# Tool and Guideline # 5

# Practical Tools on Soil and Water Conservation Measures

**Rwanda Environment Management Authority**
**Republic of Rwanda**
**Kigali, 2010**

# PREFACE

In 2010, REMA prepared 11 practical technical tools intended to strengthen environmental management capacities of districts, sectors and towns. Although not intended to provide an exhaustive account of approaches and situations, these tools are part of REMA's objective to address capacity-building needs of officers by providing practical guidelines and tools for an array of investments initiatives.

Tools and Guidelines in this series are as follows:

| # | *TOOLS AND GUIDELINES* |
|---|---|
| 1 | Practical Tools for Sectoral Environmental Planning :<br>A - Building Constructions<br>B - Rural Roads<br>C - Water Supply<br>D - Sanitation Systems<br>E - Forestry<br>F - Crop Production<br>G - Animal Husbandry<br>H - Irrigation<br>I - Fish Farming<br>J - Solid Waste Management |
| 2 | Practical Tools on Land Management - GPS, Mapping and GIS |
| 3 | Practical Tools on Restoration and Conservation of Protected Wetlands |
| 4 | Practical Tools on Sustainable Agriculture |
| 5 | Practical Tools on Soil and Water Conservation Measures |
| 6 | Practical Tools on Agroforestry |
| 7 | Practical Tools of Irrigated Agriculture on Non-Protected Wetlands |
| 8 | Practical Tools on Soil Productivity and Crop Production |
| 9 | Practical Technical Information on Low-cost Technologies: Composting Latrines & Rainwater Harvesting Infrastructure |
| 10 | Practical Tools on Water Monitoring Methods and Instrumentation |
| 11 | 11.1 Practical Tools on Solid Waste Management of Imidugudu, Small Towns and Cities : Landfill and Composting Facilities |
| | 11.2 Practical Tools on Small-scale Incinerators for Biomedical Waste Management |

These tools are based on the compilation of relevant subject literature, observations, experience, and advice of colleagues in REMA and other institutions. Mainstreaming gender and social issues has been addressed as cross-cutting issues under the relevant themes during the development of these tools.

The Tool and Guideline # 5 provides practical methods on how to restore and conserve agricultural land including technical information on soil and water conservation measures such as radical terraces and gullies.

These tools could not have been produced without the dedication and cooperation of the REMA editorial staff. Their work is gratefully acknowledged.

**Dr. Rose Mukankomeje**
*Director General, Rwanda Environment Management Authority*

# TABLE OF CONTENT



# TABLES

# Tool and Guideline # 5

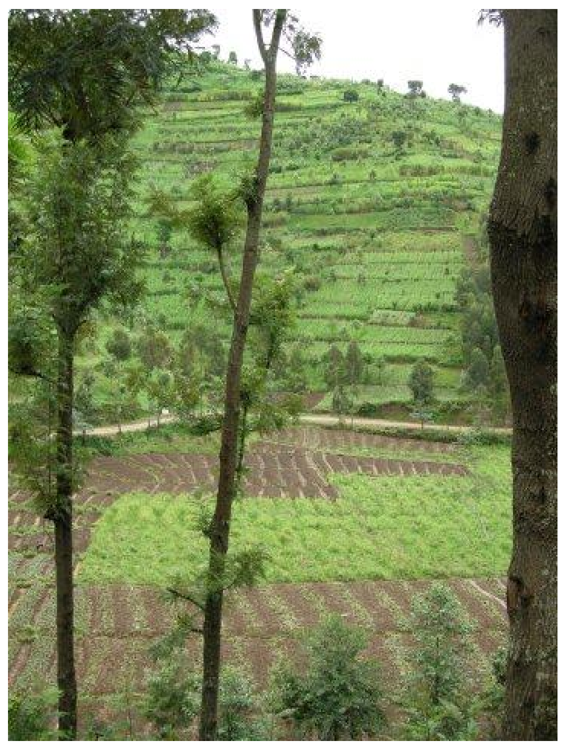
# Practical Tools on Soil and Water Conservation Measures

## 1. INTRODUCTION

### 1.1 Overview

Unsustainable land-use, in combination with Rwanda's steep topography, fragile soils, and climate, is the driving cause of soil erosion. Unsustainable land-use practices include deforestation, agricultural expansion into fragile ecosystems, over-cultivation, overgrazing, and poor road construction. High demands for arable land results in extensive deforestation, reducing the total forest cover. Deforestation is most severe in the northwest of the country, where farming of very steep slopes has resulted in catastrophic erosion and slope failure.

Acute land scarcity has led to the over-cultivation of land. Fallow periods have grown much shorter or have become non-existent. In many cases, cultivation periods have been extended, up to two to three times per year, with very limited soil inputs or soil conservation measures. Over-cultivation has had a major impact on reducing soil fertility and productive capacity. Farmer response to offset low production yields by over-cultivation that only worsens land degradation. A practical way to break out of this cycle is to increase both soil nutrient capital and soil organic matter through the simultaneous application of organic inputs (e.g. animal manure) and chemical fertilisers.

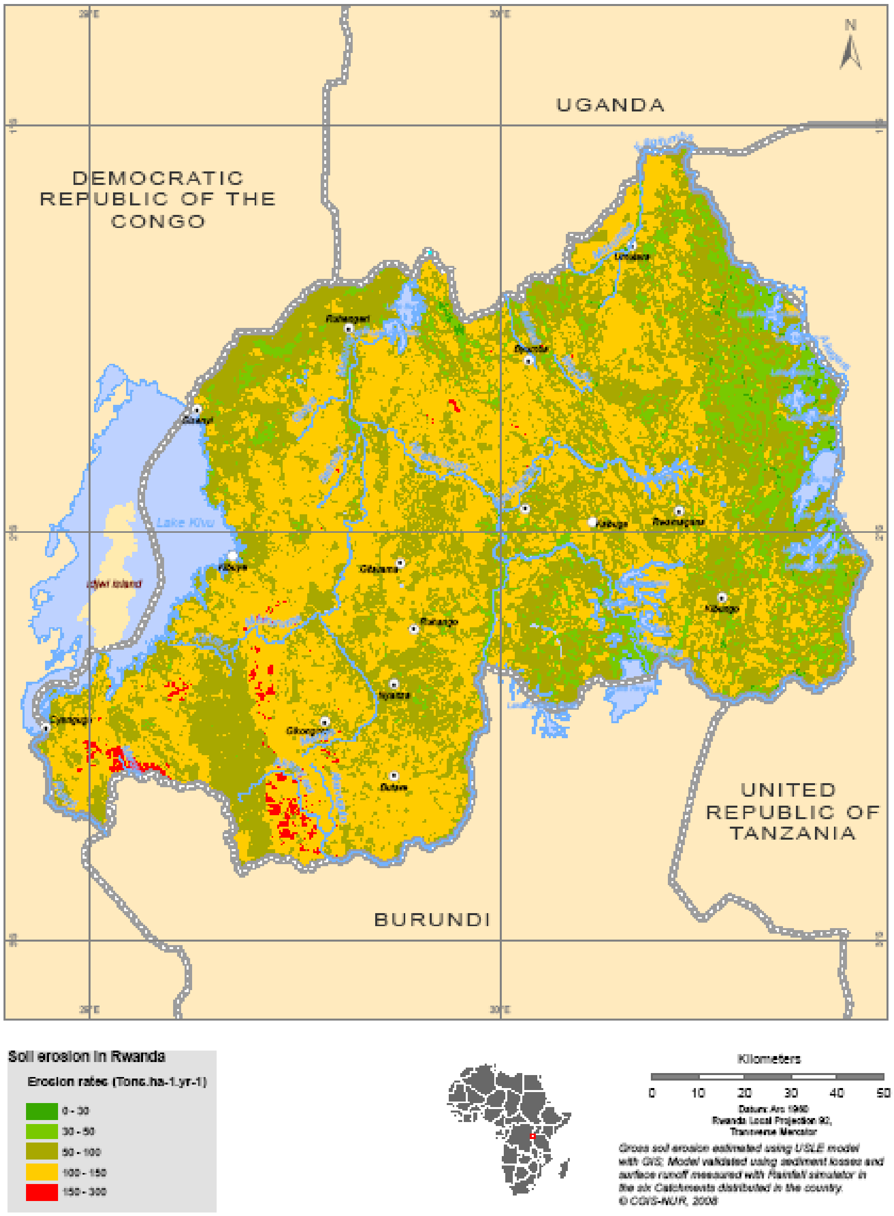


**Rwanda's Steep Topography**

Despite government efforts to reduce the size of cattle herds, overgrazing remains a serious problem. Overgrazing is characterised by a significant reduction in plant cover, soil organic matter content, and soil biological activity. As a consequence, there is increased exposure to erosion by rainfall, which degrades the soil physical structure and reduces soil nutrients.

Agriculture practised on the slopes of hills and mountains caused land degradation and soil erosion. The increasing levels of soil erosion and reduced soil fertility in the acid-soil mountainous areas of Rwanda have resulted in ecosystem degradation, lowered agricultural yields which severely impacted on rural livelihoods and the national economy. Land degradation continues to worsen in the country despite efforts to prevent it. Comprehensive long-term programme and policies for soil and water conservation measures are required.

GIS models can estimate the rate of sediment accumulation to evaluate average soil loss rates within catchment areas. Sedimentation measurements provide information on the extent of soil erosion that was estimated using the USLE GIS model as presented in this next map.




