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A Field Guide on

Gully Prevention and Control

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1. Introduction

Soil erosion is one of the major problems confronting agriculture worldwide. It is a major threat to the soil resource, soil fertility, productivity, and, lastly to food and fiber production, mainly on farm and range lands. Although the problem is as old as settled agriculture, its extent and impact on human welfare and global environment are more now than ever before. A continuation of high soil erosion will eventually lead to a loss in crop production even though fertilizers and other inputs often result in increased yield in the short term. These problems are referred to as **on-site effects of erosion**. Soil erosion also leads to environmental pollution. Further downstream, erosion leads to flooding, sedimentation of water reservoirs and poor water quality. A decrease in soil quality invariably leads to a decrease in water quality, and often in air quality. These are **off-site effects of erosion**.

In Ethiopia, extensive areas of agricultural lands are eroded every year and most of these lands (cultivated and grazing) are changed in to gullies. Gully erosion is geographically a widespread problem and is the worst stage of soil erosion (plate 1). It is common in the semi-arid region, characterized by denuded landscape and flash floods. In the Ethiopian highlands, gullies are particularly severe and widespread covering large tracts of areas. Gully erosion is more difficult and expensive to control than sheet and rill erosion. It is also more spectacular than the other forms of erosion. Contrary to sheet and rill erosion, the damage done to land by gully erosion is permanent. Gully erosion also causes depreciation in land value by lowering the water table and depleting the available water reserves. Buildings and infrastructures are also undermined by rapidly advancing gullies.

Plate 1: An overview of sever gully grosion in Amhara region, Ethiopia

On the other hand, in a lot of places poorly managed footpaths and cattle trafficking lines have been transformed to sever gully areas.

Land degradation due to soil erosion, particularly gully erosion by water, is the main threat in the Amhara Region. This is manifested by the presence of a lot of gully affected area in all parts of the region. Fertile farming / cropping fields, grazing fields, foot slopes of degraded hillsides, foot trails and cattle trafficking lines have been significantly affected by gully erosion. Besides, side drains of tarmac and gravel roads, access and internal access roads, downstream areas from bridges, culverts and fords have also been seriously affected. In the Tana Beles Integrated Water Resources Development Project (TBIWRDP) area only, which is covering 85,026ha about 2% or 1370ha is affected by gully erosion. This has been verified by the Baseline Study carried out in 2010. By implication, it means that Amhara National Regional State with a total area of 157,077 km^2 (15% of the country) well over 300,000ha of its land is affected by gully erosion. This is disregarding other stages of erosion such as sheet, rill and stream bank erosion. The severity of gully affected area has also been well noted at national and regional levels.

As it is known by many, gully erosion is the worst form of erosion that apart from snatching fertile lands is the main source of sediment load arriving at reservoirs. The spread of gully is seen as a cancer affecting many communal grazing spots, foot paths, cattle trafficking lines, roads, etc. It also obstructs field operations and movement. The subsoil and gravel mined by erosion is a major threat on lower lying fertile agricultural fields by burying them under. A lot of farmers' fields are presently affected and complaining that their lands have been taken away by debris which they cannot remove. Many low-lying areas and public infrastructure facilities have been overburdened / overlaid by subsoil which is not fertile. The subsoil is composed of course sand, gravel, cobbles and boulders. Although there are many on-going efforts carryon by the various supporting projects and the regular government's land management program to rehabilitate gullies, the scale at which it is expanding has not been adequately coped up with the existing level of treatment.

In many places the quality of executed gully rehabilitation measures are found below the standard and often seen as runoff concentrations and further gully initiation and aggravation reasons. It should be well known that gully should be treated as a subset activity of the overall community watershed development approach. The catchment contributing to the gully formation should be attended which otherwise will be treating the symptom rather than the cause. Having known this basic principle, due to its severity, magnitude and the damage it is presently causing to many fertile lands the need of intensive and quality approach to its treatment has been identified. Therefore, intervening on focused training on gully mapping and its rehabilitation methods has been considered as a top priority.

Therefore, this Gully Prevention and Control Guideline is prepared to provide consolidated and detail information for field workers, Woreda experts and discusses the characterization and its different control options in delivering advices to farmers to prevent any gully formation and also cure existing ones. When gully rehabilitation is planned, it will be important to consider the priority areas, its purpose, the required amount and type of physical and biological structures to be used, which would have the potential to heal the gully are crucial elements that need to be considered during planning and implementation phases. It is in line with this that the preparation of the guideline has got prime attention and provided detail descriptions on how to rehabilitate gully affected areas and bring them under productive use.

In view of the aforementioned facts, this Gully Characterization and Gully Control Guideline is timely, with the objective to provide basic knowledge of gully formation, its characterization/mapping and practical approaches for its control in the context of overall watershed development and management. The manual will be useful to professionals working at regional, zonal and woreda levels including development agents in delivering their technical advice effectively and efficiently to farmers in order to reduce the problems associated with gully and promote application of effective gully rehabilitation measures. It will enable watershed managers in assessing gully erosion and guide them about the actual biophysical gully treatment measures. It also serves as a reference material to cascade down similar trainings to development agents and the land users at large. Therefore, readers of this guideline are advised to use the guideline as a learning tool and a practical guide, which could be further enriched through practical field experiences considering the specific situation of a given area.

2. Process of Soil Erosion and Gully Formation

Commonly speaking, soil erosion generally refers to detachment and transportation of soil and soil material from the place of origin by water, wind, ice or gravity and deposition to another place. Broadly, erosion can be classified in to two categories:

- Geological Erosion – natural erosion
- Accelerated Erosion – caused by mankind

Geological type of soil erosion is a natural phenomenon and happens without the intervention of human being. When the soil removal to that of soil formation is compared, it is not critical to consider geological erosion as that of accelerated erosion.

Accelerated (manmade) soil erosion is defined as the rapid removal of soil brought about by the intervention of man in the process of earning livelihood. When soil is bare of its natural protective vegetation because of human intervention, the soil is exposed directly to the abrasive action of the elements of erosion mainly wind and water of which erosion by water is a significant contributor for soil erosion and land degradation.

The process of water erosion starts with rainfall. Raindrops which do not touch plants will have the splash effect, defined as the impact of raindrops on the soil surface. Soil aggregates are smashed and their particles thrown in all directions. From the surface, water can infiltrate the soil through pores, as long as they are not saturated. Excess water moves as overland flow ("runoff") down slope and detaches additional soil particles. When runoff is evenly distributed, sheet erosion occurs. Water usually tends to concentrate along the lowest parts of a soil surface and forms small channels called rills. Overland flow that concentrates in channels leads to the formation of rills and gullies. Rills are usually small and can be easily removed by tillage. Rill erosion is much more easily noticed than inter rill erosion. If unchecked, rills may extend into the subsoil resulting in gully erosion. Another cause of gully erosion is an increase in flood flow, which may be caused by deterioration of vegetation in a catchment, and the concentration of flow in roads, footpaths, poorly maintained cutoff drains, waterways and cattle tracks, etc.

Erosion by water can occur as splash, sheet, rill, stream bank and gully erosion. This manual gives emphasis for gully rehabilitation but also a brief discussion is given for other types of erosion as follow:

a/ Raindrop erosion/splash erosion

When the raindrops strike the ground surface, the soil particles become loose and splashed due to its impact force. Momentary build up of the pressure gradients towards the edges of the drop disintegrates the soil and shoot some particles out. To produce significant erosion, the splashing must throw soil particles into a place where there is a water stream for transportation. The forces that influence splashing are: the raindrop mass and velocity, surface slope (gradient and aspect) and soil characteristics (hydraulic conductivity, moisture content, roughness, particle size, elasticity, and associated mass of the surface). The following are some basic principles to be considered in splash erosion:

- Soil splashing is resulting from the impact of water drops directly on soil particles.
- If a raindrop strikes a land covered with a thick blanket of vegetation, the drop breaks into a spray of clean water- it then slowly finds its way into soil pores. But if it strikes bare soil, considerable splashing occurs
- The falling drops break down soil aggregates and detach soil particles and the fine materials from the soil are removed, less fertile sands and gravels remain behind.
- The principal effect of splash erosion is to detach soil and transportation of the detached soil takes place then after.
- The number and size of drops and the velocity of drops determine the impact of raindrops per unit area. Large drops may increase the sediment carrying capacity and the velocity of raindrops, on the other hand, is affected by its size, height of fall, wind velocity and air resistance.
- It has been observed that a single raindrop may splash wet soil as much as 60cm high and 150cm from the spot where the raindrop hits.
- Continuous bombardment in a rainstorm by millions of raindrops causes damage by beating the bare soil into a flowing mud.

Factors affecting the direction and distance of soil splash are: presence of wind, land slope, Soil surface conditions (vegetative cover and mulches). Splash erosion is the worst form of water erosion as it gives a start for the other forms of erosion.

(b) Sheet Erosion

As water passes over a soil on gentle and smooth slope, it follows along a sheet of more or less uniform depth. Under such conditions, there occurs relatively uniform removal of soil from all parts of the area having a similar degree of slope. This moderately uniform removal of surface soil by the action of rainfall and runoff water is known as sheet erosion. More particles will naturally be washed from a bare soil than from those protected by vegetation.

Sheet erosion is the most damaging form of soil erosion by water. Many times it is difficult to recognize that any soil has disappeared but after this process has repeatedly occurred, much of the original surface soil is gone, exposing the subsoil which is not as good a medium for plat growth as was the surface soil. Shallow soils suffer greater reduction in productivity than deep soils. Areas where loose shallow top soil overlies light subsoil are most susceptible to sheet erosion.

The following signs are indicators of sheet erosion:

- Roots are exposed
- Stones are exposed
- Soils become more of gravel
- Deposits of eroded soils at bottom slops
- Sub soil becomes mixed with topsoil
- Crop yields fall gradually

(c) Rill Erosion

Rill erosion is the removal of soil by runoff water with the formation of shallow channels that can be smoothed out completely by normal cultivation. Rills develop as a result of concentration and flowing of runoff water along the slopes through small finger-like channels. The soil eroded from upland areas comes from these small channels, called rills, and from inter-rill areas between them.

The primary mechanism for soil detachment and transport from inter-rill areas is the energy resulting from raindrop impact while the primary for soil detachment for rill erosion is the distributed shear force on the rill channel boundary due to concentrated flow of runoff water.

During a rainfall event, flow is quickly concentrated in micro-rills, which in turn flows into larger rills and eventually discharge to an existing channel system. The concentration of flow in rills increases the erosive power of the flow resulting in increased soil detachment from the rill channel boundary. In general, rill erosion is incipient gully erosion.

