas offers a drought mitigation strategy.

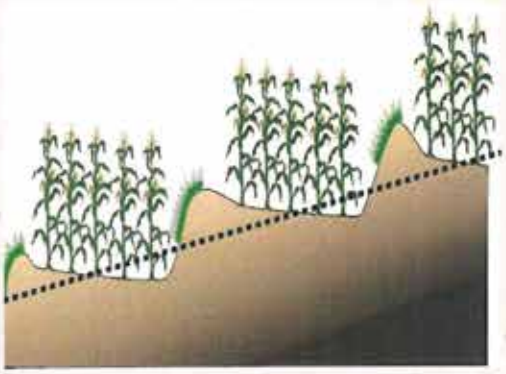

Figure 3.11 (a) Sketch of reverse slope bench terrace *(b) Newly constructed reverse slope bench terrace (Photo courtesy of J.J. Muhinda)*

3.6.5 Irrigation terrace

Farming on steep slopes sometimes requires irrigation of such crops using surface methods. Thus, an irrigation terrace is designed which is really a level bench terrace having a raised lip at the outer edge to retain irrigation water. Irrigation terraces are used mostly for the production of rice, and to a lesser extent for tea, fruit trees, and other high value crops. For paddy, the terraces are also level along their length, so that each becomes a flooded shallow pond. In areas where intermittent water application is needed, there can be longitudinal gradient similar to that for border irrigation, to allow the water to flow across the terrace.

3.7 Intermittent terraces

Intermittent terracing involves construction of small bench terraces in which only part of the slope is re-shaped, to create a level or nearly level space, leaving the rest of the slope in its natural condition

3.7.1 Hillside ditch

A hillside runoff system comprises a small hillside ditch/channel dug across the slope in a hilly area, but the channel is graded to allow the water it collects to be diverted to flatter cropped field's down-slope. The fields are levelled and surrounded by earthen bunds so as to retain the inflow. Spillways are used to drain excess water from one field o the next. Several feeder ditches can be constructed and the distribution system made into a pattern of fields resembling a conventional check basin irrigation scheme. Hillside runoff systems are useful for utilizing runoff from bare, or sparsely vegetated, hilly or mountainous areas.

3.7.2 Orchard terraces

An orchard terrace is a variation of step-bench terraces, whereby a small level or reverse–slope terraces bench is constructed to accommodate a row of trees leaving the land in-between fallow and un-terraced. It is suited to fruit tree orchards on steep slopes, where tree spacing is relatively wide. On such a farm, the construction of ordinary bench terraces would involve too much earth moving an unnecessary labor. The orchard terrace is thus an intermittent form of terracing designed to save labor and cost (Figure 3.12). It works by slowing down runoff to infiltrate around the tree area, and any excess is dissipated onto adjacent uncultivated areas. The steep uncultivated space between the tree rows is protected by the natural vegetation, particularly grass. Orchard terraces are also used on soils which are too shallow, or land slope too steep, and where bench terracing may not be practical. The intervening land has a permanent cover of grass, which can be cut for livestock fodder.

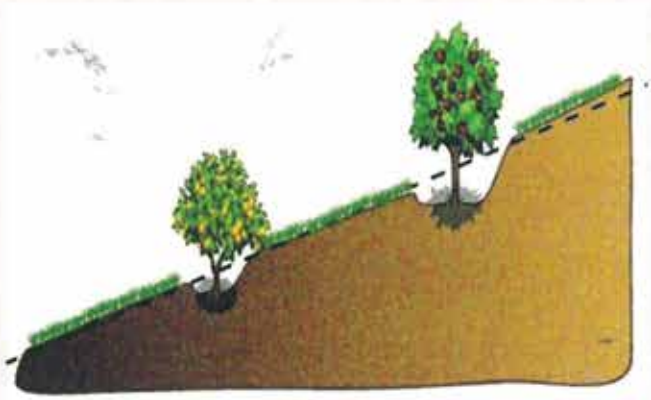

Figure 3.12 (a) Sketch of a single tree orchard terrace *(b) Sketch of orchard terrace with rows of tree crops*

3.8. Management and maintenance of terraces

(i) To stabilize newly constructed soil bunds a good vegetative cover should be established as soon as possible. This should be done during the first rainy season, and particularly in the first few seasons they should be carefully protected from livestock.

(ii) Regular maintenance of terrace risers is required to prevent soil erosion. The bunds must be maintained whenever they tend to break.

(iii) In the case of progressive terraces, the bund height is increased annually until bench terrace is developed.

(iv) Where embankments are used for fodder grasses, periodic application of manure or fertilizer helps to maintain productivity.

(v) Regular cutting of the grass is required to prevent excessive competition or interference with the crop.

(vi) Livestock grazing should not be allowed on terraced cultivated lands. Instead, cut and carry systems should be used as an alternative.

(vii) Stabilization of terrace banks demands the selection of proper species to plant on the bunds.

4. ARTIFICIAL WATERWAYS

4.1 What is an artificial waterway?

An artificial waterway (or grassed waterway) is a broad, shallow channel, normally planted with short, closely growing grass, and used for disposal of concentrated flows at safe velocities. They are usually made where excess surface runoff must be disposed off, particularly from cutoff drains, terraces and other structures. Artificial waterways can be natural or constructed, in which case they are graded and shaped to form a smooth, shallow drainage-way (Figure 4.1). Most artificial waterways are designed to run up-and-down the predominant slope, and are thus connected to other soil and water conservation structures so as to receive excess flows from across fields for disposal without causing soil erosion. Since they carry large volumes of runoff, artificial waterways are sometimes fitted with erosion control structures, such as small check dams or drop structures, especially on steep slopes or if the risks of erosion damage are high. They are suited to high rainfall areas, but may be constructed in semi-arid zones where high runoff flows could cause damage to other conservation structures.

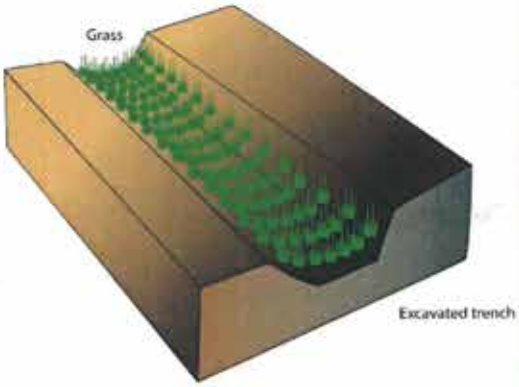

Figure 4.1 Sketch of grassed artificial waterway

(b) Grassed artificial waterway in cropped land (Photo by B. Mati)

4.2 Functions of an artificial waterway

The main function of an artificial waterway is to act as a safe conduit of excess runoff flows from other conservation works on a farm. It is therefore a water conveyance structure more or less like a canal, and can have several inlets and at least one outlet. Waterways are also used to drain run-off safely from hill slopes to valley bottoms where

it can join a stream or river. Artificial waterways re required where other conservation structures e.g. terraces, cutoff drains are also graded. The grass lining increases channel roughness, which enables runoff to slow down, causing deposition of sediments, and subsequently reducing channel erosion. The grass in the channel also traps the sediment washed from cropland, thus absorbing some chemicals and nutrients in the runoff water. Thus, artificial waterways can play a great role in the reduction of pollution of downstream water resources as well as sedimentation of infrastructure such as dams. They also facilitate soil and water retention within the farm.

In addition to their role as a measure against erosion, waterways can have significant contribution in the collection and conveying of runoff water to a storage location. If aligned along a pervious formation, they could serve as a means of recharging the ground water. However, the construction of artificial waterways in smallholder farms is limited by lack of space as they require ample width.

4.3 Design of a artificial waterway

The main factors to be considered when designing waterways are: discharge capacity, permissible velocities of flow down the channel, the slope gradient, shape and size, channel lining and roughness, freeboard, type and location of a suitable outlet.

4.3.1 Discharge capacity

The design capacity of a waterway must be adequate to accumulate all discharge from the other structures. It is thus designed to have a velocity that will not cause either scouring or silting. The dimensions of a waterway depends on the expected discharge calculated in cubic meters per second. The capacity of an artificial waterway should accommodate the peak runoff flows expected from a storm of 10-year frequency, 24-hour duration. This is estimated in exactly the same way as for diversion ditches (see chapter 2). The design flow volume, is equivalent to the channel peak flow rate (m^3/s) or discharge through the outlet, and is determined using Manning's equation below:

$$q = \frac{A.R^{2/3}S^{1/2}}{n}$$

Where;

R is the hydraulic radius for the depth of flow (m),

S is the slope of the channel segment (m/m),

A is the cross-sectional area of the waterway, and

N is the Manning's coefficient for the channel section.