**GIS Modelling of Soil Erosion Rates**

The three major factors limiting production in small farms are low soil fertility, shortages of water in the root zone soil, and soil degradation. Soil fertility is often low because many soils are strongly weathered. Moreover, many farmers do not add adequate fertilizer to compensate for the nutrients that their crops take from the soil. These three factors often lead to low production levels, making it difficult for many small farmers to escape a life of subsistence.

Farmers are willing to make investments in the soil to overcome these constraints, but they require incentives to do so such as

(i) Making fertilizers more affordable for all farmers (e.g. fertilizer prices inland can be four to five times those at the port);
(ii) Providing financial support for farmers to invest in soil and water conservation measures; and
(iii) Promoting the development of agricultural training and information facilities for farmers.

## 1.2 Purpose

The objective of this tool is to propose practical information on how to restore and conserve agricultural land including technical information on soil and water conservation measures such as radical terraces and gullies.

Although not intended to provide an exhaustive account of approaches and situations, this tool is intended to address capacity-building needs of officers by providing practical information on soil and water conservation measures. This tool can be used as field guides or as checklists of elements for discussion during training and during implementation of soil and conservation measures.

This document was produced to address REMA's proposed policy action to strengthen the resource capacity of environmental and related institutions at national and district level for environmental assessment, policy analysis, monitoring, and enforcement.

## 1.2 Why Restore and Conserve Agriculture Land?

Land degradation is a significant issue in Rwanda as it affects the environment, agronomic productivity, food security, and quality of life resource-poor farmers. These farmers can neither afford the much needed off-farm input essential to sustainable use of soil and water resources, nor are they sure of their effectiveness because of the harsh climate, structurally fragile soils and land tenure.

Soil degrading processes include the loss of topsoil by the action of water or wind, chemical deterioration such as nutrient depletion, physical degradation such as compaction, and biological deterioration of natural resources including the reduction of soil biodiversity. The expansion of agriculture into marginal areas, deforestation, the shortening or elimination of fallows, inappropriate farming practices, and low input inevitably have several environmental and economic impacts. This expansion of agriculture causes on-site degradation of natural resources and productivity decline.

In Rwanda, soil conservation has a long tradition. Indigenous techniques from the pre-colonial era focused on erosion control in combination with water conservation by ridging, mulching, constructing earth bunds and terraces, multiple cropping, fallowing, and the planting of trees. This document provides extensive information on soil conservation strategies and their application in Rwanda. Based on this, the most promising soil conservation technologies are identified to improve the management and conservation of soil resources in the country.

## 1.3 Gender and Social Issues

The different roles and responsibilities of women and men in water resources use and management are closely linked to environmental change and well-being. This is true both for how women and men affect the environment through their economic and household activities and how the resulting environmental changes affect people's well-being. Understanding these gender differences is an essential part of developing policies aimed at both better environmental outcomes and improved health and well-being.

Women play a critical role in the field of environment, especially in the management of plants and animals in forests, arid areas and wetlands. Rural women in particular maintain an intimate interaction with natural resources, the collection and production of food products, fuel biomass, traditional medicine and raw materials. Poor women and children especially may collect grasshoppers, larvae, eggs and birds' nests to sustain their families.

As their knowledge is transmitted through generations, girls and women often acquire a thorough understanding of their environment, and more specifically of its biodiversity. Their experience gives them valuable skills required for the management of the environment. Women have an important role to play in preserving the environment and in managing natural resources to achieve ecologically sustainable production. Despite women's assumed special relations to nature it should be stressed that all people depend on the environment and all should share the responsibility for sustainable use of water and other natural resources.

The impacts of the degradation of the environment on people's everyday lives are not the same for men and women. When the environment is degraded, women's day-to-day activities, such as fuel and water collection, require more time, leaving less time for productive activities. When water becomes scarce, women and children in rural areas must walk longer distances to find water, and in urban areas are required to wait in line for long hours at communal water points. Despite their efforts, women living in arid areas tend to be categorised among the poorest of the poor, and have absolutely no means to influence real change. They are often excluded from participating in land development and conservation projects, agricultural extension activities, and policies directly affecting their subsistence. Men make most decisions related to cattle and livestock, and even in households headed by women, men still intervene in the decision-making process through members of the extended family. However, because of the important contribution of women, the fight against the degradation of arid areas requires a gender-inclusive approach.

Women participate in watershed management, for example, by maintaining forest cover to reduce soil erosion which often floods and silts reservoirs and waterways. Training programmes on the technical and scientific aspects of watershed development including soil and water conservation measures and techniques on wetland restoration must include women. Women need the necessary skills, knowledge and confidence to participate in community decision-making and to assume leadership roles in management of watershed development. Gender analysis is need for all components of most watershed development activities.

Women's status in conserving biodiversity may be enhanced through the following types of actions to integrate gender concerns into environmental planning:

- Improve data collection on women's and men's resource use, knowledge of, access to and control over resources. Collecting sex-disaggregated information is a first step toward developing gender-responsive policies and programmes.
- Train staff and management on the relevance of gender issues to water resources and environmental outcomes.

**Women Participate in Watershed Management**

- Establish procedures for incorporating a gender perspective in planning, monitoring, and evaluating environmental projects.
- Ensure opportunities for women to participate in decisions about environmental policies and programmes at all levels, including as designers, planners, implementers, and evaluators. Women need official channels to voice their environmental concerns and contribute to policy decisions.

Women and men around the world play distinct roles in managing plants and animals, in use of forests, drylands, wetlands and agriculture. Moreover, gender roles are differentiated in collecting water, fuel, and fodder for domestic use, and in generating income. Due to their distinctive engagements with the natural environment, women's experience and knowledge are critical for environmental management. Using a gender perspective and enabling the integration of women's knowledge of the environment will increase the chances of environmental sustainability.

# 2. SOIL AND WATER CONSERVATION MEASURES

This section provides technical guidance and specifications related to soil and water conservation measures of sloping land for sustained agricultural and agroforestry production. It describes the various measures and how to apply them, assuming that the decision to reforest, terrace, etc., is economically sound. Whether this is so or not depends on a series of factors and circumstances. However, with population pressure on mountain areas showing no signs of diminishing, it is becoming increasingly clear that watershed protection is vital to increase upland production while providing the necessary protection.

Watershed rehabilitation generally requires land use adjustment measures which contribute to a reduction in soil erosion rates, and at the same time increase rural employment and income. The three main techniques considered are agronomic or biological measures, soil management strategies and mechanical or physical methods. Suggested measures in these on-farm erosion control strategies are underlined in the next Table.

| ***Agronomic or Biological Measures*** | ***Soil Management Strategies*** | ***Mechanical or Physical Methods*** |
|---|---|---|
| ***Mulching*** | ***Conservation Tillage*** | ***Terracing*** |
| | *Minimum tillage* | |
| ***Crop Management*** | *Improved fallows* | ***Contour Bunds*** |
| *Cover Crops* | *No-till* | |
| *Improved Fallows* | | ***Infiltration Galleries*** |
| *Intercropping* | ***Contour Tillage*** | |
| *Planting Pattern/Time* | | ***Waterways*** |
| *Crop rotation* | ***Strip farming*** | |
| | | ***Gully Controls*** |
| ***Agroforestry*** | | *Stabilisation structures* |
| | | *Stone check dam* |
| | | *Gabion baskets* |
| | | *Reno Mattresses* |
| | | *Stone lining* |

**Table 1 : On-farm Erosion Control Strategies**

## 2.1 Agronomic or Biological Measures

Agronomic or biological measures utilise the role of vegetation in helping to minimise erosion. Soil management is concerned with ways of preparing the soil to promote dense vegetation growth and improve its structure so that it is more resistant to erosion. When deciding what conservation measures to employ, preference is always given to agronomic treatment. These are usually less expensive and deal directly with reducing raindrop impact, increasing infiltration, reducing runoff volumes and decreasing water velocities. Agronomic measures include mulching, crop management and agroforestry. These measures use the effect of surface covers to reduce erosion by water and wind.

### 2.1.1 Mulching

Mulch is a layer of dissimilar material placed between the soil surface and the atmosphere. Different types of material such as residues from the previous crop, brought-in mulch including grass, perennial shrubs, farmyard manure, compost, by products of agro-based industries, or inorganic materials and synthetic products can be used for mulching.

Mulch's impact in reducing the splash effect of the rain, decreasing the velocity of runoff, and hence reducing the amount of soil loss has been demonstrated. Other reasons that reduce the amount of residues are bush fire or termites. The complete removal of crop residues from the field for use as animal fodder, firewood, or as construction material is another factor that makes this soil conservation technology less applicable. A possible solution might be mulching with brought-in organic material.

**Mulching (rice husk as mulch)**

In general, mulching is likely to be a useful erosion control technology in some parts of Rwanda as this method both reduces soil loss and enhances soil productivity and crop yields. Soils with shallow surface horizon, a high sand content and soils located in semi-arid areas will benefit from this technology as the water holding capacity will be improved. Hence, mulching should be integrated into the existing farming systems of smallholders.

### 2.1.2 Crop Management

Soil loss can also be prevented or reduced by appropriate crop management, which includes cover cropping, multiple cropping, and high density planting. Diverse crop management practices have various beneficial effects as erosion is reduced, the physical, chemical, and biological soil properties are improved, and crop production is increased. Additional advantages are a decreased risk of total crop failure and the suppression of weeds. As product diversification and higher crop yields help to ensure both subsistence and disposable income, polyculture (multiple crop types grown together) is of huge economic value for the farmers.