(d) Stream Bank Erosion

Stream erosion is the scouring of soil material from the stream bed and cutting of the stream banks by the force of running water. Stream bank erosion is often increased by the removal of vegetation, overgrazing, or tillage near the banks. Scouring is influenced by the velocity and direction of the flow, depth and width of the stream, soil texture and alignment of the stream. Rivers and streams often meander and change their course by cutting one bank and depositing sand and silt loads on the other. The damage manifolds during flush floods.

(e) Gully Erosion

Gully erosion is the erosion process whereby water concentrates in narrow channels and over short periods removes the soil. Gully erosion produces channels larger than rills. As the volume of concentrated water increases and attains more velocity on slopes, it enlarges the rills into gullies. Gully can also originate from any depression such as cattle trails, footpaths, cart tracks, and traditional furrows and indicates neglect of land over long period of time.

Some gullies may be formed as a result of tunnel erosion, also known as piping. Tunnels develop particularly where the soil is highly sodic. Runoff water passes through cracks and macrospores (mole channels, termite holes, etc.) and on reaching the slowly permeable sodic subsoil, it moves laterally as sub-surface flow. Clay dispersions (as a result of high sodium content) may occur along the flow lines and lead to the formation of tunnels. Eventually, the roof of the tunnel may collapse and a gully is created.

The gully channels carry water during and immediately after rains and distinguished from rills, gullies cannot be obliterated by normal tillage. Thus, gully erosion is the advanced stage of rill erosion much as rill erosion is the advanced stage of sheet erosion. The Soil Conservation Society of America defines a gully as "a channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains: it may be dendritic or branching or it may be linear, rather long, narrow and of uniform width". On the other hand, in terms of stability criteria it can be classified as stable, meta-stable and unstable.

The rate of gully erosion depends primarily on the runoff producing characteristics of the watershed, soil characteristics, alignment, size and shape of the gully and the slope in the channel. The following stages of surface gully development are generally recognized:

Stage 1: Formation stage - In this stage the rill erosion scour of the top soil in the direction of general slope as the runoff water concentrates. This stage normally proceeds slowly where the top soil is fairly resistance to erosion.

Stage 2: Development stage – In this stage there occurs upstream movement of the gully head and enlargement of the gully in width and depth. The gully cuts to the C-horizon, and the parent material is also removed rapidly as water flows.

Stage 3: Healing stage – In this stage, vegetation starts growing in the gully.

Stage 4: Stabilization stage - In this stage, gully reaches a stable gradient, gully walls attain a stable slope and sufficient vegetation cover develops over the gully surface to anchor the soil and permit development of new topsoil.

3. Factors Affecting Gully Formation

Most of the gullies are formed due to human activities. Some of the major causes of gully formation are over grazing due to high cattle population, expansion of cultivation in steeper or marginal lands, cultivation without taking care of surplus runoff water, deforestation due to clearing of vegetation, unsatisfactory waterways and improper design of culverts and other structures. Generally a gully is caused by a rapid expansion of the surface drainage system in an unstable landscape. Gully erosion is affected by several factors. Some factors determine the potential hazard while others determine the intensity and rate of gully advance. The factors affecting gully erosion can be categorized in to two groups: man-made and physical factors.

3.1. Man-made factors

3.1.1. Improper land use

In developing countries, rapidly-increasing population usually migrate upland to occupy forests or rangeland. Most migrants cut trees, burn litter and grasses, and cultivate crops on hillsides without using appropriate 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 gulling as the gully heads advance to the upper ends of the watershed.

Often the land development works, like, construction of water storage structures, drains and bunds, are not done properly. Consequently failure of hydraulic structures or breaching of bunds occurs often resulting in sudden release of high volume of water. This results in the formation of gully particularly on steep lands.

3.1.2. 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.

3.1.3. Overgrazing/Free grazing

High cattle population and overgrazing constitute a major factor for gully formation in Ethiopia in general and Amhara region in particular. Uncontrolled overgrazing leads to denudation of vegetation and exposure of land to torrential rains. Overgrazing removes too much of the soil's protective vegetative cover and trampling compacts the soil; thus the infiltration capacity of the land is reduced. The increased run-off, caused by the insufficient water holding capacity of the soil, produces new gullies or enlarges old ones. Cattle grazing in and around active gullies extend the nick point and dimensions of the gullies. The fact that many gully affected lands are concentrated in the lower lying grazing fields is also adhered to the communal ownership of these lands.

Plate 2: Overgrazing Vs Land degradation

Box 1: Effect of overgrazing

"Free Grazing" stands for a traditional system, which allows livestock owners to indiscriminately have their livestock graze on the village land. There is no limitation on the number of livestock an individual household can own. When the crops are growing in the fields, they are off limit for livestock. However, after harvest time, all fields are accessible to all village livestock to feed on the crop residues. So, it follows, that during the cropping season, all livestock is confined to the scarce grazing land which during 5-6 months of the year is subject to immense grazing pressure.

The picture in the right (Kanat grazing land, South Gondar zone), shows the seriously damaged and heavily grazed area before treatment commenced. The left picture gives an indication of the livestock population. In August 2004 a livestock count has been conducted on 3 consecutive days. The average numbers are: Cattle: 580, Equine (horses, donkeys, mules): 220, sheep: 760. Official data suggest an overstocking factor of between 10 and 20 in the highlands. This means that there are between 10 and 20 times too many animals grazing on the land. The result: a) animals cannot get enough fodder to stay healthy and in a reasonable good condition and b) because of permanent grazing, the natural vegetation has no chance to recover at any time of the year. There is no reseeding effect, the most palatable grasses and legumes disappear, and bare patches develop giving room to accelerated soil erosion, eventually culminating in serious gully formation. This obviously is a very serious problem. In 2004, the Government had decided to reduce the "Free Grazing" areas by 30% in every village. However, so far guidelines are missing as to how to cope with the reduced fodder availability.

3.1.4. Road construction

Road construction through steep lands, without adequate provision for drainage systems, is a major cause of gully erosion. Inadequate drainage systems for roads (small number of culverts, insufficient capacity of road ditches, etc.) are a major cause of gulling. 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. 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. Although the road-caused erosion may occur anywhere in the world, the problem is particularly severe in developing countries due to neglect in maintenance and the lack of provision of safe outlets for excess runoff. Related to roads, poorly managed and abandoned quarry sites are also potential sites for runoff generation and its concentration flow to low lying farmlands and drainage ditches.

3.1.5. Trails and foot paths

Gullies are also formed on livestock and vehicle trails that run along hillsides. This is because the traffic on them compact the soil and reduces the water holding capacity. Sunken footpaths made up-and-down the slope become the focus of concentrated flow that eventually turns into gullies. This leads to the development of new foot paths that also turn in to gullies later on. Improper handling of footpaths and cattle trafficking lines and poorly designed and constructed roads further aggravate gully erosion. Unplanned land use can disturb the natural drainage ways.

3.2. Physical factors

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

3.2.1. Rainfall

Rainfall is obviously an important factor. For a given condition, there is direct relationship between the rainfall and runoff. Big storms can cause sever gullying. Intense rains coupled with soils prone to sealing and crusting, generate high runoff volume and concentrated flow. The force generated by the runoff flow causes gully erosion especially in semi-arid regions characterized by scanty vegetation cover.

3.2.2. Topography

The size and shape of a drainage area, as well as the length and gradient of its slopes have an effect on the run-off rate and amount of surface water. Therefore, all topographic characteristics should be studied in detail before gully control work begins. Experiments have shown that when the velocity of runoff is doubled, the amount material of a given size that can be scratched and carried is increased about 32 times: and the size of the particle that can be transported by pushing or rolling is increased about 64 times.

(a) Shape and size of watershed

The shape of the watershed has strong relationship with the time of concentration and peak runoff rate. If the time of concentration is high, pick runoff rate is low. In Figure 1 below, the two catchments have the same area, but have different shapes. Both have symmetrical drainage patterns, but the distance to the outlet in the long catchment is greater than in the short one. Therefore, the long catchment's gathering time (time of concentration) will be longer, its corresponding intensity lower, and its maximum run-off rate (Q max, cubic m/second) is less. This explains why; if all other factors are equal, long narrow catchments have fewer flash floods than square or round catchments.

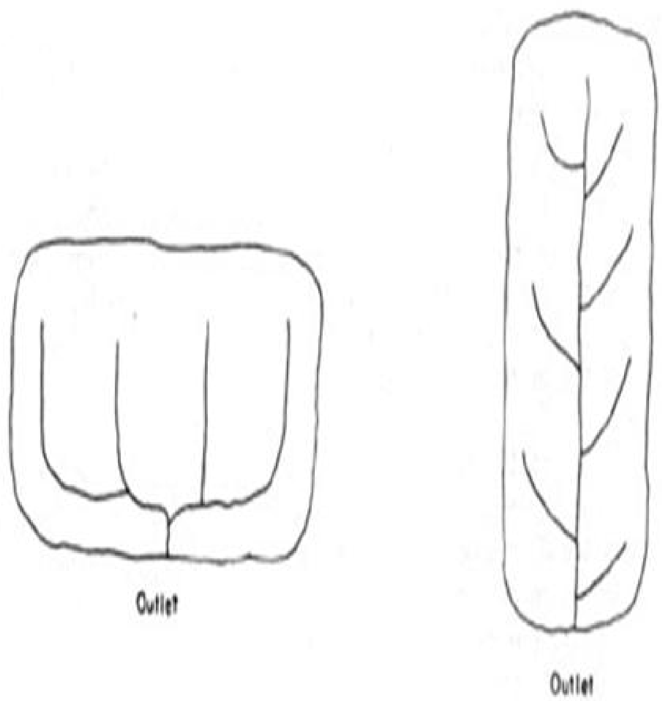


Figure 1: Different shapes of watersheds

The larger the watershed, the greater will be the amount of run-off. As a result large watersheds have greater chances of gully erosion than small watersheds.

(b) 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 (run-off) 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 different land treatment measures. The steeper the slope, the higher will be the velocity and erosive power of the run-off. This is one of the most important factors for gully erosion. Also, if the slop length is large, the possibility of gully formation is high. Soil and water conservation measures not only reduce the amount of surface water, but they also decrease its velocity, and so it's erosive power.

3.2.3. Soil properties

Some soils are more prone to gully erosion than others. A soil with a coarse textured highly permeable surface horizon with an abrupt transition to slowly permeable subsoil is normally prone to gully erosion. The vertisols with cracking properties are also highly susceptible to sever gullying. Compared to the upper catchment, gully is severing on bottom lying field with deep soil because this soil is transported recently. Transported soil has lost its cohesive property and individual grains are usually isolated, so prone to detaching forces.