The cross-sectional area of the channel can be calculated as follows:

A= q/v

where v is the maximum permissible velocity (m/s

The depth of channel is determined by channel shape as follows:

For parabolic section, the design depth (d) = 1.5r; while the design to width (w) = A/0.67d;

The capacity of a parabolic channel may be calculated using the formula:

q = Av = 0.67(wxdxv)

The estimate of discharge should be based on the peak flow at the outlet end of the waterway rather than the amount expected at the inlet, which is usually less. The design width of an artificial waterway increases rapidly with increasing discharge and/or slope in order to avoid scouring and erosion. The width can be reduced if stone is combined with grass, as indicated on the right of the table. If land is scarce and/or steep, narrow waterways lined by brick, stone or masonry will be needed. The estimate of discharge should be based on the peak flow at the outlet end of the waterway rather than the amount expected at the inlet, which is usually less. Some recommended dimensions for artificial waterways for different situations are presented on Table 4.1. The design width of an artificial waterway increases rapidly with increasing discharge and/or slope in order to avoid scouring and erosion. The width can be reduced if stones are combined

with grass as indicated on Table 4.1. If land is scarce, narrow waterways lined by brick, stone or masonry will be needed

Table 4.1 Permissible velocities on waterways for various slope and lining conditions

Design velocity	Ground slope and type of waterway lining				
	5%	10%	15%	20%	30%
	Close grass 2 m/s	Close grass 2m/s	Close grass 2m/s	Grass/ stone 3 m/s	Grass/stone 3m/s
Discharge 0.2 m^3/s					
Depth (m)	0.40	0.24	0.18	0.26	0.19
Width (m)	0.65	1.10	2.30	0.67	0.91
Area$(m)^2$	0.13	0.13	0.13	0.08	0.08
0.50 m^3/s Depth (m)	0.40	0.24	0.18	0.26	0.19
Width (m)	1.30	2.20	4.43	1.34	1.82
Area$(m)^2$	0.25	013	0.25	0.17	0.17
0.75 m^3/s					
Depth (m)	0.40	0.24	0.18	0.26	0.19
Width (m)	1.96	3.30	6.73	2.01	2.73
Area$(m)^2$	0.38	0.38	0.38	0.25	0.25

1.00 m^3/s					
Depth (m)	0.40	0.24	0.18	0.26	0.19
Width (m)	2.61	4.39	8.86	2.68	3.63
Area$(m)^2$	0.50	0.50	0.50	0.33	0.33
1.25 m^3/s					
Depth (m)	0.40	0.24	0.18	0.26	0.19
Width (m)	3.27	5.49	11.16	3.35	4.54
Area$(m)^2$	0.63	0.63	0.63	0.42	0.42
1.50 m^3/s					
Depth (m)	0.40	0.24	0.18	0.26	0.19
Width (m)	3.92	6.59	13.28	4.02	5.45
Area$(m)^2$	0.75	0.75	0.75	0.50	0.50
1.75 m^3/s					
Depth (m)	0.40	0.18	0.18	0.26	0.19
Width (m)	4.57	15.58	15.58	4.69	6.36
Area$(m)^2$	0.88	0.66	0.66	0.58	0.58
2.00 m^3/s					
Depth (m)	0.40	0.24	0.18	0.26	019
Width (m)	5.23	8.79	17.71	5.36	7.27
Area$(m)^2$	1.00	1.00	1.00	0.67	0.67

Source: Thomas, 1997

4.3.2 Channel shape and gradient

Artificial waterways are of various shapes (e.g. trapezoidal, parabolic, rectangular or V' shaped) depending on the discharge expected and the material used for stabilization, i.e. whether grass, stone, masonry or concrete. They are designed with a short, wide bank on each side to contain the water. Grass-lined waterways are usually designed with a parabolic shape, whereas stone-lined waterways may be parabolic or trapezoidal. Waterways constructed from masonry or reinforced concrete can be made rectangular in shape.

The slope of a waterway is normally the slope of the land at right angles to the contour. Waterways running diagonally across the slope are not recommended because if they break or over-top the damage can be serious. Artificial waterways should generally be on slopes not exceeding 5 percent. On steeper slopes, drop structures should be incorporated in the design or the waterway lined with concrete. The bottom width of trapezoidal waterways should not exceed 15 m unless multiple or divided waterways or other means are provided to control meandering of low flows. Where slopes are steep, artificial waterways should be made wide enough to spread the water and prevent high velocities of the water. An alternative to wide artificial waterways is to make narrower waterways that are lined with stone, or to install check structures to slow down the velocity of water and dissipate the energy.

4.3.3 Channel roughness

The rougher the surface over which water flows, the greater the resistance to flow. The velocity of water in a channel can be reduced by making it wider and shallower (i.e. lowering the hydraulic radius) or by making the surface rougher. One of the ways of making the surface rougher is by planting grasses. A tall grass will provide more resistance to flow than a short one, although the resistance will be lowered if it is pushed over and flattened during heavy run-off. Growing perennial shrubs as contour hedgerows is another commonly used form of vegetative hedge. This topic is discussed under the subsection on agroforestry under nutrient management systems. A rough stone surface will provide more resistance than a smooth concrete surface.

The effect of reduced scouring on a waterway varies with the type of lining, which can be packed clay, grass, stone, or drop structures made using local materials (Figure 4.2). For each of these alternatives there is a maximum permissible velocity above which scouring can occurs. The waterway should be able to dispose of run-off at a safe velocity. Artificial waterways are thus recommended for slopes up to 25%. On steeper slopes, the channel should be lined with stones, masonry or reinforced concrete (Table 4.2).

Figure 4.2 (a) Artificial waterway with scour checks (Photo by B. Mati) (b) Grassed Artificial waterway (Photo courtesy of J.J. Muhinda)

Table 4.2: Maximum permissible velocity in channels (m/sec)

Surface material	Bare	Medium grass cover	Very good grass cover
Very light silty sand	0.3	0.75	1.5
Light loose sand	0.5	0.9	1.5
Coarse sand	0.75	1.25	1.7
Sandy soil	0.75	1.5	2.0
Firm clay loam	1	1.7	2.3
Stiff clay or stiff gravelly soil	1.5	1.8	2.5
Coarse gravels	1.5	1.8	Unlikely

Shale, hardpan, soft rock, etc.	1.8	2.1	-
Hard cemented conglomerates	2.5	-	-

Source: Hudson, 1981

4.3.4 Freeboard

Waterway designs are normally based on the peak run-off expected in a ten-year return period, but to cater for exceptional conditions a safety margin (freeboard) is added by increasing the design depth by 25% for grass waterways and 10% for stone-lined waterways.

4.3.5 Outlets

It is usually necessary to first identify a suitable outlet for the artificial waterway. Such outlets can be a natural watercourse, old gully, open grasslands, percolation or water harvesting structures. Where there is a natural depression or small valley that is well stabilized with vegetation this may be adequate to take the discharge from diversion ditches or graded terraces, but where there is no such natural waterway, an artificial waterway (drainage way) must be installed. In certain circumstances where a proper natural outlet cannot be found, the excess water can be disposed by digging very large retention ditches, but this is only allowable if the waterway carries small flows. Failure to dispose runoff to a good outlet can lead to the formation of gullies and other erosion problems.

4.4 Other structures to dissipate runoff energy

Other than grass, the erosive energy of flows in artificial waterways can be dissipated using engineering devices. Some commonly used structures include drop structures, chute spillways and porous barriers. These function as follows:

4.4.1 Drop Structures:

Drop structures are commonly made where the waterway runs down a very steep slope. They can be in the form of a small check dam which allows flow to slow down, pond and dissipate at non-erosive velocities past the barrier. They stabilize flow through a steep gradient in the waterway. Drop structures also level waterways so that they need not be planted with grass. They serve as outlets for concentrated flow from sods and drain bed culverts; as well as serving as sediment traps, thus conserving water and soil.