*Cover Crops*

Broadly defined, a cover crop is any annual, biennial, or perennial plant grown as a monoculture (one crop type grown together) or polyculture (multiple crop types grown together), to improve any number of conditions associated with sustainable agriculture. Cover crops are fundamental, sustainable tools used to manage soil fertility, soil quality, water, weeds (unwanted plants that limit crop production potential), pests (unwanted animals, usually insects, that limit crop production potential), diseases, and diversity and wildlife. Cover crops such as the legumes or the grasses are plants that grow rapidly and close. Their dense canopy prevents rain drops from detaching soil particles and this keeps soil loss to tolerable limits, so cover crops play an important role in soil conservation.

**Cover Crops**

Cover crops also positively influence physical soil properties such as the infiltration rate, moisture content, and bulk density. They increase the organic matter content, nitrogen (N) levels by the use of $N_2$-fixing legumes, the cation exchange capacity, and hence crop yields.

Farmers benefit from cultivating cover crops as soil loss is educed and physicochemical soil properties are improved. However, a problem can be the intensive growth of several cover crop species that might result in competition with food crops for growth factors. This problem can be combated by choosing compatible crops and by controlling the cover crop by timely cutting.

*Improved Fallows*

Improved fallows of short periods with selected tree or herbaceous species remain important as the long fallow periods that were part of the traditional shifting cultivation system for encouraging soil regeneration are possible. Hence, improved fallows have a high potential for soil conservation especially in farming systems without fertilizer input.

*Intercropping*


**Intercropping (Jatropha & onions)**

Intercropping systems including different kinds of annual crops planted in alternating rows also reduce soil erosion risk by providing better canopy cover than sole crops. The high amount of eroded sediment from the plots with the sole root and tuber crop is caused by its slow growth and small canopy cover at the beginning of the rainy season. Growing maize between the cassava ridges increases the soil coverage and hence reduces the impact of rain. Intercropping systems generally contributes to erosion control. The increased coverage of the soil surface and the enhanced stability of soil aggregate reduce the erosivity of the rain and the erodibility of the soil. As the productivity of soils cultivated with different crop species is also increased, this measure is likely to be adopted as a soil conservation technology.

*Planting Pattern/Time*

Planting pattern, plant density, and time of planting also play an important role in soil conservation. Crops planted at close spacing or at a certain time provide a higher canopy during periods with high rainfall intensities and hence protect the soil from erosion.

*Crop Rotation*

Crop rotation is the practice of growing a series of dissimilar types of crops in the same area in sequential seasons for various benefits such as to avoid the build up of pathogens and pests that often occurs when one species is continuously cropped. Crop rotation also seeks to balance the fertility demands of various crops to avoid excessive depletion of soil nutrients. A traditional component of crop rotation is the replenishment of nitrogen through the use of green manure in sequence with cereals and other crops. It is one component of polyculture. Crop rotation can also improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants.

### 2.1.3 Agroforestry

Agroforestry is a collective name for a land use system in which woody perennials are integrated with crops and/or animals on the same land management unit. Agroforestry is an integrated approach of using the interactive benefits from combining trees and shrubs with crops and/or livestock. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy and sustainable land-use systems. In agroforestry systems, trees or shrubs are intentionally used within agricultural systems, or non-timber forest products are cultured in forest settings.

Knowledge, careful selection of species and good management of trees and crops are needed to optimize the production and positive effects within the system and to minimize negative competitive effects. Agroforestry systems can be advantageous over conventional agricultural and forest production methods through increased productivity, economic benefits, social outcomes and the ecological goods and services. Biodiversity in agroforestry systems is typically higher than in conventional agricultural systems.

Agroforestry incorporates at least several plant species into a given land area and creates a more complex habitat that can support a wider variety of birds, insects, and other animals. Agroforestry also has the potential to help reduce climate change since trees take up and store carbon at a faster rate than crop plants. Alley cropping in radical terraces is a form of intercropping, and can be applied by farmers as a strategy to combat soil erosion, to increase the diversity of farmland, as a means for crop diversification and to derive other integrated benefits. In this practice, crops are planted in strips in the terraces between rows of trees and/or shrubs. The potential benefits of this design include the provision of shade, retention of soil moisture, and increase in the structural diversity of the site and wildlife habitat. The woody perennials in these systems can produce fruit, fuelwood, and fodder.

**Tree Nurseries**

The integration can be either in a spatial mixture or in a temporal sequence. Investigations on alley cropping where trees or shrubs are planted as contour hedges between strips of cropland are also common. The reduction of soil erosion by alley cropping obviously depends on the spacing between the hedges and the species.

2 to 4-m spacing is adequate for erosion control depending on species. The age of the perennials is also important as most species become effective sediment traps about two to three years after planting. One potential of agroforestry as an erosion control measure is its capacity to supply and maintain a good soil surface cover by the tree canopy and the pruning material. Another potential is the effect of a runoff barrier when trees are planted across the slope. As the intensive rooting by the woody perennials also improve the structure and infiltration rate of the soil, the amount of runoff and hence soil loss are reduced by alley cropping.

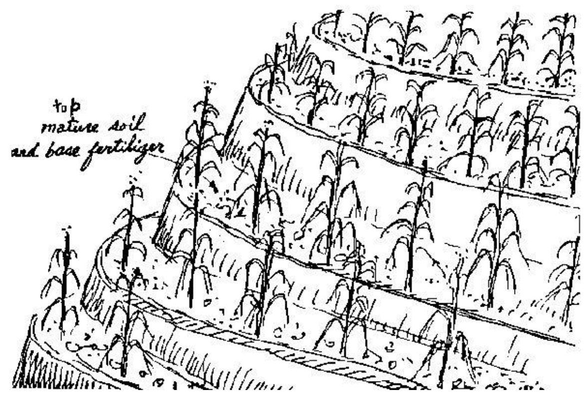
Tool and Guideline # 6 provides additional information on ago-forestry principles and methods.

## 2.2 Soil Management Strategies

### 2.2.1 Conservation Tillage

Conservation tillage describes the method of seedbed preparation that includes the presence of residue mulch and an increase in surface roughness as key criteria. The practices therefore range from reduced or no-till to more intensive tillage depending on several factors, such as climate, soil properties, crop characteristics, and socio-economic factors.

- Minimum Tillage: Minimum tillage describes a practice where soil preparation is reduced to the minimum necessary for crop production and where 15% to 25% of residues remain on the soil surface.
- No-Till: No-till or zero-tillage is characterized by the elimination of all mechanical seed bed preparation except for the opening of a narrow strip or hole in the ground for seed placement. The surface of the soil is covered by crop residue mulch or killed sod.

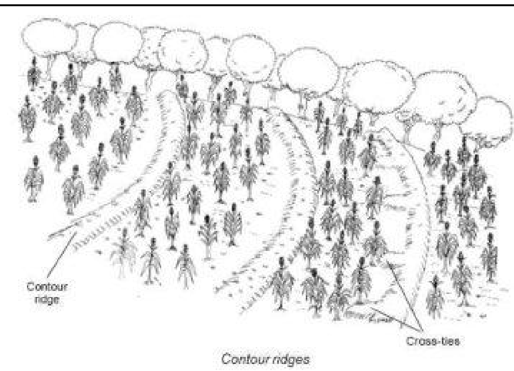


**Ditch and ridge tillage**

- Ridge Tillage and Ridge Tying: Ridge tillage is the practice of planting or seeding crops in rows on the top, along both sides or in the furrows between the ridges which are prepared at the beginning of every cropping season. Tied ridging or furrow diking includes the construction of additional cross-ties in the furrows between neighbouring contour ridges. This consists of covering the whole surface with closely spaced ridges in two directions so that the ground is formed into a series of rectangular depressions. The rainfall is held in place where it falls until it infiltrates into the soil. There will be no runoff and therefore no overland flow erosion. If the soil becomes saturated and the depression fill up and then overflow, the ridges will break. If they fail, the sudden release of runoff is likely to cause more serious damage.

### 2.2.2 Contour Tillage

Contour tillage is the farming practice of plowing across a slope following its elevation contour lines. The rows formed have the effect of slowing water runoff during rainstorms so that the soil is not washed away and allows the water to percolate into the soil. In contour plowing, the ruts made by the plough run perpendicular rather than parallel to slopes, generally resulting in furrows that curve around the land and are level. This can reduce soil loss from sloping land up to 50% compared with cultivated up-and-down the slope land. The effectiveness of contour farming varies with the slope steepness. Protection against more extreme storms is improved by supplementing contour farming with strip-cropping.



**Contour Tillage**

### 2.2.3 Strip farming

Strip farming is a method of farming used when a slope is too steep or too long, or when other types of farming may not prevent soil erosion. This is a method by which strips of row crops and closely growing crops, planted on the contour, are alternated. Erosion is largely limited to the row-crop strips and soil removed from these is trapped in the next strip down slope which is generally planted with a leguminous or grass crop.