3.2.4. 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 multistory forest cover. Under some 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. Whenever possible, however, it is desirable to establish a vegetative cover which serves a dual purpose, for example, provision of fodder, fuel wood, fruit, etc.

4. Occurrence, Development and Classification of Gullies

4.1. Occurrence of gullies

Gullies are more frequently found on bush and grasslands than on cultivated lands because rills on cultivated lands are removed by plowing and other recurrent cultivation measures. However, these rills continue to enlarge unhindered on grazing lands and forest areas. Nowadays, even in cultivated areas, the number and size of gullies are increasing due to several factors of which traditional ditches are the main ones. Gullies are mostly initiated during major storms. Once such gullies are formed, they tend to become further enlarged in subsequent years.

4.2. Development of gullies

It is difficult to achieve gully stabilization without a full understanding of the erosion processes or stages of gully development. Otherwise, it would be risky because expensive measures taken would be unnecessary or ineffective. Gullies are established by the deepening of rills and slumping of side slopes through the shearing effect of concentrated overland flow. Also, increase in pore-water pressure, and decrease in soil strength along seepage line close to the streams and rivers, and slumping due to excessive formation of tunnel or pipe flow can contribute to gully occurrence. Once gullies are established, they form permanent locations for concentrating the overland flow. Consequently, progressive deepening and widening of the gully continues until the gully has adjusted to a new set of equilibrium conditions.

After its initial incision, a gully usually extends backwards and sideways through the development of secondary gullies. Gully erosion is caused by head-ward advance, upstream migration of secondary nick points, widening of the gully channel by slumping and mass soil movement, and deepening by mobilizing or transporting sediments from the gully floor. Generally, 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.

4.2.1. Waterfall erosion /gully head advancement

First, sheet erosion develops into rills, and then the rills gain depth and reach the B-horizon of the soil to form gully. The gully reaches the C-horizon and the weak parent material is removed. A gully head often develops where flowing water plunges from the upstream segment to the bottom of the gully.

In the initial stages of development when the gully cuts through the arable soil profile, erosion rates are low. As the erosion reaches down into the subsoil, the rate increases greatly because the subsoil is generally prone to be more erodible. The water holding capacity of the subsoil is low as it is with less organic matter and poor aggregation. Consequently the topsoil profile is undermined. A waterfall is created. The eroding action of the waterfall and its splash deepens a round pit in to the subsoil, which acts as a plunge pool for the falling water (Figure 2). Due to successive undermining, the head of the gully moves up the slope or backward. This head-ward cutting does not stop until the erosion reaches solid bedrock or the top of the slope. 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.

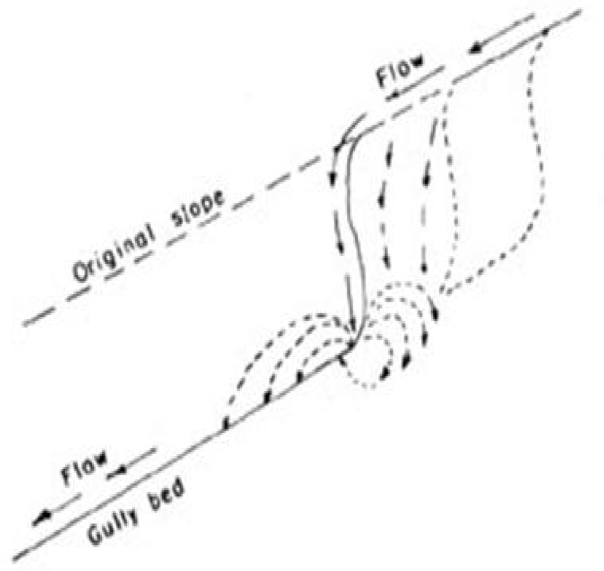


Figure 2: Water fall erosion at gully head

4.2.2. 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 deep as several meters. The deepening of the gully further downstream depends on the erosive capacity of the water flowing through the gully. Particularly, in the bottomlands as the soil in this land segment is a recently transported and piled up soil (i.e. not formed or developed in situ). In some places, farmers express that the soil in such areas is as soft as "liver".

4.2.3. Land-slide erosion on gully banks

Channel erosion along gully beds is the main cause of landslides 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.

Land-slide erosion on gully banks also occurs in regions with temperatures that alternate between freezing and thawing. When the temperature drops below zero (Celsius), wet gully banks freeze. After the temperature rises above zero, the banks thaw, the soil loosens, and the loose gully banks easily slide during the first rainy season. After landslides have occurred on all gully banks, a considerable number of new branch gullies may begin along the disturbed banks. During the third stage of gully development, gullies become deeper and longer as well as wider.

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 and or vegetative control measures.

4.3. Gully Classification

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

4.3.1. 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 as per the standards commonly used in many soil and water conservation manuals. Some literatures may put slightly different numbers.

Table 1: Gully Classes Based on Size

Gully classes	Gully depth (m)	Gully drainage area (ha)	Discharge (m^3/sec)
(a) Small gully	< 1.5	< 10	< 0.1
(b) Medium Gully	1.5 to 3	10 to 30	0.1 to 1
(c) Large gully	> 3	> 30	> 1

(Source: Thomas, 1997)

4.3.2. Gully classes based on shape

This system classifies gullies according to the shape of their cross-sections (Figure 3).

(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. These types of gullies are created in areas where the soil is cohesive with high clay content.

(b) V-Shaped gullies develop where the subsoil has more resistance than topsoil against erosion. This is the most common gully form particularly in sandier and less cohesive soils. In the long term, many U-shaped gullies become V-shaped as the sides continue slumping until a stable angle develops.

(c) Trapezoidal gullies can be formed where the gully bottom is made of more resistant material than the topsoil and sub soil because the erosion rate along the gully bank is greater than along the bottom.

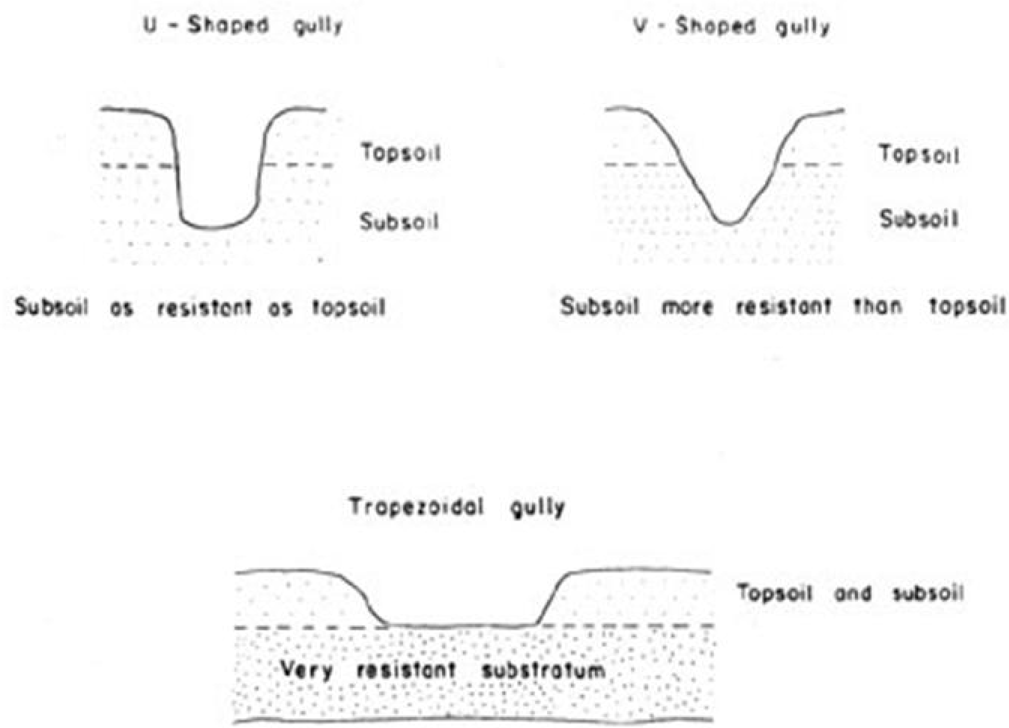


Figure 3: Gully classes based on shape of gully cross-section

(Source: Thomas, 1997)

4.3.3. 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.

4.4. Effects of Gully Formation

The existences of gullies in an area do have a multitude of influences on development endeavors. These effects can be summarized but not limited to the following;

- Loss of productive land (gullies often occur in the most productive area of a watershed)
- Dissection and fragmentation of plots causing access and management difficulties
- Reduced amenity and property values including destruction of farm facilities such as fences or roads
- Silting up of storage dams, ponds, waterways and irrigation canals, and even fertile agricultural fields. There are farmers who say "our land has been buried to a height/depth of bird scaring platform – "Mama" by debris originating from gullies.
- Local lowering of the water table (gullies suck water from springs, dug-wells and hand pumps, because by lying below they have an effect of negative pressure).
- Damage to infrastructures such as roads, bridges, culverts, buildings, altering transportation corridors and irrigation or water supply schemes
- Gully erosion dramatically affects sediment budgets and flux rates, and influences stream dynamics
- In the worst scenarios, gully erosion is directly linked to changing climatic conditions

5. Assessment and Mapping of Gullies

Development partners, farmers and conservationists are confronted with soil and water conservation tasks as one of their regular activities. An approach to soil and water conservation has to be differentiated and problem-oriented. In any soil and water conservation endeavor, particularly for gully rehabilitation schemes, it is always a paramount importance to undertake assessment of the existing scenario in the respective watersheds. For a specific area it is necessary to consider when, where and how to start the rehabilitation process. If the basics of the process that lead to erosion damage are understood, many clues about soil and water conservation are already given.

Assessment and mapping of gully erosion has multiple advantages, of which the following can be taken as the most important ones:

- helps to have an overview of erosion in a particular area/watershed
- helps to document the extent of damage/severity as a result of gully formation
- enables to identify the nature of a gully and causes of its formation
- gives relevant information to design appropriate measures for gully treatment

There are various methods used to quantify soil erosion. Commonly, erosion research is based on devices like test plots and gauging stations. These are time taking- and labor consuming and measurement normally takes several years. Quick prediction models like the Universal Soil Loss Equation (USLE) are useful, yet they give only long-term erosion rates. Gully erosion can also be mapped by undertaking spatial and temporal analysis using GIS and remote sensing tools. This also cannot be applied anywhere, particularly at field level.

The main aim here is to fill the existing gap and present an alternative method for rapid assessment of the gully situation at the farm/watershed level, and to indicate possible options for prevention and control. Towards this end, a one page assessment form (Table 2) which is manageable to be filled at watershed level can be used and later on the information can be analyzed for necessary recommendations.