Figure 4.3 (a) Sketch of artificial waterway with drop structures made with logs (b) Drop structures made of local materials (Photo courtesy of Faith Muthoni)

4.4.2 Chute spillways

Chutes are specially designed spillways that collect flow at one elevation and discharge it down a slope at a lower elevation. The shape of the inlet and outlet is important to stabilize the chutes and prevent failure. Some energy-dissipating structures are necessary at the outlet of the chutes. A box-like device filled with stone is generally suitable for most conditions. Most chutes connect a elevated area e.g. an upper terrace with a lower area e.g. the next terrace downhill, where there is a sudden change in gradient. They can be made of concrete, sheet metal, plastic or wood. The design must consider both inlet and outlet conditions of the chute to prevent damage to land.

4.4.3 Porous barriers

Porous barriers are small check dams constructed using material that allows water to filter through. The most common are loose stones and brushwood check dams. Porous barriers simply slow down runoff allowing it to seep through at non-erosive velocities. They also serve as sediment traps, and in the long run, they look like drop structures.

4.5. Layout and construction of an artificial waterway

Reconnaissance field surveys and contour maps, where available, are used to locate the appropriate position of a waterway. This considers the location of other structures such as terraces, roads, farm orientation and availability of an outlet. Where possible, the waterway should be located in a natural depression or drainage way. It is usually better to have several small waterways than one very large one, and the waterways should be close enough to each other to avoid the terraces being excessively long. After the

waterway has been staked out, construction can start from the lower end by excavating soil from the center and throwing it to each side to form the banks.

Artificial waterways are normally constructed to run straight down the steepest slope. The channel may be created by excavating from the inside and creating shallow parabolic with two bank on each side. The waterways may be natural or artificial drainage channel to collect run-off in the conservation system and lead to a suitable outlet. Natural waterways are usually improved while artificial ones are grassed or stone paved. An alternative method, normally used where a closely growing grass already exists, is to excavate the spoil from the outer limits and use it to build the banks leaving undisturbed, the level ground surface in the middle, and thus achieving a fully protected waterway. After excavation of the waterway channel, it should be lined by planting a suitable spreading grass, or with stone or a combination of grass and stone. The process of excavation may expose less fertile sub-soil and, if so, it is advisable to use manure and mulch to ensure quick establishment of the grass. Every effort should be made to avoid discharging run-off into the waterway until the grass is established. Where the costs allow, an artificial waterway can be lined with concrete, rubble stone or stone masonry.

4.6 Maintenance of artificial waterways

Regular maintenance of an artificial waterway is essential, since it has high risks of failure. The waterway should be inspected after every heavy storm, especially during the first year while the grass cover is being established. Any damage should be repaired immediately, and grass re-planted. The outlet should also be checked to ensure that no erosion is taking place. The waterway should not be used as a road or footpath. Neither should it be used to dissipate flows for which it was not designed e.g. as a canal. The utility of the artificial waterway, being linked to terraces, cutoff drains and other structures should be checked as part of regular maintenance.

5. GULLY CONTROL AND UTILIZATION

5.1 What is a gully?

A gully is a deep channel created as a result of severe soil erosion, usually caused by running water. Gully erosion occurs when concentrated flows of water scouring along flow routes cause channels deeper than 0.5 m. It is an advanced stage of rill erosion whereby surface channels have been eroded to the point where they cannot be smoothed over by normal tillage operations. Gullies can also be triggered by diversion of large quantities of flowing down a slope e.g. from a road drain, home compound, pipe washout, rocky or hilly areas. They carry large loads of sediment and display erratic behavior. In severe cases, gullies leave the land physically dissected, with excessive draining and drying of depressions, creating the cycle of excessive runoff and further escalation of erosion (Figure 5.1). Gullies degrade agricultural land and can damage infrastructure such as buildings and roads.

Figure 5.1(a) Active medium sized gully showing gully head (Photos by B. Mati) *(b) Advanced gully erosion on scarified land*

5.1.1 Causes of gully erosion

Gullies are caused by land husbandry activities that result in increased surface runoff. These include

(i) improper land use, such as slash and burn or shifting cultivation, failure to terrace sloping land, reduced vegetation cover as a result of burning of vegetation and bush fires and poorly managed croplands.

(ii) Livestock management, particularly overstocking of livestock leads to overgrazing further reducing soil cover which results in excessive runoff.

(iii) Other activities which result in earth moving such as road construction and mining can also cause gullies. Road drains are particularly notorious for triggering gully erosion as they discharge large volumes of runoff down steep slopes. Footpaths and animal tracks, if they run down a steep slope can also result in gullying.

Gullies can form slowly over many years, as for instance if soil erosion is left unchecked. However, they can be triggered by a sudden increase in runoff, for instance due to high rainfall intensities or by diversion of runoff from one catchment to another. Also, construction of infrastructure e.g. road culvert, can trigger a gully overnight. The severity and rate of gully development also depends on the runoff producing characteristics of the watershed, the drainage area, slope steepness, surface culture e.g. presence of large rocks, and soil characteristics, being worse on silty and loamy soils. Thus, gullies are classified as small, medium or large (see Table 5.1). Other than natural factors, most gullies are caused by human interference with natural ecosystems.

Table 5.1 Gully classification based on size

Gully Size	Gully depth (m)	Gully drainage area (ha)
(a) Small gully	Less than 1	Less than 2
(b) Medium gully	1 to 5	2 to 20
(c) Large gully	More than 5	More than 20

Source: FAO, 1986

5.1.2 What is gully control?

Gully control includes all preventative and restorative activities and structures used to rehabilitate a gully and the affected land. The goal is to return the land back to its original profile and possibly productivity, albeit this may be difficult to achieve if the gully erosion is too advanced. Gully control can be expensive, and the method or structures used depend on its sizes, severity of erosion, available materials and cost implications.

Generally, the larger the gully, the more expensive it is to control. If incipient gullies are not stabilized, they become longer, larger and deeper. Under certain climatic and

geological conditions, the gully can cut landscapes creating gorges that can easily be as high as 20-30 meters deep or more. This type of gully can engulf hillside farming areas, grass lands and even forest lands. In most cases, it is not possible to stabilize those gullies because of the huge landslides which occur on vertical gully banks after heavy rains. Thus, it is recommended to rehabilitate gullies while they are still small before too much damage is caused, as it is also less costly.

5.1.3 Design of gully control measures

The design of gully control measures follows the same process as that of check dams for water harvesting (see Training Manual 3 of these series). This is because gullies exhibit channel flow, but which can be quite turbulent. Thus, all gully control structures are designed with a spillway at the center of the structure. Also, porous structures are more preferred than airtight structures for safety reason. The planning of a gully control systems involves the following:

(i) The gully itself and the surrounding areas, including the source of runoff are inspected to determine why the problem occurred; what possible changes have taken place to aggravate the problem and if there is there a spring at the gully base.

(ii) The approximate size and slope of the gully are measured.

(iii) The peak flow of water entering the gully is estimated using measuring equipment or empirical equations e.g. Rational formula (see Chapter 2). This quantity depends on the watershed's topography, size, vegetation, and soil type and water storage capacity. Technical expertise is required for this step.

Using this information, a control system can be selected. In general, -The depth of the foundation is equal to one-half of the effective height of the dam, which means that the foundation depth is one-third of the dam's total height. There are very many types of structures and control methods for gully rehabilitation. However, these can grouped into four broad categories as follows:

a) Preventative measures

b) Control measures for small gullies

c) Control structures for medium sized gullies

d) Control measures for large gullies

5. 2 Preventative measures against gully erosion

Preventing the formation of a gully is much easier than controlling it once it has formed. Prevention is also more economical because structural measures are considerably more expensive than preventive measures. Generally, it is better to prevent a gully from forming as sometimes, the damage can be irreversible. The preventative measures are needed even when rehabilitating large gullies, and should be core component of overall gully reclamation process.

5.2.1 Soil conservation in the catchment area

For gullies which developed due to uncontrolled surface runoff from denuded catchments, soil and water conservation activities in the catchment area are sometimes all that is needed for the gully to heal. Natural catchments may require re-establishment of vegetation, e.g. through tree planting, controlled grazing and prevention of wild fires and reseeding the catchment with grass. The cultivated areas may require terracing, agroforestry and other practices that reduce erosion to improve infiltration and reduce the amount of water entering the gully.

5.2.2 Retention and infiltration of surface water

In addition to soil conservation structures, gully erosion can be prevented through proper land-management practices and infrastructure development that takes care of excess runoff. Good tillage and cropping practices increase the absorptive capacity of the soil resulting in less run-off and also protect the land surface from erosion. Surface water should be conveyed from lands through proper waterways so as not to create potential gully problems. Buffer strips should be located at potential gully start points such as open ditches or deep depressions. Other specific slope-treatment measures, such as retention and infiltration ditches should be carried out above the gully area, and in the eroded area between the branch gullies, to reduce the rate and amount of surface run-off. These also decrease the cost of structural gully-control measures.