The grass strips are about 2-4m wide and the cropped area about 15-45m wide depending on the slope. The size of strip will be determined by the number of passes one would make - meaning that the size of strip will be a function of the machinery to be used. The slope will also limit the strip size e.g., sloppy lands requires a smaller strip width, yet a rather flat land will necessitate a wider strip. The following equation can be used to determine the width of strip:

W = 51.2 - (2.1 x S), Where: W = strip width (m), S = slope (%).

For example; if the slope of an area is 8%, then the appropriate stripe width would be: 51.2 - (2.1 x 8) = 35.3 m. This works for slopes of between 3 -18%.

Strip farming helps to stop soil erosion by creating natural dams for water, helping to preserve the strength of the soil. Certain layers of plants will absorb minerals and water from the soil more effectively than others. When water reaches the weaker soil that lacks the minerals needed to make it stronger, it normally washes it away. When strips of soil are strong enough to slow down water from moving through them, the weaker soil can't wash away like it normally would. Because of this, farmland stays fertile much longer. Strip farming helps to prevent mass erosion by having the roots of crops hold onto the soil to prevent it from being washed away. The main disadvantage with strip cropping is the fragmentation of the land which limits the efficient use of machinery so it is not suitable for highly mechanised systems. Smallholding is better served with strip cropping.

## 2.3 Mechanical or Physical Methods

Mechanical or physical methods depend upon manipulating the surface topography, for example, by installing terraces to control the flow of water. Mechanical measures are largely ineffective on their own because they cannot prevent detachment of soil particles. Their main role is in supplementing agronomic measures, being used to control the flow of any excess water that arises.

In general, mechanical measures are effective soil conservation technologies as they reduce soil loss. But as the installation and maintenance is usually labour-intensive. Mechanical methods, including bunds, terraces, waterways, and structures such as vegetative barriers or stone lines installed on farm also can break the force of winds or decrease the velocity of runoff to reduce soil erosion.

### 2.3.1 Terracing

In agriculture, a terrace is a levelled section of a hill cultivated area, designed as a method of soil conservation to slow or prevent the rapid surface runoff of irrigation water. Often such land is formed into multiple terraces, giving a stepped appearance. This form of land use is prevalent in Rwanda, and is used for crops requiring a lot of water. Terraces are also easier for both mechanical and manual sowing and harvesting than a steep slope would be.

Arguments continue today about whether radical terracing, involving the physical movement of soil into contoured terraces, is best. Some argue that a more passive and slower option, vegetative contour bunds, is more effective and sustainable. Radical terraces tend to be fairly expensive to construct and are labour intensive.

Installation of radical terraces can increase the risks of landslides and the leaching of nutrients if these are not well constructed and maintained. Radical terraces are generally accepted as the ultimate intensity in physical management of soil runoff and water retention management. Radical terraces require deep and fertile soils to justify the amount of time required for construction. Crops may respond poorly for one or more growing seasons on sites where subsoil is excavated during construction. Radical terraces are generally graded backwards or "reverse slope" so that rainfall flows back toward the foot. Rooting depth and available soil moisture is increased, and when properly constructed, there is no net loss in planting surface area. Increased yields and increased growing provides a good solution for Rwanda in areas that may be converted.

**Radical Terraces**

Once they are built, soil fertility must be restored with the use of manure, lime and phosphorus if yields are to double or triple after some years. Since the risers are almost vertical, only 20 % of the land area cannot be cropped, although it can still produce forage. Terracing, especially radical terracing is generally not carried out as a large-scale operation on public lands. More often, the work is done by small farmers, assisted technically and financially by the government or projects.

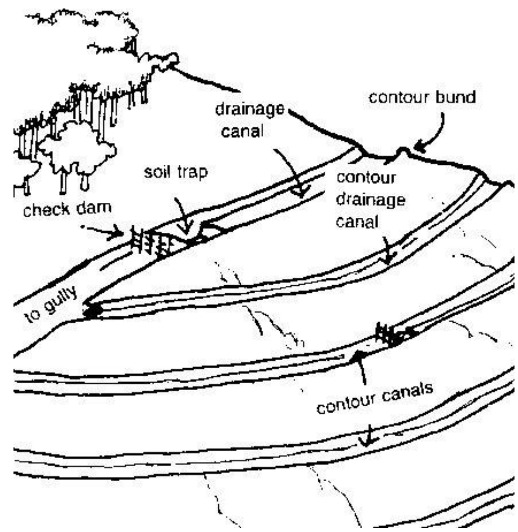
The argument most often heard against radical terracing is its cost, a conclusion often reached by multiplying the amount of soil to be cut and filled and the resulting work required per hectare by the official daily wage. The result usually shows a cost per hectare which no farmer can afford. However, the fact that farmers in Rwanda have constructed terraces for centuries shows clearly that when population density and intensity of cultivation reach certain thresholds, radical terraces are a workable solution.

Incentives to farmers may be necessary to accelerate the development of terraces. Furthermore, it is often found that cultivation on terraces is so intensive that a quarter of a hectare can generate full-time employment for one person. The construction of the terraces can be divided over several years. In order to "create" 0.25 ha of cultivable land, the upland farmer may work one month per year over four years, during periods of low agricultural activity.

Permanent structures of these kinds are effective soil conservation technologies as excessive soil loss and silting up of the fields are reduced. However, high labour intensity, time-consuming regular inspections, high consumption of scarce farmland, and the large amounts of construction material required are factors that stop farmers from installing or maintaining terraces.

### 2.3.2 Contour Bunds

Contour bunds made of earth or stones or terraces that consist of an excavated channel and a bank or ridge on the downhill side for cultivating crops are permanent erosion control technologies. The first are installed across slopes of low gradients, the latter at right angles to the steepest slope in hilly areas. Contour bunds are earth banks, 1.5 to 2 m wide, thrown across the slope to act as a barrier to runoff, to form a water storage area on their upslope side and to break up a slope into segments shorter in length than is required to generate overland flow. They are suitable for slopes of 2 to 15% are often used as permanent buffers in a strip-cropping system. The banks are spaced at 10 to 20m intervals and are normally hand constructed.



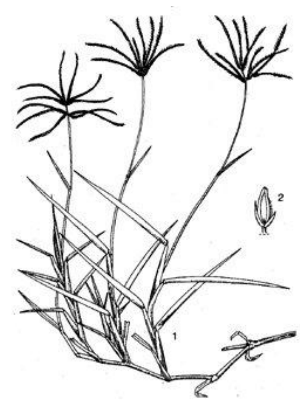

**Contour Bunds**

### 2.3.3 Infiltration Galleries

These trenches are mostly used in rocky and sloped areas where other measures cannot work. They reduce surface runoff.

### 2.3.4 Waterways

Waterways such as cut-off drainage are permanent structures that aim to collect and guide excess runoff to suitable disposal points. They are constructed along the slope, often covered with grass to prevent destruction, and primarily installed in areas with high rainfall rates. The purpose of waterways in a conservation system is to convey runoff at non-erosive velocity to a suitable disposal point. A waterway must therefore be carefully designed. The most satisfactory location of a waterway is in a well vegetated natural drainage line where the slopes, cross-sections, soil and vegetation have naturally developed to received and carry the runoff - it therefore needs only to be protected against deterioration. If there is no natural waterway, than an artificial waterway needs to be constructed.

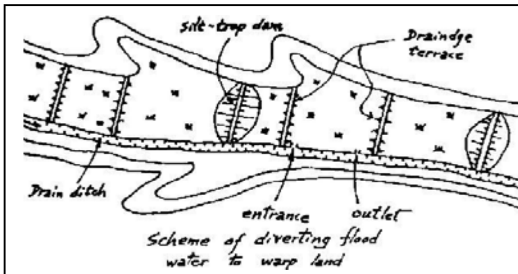


**African Star: excellent for waterways**

Artificial waterways are normally protected by grass (Paspalum spp, kikuyu, African star grass) and so are referred to grass waterways. Grass waterways are shallow and wide to obtain the maximum spread of water over a wide cross-section. A certain area of land has to be withdrawn from production and dedicated to the protection of the soil. Grassed waterways can be used in areas where there is sufficient moisture available to sustain a good grass cover. Where moisture is not sufficient and irrigation is not feasible, then the waterway may be paved with stone, masonry, concrete or some other durable material.

The cross-section of waterways depends on the slope, soil texture and the area to be drained. Waterways should have a parabolic cross-section and be covered densely with locally adapted grasses. The deepest cut should be between 0.5 and 1.0 m. Generally, grasses which spread by rhizomes are the best types for the purposes. Once a waterway is in place, it should always be crosses with raised implements; otherwise the vegetation will be destroyed. In the case of implements which cannot be raised, crossing lanes should be provided. Before the onset of the rains, the grass in the waterway must be cut, so that the flow of water can proceed smoothly without causing eddies. Fertilisers should be applied regularly according to the requirements of the grass stand.

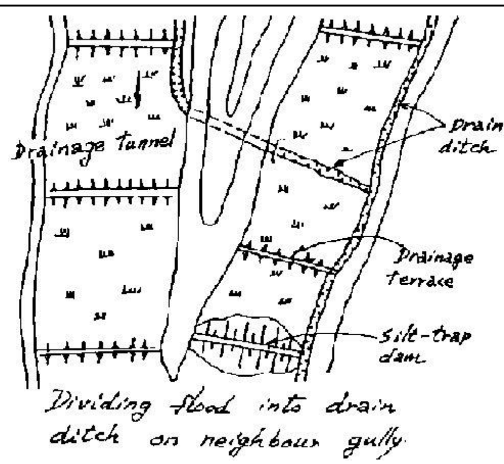
### 2.3.5 Gully Controls




**Gully Control**

Gullies usually develop because of an imbalance in runoff conditions, and are almost always due to man's activities. Gully control is therefore often an effort to restore a balance which need not have been destroyed in the first place.