Table 2: Assessment of gully erosion: A field form with example

Observer: B A Name of the area: 1 Gully size: Large Date:12/10/2010	1 Number of gullies	2 Av. Length (m)	3 Av. Width (m)	4 Av. Depth (m)	5 Field/ watershed size (m^2)	6 Gully Density (m/ m^2) Or ~~Km/km²~~	7 Soil loss M^3	8 Possible reasons for gully formation	9 Recommendation for rehabilitation
Land use type /site name/location name									
Grazing land	4	100	6	5	40,000	0.0025	12,000	Overgrazing	Check-dam construction
Cultivated land	2	50	3	4	15,000	0.003	1,200	Traditional furrow	Terracing and planting
Bush covered	1	100	5	5	50,000	0.002	2,500	Bush clearing	Area closure
Miscellaneous (footpaths, cattle trafficking lines…)	5	200	4	4	10,000	0.02	16,000	Improper design and lack of maintenance	Cutoff drains, proper alignment

Instructions to use table 2 :

1. The conservation measures to be chosen for gully control may vary as per the size of a gully. As a result the table should be filled separately for big, medium and small sized gullies.
2. The land use type is the name of the land use where the gully is observed. If a gully crosses several land use types, the name of the site or village can replace the land use type
3. **Column 1** is the total count of the gullies existing in a particular land use or location
4. **Column 2 , 3 and 4** are the average values of that size gully for each parameter indicated
5. **Column 5**, the estimated/calculated size of the runoff area for the existing gully
6. **Column 6** can be filled by dividing the total length of the gully existing in a particular location by the total area of that site/watershed
7. **Column 7** is calculated by multiplying columns 1, 2, 3, and 4 together. It shows the volume or mass of soil that has actually been moved from the gully area and possibly accumulated at other sites down slope. A soil and water conservation measure at the site of damage must be able to cope with such amounts.
8. It is always important to use appropriate units while doing various calculations in the table above.

Understanding the causes of gully erosion and considering it not only as a biophysical or natural problem, but as a problem of land use and the socioeconomic framework gives a less theoretical and more practice-oriented view. If one formulates recommendations based on this background, it is more likely that feasible compromise that also involves land users can be made. This kind of analysis will bring an understanding of the erosion process and thus enable to detect critical locations of erosion specific to the respective areas. In addition, the erosion topo-sequence which highlights the spatial arrangement and linkage of erosion features typical to a specific area can be derived. This helps to formulate plans, recommendations and arguments for soil and water conservation in a discussion with planners and decision makers, etc.

Box 2. Gully erosion assessment:

A gully near Debre-Taborabor, Amhara region have been assessed and the following hard facts were documented:
Total gully length, 1,150 meters. Average width: 6.5 meters (vertical walls) average depth: 3.5 meters. Total soil lost = 26 000 cubic meters, equivalent to about 3 700 lorry loads.

With a total of 131 check-dam structures constructed along the length of the gully which were filled with sediments already after 3 or 4 heavy rains, it was able to trap about 5 800 cubic meters of soil (828 lorry loads) which otherwise would have ended up in Lake Tana. The various grass and tree species planted into the gully bed filter out even more sediments.

While the figures above are quite impressive already, the real damage in terms of soil erosion comes from the sheet erosion and here predominately from cultivated land. Soil loss estimates in the highlands range from 20 to 400 tons per Hectare. Only 100 tons of soil loss per hectare translates into 10, 000 tons per 100 hectares or 1 430 lorry loads.

6. Principles of Gully Prevention and Control

As gully control can be an expensive undertaking, *prevention is always better than cure*. Gully formation is often a symptom of land misuse and can be prevented by good land husbandry. The engineer in charge of road construction should make sure that runoff does not damage the adjoining land. Planning of any infrastructural development should take into consideration the safe disposal of the runoff water. Sometimes, a gully will develop even though much care has been taken.

Generally, gullies are formed due to high run off volume and peak run off rate. Therefore, reducing surface run-off volume and peak runoff rate through improved land use system is essential in gully control. Watersheds deteriorate because of man's misuse of the land, short intensive rainstorms and prolonged rains of moderate to high intensity. These precipitation factors also turn into high run-off which causes flooding and forms gullies.

Retention of water on the watershed through mechanical and vegetative measures is useful for effective gully control program. It is advisable to retain as much runoff water as possible in the gully catchment through different moisture retention techniques. Proper management of the runoff water and increasing the vegetative cover of the watershed improves the watershed hydrology, improves the watershed conditions, increases infiltration, reduces overland flow, and enhances the gully healing process.

In gully control, the following three methods must be applied in order of priority:

(a) Improvement of gully catchments to reduce and regulate the run-off volume and peak rates;

(b) Diversion of runoff water upstream of the gully area;

(c) Stabilization of gullies by structural measures and accompanying re-vegetation.

In some areas, the first and/or second methods may be sufficient to stabilize small or incipient gullies. In some other areas which receive large rains, all three methods may have to be used for successful gully control. Runoff control is the first, foremost and effective way of gully control. If runoff entering into a gully can be controlled, then it is easily possible to grow vegetation in the gully.

Controlling gully erosion can be an elusive process. The rate of success in such schemes depends on the planning, design and techniques employed. The ultimate success depends up on the proper diagnosis of the problem, steps taken to eliminate the causes, and drastic changes in land use to stabilize the ecosystem.

The benefit-cost ratio of gully control must be carefully assessed. Some gully control measures are extremely expensive, and resource-poor farmers cannot afford to invest in them. This means that gully preventive or control measures must produce short-term benefits in terms of increased yield, availability of more land for cultivation, and reliable crop yield through improved soil-water use. Above all expensive measures of gully control and/or restoration have not been widely successful.

Exact gully control rules are difficult to establish because gullies are not similar: one gully is never exactly the same as another one, even in the same area. Therefore, good judgment and experience are essential in assessing and solving the problem. The treatment of gullies is an expensive operation and it would therefore be necessary to set priority for treatment because resources and finance is always limited.

7. Basic Gully Treatment Measures

7.1. Prevention of gully formation

The principle of "*prevention is better than Cure*" is highly relevant for gullies. Preventing the formation of a gully is much easier than controlling it once it has formed. If incipient gullies are not stabilized, they become longer, larger and deeper. Under certain climatic and geological conditions, vertical gully banks can easily become as high as 20-30 meters 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 (20-30m) gully banks after heavy rains and alternate freezing and thawing.

Prevention is also more economical than cure because structural measures are considerably more expensive than preventive measures. Even if the resource is available, the technique of its rehabilitation is more difficult and complex. Therefore, in gully control, emphasis should be given to the following practices:

(a) Proper land-management practices:

- Adoption of conservation effective, improved soil, water and crop management practices in a ridge to valley approach for all catchment contributing to the gully.
- Protection of the soil by good canopy during rains,
- Prevention of forest fires and illegal wood cutting in plantations and natural forests,
- Prevention of grass fires,
- Applying control grazing, and re-vegetation of open grazing lands,

- Maintenance of soil fertility through proper inputs, crop rotation and control of land degradation,
- The immediate stabilization of moderate sheet and rill erosion, and incipient gullies in forest, rangeland and cultivated areas.

(b) Retention and infiltration of surface water:

In addition to proper land-management practices, specific slope-treatment measures, such as retention and infiltration ditches, terraces, wattles, bundles and grass sods 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.

(c) Diversion of surface water above the gully

In many cases, the simplest, cheapest and safest gully control method is to divert runoff before it enters into the gully. This practice is particularly useful in forest land and grasslands. Diversions constructed above the gully area can direct run-off away from gully heads, and discharge it either into natural waterways or vegetated watercourses, or onto rock outcrops and stable areas which are not susceptible to erosion. Surface water must not be diverted over unprotected areas or it will cause new gullies. The basic aim of diversions is to reduce the surface water entering into the gully through gully heads and along gully edges, and to protect critical planted areas from being washed away.

Cutoff drains and waterways are drainage management structures which are commonly used to divert runoff before reaching gullies, cultivated lands and residences. They are effective measures for soil and water conservation in general and gully rehabilitation in particular. Though the experience of cutoff drain construction seems old enough, particularly in high rainfall areas, there are always problems in keeping the standard and technical specification during designing, layout and construction. As a result, most of the old cutoff drains and waterways are destroyed and gradually changed into gullies. As far as the failures in quality of construction are avoided, cutoff drains can be considered as potential options for gully prevention and control.

7.2. Gully control measures

Stabilization of gullies involves the use of appropriate structural and vegetative measures in the head, floor and sides of the gully. Once gullies have begun to form, however, they must be treated as soon as possible, to minimize further damage and restore stability. There are a multitude of physical and biological techniques which can be applied for effective gully treatment. The combination of the two measures (biophysical approach) is the best solution for effective gully control and for productive use of the gully area. The construction of gully physical structures will be followed by the establishment of biological measures. The natural regeneration which is coming after the gullies are protected and enclosed should also be considered in the overall rehabilitation scheme.

To obtain satisfactory results from physical and biological measures, it is vital to understand the nature of the whole gully system/network and properly diagnosing of the different parts in the gully section: the gully bed, gully sidewall and gully offset. Overall, 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. If this fails, the biophysical gully control measures which are executed with huge investment will fail as well. The rest of this section is dedicated to basic gully treatment measures. Some of the most common physical and biological measures which have been proven for their effectiveness are explained below:

7.2.1. Physical measures

In gully control, temporary physical structural measures such as gully reshaping, brushwood, sandbag, loose stone, gabion and arc-weir check-dams are used to dissipate the energy of runoff and to keep the stability of the gully. Check-dams are constructed across the gully bed to stop channel/bed erosion. By reducing the original gradient of the gully channel, check-dams diminish the velocity of water flow of runoff and the erosive power of runoff. Run-off during peak flow is conveyed safely by check-dams. 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. To give vegetation an opportunity to establish, runoff control structures may be needed in the gully. The structures can be either temporary or permanent. The choice of the measures and extent of their use will depend on the amount of the runoff and the status of the gully whether young and actively eroding or mature and establishing naturally. Good judgment is required in determining what measures to use and it would be a mistake to use expensive measures where more economical ones would do. Consideration should then be given to ways of stabilizing the gully head, floor and sidewalls.