5.2.3 Diverting runoff from gully head

Surface runoff can be diverted from a gully by constructing a diversion ditch above the gully head. Gully heals naturally. The water so diverted must be disposed off onto a natural watercourse, vegetated waterways or onto rock outcrops and stable areas which are not susceptible to erosion. Surface water must not be diverted over unprotected areas or it could cause new gullies. Runoff diversion is effective where gully is caused by non-point source runoff, e.g. a hilly area or unprotected open surfaces.

To prevent scouring along the diversion channel, the gradient of small diversion ditches must be less than 1%, and preferably 0.5%. However, if there is a permanent vegetative cover in the channel, the gradient may be as high as 2 to 3%t. The protective vegetation must be maintained during the entire rainy season, or these steeper gradients will cause channel erosion. Diversion ditches should be large enough to carry all the water that is discharged from the gully catchment area during periods of maximum run-off. In areas receiving heavy rains, in addition to diversions established above the gullied area, a series of check dams should be constructed along the gully channels.

5.3. Control of measures for small gullies

Small gullies those which can be rehabilitated without the need for physical structures. Such gullies measure less than 0.3 m deep. The measures presented here work well if the gully lies on a slopes less than 5% and carries small flows, not exceeding 1 m^3/s. Sometimes, small gullies can be controlled with just the preventative measures described above. Other methods may include the following.

5. 3.1 Gully reshaping with grass planting

Small gullies that carry little water flow can be stabilized by filling and shaping, that is, if the surface water is diverted, and livestock are kept out. Steep gully heads and gully banks should be shaped to a gentler slope (about a 1:1 slope). Rills and incipient branch gullies may be filled in by spade, shovel or plough on cultivated lands). Then the gully area should be planted with natural vegetation or grass. Typical grasses include; napier grass, (*Pennisetum Purpureum*), Guatemala grass *Tripsacum laxum*), Kikuyu grass (*Pennisetum clandestinum*), *Aspalum* spp., and African star grass (*Cynodon plectostachyus*). Leguminous covers are preferred as they improve soil fertility. Possible species include: Green leaf desmodium (*Desmodium intortum*), Silver leaf desmodium (*Desmodium uncinatum*) grown in lowlands and stylo (*Stylosanthese guyanensis*) among others. In the long run, natural vegetation endemic to the area should cover the gully as part in a natural healing process, to provide good protection for the soil. The choice of vegetation depends on how the planted area will ultimately be utilized. However, a reshaped gully should not be cultivated.

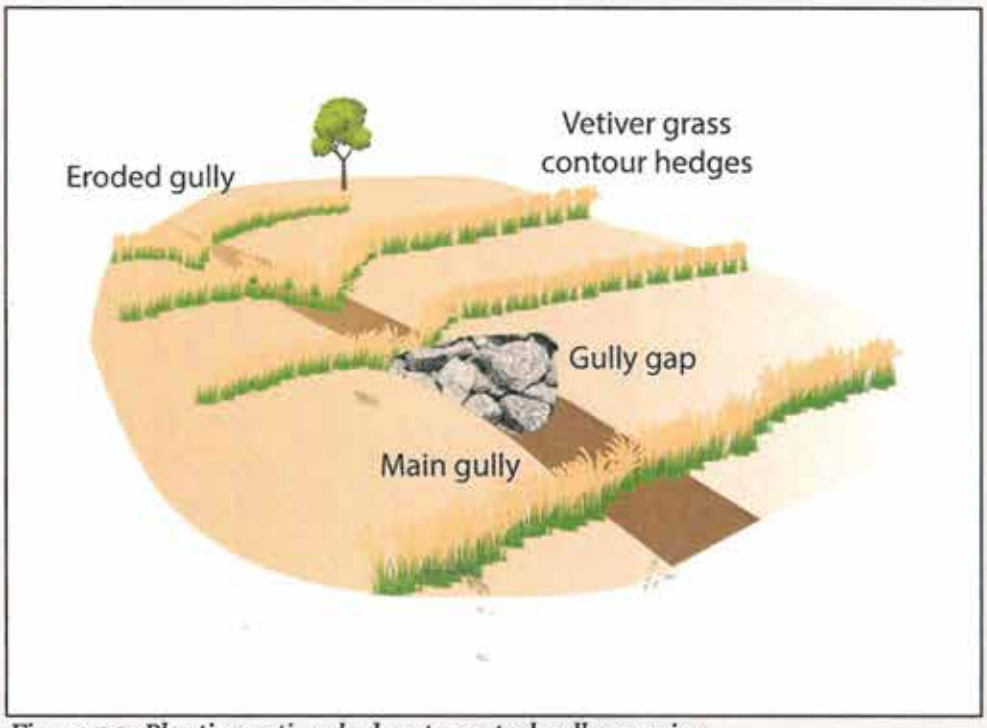

Figure 5.2: Planting vetiver hedges to control gulley erosion

5.3.2 Convert gully into grassed waterway

A gully is actually a waterway. Thus it can be improved to serves as a non-erosive grassed waterway. This involves digging and reshaping the gully, then planting grass and utilizing the gully as a conduit to discharge water safely. This works well where the gully slope is small (less than 5%) and the available channel is relatively wide (more than 5 m wide). The grassed waterway can carry a medium to large flows of water.

Initial establishment of the vegetation can be a problem, especially due to uncontrolled flooding. Maintenance practices such as fertilization and mowing of the vegetation as well as land management practices above the gully area to prevent sedimentation of the waterway are necessary for this control system to be successful.

5.3.3 Grassed waterway with soak pits

If a channel slope is too steep (5-10%) for a grassed waterway, a series of drop structures can be used to reduce the effective slope of the waterway below the upper limit of 5% for a grassed waterway installation. Drop structures can either take the form of a chute spillway or a grade control structure (as described in Chapter 4). An alternative method which is quite inexpensive involves digging a series of soak pits along the gully length.

The pits act as drop structures, dissipating the velocity and energy of runoff, which is ponded and infiltrates slowly (Figure 5.2). Sometimes a tree crop is planted in the pit to make use of the ponded water. Soak pits should only be dug where the soil is stable and unlikely to collapse. Regular de-silting of the pits is usually necessary.

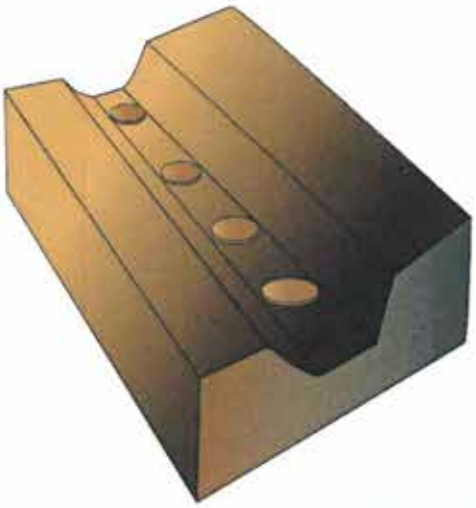

Figure 5.2 (a) Sketch of soak pits dug to reduce flow velocity in a gully (b) Soak pits dug in cascade to control gully erosion (Photo by B. Mati)

5.3.4 Convert gully into lined waterway

The gully may be small, but lying on a steep slope in the range of 10-25% over a significant portion of its length. The gully is converted into an artificial waterway, but a stronger lining material is used instead of grass. Acceptable lining materials are rock riprap, wired stone mattresses, interlocking or cable-connected concrete blocks. An inflexible channel lining such as poured concrete does not have the ability to move with the base material shifts caused by settling or possible erosion. Thus, concrete is not recommended as a waterway lining. These types of lining can be expensive. Therefore, if the gully has a long profile, the lining can be done for the most critical sections on the steeper portions of the slope. A major limitation is that the velocity of water exiting this structure may be excessive, causing further erosion problems downstream. A deceleration device such as large rock riprap may be required to dissipate excess energy of the flow through the gully.

5.3.5 Scour check dams.

A scour check dam is a small row of either sticks or stones arranged across the gully to reduce runoff velocity of small flows. In the case of sticks, they are about 3 cm diameter 40cm long, then hammered into the ground so check is about 15cm high. An apron made of stones or grass sods is made at the downstream side to absorb the water falling for the small structure (Figure 5.3).