In most cases, gullies can be prevented through good land husbandry - by maintaining infiltration capacity, vegetative cover, soil structure, etc. - and by simple measures to avoid concentration of excess runoff. These are also the measures which ensure good crop yields, growth of forest vegetation and fodder production. The prevention of gully formation is not a burden on the land user but a natural consequence of good land management.




**Gully Control**

Early interventions are far more economical than late ones. A small gully or rill can easily be repaired. But if the situation is allowed to deteriorate, the same gully may develop into something beyond economic recovery. In most cases, gully control is aimed at preventing further damage and loss of productive land rather than at reclaiming gullied land for agricultural use.

An eroded rill, on deepening and widening, becomes a gully. A gully is sufficient deep that it will not be obliterated by normal tillage operations, whereas a rill is of lesser depth and would be smoothed by ordinary tillage. Although there is loss of land due to gully erosion, often the eroded soil is relocated to the lower parts of the same catchment. Gully erosion is formed by many factors i.e. rainfall, vegetation cover, lithology, land form, and land use. Controlling gully erosion can be difficult. Proper diagnosis of the problem, steps taken to eliminate the causes, and the drastic changes in land use to stabilise the ecosystem is often required.

The benefit/cost ration of gully control must be carefully assessed. Some gully control measures are extremely expensive and resource-poor farmers cannot afford to invest. Furthermore, subsistence farmers, pre-occupied with food production for consumption, are not always concerned with the stewardship appeal for preserving the resources for future generations. This means that gully preventive or control measures must produce short-term benefits in terms of increased yield, more land available for cultivation, and reliable crop yields through improved soil-water use. Expensive measures of gully control and/or restoration are not always successful.

A sequence of steps recommended for restoring land degraded by severe gully erosion includes the inventory of land, vegetation, hydrology and drainage pattern, climate, and land use. It is also important to assess the capability and suitability of major landscape units and to evaluate various options and priorities them with due considerations to socio-economic factors.

The first step in controlling gully erosion is fencing of the gully head to protect it from grazing cattle and/or wild animals. Second, diversion ditches or waterways should be installed to divert the surface runoff away from the gully head. The waterways should be properly designed and laid out. The runoff should be properly disposed to avoid erosion. The land use and soil management in the watershed area feeding into the gully should be changed to soil-enhancing practices, i.e. planting cover crops and trees. Stabilising the eroding faces and bed of gully is an important step. Establishing vegetation at the gully bed to provide more biomass is an important factor in decreasing the sediment-carrying capacity of the gully runoff.

Engineering structures for gully erosion are however expensive to install and maintain. There are a wide range of engineering structures, i.e. diversion channels, gabions, and check dams.

*Stabilisation Structures*

Stabilisation structures play an important role in gully reclamation and gully erosion control. Small dams, usually 0.4 to 2.0 m in height, made from locally available materials such as earth, wooden planks, brushwood or loose rock, are build across gullies to trap sediments and thereby reduce channel depth and slope. These structures should be used in association with agronomic treatment of the surrounding land where grasses, trees and shrubs are planted. The dams have to be carefully designed.

*Stone Check Dam*

Construction of a stone check dam begins by sloping back the tops of the banks. A trench is then dug across the floor of the gully and into the banks into which the large rocks are placed to form the toe of the structure.

Rocks smaller than 100 mm in diameter should not be used because they will be quickly washed out. A dam made of large rocks will leave large voids in the structure through which water jets nay flow, weakening the dam. To avoid these effects, the dam should be made with a graded rock structure. An effective composition is 25% of rocks between 100 and 140 mm diameter, 20% between 150 and 190 mm, 25% between 200 and 300 mm, and 30% between 310 and 450 mm. A second trench should be made to mark the downstream end of the apron and filled with heavy rocks. A 100 mm thick layer of litter, such as leaves and straws is laid on the floor of the apron and covered with a solid pavement of rock. A thick layer of litter is also placed on the upstream face of the dam.

*Gabion Baskets*

Box gabions consist of rectangular units, fabricated from a double twist hexagonal mesh of soft annealed, heavy zinc coated wire. The wire quality and the zinc coating meet all international specifications. The mesh panels are reinforced at all edges with wires of a longer diameter than that used for manufacturing the mesh, to strengthen them and to facilitate construction. The double twist hexagonal mesh construction of the gabion permits it to tolerate differential settlement without fracture.

**Gabion Baskets**

A gabion basket is a heavy monolithic unit able to withstand earth thrust. It efficiency increases instead of deceasing with age since further consolidation takes place as silt and soil collect in the voids and vegetation establishes itself. There is little maintenance required for gabions. A minimum foundation preparation is required. The surface needs to be only reasonably flat. There is no costly drainage required, as gabions are permeable. Because gabion baskets permit the growth of vegetation and maintain the existing environment, they provide attractive and natural building blocks for decorative landscaping. They can also be used in gully control and reclamation structures.

*Reno Mattresses*

The Reno Mattress is a special form of gabion with a large plan area. It is fabricated from similar but smaller double-twist hexagonal mesh of that used to manufacture the gabions. The wire characteristics are the same. The diaphragms are spaced usually at 1.0 m, and a continuous panel of mesh forms the base, the side and the walls of the unit to obtain an open topped multi cell container. The same mesh is used for the base, diaphragms and the separate lid. All panel edges are salvaged with a wire of larger diameter than that used for the mesh, so as to strengthen the structure.

**Reno Mattresses**

The Reno Mattress is often referred to as "the African gabion". An outstanding advantage of the Reno Mattress is its flexibility. It’s double twist hexagonal mesh construction permits it to tolerate differential settlement without fracture. This property is especially important when a structure is on unstable ground. Reno Mattresses can be used to stabilise gully heads of less than 1 m deep. They can also be used to dissipate the kinetic energy below spillway walls to prevent erosion on the spillway.

*Stone Lining*

The first point to be considered in simple and easy measures of soil conservation is farming on the contour. Structures on the contour are simpler and cheaper than graded channel terraces as there is no need to set them out on a precise gradient. They should be more or less on the contour, but small errors are not as important as in the case of graded channel terraces. A general term for simple structures on the contour is "stop wash lines". The form of such line will depend on what materials are available. On stony ground, using the stones to build stone lines serves the dual purpose of clearing them from the filed as well as building the stop wash line. Where stones are not available, lines can be formed by piling up crop residues, perhaps with a few shovels of soil, and progressively built up later by adding weeds from hand hoeing. Stone lines can be used effectively to control sheet erosion as well as erosion along minor cattle tracks.

## 2.4 What Methods to Use?

The ultimate success of soil conservation schemes depend on how the nature of the erosion problem has been identified and on the suitability of the conservation measures selected to deal with the problem and relate to the agricultural or land-use system so that farmers and others are willing to implement them.

A sound land-use plan is important for soil conservation, whereby the land is used for what it is best suited under present or proposed economical and social conditions, land tenure arrangements and production technology. By adopting the land capability classification as the methodology for land-use planning, the distinction will be made between areas where erosion is likely to occur when the land is used in accordance with its capability and that which will arise from misuse of the land. Once the most appropriate land use has been determined, soil conservation is a matter of good management of the land. Erosion-control measures proposed must be relevant to the farming system.

# 3. TECHNICAL DESIGN

These sections provide technical specifications for the construction of radical terraces and gull controls, important soil and water conservation measures that are used in Rwanda. Many other conservation measures are also used. Some technical specification can be found in reference documents identified in Annex 1 for watershed survey and planning, slope treatment measures and practices, vegetative and soil treatment practices, landslide prevention measures and water harvesting.

## 3.1 Radical Terraces

### 3.1.1 Overview

Radical terraces are a series of level or virtually level strips running across the slope at vertical intervals, supported by steep banks or risers. The following are two main types of radical terraces:

- Irrigation or level radical terraces: These are used where crops, such as rice, need flood irrigation and impounding water.
- Upland radical terraces: These are used mostly for rain-fed crops or crops which only require irrigation during the dry season. They are generally sloped for drainage.

In humid regions, reverse sloped radical terrace types are used. In arid or semi-arid regions, outward-sloped radical terraces types are used.

The radical terraces are used to reduce runoff or its velocity and to minimize soil erosion, to conserve soil moisture and fertility and to facilitate modem cropping operations and to promote intensive land use and permanent agriculture on slopes and reduce shifting cultivation. Generally speaking, radical terraces are particularly suited for these macro conditions:

- Severe erosion hazards;
- Areas with small holdings and a dense population;
- Areas where there are food shortages or high unemployment rates;
- Areas where crops require flood irrigation.

For micro or site conditions, radical terracing is suitable in the following cases:

- Where there are relatively deep soils;
- On slopes not exceeding 25 degrees (47%);
- On sites which are not dissected by gullies and not too stony.

Radical terraces are much more cost-effective if there is potential for mechanization, irrigation and for growing high-value crops.