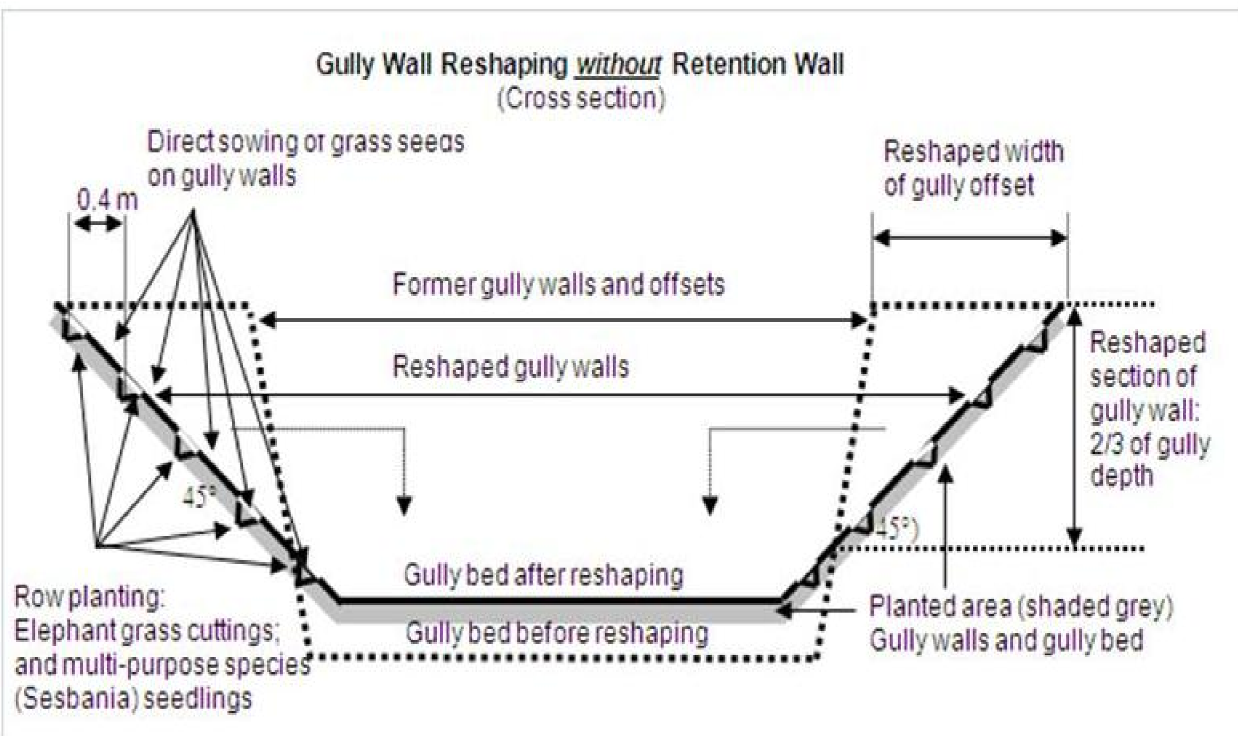
The gully head is often the most difficult to deal with, especially if it is more than about 2 m high because of the erosive power of falling water. Control structures for large gullies require an engineering design and are expensive. If the stabilization of gully head appears too costly or difficult, there are two approaches: One is to divert runoff away from the gully head so that it ceases to erode. The other is to place a check-dam close enough to the gully head so that it will trap sediment, raise the floor level and submerged the head. The use of stepped gabions, stone *rip-rap*, brushwood carpet, sandbag and planting grass sod are alternative measures which can be sued for gully head treatment. For stability of structures and quick healing the gully head should be reshaped and planted with grass sod.

Plate 3: Gully head control with sand bags and other vegetative measures.

(a) Gully reshaping and filling

Gully wall reshaping is cutting off steep slopes of active gully flanks in to gentle slope (Minimum at 45% slope), up to two-third of the total depth of the gully and constructing small trenches along contours for re-vegetating slanted part of the gully walls and beds. If the gully is wide and has meandering nature with huge accumulation of runoff flowing down, cut off soils and soil materials can be washed away by runoff water and requires constructing of retaining walls, to protect displaced (not yet stabilized) soils and soil materials and newly created sidewalls of the reshaped gully.

Gullies with very 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 one-to-one slope). Filling of gullies is applicable only for small discontinuous gullies, in their early stages of development. The filled gully area can be planted even be used for cultivation. Rills and incipient branch gullies may be filled in by spade, shovel or plow (on cultivated lands).



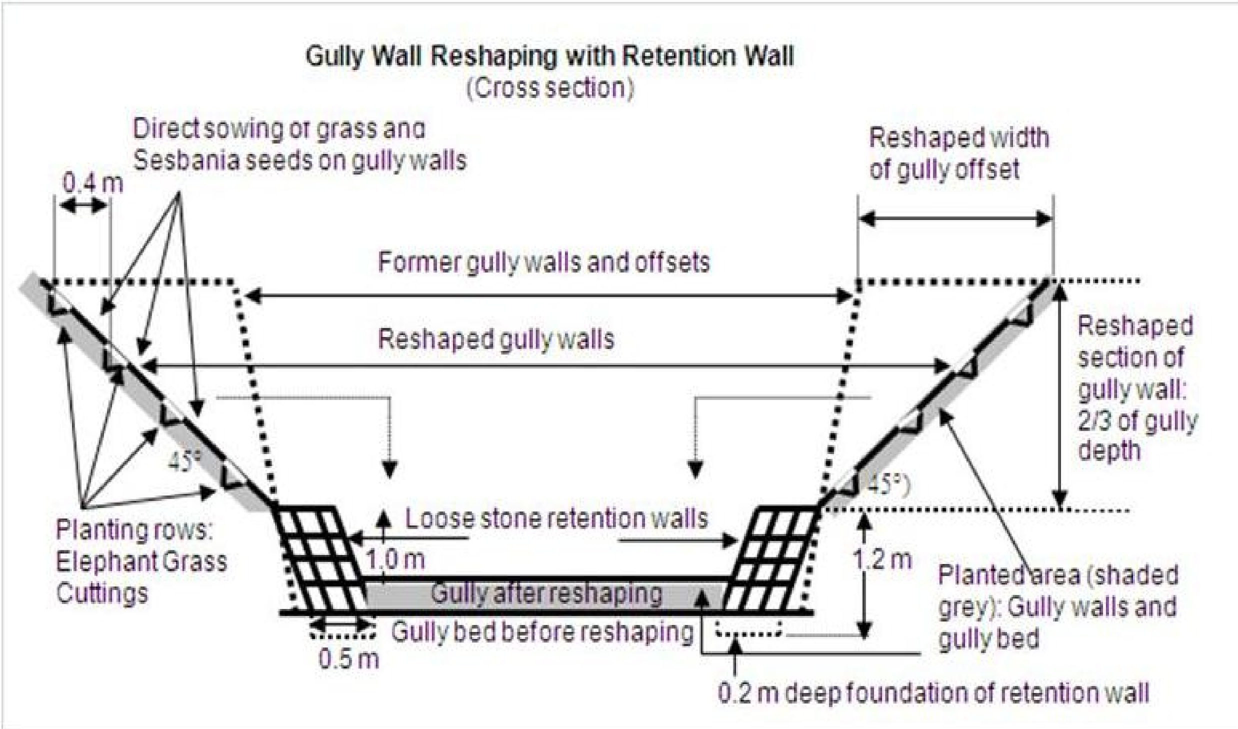


Figure 4: Designs and working procedures of gully reshaping

The practicability of shaping a gully depends on its size and the amount of fill needed to restore the gully to its desired shape. Steep gully sides can be reshaped. Topsoil should be stockpiled and re-spread over exposed areas to ensure the rapid establishment of vegetation. Annual grass and crops such teff, oats or barley can be used to provide a quick cover. It may be possible to temporarily divert water from the battered gully while grass is establishing.

Filling should only be attempted after the water flow that caused the gully has been controlled or diverted above the gully head. Otherwise fill placed in the gully is likely to be undermined and washed away. The common practice of filling gullies with rubbish, logs, rocks, branches, twigs and other materials does very little to solve the problem. In most cases, it makes the gully worse particularly if the placement and anchorage of those materials is not done properly. Generally, in the filling and shaping process the following need to be considered:

- The soil should be well compacted
- The filling operation should be done before the rains
- To protect it from erosion, close growing crops should be planted or seeded immediately
- The entire work of shaping and filling should be done in one operation

(b) Brushwood check-dams

Brushwood check-dams made of posts and brushes are placed across the gully (Figure 5). The main objective of brushwood check-dams is to hold fine material carried by flowing water in the gully. Small gully heads, no deeper than one meter, can also be stabilized by brushwood check-dams. Brushwood check-dams are temporary structures and should not be used to treat ongoing problems such as concentrated run-off from roads or cultivated fields. They can be employed in connection with land use changes such as reforestation or improved range management until vegetative and slope treatment measures become effective.

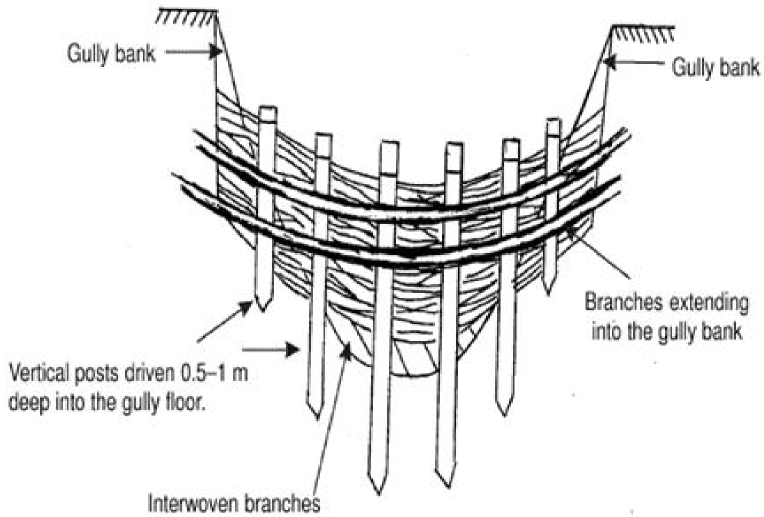


Figure 5: A single row brushwood check-dam, front view

In areas where the soil in the gully is deep enough, brushwood check-dams can be used if proper construction is assured. The gradient of the gully channel may vary from 5 to 12 percent, but the gully catchment area should not be as such huge which produces high amount of runoff volume. Similarly, in the gullies which are long enough and have high pick runoff rate, the utilization of brush wood check-dams is very limited.

There are two types of brushwood check-dams: these are single row and double row brush wood check-dams. The type chosen for a particular site depends on the amount and kind of brush available and on the rate and volume of runoff. Whatever sort is used, the spillway crest of the dam must be kept lower than the ends, allowing water to flow over the dam rather than around it. The maximum height of the dam is one meter from the ground (effective height). The spillway form is either concave or rectangular.