Scour checks made of stones usually require a small foundation about 0.3 m deep and 0.3 m wide is dug across the gully floor. Then stones are arranged in the trench until they are flush with the floor of the gully. The stones are then arranged as to anchor the structure in place properly. The middle is left lower so as to act as a spillway. A small stones apron is made to absorb the energy of the water as it crosses the structure.

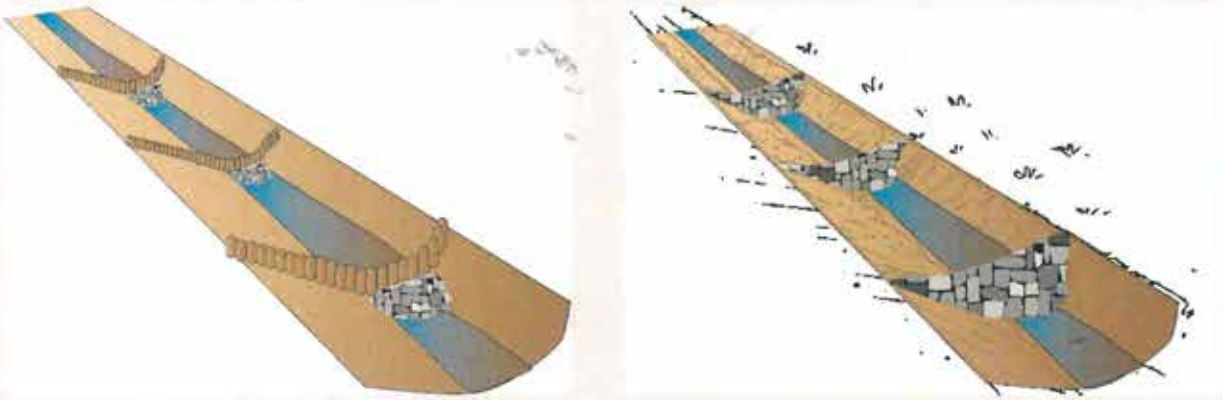

Figure 5.3 (a) Sketch of scour check made using sticks (Source; Desta et al, 2005) *(b) Sketch of cour check made with stones*

5.4. Control of medium sized gullies

For medium sized gullies or where larger runoff flows are expected, reshaping, filling diversions or vegetation alone will not suffice to control gullies. The establishment of vegetation is difficult because the newly planted material gets swept away, or sometimes, there is no topsoil to support proper re-vegetation. In such circumstances, additional gully control and slope stabilization measures are required. These could be temporary structures whose purpose is to provide protection for just long enough to enable vegetation to establish. The purpose of such structures is to slow down the runoff and cause deposition of silt. This function is better served using structures which are not watertight, as they tend to be cheaper and less likely to collapse. Thus medium sized gullies can be controlled using temporary structures or porous check dams.

5.4.1 Functions of check dams for gully treatment

Check dams are barriers constructed across a gully bed to stop channel and lateral erosion. They are made using woven-wire, brushwood, logs, loose stone or such other material. They act like drop structures, helping to reduce the original gradient of the gully channel. Thus check dams slow down the velocity of water and the erosive power of run-off, conveying it safely over the structure. Temporary check dams, which have a life-span of three to eight years, collect and hold soil and moisture in the bottom of the gully. Tree seedlings, as well as shrub and grass cuttings planted in the gully establish much faster and can grow without being washed away by flowing water. Thus, a permanent vegetative cover can be established in a short time.

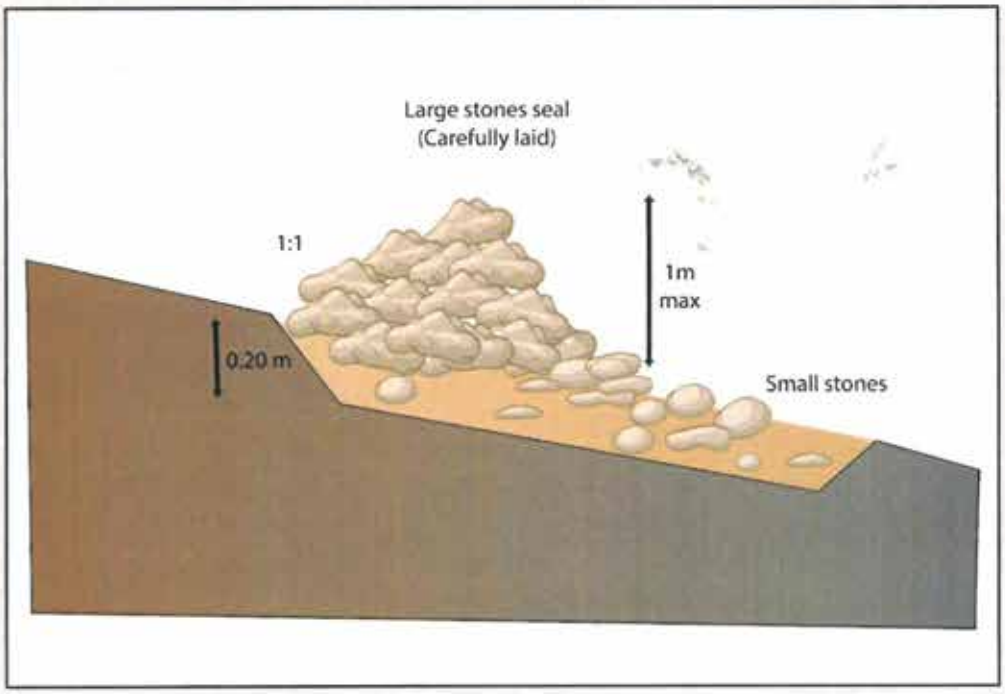

Figure 5.4 Cross-sectional impression of a check dam

To obtain satisfactory results from structural measures, a series of check dams should be constructed for each portion of the gully bed. To avoid failure by undermining or bed erosion, check dams are made low, with a notch at the center of the structure for excess flows to safely dissipate without scour of the gully sides. The check dam could be increased gradually as it gets submerged by silt. Check dams are not necessary on those gully portions which are protected from erosion by continuous rock outcrops along their gully beds. Check dams may also be combined with retaining walls parallel to the gully axis in order to prevent the scouring and undermining of the gully banks.

5.4.2 Cushion check dams

Cushion check dams are a quick and cheap way to fix gully erosion (Figure 5.5). They are made old gunny bags with soil, which are then packed onto each other across a gully to

create a check dam. This type of check dam is used as an emergency measure which can be used to help establish vegetation across the gully. The bags are held in position by a single row of posts. The structure should be able to retain the major portion of the run-off discharged from the catchment area. The method is suited to humid areas where vegetation is likely to establish quickly. Because silt deposits gradually reducing the storage capacity of the check dam, the structures has to be rebuilt every season.

Figure 5.5 Gully control with cushion check dams (soil filled bags)(Photo by B. Mati)

5.4.3 Loose stone check dam

A loose stone check dam (or simply stone check dam) is made by packing large stones across the gully to create a porous retaining wall (Figure 5.6). A spillway is made at the center of the stone structure to allow excess flows through the middle of the valley. Stone check dams control channel erosion along the gully bed, and to stop waterfall erosion by stabilizing gully heads. They can also be used for gully control or for runoff harvesting. It is usually recommended that the structures should be made short at first, then built in stages, each time building a wall that does not exceed 0.5 m high, so as to avoid failure of the structure from overload. Over a period of time, while the water is stopped by this wall, sediment settles and accumulates creating new land which can be cultivated. Usually, a series of stone check dams are placed along the valley length to enable more conservation of water and increase area that can be vegetated. The system requires regular maintenance.