### 3.1.2 Design Specifications

These typical design specifications are common and can be uses in Rwanda:

- *Length*: The length of a terrace is limited by the size and shape of the field the degree of dissections and the permeability and erodibility of the soil. The longer the terraces, the more efficient they will be. But it should be borne in mind that long terraces cause accelerated runoff and greater erosion hazards. A maximum of 100 m in one draining direction is recommended for typical conditions in a humid tropical climate. The length can be slightly increased in arid and semi-arid regions.

- *Width*: The width of the bench (flat part) is determined by soil depth, crop requirements, and tools to be used for cultivation, the land owner's preferences and available resources. The wider the bench, the more cut and fill needed and hence the higher the cost. The optimum width for handmade and manual-cultivated terraces range from 2.5 to 5 m; for machine-built and tractor-cultivated terraces, the range is from 3.5 to 8 m.

- *Gradients*: Horizontal gradients range from 0.5 to 1% depending on the climate and soils. For example, in humid regions and on clay soils, 1% is safe for draining the runoff. In arid or semi-arid regions, the horizontal gradients should be less than 0.5%. The reverse grade for a reverse-sloped terrace is 5% while the outward grade for an outward-sloped terrace is 3%.

- *Slope limit*: if soil depths are adequate, hand-made terraces should be employed on 7 to 25 degree (12%-47%) slopes and machine-built terraces should be employed on 7 to 20 degree (12%-36%) slopes. If the soil depths are not adequate for radical terraces, hillside ditches or other types of rehabilitation measures should be used. Radical terraces are not recommended for slopes below 7 degrees. Broad-base terraces and other simple conservation measures should be used instead.

- *Risers and riser slopes*: Riser material can be either compacted earth-protected with grass, or rocks. In order to ensure easy maintenance, terrace riser height should not exceed 2 m, after allowing for settling, especially for earth risers. Riser slopes are calculated by the ratio of the horizontal distance to the vertical rise as follows:
    - Machine-built with earth material: 1:1
    - Hand-made with earth material: 0.75:1
    - Hand-made with rocks: 0.5:1

The step-by-step computations, using only simple mathematics, should present no difficulties to technical field experts.

### 3.1.3 Surveying

The simple equipment usually consists of Dumpy level or A-level, measuring tape, rod and soil auger. GPS and GIS tools may also be used to design terraces. The basic techniques for level terraces are contouring or levelling techniques and graded-contouring techniques for upland radical terraces.

- *Setting of base-line*: An up-and-down base-line should be set at the site along a representative slope.

- *Use of centre-line method*: A quick calculation of the terrace location can be made in the field. Use a level to determine and stake the terrace location base line. This should be followed by graded contouring or levelling surveys according to the type of terrace to be built. After staking out all the contours or graded contours, add one line of marked stakes in between them. This line serves as the bottom line of the upper terrace and the top line of the lower one. Continue adding stakes so as to cover the whole area. A top line should be added to the first terrace on the upward slope, and a bottom line to the last terrace on the downward slope. This method is recommended for hand-made terraces where centre-lines should be kept and observed as non-cut and non-fill lines.

- *Use of two-line method*: Design details can be readily obtained when a set of specification tables are available. The base line should be staked out with the width of the terrace (Wt), using a tape. A contour or graded contour line should be run from each stake until the whole area is covered. These lines serve as the bottom lines of the upper terraces as well as the top lines of the succeeding terraces. This method is recommended for terrace construction using mechanical or animal power, as any centre-lines will obstruct the construction operation and should be omitted.

### 3.1.4 Construction Methods

The cut and fill of the terraces should be done gradually and at an equal pace so that there is neither an excess nor a lack of soil. This principle applies regardless of what tools are used for the operation.

- *By manual labour*: The terrace must be built when the soil is neither too dry nor too wet. Start building the terrace from the top of a hill and proceed downwards. It will not be washed away in the case of heavy rain. However, when topsoil treatment or preservation is carried out, it is necessary to start building from the bottom of the hill upwards. In this case, temporary protection measures should be undertaken. Tie cord or rope around the stakes to mark each constructed terrace in sequence. The initial cut must be made immediately below the top stakes while the fill work should be started against the bottom stakes. This is done in order to ensure that the correct grade is attained without overcutting. Sometimes, rocks or earth can be placed along the bottom line of the stakes to serve as a foundation before filling. During the filling operation, the soil should be compacted firmly by a beater every 15 cm. If the layer of soil fill is thick, the compacting process becomes difficult. Terraces which go across existing depression areas should be built particularly strong. The edge of a terrace should be built a little higher than planned because of settling. The rate of settling may be as high as 10% of the depth of the fill. Both the reverse and horizontal grades should be checked by a level during construction work and corrections must be made promptly wherever necessary. The slope of the riser should be shaped to 0.75:1. Waterway shaping should be commenced only after the terraces are cut. Make sure all the terrace outlets are higher than the waterway bottom.

- *Construction using draught animals and tools*: Ploughs and Fresno Scrapers, pulled by oxen, horses or buffaloes, are used to build terraces. The Fresno Scrapers, however, cannot be used to build terraces less than 3 m wide. In addition, they are not suitable for use in soils which have many rocks exceeding 25 cm in diameter. In general, Fresno Scrapers should not be used when the soils are wet and sticky, and if the cut area of the terrace is very hard nor has a lot of grass, it must first be ploughed to allow the scraper to move the soil. To begin the operation, raise the handle of the scraper so that the rear of the floor is 10 cm higher than the cutting edge. This angle will enable the scraper to cut into the soil more easily. After the bucket is loaded, the handle should be lowered to let the scraper slide flat on its bottom to the fill area in order to dump the dirt. Always begin loading the scraper at the high point of the cutting area. As soon as it is filled, turn the animal and dump the soil parallel to the lower line of the stakes. Never load the Fresno beyond the pulling capacity of the draft animal. When dumping dirt from the scraper, the handle should be raised to a vertical position so that the scraper rides on the runners and the dirt slides forward out of the bucket. A more efficient operation can be achieved if the cutting and filling are done by following a eight pattern in which the animal is turning continuously, without stopping.

**Fresno Scraper**

- *Topsoil treatment or preservation*: Radical terraces usually expose the infertile subsoil and this can result in lower production unless some prevention or improvement measures are undertaken. One such measure is topsoil treatment or preservation. When fertile topsoil exists, topsoil treatment is always worthwhile. Two alternative methods follow:
    - The terraces should be built from the bottom of the slope upwards. After the bottom terrace is roughly cut, the topsoil from the slope above is then pulled down to the bench and spread on top of it. Repeat this procedure for the next terrace up the slope and proceed uphill in this way until the top terrace is built. The top terrace will not have topsoil unless it is obtained from another place.
    - The second method is to push the topsoil off horizontally to-the next section before cutting the terrace. The topsoil should be pushed back when the cutting is completed. For hand-made terraces, the topsoil can be piled along the centre line provided that the bench is wide enough.

### 3.1.5 Physical Output

- *By manual labour*: Generally-speaking, a man can cut and fill 3 to 4 cubic m of earth in eight hours of supervised work, although output may vary depending on the type of soil and if rocks are present. If a terrace is wider than 4 m, output will be reduced because the transporting of the earth requires extra time. A team of 3 men for narrow terraces and 4 men for wider terraces is recommended for efficient terracing work. In the case of wider terraces, two men should be employed for cutting, the third for compacting and consolidating the risers, and the fourth for transporting the dirt.

- *Using draught animals and tools*: On terraces exceeding a width of 3.5 m, an animal with a plough and a Fresno Scraper can complete 12 to 16 cubic m of dirt moving in an 8-hour period.

### 3.1.6 Protection and Maintenance

New terraces should be protected at their risers and outlets and should be carefully maintained, especially during the first two years.

After cutting a terrace, its riser should be shaped and planted with grass as soon as possible. Rhizome-type grasses are better than those of the tall or bunch-type. Although tall grasses may produce considerable forage for cattle, they require frequent cutting and attention. The rhizome-type of local grass has proved very successful in protecting risers. Stones, when available, can also be used to protect and support the risers. An additional protection method is hydro-seeding.

The outlet for drainage-type terraces is the point where the runoff leaves the terrace and goes into the waterway. Its gradient is usually steep and should be protected by sods of earth. A piece of rock, a brick, or a cement block, is sometimes needed to check the water flow on steeper channels. Similar checks on water flow are required for level radical terraces where the water falls from the higher terraces onto those below. A piece of rock should be placed on the lower terrace to dissipate the energy of the following water. Grasses should also be established on the area of the bench crossed by the waterway.

Radical terraces require regular care and maintenance. If a small break is neglected, large-scale damage will result. Following is a list of maintenance work that should be carried out after heavy storms and cropping, especially in the first two to three years period.

The toe drains should be always open and properly graded; water must not be allowed to accumulate in any part of the terrace. All runoff should be allowed to collect at the toe drains for safe disposal to the protected waterway. Obstacles such as continuous mounds or beds must be removed at regular intervals to allow water to pass to the toe drain. Grasses and weeds should be removed from the benches. Correct gradients should be maintained and reshaped immediately after crops are harvested. Ploughing must be carried out with care so as not to destroy the toe drains and the grade.

Keep grasses growing well on the risers. Weeds and vines which threaten the survival of the grasses should be cut back or uprooted. Grasses should not be allowed to grow too high. Any small break or fall from the riser must be repaired immediately. Cattle should not be allowed to trample on the risers or eat the grass. Runoff should not be allowed to flow over the risers on reverse-sloped terraces.