1. Single row brushwood check-dams:

These check-dams can be used where the flow of runoff is less than $0.5 m^3/sec$. The structure is temporary and its durability will depend on the quality of posts used. If possible live posts of willow, Popular and other should be used (8 – 10 cm in diameter). Flexible branches are cut and woven around the posts as shown in figure 5.

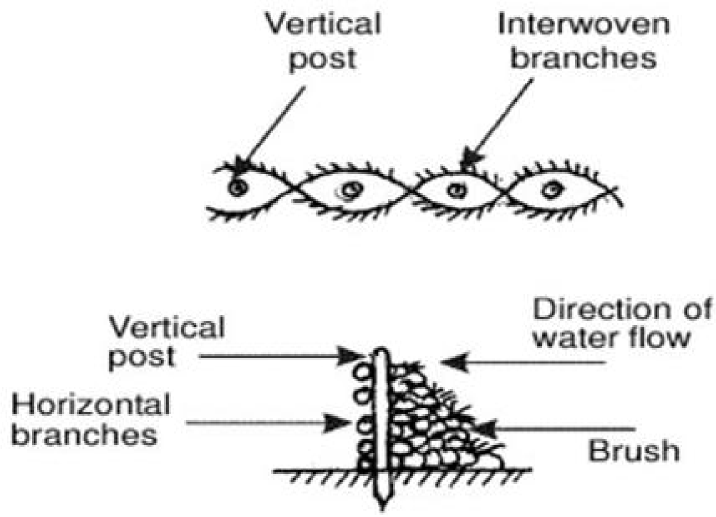


Figure 6: Vertical and side views of single row check-dam

Thicker branches are used as vertical posts driven in to the soil to about 50 cm – 100 cm (1/3 to half of the post length) depth and spaced about 30 to 50 cm apart. The posts will have a length of 1 – 2 m. The space between the posts will depend upon the height of the check-dam. The higher the dam, the closer will be the distance between the posts.

2. Double row brushwood check-dam

This type of brushwood check-dam is suited where the flow of runoff is less than $1 m^3/sec$. The construction of the dam starts with an excavation in the floor and into the sides of the gully to a depth of 0.3 – 0.5 m. Two rows of posts, 5 -10 cm in diameter and 1 - 2 m in length are placed into the holes, across the floor of the gully to a depth of 0.5 – 0.6 m. The spacing between the posts is 0.5 m. Brushwood or branches are packed between the posts. The height of the posts in the center should not exceed the height of the spillway otherwise the flow will be blocked and water may be forced to move to the gully sides.

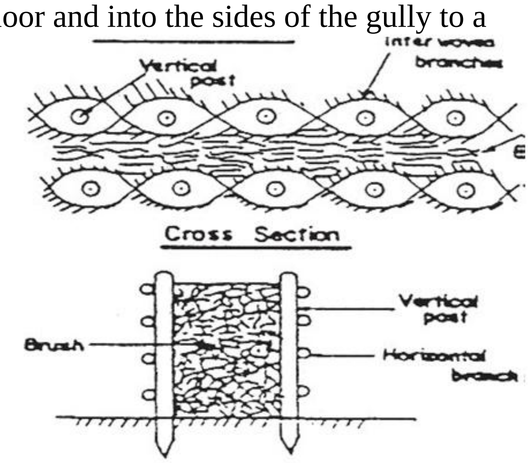


Figure 7: Double row brush wood check-dam

Other specifications for brushwood check-dams

- The choice for post brush check-dam must be made after careful examination of material availability in the near vicinity. Otherwise, problem of cutting all the scares vegetation in the area would bring in undesirable results
- Brush wood check-dams particularly single rowed ones can be strengthened with bamboo mat or sand filled bags on the upstream part to serve as a shock absorber and to dissipate the runoff energy during pick flows.
- Any tree or shrub species can be used as posts. But the wooden posts should be rot resistance and termite proof. The brushwood must not be very dry and easily breakable.
- To avoid the brushwood being removed by flowing water, it is necessary to fix the brushwood with rope, wire or nail.
- The flexible and long branches of trees (*popular, A. Angustisma*, …), flexible stems of shrubs (*mulberry, Sesbania, Saligna, Salix…)* and the strips made of bamboo, spanish reed, Elephant grass stems/canes may be used as interlink material. These materials are woven between wooden posts driven into the ground.
- The ends of interlink materials should enter at least 30 cm into the sides of the gully.
- The space behind the brushwood check-dams must be filled with soil to the spillway, if either sand bag or bamboo mat is not used.
- If sprouting species (Salix, poplar,…) are selected as posts and interlink materials, brushwood check-dams should be constructed when the soil in the gully is saturated or during the early rainy season.
- If non sprouting species are used as strips and interlink materials, brushwood check-dams can be constructed during any season.

(c) Loose stone check-dam

Loose stone check-dam is a structure made of relatively small rocks and placed across the gully or small stream, which reduces the velocity of runoff and prevents the deepening and widening of the gully (Figure 8). Sediments accumulated behind a check-dam could be planted with crops or trees/shrubs, grasses and thus provide additional income to the farmer. It is commonly used to check gullies on highly eroded grazing and cultivated lands and hillsides.

Stone check-dams are commonly used for gully treatment all over Ethiopia. Yet during implementation three common mistakes have been occurring:

- The base of the check-dam is often built to narrow and therefore the final structure will lack the recommended trapezoidal cross-section.
- The flanks or the anchorage into the sides of the gully are not cut in deep enough and when building up the check-dam larger stones on the outsides are not properly combined with smaller stones on the inside.
- Spill ways should be built having a parabolic/concave shape instead of the window-shape and the width of the apron needs to be at list 1.5 times the effective height of the spill way.

Check-dams could be constructed in a wide range of conditions: (1) small gullies serving large one, (2) as outlets for traditional or newly constructed bunds or terraces unable to accommodate all runoff and, (3) to trap silt before a water pond.

Design and construction specifications of loose stone check-dam:

- The foundation of the dam is dug so that the length of the foundation will be more than the length of the spillway.
- The width of the foundation depends up on the reservoir level height.
- The dam should be properly keyed across its base and up the abutments to the crest elevation.
- An adequate spillway should be provided for safe disposal of water.
- An apron of non erodible material should be provided at the base, to dissipate the energy of water falling through the spillway.
- Proper spacing between the successive dams should be ensured
- The height of the dam should be properly planned
- Stones should be placed such that they interlock easily and form a denser structure. If small stones are to be used they should be placed in the center and the outer surface covered with large stones to strengthen the dams.
- Loose stone check-dams can be strengthened by covering the upstream wall and the crest with bamboo/reed-mat.

- It is very much important to plug the scouring places with jut bag after every run off, until it is fully sedimented up to the reservoir level.

As per the above consideration, a loose stone check-dam should full fill the following minimum standards.

- Spacing estimated on the safe side S (spacing) $= \frac{H\ (m) \times 1.2}{\text{Gully bed slope (decimal}})$

  Where, H is the effective height from gully bed to the spillway
- Bottom key and foundation; 0.5 m deep
- Side key: 0.5 – 1 m per side
- Height: 1 – 1.5 m excluding the foundation, mostly 1 m is suffice to avoid failures
- Base width: 1 m – 3. 5 m
- Spill way (trapezoidal/parabolic): 0.25 – 0.5 m permissible depth and 0.25 m free board; and width 0.5 – 1.2 m.
- Apron length should be at least 1.5 times of the effective height of the check-dam and as wide as the gully bed.
- The apron should be placed in an excavation of about 0.3 – 0.5 m to ensure stability and prevent wash away. A sill of about 15 cm should be constructed on the lower end of the apron.

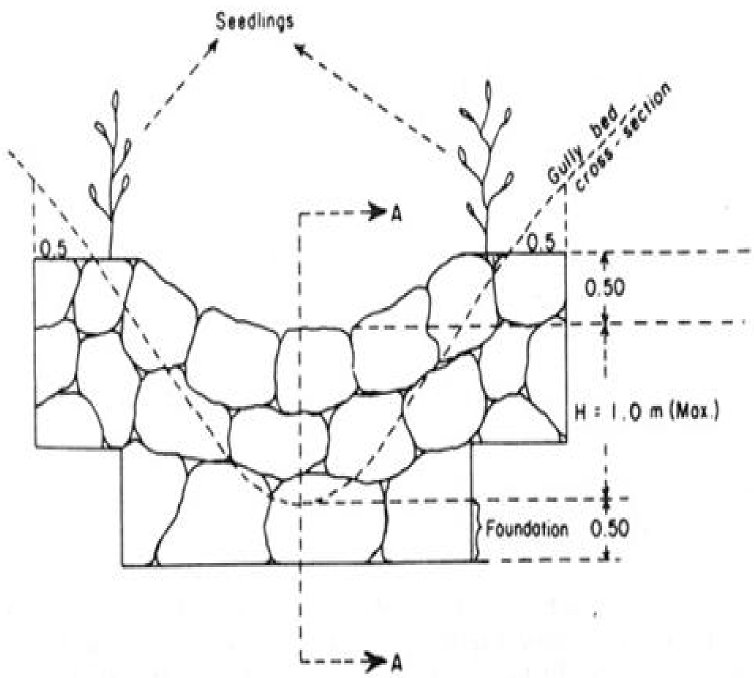


Figure 8: Front view of a loose stone check-dam

Site selection:

- The gully bed slope at the construction site must not be more than 5 %.
- The soil depth of the site should be more than 50 cm. It shouldn't be constructed on impervious layer foundation.
- Relatively wider locations of the gully are most appropriate for construction of loose stone check-dam.
- Cross-sections where the reservoir level requirement is not more than one meter is appropriate for loose stone check-dam
- Avoid locations where the gully is meandering/turning

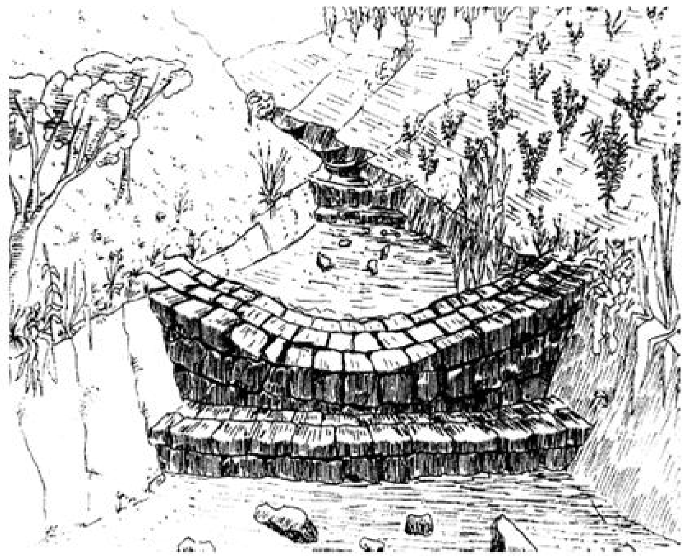


Figure 9: A typical loose stone check-dam

(d) Gabion check-dam

Gabions are rectangular boxes of varying sizes and are mostly made of galvanized steel wire woven into mesh. The boxes are tied together with wire and then field with either stone or soil material and placed as building blocks. Small stones can be used as the wire mesh will prevent them being washed away. If large stones are used, they must be placed carefully with small stones filling the spaces between them otherwise water may jet through the gabion and undermine the ground beneath. Gabions are filled in situ and as they are very heavy they will not be washed away provided they have been correctly installed.