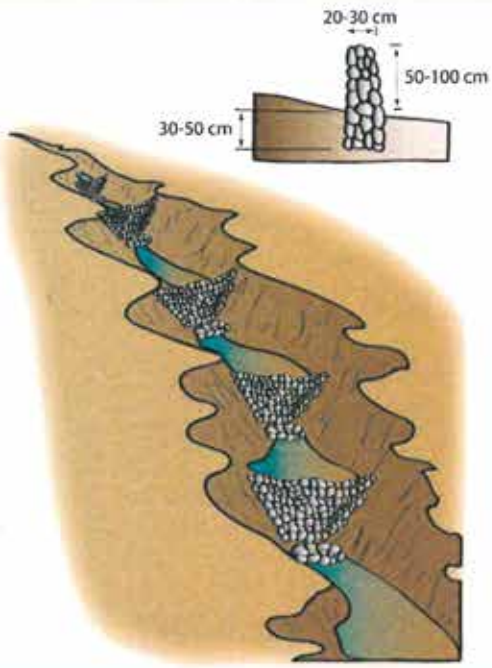

Figure 5.6 (a) Sketch of a stone check dam

(b) Gully controlled with stone check dam (Photo by B. Mati)

5.4.4 Stone-wire check dams

A stone wire check dam (sometimes called woven-wire check dam) are small barriers which are usually constructed to hold fine material in the gully. They are used in gullies with moderate slopes (not more than 10 percent) and small drainage areas that do not have flood flows which carry rocks and boulders. The dam is either constructed straight across the gully or in a crescent shape with its open end upstream. The crescent shape check dam is commonly used to allow a longer spillway than is possible on a straight one. At the same time it anchors and protects the ends of the dam. An offset equal to about one-sixth of the gully's width at the dam site will generally provide sufficient curvature.

5.4.5 Single row stone-post check dam

A single row stone-post check dam is a stone check dam anchored by a row of closely spaced posts, driven into the ground on the lower end. The posts can be tied together with a wire for added strength. The stones are packed on the upstream side of the check dam, ensuring that the middle is lower to act as a spillway. A stone apron is normally provided just behind the posts.

5.4.6 Double row stone-post check dam

In a double row stone-post check dam, as the name suggests, is one in which the stones are packed between two rows of posts. The posts and stones should reach 0.5 m deep and 0.5 m into the wing walls excavated across the gully. After packing the stones between the posts, they may be tied with wire for added strength. It is important to keep the top of the wire as level as possible along the central portion (the crest of the spillway) to obtain a much better spread of water over the structure. Rocks, brush or sod may be used for the apron. Double row stone check dams utilize fewer stones as it gets its strength from the posts.

5.4.7 Brush fills

Brush fill (or brushwood carpet), is a continuous filling on small gullies with brush, branches of trees, stems of bushy vegetation, etc. If brush is placed across the gully, it is called a "brush plug". The main purpose of brush fills is to obliterate the gully with the soil that brush holds (Figure 5.7). The method is suitable for incipient and small which do not exceed 0.6 deep and 0.6m wide in size. The gradient of the gully channel should not greater than 10 percent. The method is economical where vegetative material is abundant e.g. in humid zones. However, it is a temporary measure as the brushwood rots in the end. Brush fill work starts at the head. First, the gully bed is lined with small tree and shrub branches to protect the soil; then larger branches are placed over them. A brush fill should rise above the gully banks so it can be weighted down with rocks or heavier wood pieces. The brush should be compacted to permit compost placement.

Figure 5.7: Gully control with stone check dams and brushwood fills (Photo by B. Mati)

5.4.8 Brushwood check dams

Brushwood check dams are vegetative measures differ from brush fills in that the vegetative material is arranged across the gully bed in the form of a check dam. It utilizes big and small tree branches for the fill material. Posts are sometimes driven into the ground to stabilize the structure, and the whole structure can be tied up using wire to stabilize it. An apron made of twigs and branches is usually made. Wherever possible the posts can be plant types which sprout in the ground e.g. *Acacia Comiphora*. Brushwood check dam can handle larger flows the simple brush fills. Since brushwood is degradable, the structure should be made for temporary measure, e.g. to facilitate the establishment of vegetation.

5.4.9 Netting dams

A wire netting dam is usually used to control a gully head, or at the inlet to a gully e.g. culvert outlet. In construction, wooden posts are driven into the bed of the gully, and used to support a trip of wire netting which forms a low wall across the gully. The height should be only a half meter or so and the lower edge of the netting is buried. Light brush or straw is piled loosely against the upstream side of the netting wall and is packed by the flow of water against the netting to form a barrier, which is porous but slows down the flow and causes a buildup of sediment on the upstream side. It acts like a reinforced brushwood check dam, while the posts anchor the structure in place.

5.5. Control of large gullies

The control of large gullies and those lying on gradients exceeding 25% may require the construction of permanent structures which can withstand the onslaught of torrential floods. Such structures are usually expensive requiring expertise, material and capital investment. Such costs are warranted if the gully threatens important infrastructure e.g. road, railway or a reservoir. These are usually check dams made of masonry, concrete, logs, gabions or other material.

5.5.1 Gully-head dams

A gully head dam is a permanent structure created to control an active gully head that is eating its way steadily upstream and must be stopped before it threatens a road or bridge or similar assets. An effective way of controlling the erosive force of the runoff over the gully head is to submerge the head in the pond of a permanently impounding dam. The energy of the in-rushing water is dissipated as it flows into the dam, reducing its erosive power.

By controlling the gully head, the rest of the gully can heal more easily especially if other types of check dams are constructed and vegetation planted. The water stored in the gully head dams infiltrates into the soil and helps recharge the catchment, further improving soil moisture content of surrounding areas. Care should be taken to avoid submerging a gully head on unstable ground, which could collapse even more due to ponding. In climates with marked wet and dry seasons, it is possible for the gully head to move back a little each year before the dams fills until eventually the head is at the full supply level of the dam and so is no longer submerged and continues to eat back unchecked. This is called the 'gully climbing back out of the dam' and should be avoided by allowing adequate freeboard. Another way of controlling gully head erosion is to use drop structures made of stone masonry, brick, or concrete which allows the flood run-off to pass over the head harmlessly.

5.5.2 Boulder check dams

Boulder check dams placed across the gully are used mainly to control channel erosion and to stabilize gully heads. In a gully system or multiple-gully system all the main gully channels of continuous gullies can be stabilized by boulder check dams. The maximum total height of the dam is 2 m. Foundation depth must be at least half of effective height. The thickness of the dam at spillway level is 0.7 to 1.0 m and the inclination of its downstream face is 30 percent. The thickness of the base is calculated accordingly. The upstream face of the dam is usually vertical. These dimensions ensure stability of the dam against overturning, collapsing and sliding (Figure 5.8). But, the dimensions of the spillway should be computed according to the maximum discharge of the gully catchment area. The form of the spillway is generally trapezoidal.

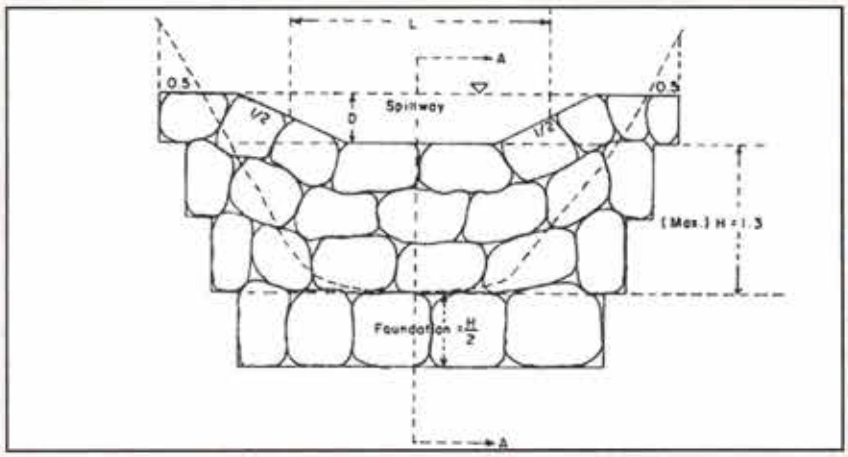

Figure 5.8 Sketch of a boulder check dam for gully control (Source: FAO, 1986)

5.5.3 Gabions

Gabions (or wire bolsters) are porous structures comprising pre-fabricated heavy-duty wire netting filled with stones. They are preferred in areas where plenty of loose stones are available to build loose rock-fill dams with the stones anchored in place by wire netting. The dimensions of gabion nettings are variable, but they can be 4 m long and 1 x 1 m in cross-section, or 1 m cuboids. The empty gabion box is laid out flat across the gully bed. Loose rock is packed on one half of the width of the netting and the other half wrapped over the stones and laced to the other edge, forming a sausage or rock contained in a skin of wire netting. Several gabion boxes are placed adjacent to each other and on top of one another to create a check dam. The main advantage of these structures is that there is sufficient flexibility for the structure to adjust to settlement resulting from scouring of the foundations without any loss of strength. Also, gabions have higher tensile strength and are semi-porous, thus offer better safety against failure. Unlike concrete structures, they are easier to repair and extend as necessary.