Deep ploughing, ripping or sub-soiling is needed to improve the structure of the soils on the cut part of the radical terraces. Green manuring, compost or sludge is needed in the initial period in order to increase soil fertility. Soil productivity should be maintained by means of proper crop rotation and the use of fertilizers.

## 3.2 Gully Controls

### 3.2.1 Overview

Generally, gullies are formed by an increase in surface runoff. Therefore, minimizing surface runoff is essential in gully control. Watersheds deteriorate because of man's misuse of the land, short intensive rainstorms, and prolonged rains of moderate intensity. These precipitation factors also turn into high runoff which causes flooding and forms gullies. In gully control, the following three methods must be applied according to the order given:

(1) Improvement of gully catchments to reduce and regulate the runoff rates (peak flows);
(2) Diversion of surface water above the gully area;
(3) Stabilization of gullies by structural measures and accompanying re-vegetation.

When the first and/or second methods are applied in some regions with temperate climates, small or incipient gullies may be stabilized without having to use the third method. In some areas all three methods must be carried out for successful gully control.

### 3.2.2 Factors Affecting Gully Formation

The factors affecting gully formation can be categorized into two groups, man-made factors, and physical factors.

*Man-made factors*

- Improper land use: In Rwanda, rapidly-increasing population usually migrate upland to occupy forests or rangeland. Most migrants cut trees, burn litter and grasses, and cultivate hillsides without using conservation measures. After a few years, the productivity of the soil is lost because of sheet, rill and gully erosion, and the land is abandoned. This kind of cultivation, (slash and burn or shifting cultivation) is repeated by farmers on other hillsides until the land loses its productivity there as well. Thus, the whole of an area may be completely destroyed by gullying as the gully heads advance to the upper ends of the watershed.

- Forest and grass fires: Many forest fires are caused by the uncontrolled burning used in shifting cultivation. These fires can easily spread into the forest and destroy the undergrowth and litter. Grass fires are usually ignited by farmers near the end of the dry season in order to obtain young shoots for their livestock or new land for cultivation. On slopes, the soil that is exposed after forest and grass fires is usually, gullied during the first rainy season.

- Overgrazing: Overgrazing removes too much of the soil's protective vegetal cover and trampling compacts the soil; thus the infiltration capacity of the land is reduced. The increased runoff, caused by the insufficient water holding capacity of the soil, produces new gullies or enlarges old ones.

- Road construction: If road cuts and fill slopes are not re-vegetated during or immediately following road construction, gullies may form on both sides of the road. Inadequate drainage systems for roads (small number of culverts, insufficient capacity of road ditches, etc.) are a major cause of gullying. Widening operations along roadsides do not often follow road construction but, where widening is practiced, the operation usually causes landslide erosion and then gullying during the first rainy season.

- Livestock and vehicle trails: Gullies are also formed on livestock and vehicle trails that run along hillsides. This is because the traffic on roads compact the soil and reduces the water holding capacity.

- Destructive tree harvesting: In forest regions, highland tree harvesting can causes gullying on forest land.

*Physical factors*

As mentioned before, gullies are formed by increased surface runoff which acts as a cutting agent. The main physical factors effecting the rate and amount of surface runoff are precipitation, topography, soil properties and vegetative cover.

Precipitation

- Monthly distribution of rainfall: The duration of wet and dry seasons cannot be deduced from total annual rainfall. The monthly distribution of rainfall is more significant than total annual rainfall because of its effects on the growth of vegetation, as well as the fact that it gives some indications about rainfall intensity. In humid regions with uniform distribution of rainfall, surface erosion, including gully formation, may not be a serious problem because vegetation grows throughout the year. However, in areas that does not have uniform rainfall; the vegetation (especially grass) dries up during the prolonged dry season. If the land is not properly used, or if forest or grass fires occur during the dry period, it cannot sufficiently hold rainwater and so the increased surface runoff in the rainy season produces large scale landslides and gullies.

- Rainfall intensity and runoff: There is a relationship between rainfall intensity, rate of runoff, density of vegetative cover, and the size of a catchment area. This relationship is generally expressed in equations. The Rational Formula which is used in engineering designs for gully and torrent control is a good way to demonstrate this relationship. If the amount of rainfall is more than the holding capacity of the soil, there will be an increase in surface runoff, followed by surface erosion and gullying. In Rwanda prolonged rains of moderate intensity or short intensive rain storms lasting from 15 to 90 minutes (maximum rainfall intensity about 3mm/minute), cause landslides, gullies and floods because of the increased runoff in the watersheds. Torrential floods, which generally occur after the short, intensive rain storms, destroy agricultural lands, residential areas, roads, irrigation ditches and canals at the base of the valley below a deteriorated watershed. Rainfall intensity and runoff rates (peak flows) are expressed in millilitres per hour or minute and cubic meters per second, respectively. In designing engineering measures such as check dams or diversions in gully and torrent control, the rate of runoff is more important than the amount of runoff.

Topography
The size and shape of a drainage area, as well as the length and gradient of its slopes have an effect on the runoff rate and amount of surface water. Therefore, all topographic characteristics should be studied in detail before gully control work begins.

- (a) Shape of catchment : The long catchment's gathering time (time of concentration) will be longer, its corresponding intensity lower, and its maximum runoff rate (Q max, cubic m/second) less. This explains why, if all other factors are equal, long narrow catchments have fewer flash floods than square or round catchments.
- (b) Size of catchment: The larger the catchment, the greater the amount of runoff. The catchment area of a gully can be measured easily and accurately by using a 1/10 000 scaled map. If it is not available, a map can be prepared after surveying the catchment area of the gullies and torrents with a theodolite or transit. Mapping continuous gullies or gully networks can also be undertaken by surveying the closed traverses with a clinometer (0-90 degrees), hand compass (0-360 degrees) and 50 m measuring tape.
- (c) Length and gradient of the slope: On long slopes, there is generally an accumulation of water towards the base. To prevent the gully formation, this water (runoff) should be conducted safely downhill over a long distance to stable, natural water courses or vegetated outlets. Otherwise, the water should be infiltrated into the ground by land treatment measures such as contour ditches or terraces. The steeper the slope, the higher the velocity and erosive power of the runoff. Watershed land treatment measures not only reduce the amount of surface water, but they also decrease its velocity, and so it's erosive power.

Soil properties
The following seven soil classes are based on soil texture: sand, loamy sand, sandy loam, loam, silt, loam, clay loam and clay. The infiltration rate increases from clay to sand (for loamy sand 2.5-5 cm/hour), but resistance against erosion decreases.

Vegetative cover
The role of vegetative cover is to intercept rainfall, to keep the soil covered with litter, to maintain soil structure and pore space, and to create openings and cavities by root penetration. This is best achieved by an undisturbed forest cover. Under special conditions, however, a well-protected, dense grass cover may also provide the necessary protection. In general, it is management and protection rather than the type of the vegetative cover which determines its effectiveness in gully control. Any vegetation which is well-adapted to local conditions and which shows vigorous growth may be used. In some cases, these may be broadleaf species, in others conifers, tall grasses, etc. In critical areas, it may be necessary to exclude any use of the protecting vegetation. Whenever possible, however, it is desirable to establish a vegetative cover which serves a dual purpose, for example, provision of fodder, fuelwood, fruit, etc.

### 3.2.3 Development of Gullies

Sheet erosion, which is a uniform removal of soil in thin layers from sloping land, occurs where the velocity of surface runoff is about 0.3 to 0.6 meters per second. More commonly, however, the direct impact of raindrops on soil particles causes their detachment and gradual downhill movement - splash erosion.

Sheet erosion is barely detectable in the short term because it is a gradual process. However, over a long period, the consequent exposure of roots and subsoil can be easily observed. Rill erosion is the removal of soil that either form small, shallow channels or streamlets - neither is deeper than 30 cm. Because of its higher surface-flow velocities, rill erosion has a greater capacity than sheet erosion to remove and transport soil. Still, because they are small, rills can easily be eliminated by normal tilling or ploughing. Gullies are formed where many rills join and gain more than 30 cm depth.

The rate of gully erosion depends on the runoff-producing characteristics of the watershed: the drainage area; soil characteristics; the alignment, size and shape of the gully; and the gradient of the gully channel.

Gullies are very destructive and cannot be eliminated by tilling or ploughing because of their depth. A gully develops in three distinct stages; waterfall erosion; channel erosion along the gully bed; and landslide erosion on gully banks. Correct gully control measures must be determined according to these development stages.

- *Waterfall erosion*
  Waterfall erosion can also be broken down into three steps:
  (a) First Stage: First, sheet erosion develops into rills, and then the rills gain depth and reach the B-horizon of the soil.

  (b) Second Stage: The gully reaches the C-horizon and the weak parent material is removed. A gully head often develop where flowing water plunges from the upstream segment to the bottom of the gully.

  (c) Third stage: The falling water from the gully head starts carving a hollow at the bottom of the gully by direct action as well as by splashing. When the excavation has become too deep, the steep gully-head wall collapses. This process is repeated again and again, so that the gully head progresses backwards to the upper end of the watershed. This process is called gully-head advancement. As the gully head advances backwards and crosses lateral drainage ways caused by waterfall erosion, new gully branches develop. Branching of the gully may continue until a gully network or multiple-gully systems cover the entire watershed.