The main advantages of gabions are that they are tough and long lasting provided that the wire has been well galvanized. Furthermore they are somewhat flexible and can be installed where the surface is uneven. They can be used to stabilize gully sides, gully heads, roadside embankments, river banks and even landslips. However they are expensive and should only be used if no other cheaper method will suffice. Installing gabions is no substitute for land misuse and, if the land is denuded, installing gabions will not solve the problem. However, in conjunction with measures to restore vegetative cover they can play a role.

Gabion check-dams can be undermined or bypassed round the side due to incorrect installation or unstable soils. Common problems are failure to embed the gabions to a sufficient depth in the floor of the gully and failure to insert to a sufficient distance in to the gully banks. Once in placed and properly anchored, gabion check-dam can resist even strong floods and last for a long time.

Gabion check-dams are built usually not higher than 1.5 m spillway height in the first year. After sediments have been deposited behind the structure, it is possible to raise the spillway height by adding additional gabion boxes. Nowadays, different sized gabions are available commercially in the country. The sizes of gabions and the amount of wire required for each size is explained in table 3 hereunder.

Table 3: Different sizes of gabions (Length x Width x Height) and wire requirement for each

No.	**Gabion Size**	**2.5 mm wire (kg)**	**3.5 mm wire (kg)**	**Tying wire (kg)**	**Share of each size during construction (%)**
1.	2 x 1 x 1 m	12.0	2.3	0.6	60
2.	2 x 1 x 0.5 m	8.5	1.7	0.5	20
3.	1 x 1 x 1 m	7.0	1.5	0.4	15
4.	1 x 1 x 0.5 m	3.4	0.9	0.3	5

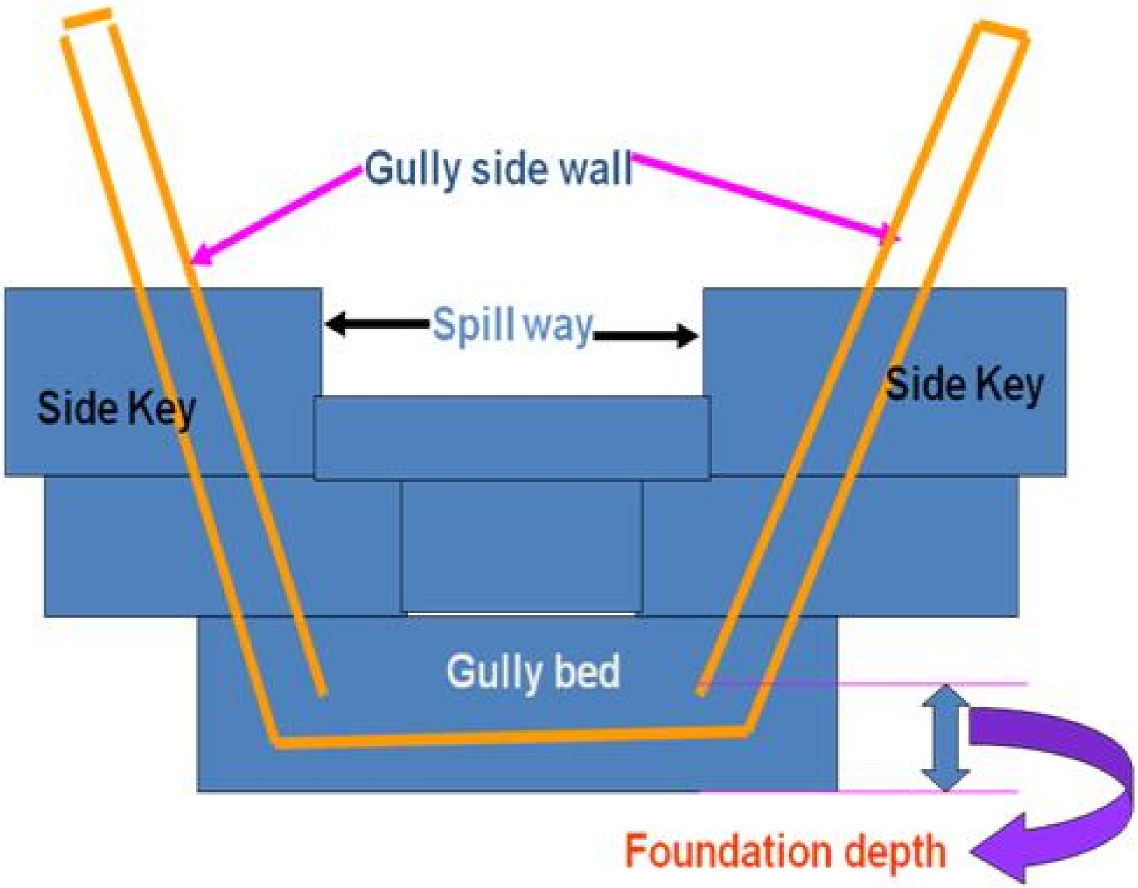


Figure 10: Schematic representation of a gabion check-dam

Design and construction specification of a gabion check-dam

- The foundation depth (key trench) should not be less than 50 cm
- The foundation width is 1m and the structure should be plugged one meter to each side of the gully wall /abutment/ right up to the height of the dam.
- Construct apron from downstream side of the structure with a foundation of 30cm from a dry stone, with a width of 1.5 times the reservoir level.
- For the spillway, the general design criteria given for loose stone check-dam is applicable here. It should be adequate to allow the peak flows, without overtopping the dam.
- An aprone of stone/similar gabion box about 1.5 m times the height of the spillway is necessary. General considerations for the apron are the same as for the loose stone check-dam.

- Stones to be used for filling the gabions should be, hard and of sufficient size and should be placed tightly together so that no large voids are created that could cause space for water to flow through and eventually result in the sinking of the dam. To avoid this, the bigger stones should be put along the sides of the box gabions while the smaller ones are filled in the middle.
- Gabions should be constructed on spots where the soil depth is higher, preferably in a wider part of the gully next after a series of loose stone check-dams
- It is neither necessary nor economical to build a series of gabion check-dams to control channel erosion along the gully beds.
- Gabions need to be closed by using large spanners (closers) and have to be wired together
- If stone is not available in close proximity, the gabion boxes can be mated in the inner part with plastic sheet and then filled with soil material. This will serve the purpose of stone filled gabion check-dam if properly constructed following the aforementioned specifications.

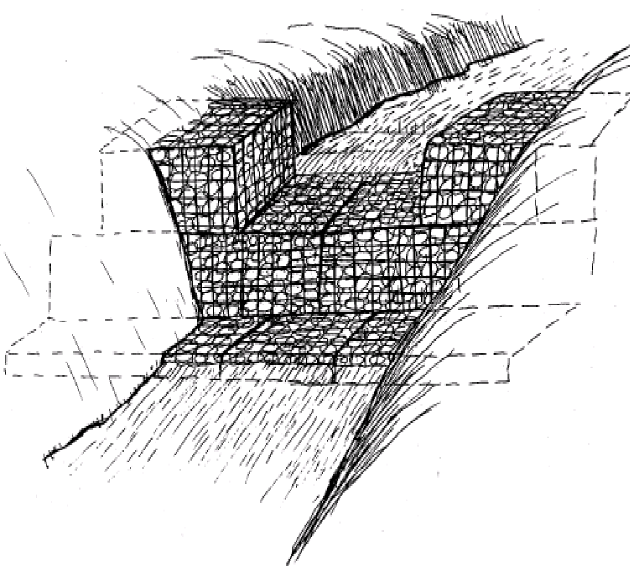


Figure 11: Installation of gabion box

Plate 4. Gabion check-dam under construction

(e) Arc-weir check-dam

Arc-weir is a structure made up of stones connected with mortar of cement and sand (Are cemented walls in horseshoe shape). The main objective of this dam is to hold fine and coarse material carried by flowing water in the gully or torrent. It is a very rigged structure highly susceptible to damage as a result of piping. When properly constructed, it is highly resistant to greater water pressure. The structure is very susceptible to damage as a result of runoff coming with boulders. From technical and economic point of view it is not necessary to build masonry check-dams to control channel erosion in every gully.

Design and construction specifications of arc-weir check-dam

- Foundation depth should not be less than 50cm. It actually depends up on the compactness of the underneath soil.
- Excavation for plugging in to the sidewall should not be less than 1m.
- The shape of the foundation is in an arc concaved to the stream flow
- The mortar ratio for the foundation is 1:4 for cement and sand respectively while it is 1:6 for the superstructure
- Plastering of the arc-weir, from the upstream is indispensable with mortar ratio of 1:3.
- Pointing is enough for the downstream face.
- The width of the foundation is 60-80 cm and gets narrower towards the upper end.
- The apron is in a form of steps at a height and width of 40 cm each.
- The number of steps depends up on the reservoir level.
- The spillway has a shape of an arc
- Lining from upstream side is important to avoid piping.
- Plugging of leakage after the very first run off up until it fills with sediment is essential.
- The dam must not be constructed on locations where there is movement of soil blocks
- The stones to be used in constructing masonry check-dams must be hard enough to withstand abrasion, non-disintegrating, and resistant to weathering.