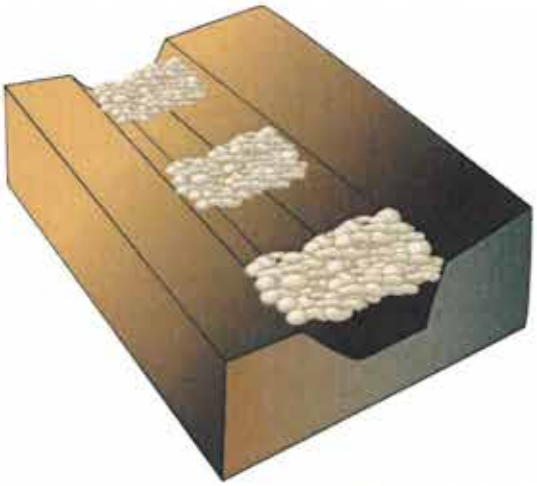

Figure 5.9 Sketch of a gabion system for gully control

(b) Gabion box filled with stones for gully control (Photo by B. Mati)

5.5.4 Log dams

Heavy timber can be used to create log-piling dams. Log dams are check dams made using logs or huge posts placed across the gully. They can also be built of planks, heavy boards, slabs, poles or old railroad ties. One method is to use logs in the same way as the brushwood check dam, but to make a much more substantial structure. Two rows of vertical posts are driven into the bed of the gully and extending up the sides to above flood level, and then logs are packed in between. The vertical posts should be at least cm diameter, 2 m long, and spaced about a matter apart in each row, with the two rows of

posts half a meters apart. A wide notch should be created to act as a spillway to the structure. When the logs are packed between the rows of posts the bottom layer should be sunk below ground surface to avoid seepage and scour underneath. After the top logs have been placed they are held in position by strong wire ties between the vertical posts. Log check dams hold fine and coarse material carried by flowing water in the gully, and to stabilize gully heads. They are used to stabilize incipient, small and branch gullies generally not longer than 100 m. and with catchment areas of less than two hectares.

5.5.5 Silt-trap dams

Silt trap dams are designed like conventional dams or weirs, but their main purpose is to hold eroded sediments so as to reduce the excessive load and to protect downstream water supplies (see Training Manual 3 of these series). Permanent silt trap dams are of many shapes and sizes and are built wherever suitable site is possible. Although they are usually designed for rivers, they can also be used for gully control.

5.5.6 Use of clay bricks

Where clay bricks are the most affordable local building material, they can be used to construct gully control structures. Burnt bricks are normally resistant to the effect of water. The bricks are used to build a retaining wall much the same way as a concrete weir. A single thickness of brick work can be built to height of one or one and a half meters over a circular span or about two meters. A straight wall of similar size would need three or four times as much brickwork to achieve comparable strength. The arch works by transmitting the load round the arch to the buttresses at each end, and to it needs good solid support in the gully walls, preferably in the form of a rock out crop.

Since brickwork has little tensile strength, the weakest feature of straight walled brick dams is their resistance to the bending moment which results from the water pressure. In other words the risk of failure is proportional not to the length of the wall, but the square of the length. A buttress at the mid-point of a straight wall reduces the effective length by a half but cuts the bending moment to a quarter and so is usually worthwhile if the site conditions allow.

5.6 Construction and maintenance

5.6.1 Construction of gully control structures

The construction of check dams or other structures for gully control generally start from the bottom to the top of the gully proceeding up. Longitudinally, control structures are first installed upstream going downhill. However, if materials such as stones used for check dams have to be transported from the bottom to the top of the gully through the

gully channel, then construction starts at the top. Gully heads are usually stabilized by building suitable check dams in front of them. The kind of check dam needed depends on the flowing water's falling distance from the gully head, and the availability of construction material.

Field activities must be planned so that all structural work is completed before the rainy season. Otherwise, the unfinished structures may be washed away. In addition, vegetative control measures rely on the functioning of the structural measures to establish.

5.6.2 Spacing between structures

The spaces between check dams can be determined according to the compensation gradient and the effective height for the check dams. The gradient between the top of the lower check dam and the bottom of the upper one is called "compensation gradient" which is the future or final gradient of the gully channel. It is formed when material carried by flowing water fills the check dams to spillway level. Field experience has demonstrated that the compensation gradient of gullies is not more than 3 percent.

The first check dam should be constructed on a stable point in the gully such as a rock outcrop, the junction point of the gully to a road, the main stream or river, lake or reservoir. If there is no such stable point, a counter-dam must be constructed. The distance between the first dam and the counter-dam must be at least two times the effective height of the first check dam.

The points where the ensuing check dams are to be built are determined according to the compensation gradient and the effective height of the check dams. At the second point, the effective height of the second check dam is marked at the edge of the gully by taking into account the depth of the gully, the depth of the spillway and the maximum height of the check dam.

5.6.3 Vegetation establishment

All structural measures used in gully control must be accompanied with vegetative measures to achieve sustainable rehabilitation (Figure 5.10). The general principles of the re-vegetation of gullied areas involve the following:

(i) All structural measures should be completed in the dry season and the accompanying vegetative measures undertaken during the immediate or following rainy season.

(ii) Suitable tree seedlings and cuttings must be planted just behind the structural measures.

(iii) Shrub and grass cuttings must be planted between the structural measures.

(iv) Tree and grass seeds should be sown between the structural measures, and on gentle, bare slopes which have sufficient soil.

(v) Gentle slopes which do not need any structural measures should be planted with tree seedlings, and grass and shrub cuttings.

Figure 5.10 (a) Sisal used to rehabilitate gully controlled with stone check dams (b) Grass cover for rehabilitated gully (Photos by B. Mati)

5.6.4 Utilizing a controlled gully

A gully could be rehabilitated and converted into agricultural land. Most gully control works involve creating check dams with locally available materials (stones, brushwood, or living vegetative hedges). The check dams are built in stages by raising the height of the check dam by about 0.3 m. each year. As runoff flow velocities within the gully are reduced, deposition causes soil build up to adequate depth. The excess flow over the gully is trapped, allowing for water harvesting, conservation and the growing of crops even in marginal rainfall areas which conserve both water and soil ahead of the structure. Such soil build up ahead of the gully could be utilized converting a gully into an asset (Figure 5.11).

Figure 5.11 (a) Sketch showing utilization of rehabilitated gully (b) Rehabilitated gully used to grow food crops and fodder (Photo by B. Mati)

5.6.5 Maintenance of gully control structures

Maintenance for structural measures must be continued for at least two years after the treatment year. Treated areas must be inspected at least once a year. The trees and grass established in gully catchment areas must be protected against fire, illegal wood cutting, grazing and encroachment. If the re-vegetated areas are properly managed for several years after the treatment, some fuel wood can be produced from tree plantations and fodder can be obtained from grass and fodder tree plantations. Erosion control systems require regular attention to check and repair weak areas before failure occurs. The critical areas of concern include:

(i) Any bare or eroded area should be repaired immediately.

(ii) Obstructions or potential obstructions in the flow path should be removed.

(iii) Any settling or shifting should be repaired.

(iv) All grassed areas should be mowed twice per year.

(v) The inlet to the control system should be cleared of impediments before the rainy season.

(vi) All berms should be checked regularly for signs of failure and remedial measures taken.

Gully control needs to be integrated with treatment of the catchment areas, and consideration as to whether the gully crosses cultivated areas and facilities such as bunds, terraces, boundaries and roads. Responsibility for maintenance management arrangements need to be agreed. If treated with large structures, a gully can also be integrated with shallow wells dug below series of soil storage dams and small scale irrigation. Stabilized watershed slopes are the best assurance for the continued functioning of gully control structures. Therefore, attention must always be given to keeping the gully catchment well vegetated.

6. BIBLIOGRAPHY

Assmo, P.; Eriksson, A. (1999). *Soil conservation in Arusha Region, Tanzania. Manual for Extension*. Technical Handbook No. 7. RELMA, Nairobi.

Blank, H. G., Mutero, C. M., & Murray-Rust, H. (2001). The changing face of irrigation in Kenya

Campbell, C. W., & Sullivan, S. M. (2002). Simulating time-Varying cave flow and water levels using the storm Water Management Model. Engineering Geology, 65(2), 133-139.