- *Channel erosion along gully beds*
  Channel erosion along a gully bed is a scouring away of the soil from the bottom and sides of the gully by flowing water. The length of the gully channel increases as waterfall erosion causes the gully head to advance backwards. At the same time, the gully becomes deeper and wider because of channel erosion. In some cases, a main gully channel may become as long as one kilometre.

- *Land-slide erosion on gully banks*
  Channel erosion along gully beds is the main cause of land slides on gully banks. During the rainy season, when the soil becomes saturated, and the gully banks are undermined and scoured by channel erosion, big soil blocks start sliding down the banks and are washed away through the gully channel.

The three stages of gully development (waterfall erosion, channel erosion along the gully bed, and landslides on gully banks) will continue unless the gully is stabilized by structural control measures and re-vegetation.

### 3.2.4 Classification of Gullies

Gullies are classified under several systems based on their different characteristics.

*Gully classes based on size*
One gully classification system is based on size - depth and drainage area. Table 1 describes small, medium and large gullies and is commonly used in manuals on erosion.

**Table 2 : Gully Classes Based on Size**

| *Gully classes* | *Gully depth* | *Gully drainage area* |
|---|---|---|
| | M | 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 |

*Gully classes based on shape*
This system classifies gullies according to the shape of their cross-sections.

(a) U-Shaped gullies are formed where both the topsoil and subsoil have the same resistance against erosion. Because the subsoil is eroded as easily as the topsoil nearly vertical walls are developed on each side of the gully.

(b) V-Shaped gullies develop where the subsoil has more resistance than topsoil against erosion. This is the most common gully form.

(c) Trapezoidal gullies can be formed where the gully bottom is made of more resistant material than the topsoil.

*Gully classes based on continuation*
(a) Continuous gullies consist of many branch gullies. A continuous gully has a main gully channel and many mature or immature branch gullies. A gully network (gully system) is made up of many continuous gullies. A multiple-gully system may be composed of several gully networks.

(b) Discontinuous gullies may develop on hillsides after landslides. They are also called independent gullies. At the beginning of its development, a discontinuous gully does not have a distinct junction with the main gully or stream channel. Flowing water in a discontinuous gully spreads over a nearly flat area. After some time, it reaches the main gully channel or stream. Independent gullies may be scattered between the branches of a continuous gully, or they may occupy a whole area without there being any continuous gullies.

### 3.2.5 Criteria for the Selection of Gully Control Measures

*Size of gully and its relationship to a torrent*:
In deteriorated mountain watersheds, each continuous gully in a gully network usually has a distinct catchment and a main gully channel, but it may or may not have a fan. The main gully channel of each continuous gully is about one kilometre long and its catchment area is not usually more than 20 hectares. In general, there is not any vegetative cover in a gully system. A torrent catchment usually comprises several gully systems; forest and rangelands destroyed or in good condition; hillside farming areas; low croplands; and urban areas (villages, towns). Therefore, the catchment area of a torrent may spread over more than 1 000 hectares and be 2 kilometres long. In order to control a torrent and avoid upstream floods, it is essential to stabilize all the gullies throughout the entire catchment area.

*Continuous gully as a basic treatment unit*:
Gully control is one of the most important restoration methods used in watershed management, and timing is an essential element. The field work in all structural and vegetative control measures selected should be completed during the dry and early rainy season. This is the most important aspect of gully control - especially in tropical and subtropical countries. Otherwise, the incomplete structural work can easily be destroyed during the first rainy season. In addition, vegetative measures such as the planting of tree, shrub and grass cuttings cannot begin until structural work is complete. Each continuous gully

in a gully system should be regarded as a basic treatment unit, and all the control measures in that unit should be finished before the rainy season.

*Selection of gully control measures*:
For a continuous gully, the main criteria for selecting structural control measures are based on the size of the gully catchment area, the gradient and the length of the gully channel. The various portions of the main gully channel and branch gullies are stabilized by brush fills; earth plugs; and brushwood, log, and loose-stone check dams. The lower parts are treated with loose-stone or boulder check dams. At a stable point in the lowest section of the main gully channel, for example, on a rock outcrop, a gabion check dam or cement masonry check dam should be constructed. If there is not a stable point, a counter-dam (gabion or cement masonry) must be constructed in front of the first check dam. The points where the other check dams will be constructed are determined according to the compensation gradient of the gully channel and the effective height of the check dams. The required structural measures for each portion of a main gully channel are shown in the last column of the table. In upstream watersheds with very steep slopes, the gradient of the main gully channel can easily reach 100 percent or even 125 percent. In using these standards, there is not much difference between the gullies located in mountain watersheds and those in rolling lands. In rolling lands, the highest gradient of a main gully channel may be 30-40 percent. In nearly-flat areas (agricultural and rangelands on foothills), this gradient is much less than 30-40 percent. The remaining criteria are the length of the main gully channel's portions (100 m or less and 900 m) and the catchment area of the gully portions (two ha or less and 2-20 ha). They are the same for gullies located on rolling land and in nearly-flat areas.

**Annex 1: References and Useful Resources**

- REMA (2009): Rwanda State of Environment and Outlook Report, Rwanda Environment Management Authority, P.O. Box 7436 Kigali, Rwanda http://www.rema.gov.rw/soe/
- The FAO Field Manuals are published within the FAO Conservation Guide Series as Conservation Guide W13 and consist of seven separate volumes. These Manuals will assist professionals with the planning and implementation of watershed management activities by providing practical information supported by examples from a wide variety of situations. However, the watershed situation in Rwanda is unique. These manuals will need to be adapted within the Rwanda context.

| ***FAO Field Manuals*** | ***Web site*** |
|---|---|
| Watershed Survey and Planning | http://www.fao.org/docrep/006/t0165e/t0165e00.htm |
| Slope Treatment Measures and Practices | http://www.fao.org/docrep/006/ad083e/ad083e00.HTM |
| Vegetative and Soil Treatment Practices | http://www.fao.org/docrep/006/ad081e/ad081e00.HTM |
| Landslide Prevention Measures | http://www.fao.org/docrep/006/s8390e/s8390e00.HTM |
| Gully Control | http://www.fao.org/docrep/006/ad082e/ad082e00.htm |
| Water Harvesting | http://www.fao.org/docrep/u3160e/u3160e00.HTM |

- FAO Soils Bulletins include several titles of particular interest to soil and water conservation, including No. 4, Guide to 60 Soil Water Conservation Practices; No. 13, Land Degradation; No. 30, Soil Conservation in Developing Countries; No. 33, Soil Conservation and Management in Developing Countries; No. 34, Assessing Soil Degradation; No. 44, Watershed Development with Special Reference to Soil and Water Conservation; No. 49, Application of Nitrogen-Fixing Systems in Soil Management; No. 50, Keeping the Land Alive: Soil Erosion, Its Causes and Cures; and No. 53, Improved Production Systems as an Alternative to Shifting Cultivation.
- FAO Web site: Intensifying Crop Production with Conservation Agriculture. http://www.fao.org/ag/ags/AGSe/General/Cont1.htm. A Web site with excellent publications and case studies, including:

    - FAO. Tillage Systems in the Tropics: Management Options and Sustainability Implications. FAO Soils Bulletin 71. http://www.fao.org/ag/ags/AGSe/7mo/furt1e.htm
    - FAO. Soil Tillage in Africa: Needs and Challenges. FAO Soils Bulletin 69. http://www.fao.org/ag/ags/AGSe/7mo/furt1d.htm
    - FAO. Tillage Systems for Soil and Water Conservation. FAO Soils Bulletin 54. http://www.fao.org/ag/ags/AGSe/7mo/furt1b.htm
    - Mulenga, N.C., et al. (1998). Conservation Tillage Technology in Africa. GCP/RAF/334/SWE (FARMESA) Programme. Harare, Zimbabwe. http://www.fao.org/ag/AGS/AGSE/agse_e/3ero/Farmesa/farmesa.htm

- FAO. (1997). Conservation Farming Handbook for Small Holders in Regions I and II. FAO Conservation Farming Unit. Zambia. http://www.fao.org/ag/AGS/AGSE/agse_e/3ero/Zambia/contents.htm

- CIDA, Environmental Handbook for Community Development Initiatives (2002), Second Edition of the *Handbook on Environmental Assessment of Non-Governmental Organizations and Institutions Programs and Projects (1997)* http://www.acdi-cida.gc.ca/acdi-cida/ACDI-CIDA.nsf/eng/JUD-47134825-NVT
- USAID, Environmental Guidelines for Small-Scale Activities in Africa: Environmentally Sound Design for Planning and Implementing Development Activities, U.S. Agency for International Development, Office of Sustainable Development, Draft Version, January 2005, www.encapafrica.org.
- Sustainable agriculture extension manual for Eastern and Southern Africa: (http://www.mamud.com/sustagafrica.htm)
- The UN Food and Agricultural Organization (FAO) Aquastat Web site: http://www.fao.org/nr/water/aquastat/main/index.stm
- UN Environment Program (UNEP) Programme on Success Stories in Land Degradation/ Desertification Control: http://www.unep.org/desertification/successstories/
- Revised Universal Soil Loss Equation project version 2: http://www.ars.usda.gov/research/publications/Publications.htm?seq_no_115=175643
- The African Conservation Tillage Network (http://www.act.org.zw/) is a network of practitioners who promote adoption of conservation tillage practices in Africa to assure a more sustainable use of soil resources, combat desertification, improve food security and alleviate rural poverty.