Critchley, W.; Cooke, R.; Jallow, T.; Njoroge, J.; Nyagah, V.; Saint-Firmin, E. (1999). *Promoting farmer innovation: Harnessing local environmental knowledge in East Africa*. Workshop Report No. 2. UNDP-

Daniel Danano, Betru Nadassa, Diribu Jamal and Birhanu Fantaw (2001), Soil and water conservation Manual for Ethiopa, MoA, Addis Ababa.

Desta, L, Carucci, V. Wendem-Ageňehu, A. and Abebe, Y. (2005) (eds). Community-based Participatory Watershed Development: A Guideline. Federal Democratic Republic of Ethiopia Ministry of Agriculture and Rural Development, Addis Ababa.

FAO Conservation Guide No. 1 - Guidelines for Watershed Management (1977) (293 pages). FAO, Rome

FAO, (1986). FAO watershed management field manual: Gully control. FAO Conservation Guide 13/2. Rome.

FAO, (2011). Sustainable Land Management in Practice Guidelines and Best Practices for Sub-Saharan Africa: Field Application. FAO, Rome

Fiener P and K. Auerswald (2006). Influence of scale and land use pattern on the efficacy of grassed waterways to control runoff. *Ecological engineering (27): 208–218.*

Frevert, R.K.; Schwab, G.O.; Edminister, T. W. and Barnes, K.K. (1971). Soil and Water Conservation Engineering.Hohn Wiley and Sons, Inc., New York.

HDRA Water Harvesting and Conservation- International Development Programme, HDRA, Coventry, UK. www.gardenorganic.org.uk/international_programme/index.php

Hudson, N. W. (1995). Soil Conservation. Third Edition. BT Batsford Ltd. London

Hurni, H. and Tato, K. (eds). (1992). Erosion, *Conservation and small-scale farming*. Geographisca Bernesia, Walsworth Publishing Company, Missouri, USA.

IIRR. (1998). *Sustainable Agriculture Extension Manual for Eastern and Southern Africa*. Nairobi. International Institute for Rural Reconstruction.

Kibwana, O.T. 2000. Farmer innovators and their innovations in land husbandry in Tanzania. In*Farmer Innovation in Land Husbandry*, eds. M. Haile; A. Waters-Bayer; M. Lemma; M. Hailu; G. B. Anenia; F. Abay; Y. GebreMichael. Proceedings of Anglophone Regional Workshop (Feb. 6-11, 2000) Mekelle, Tigray - Ethiopia. 53-58.

Landon, J. R. (1991). *BookerTropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. London: Longman.

Lindgren, B. M. (1988). *Comparison between terraced and non-terraced land in Machakos District, Kenya, 1987.* Working Paper No. 95. International Rural Development Centre. Uppsala, Sweden: Swedish University of Agricultural Sciences.

Lundgren, L. (1993). *Twenty years of soil conservation in Eastern Africa*. RSCU/SIDA, Report No. 9. Nairobi, Kenya.

Lundgren, L.; Taylor, G. (1993). *From Soil Conservation to Land Husbandry*. Guidelines Based on SIDA's Experiences. Stockholm, Sweden: SIDA.

Mati B. M. and de Lange, M. (2003). Emerging Practices and Water Management under Rainfed Agriculture in eastern Africa. In: *Water Conservation Technologies For Sustainable Dryland Agriculture in Sub-Saharan Africa*. Beukes, D., de Villers, M., Mkhize, S., Sally, H. and van Rensburg, L. (eds). Proceedings of the Symposium and Workshop (WCT), Bloemfontein, South Africa, April 8-11th 2003. 209-218.

Mati, B. M. (1993). Soil erosion and conservation activities on land affected by road drainage: A case study of Nyeri District. In: *Land and Water Management in Kenya: Towards sustainable land use*. Gichuki, F.N., Mungai, D.N., Gachene, C.K. and Thomas, D.B. (eds). Proceedings of the Fourth National Workshop held in Kikuyu, Kenya, 15-19 February 1993. Department of Agricultural Engineering, University of Nairobi and Soil and Water Conservation Branch, Ministry of Agriculture and Rural Development, Nairobi, pp.167-170.

Mati, B. M. (1989). Cultural and structural aspects of soil conservation. An evaluation report. In: *Soil and water conservation in Kenya*. Thomas, D.B. et al (editors). Proceedings of the Third National workshop, 16-19 September 1986. Nairobi, Kenya, 163-175.

Mati, B. M. (2005). *Overview of water and soil nutrient management under smallholder rain-fed agriculture in East Africa*. Working Paper 105. Colombo, Sri Lanka: International Water Management Institute (IWMI). www.iwmi.cgiar.org/pubs/working/WOR105.pdf.

Morgan, R P C (1995).*Soil erosion and conservation*. Second Edition. Longman Group Ltd. Great Britain.

Mutunga, K.; Critchley, W.; Lameck, P.; Lwakuba, A.; Mburu, C. (2001). *Farmers' initiatives in land husbandry. Promising technologies for the drier areas of East Africa*. Technical Report No. 27. RELMA, Nairobi.

Nicol, A.; Langan, S.; Victor, M.; Gonsalves, J. (Eds.) (2015). Water-smart agriculture in East Africa. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE); Kampala, Uganda: Cooperative for Assistance and Relief Everywhere (CARE). 352p. doi: 10.5337/2015.203

Negassi, A.; Tengnas, B.; Bein, E.; Ghebru, K. (2000). *Soil conservation in Eritrea: Some case studies*. Technical Report No. 23. Regional Land Management Unit, Nairobi

Ribeiro, F., Justice, S.E., Hobbs, P.R. and Baker, C.J. (2006) No-tillage drill and planter design - small scale machines.

Schwab , G.O Fangmeirer , D.D, Elliot, W.J and Frevert , R.K. (1993). .*Soil and water conservation Engineering* . 3rd edition , Wiley , New York.

Shaxson, T.F Hunter, N.D Jackson , T.R and Alder, J.R (1977). *A land Husbandry Manual*. Land Husbandry , Ministry of Agriculture and Natural Resources , Malawi.

Suresh, R. (1997). *Soil and water conservation engineering*. Standard Publishers Distribution. Second Revised and enlarged edition, Delhi, India.

Tafa Tulu. (2002). *Soil and water conservation for sustainable agriculture*. Mega Publishing Enterprise, Ethiopia.

Tariku Alemu (2008) Training manual (module).MERET Project training Kombolcha , Ethiopia.

Temu, A.E.M.; Bisanda, S. (1996). Pit Cultivation in the Matengo Highlands of Tanzania. In *Sustaining the Soil – Indigenous Soil and Water Conservation in Africa*, eds. C. Reij; I. Scoones; C. Toulmin. London, U.K.: Earthscan. 80-84.

Thomas, D. B., ed. 1997. *Soil and Water Conservation Manual for Kenya*. Soil and Water Conservation Branch, Ministry of Agriculture, Livestock Development and Marketing. Nairobi, Kenya: Ministry of Agriculture, Livestock Development and Marketing.

Thomas, D. B.; Biamah, E. K. 1991. Origin, application and design of Fanya Juu Terrace. In *Development of Conservation Farming for Hillslopes*, eds. W.C. Moldenhauer; N.W. Hudson; T.C. Sheng; San-Wei Lee. Soil and Water Conservation Society, Ankeny, Iowa, USA: 185-194. Soil and Water Conservation Society, Ankeny.

Tiffen, M.; Mortimore, M.; Gichuki, F. 1994. *More people less erosion- Environmental recovery in Kenya*. Nairobi, Kenya: Acts Press.

Wenner, C. G. 1981. *Soil Conservation in Kenya*. Soil and Water Conservation Branch. Ministry of Agriculture, Nairobi.

WOCAT (*World Overview of Conservation Approaches and Technologies*). 2000. *WOCAT, World Overview of Conservation Approaches and Technologies*- CD-Rom.

WOCAT website: http://www.wocat.net/en/vision-mission/sustainable-land-management/soil-and-water-conservation.html

Young, A. 1976. *Tropical Soils and Soil Survey*. Cambridge University Press, Cambridge. Cambridge University Press.

NELSAP-CU
NILE BASIN INITIATIVE
INITIATIVE DU BASSIN DU NIL

NELSAP-CU Offices,

Kigali City Tower, 5th Floor,
KN 81 Street,
P. O. Box 6759,
Kigali – Rwanda.
Email: nelsapcu@nilebasin.org

Website: http://nilebasin.org
http://nelsap.nilebasin.org
Tel: +25088307334
Facebook @ NelsapCu/NBI
Twitter @NelsapCu