Advantages of arch weirs:

- Strong structures
- Can be built relatively higher
- Good for building on the bedrock (no excavation)
- Good for efficient water harvesting for biological treatment
- Needs less stone compared to a gabion check-dam with similar volume

Disadvantages of arch weirs:

- Need cement and special tools for masonry
- Need experienced masons/builders
- Need sand (sometimes difficult to get in the highlands)
- Regular shapes of stones are required (square or flat, not round)
- They are not cheap to build

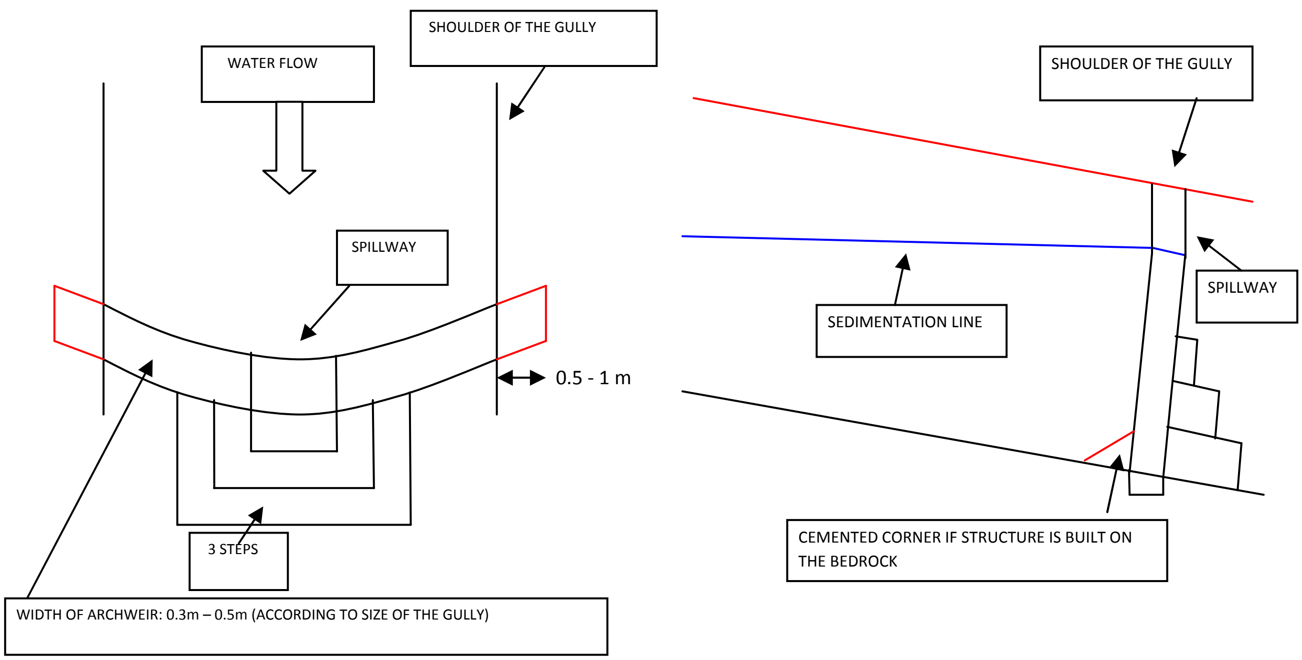


Figure 12: Top and side view respectively (from left to right) of an arc weir check-dam

Plate 5. Well constructed arc-weir and its effect on sediment trapping

(f) Locally available "organic" gabion boxes

“Organic” gabion boxes are made from locally available bamboo and reed strips, which are woven and tied together to form cubic, permeable boxes to be filled with stone. The organic gabions are placed across gully floors, and buttressed downstream for stability. The characteristic of the specific location determines the height and the width of the organic gabion check-dam, and consequently the number and size of gabions to be utilized for.

Consequently, the velocity of the run-off is reduced, and sedimentation creates a favorable atmosphere/ environment for the establishment of permanent biological structures. Accordingly, appropriate vegetative structures are put in place so as to strengthen and finally replace the "organic" gabion that rots over time.

In order to avoid the washing out of the soil in the early stages of sedimentation, leaves from the false banana (*Ensete ventricosem*) are placed inside the box to cover the holes of the mat. Thick poplar and willow stems are stuck into the soil filled boxes which after rooting stabilize the soil box after 2 years latest. This works in areas where no stones are to be found nearby.


Plate 6. Check-dams constructed out of organic boxes (bamboo and reed mat)

The same principle is followed with wire gabion boxes, lined with plastic sheeting and filled with soil (in the absence of stones nearby) as shown here below

Plate 7. A gabion check-dam filled with soil (top and bottom plates) and its effect after one year

Box 3. Example of Successful gully control

The gully treatment scheme has been undertaken in Kanat area of Farta woreda, South Gondar Zone. Since stone was not available enough in the area, the alternative intervention has been to use gabion boxes covered with plastic sheet and filled with soil which is available nearby.

The bottom left picture (plate 7) shows the first rain of the season with heavy hail. Note the totally bare land. The structure in the gully is a wire gabion lined with plastic sheeting and filled with soil. Normally such gabions are packed with stones. However, in this area no stones are found, thus they have to be "imported". In order to cut costs, the plastic sheet & soil method was invented by the then IFSP (Integrated Food Security Project). The sticks in the structure are poplar and willow cuttings (introduced by the project), 5 to 10 cm in diameter which have been knocked deep through the plastic sheeting into the soil resulting in the tall trees in the right picture. Eventually, the roots of these cuttings will stabilize the structure, even when the plastic disintegrates over time. On the right picture, see the full recovery of the area. The slim trees in the middle of the picture are the poplar cuttings in the plastic gabion.

It is hard to observe any vegetation on the left picture. It is difficult to believe these "before" and "after" pictures. Note, the gully depth and width on the left picture. If not treated, such a gully will get deeper and wider until it reaches bedrock level. There is a difference of about 1.5 meter in depth due to trapping of sediments. The various grasses planted, meanwhile cover the whole gully bed and filter out more sediment with each rain.

(g) Sandbag check-dam

Sandbag check-dams are made from used jut or polyethylene bags (50 kg) filled with soil. The bags are piled up to a maximum of 3 – 4 layers to form a small check-dam. This cheap technique is particularly useful in areas with insufficient supply of stones for building ordinary check-dams. By erecting sandbag dams large rills or small gullies (finger gullies) can be controlled, while they are not suitable for the treatment of large gullies.

Plate 8. Sandbag check-dams constructed to treat medium sized gullies

7.2.2. Use of vegetation in gully control

The use of vegetative material in gully control offers an inexpensive and permanent protection. Vegetation will protect the gully floor and banks from scouring. Grasses on the gully floor slows down the velocity of the runoff and causes deposition of silt. It can also be of economic value to the land users. Vegetation can be established in a gully by natural recovery or use of planting materials. A gully will re-vegetate naturally if the water causing erosion is conserved or diverted before it reaches the gully and if livestock are kept away. Costs are minimal but recovery will be slow if the soil is poor. Furthermore, if the gully sides are steep, vegetation may not establish itself.

Where establishment of natural vegetation is too slow to cope with the erosion or where a particular species is desired, planting should be done. The establishment of vegetation either naturally or artificially has to contend with a hostile environment. The type of planting material to be used should be seriously considered based on the specific situation of the gully. Conservationists and farmers should properly assess the soil and moisture conditions in the gully head, gully floor/bed, gully sidewall and gully offset/gully buffer zone. Practically speaking, these different locations of a gully do have different soil and hydrological characteristics which determines the type of species of grass, shrubs/bushes and trees to be planted.

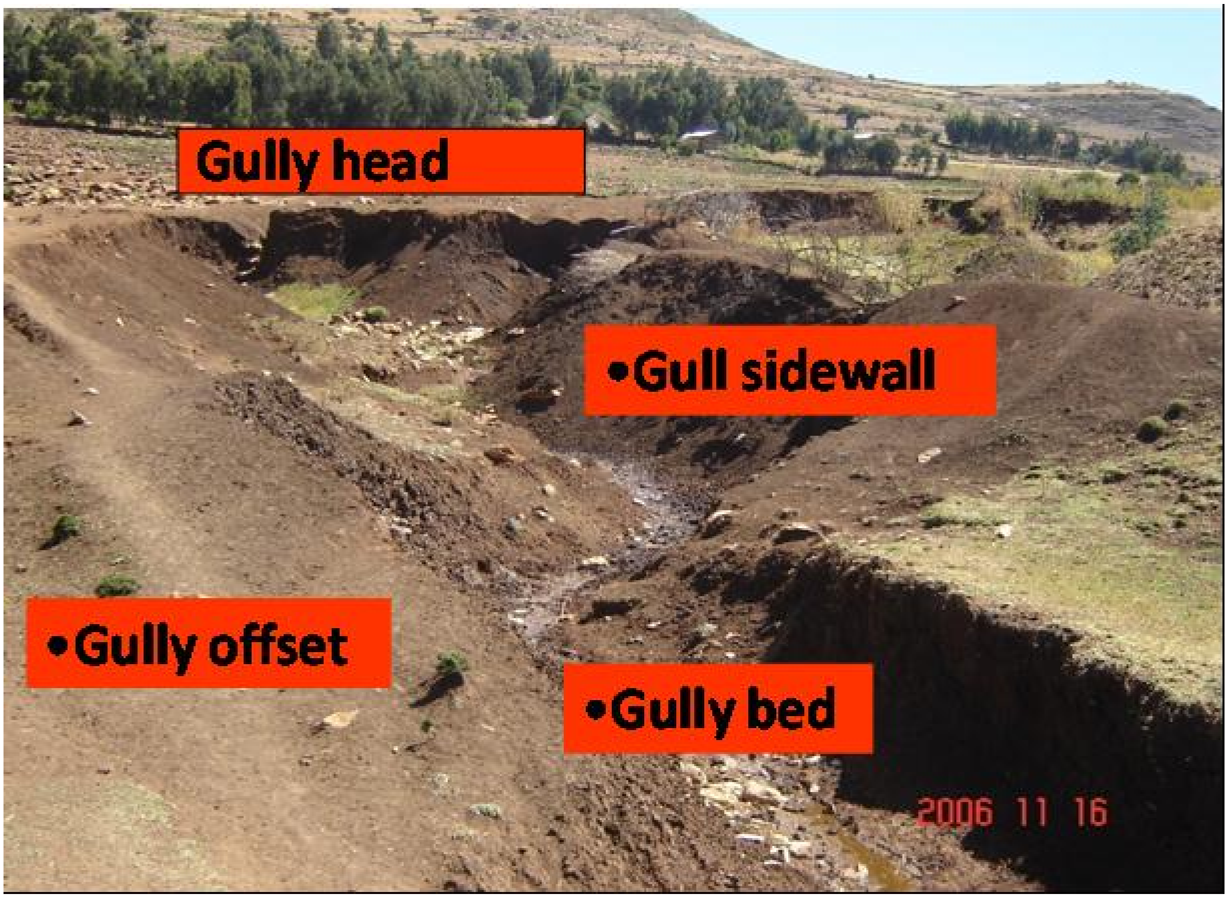


Plate 9. A typical gully showing its specific locations

(a) Gully head

- It is the upper part of the gully (in topo-sequence) where the gully starts
- It is the location through which most of the run off enters to the gully
- This part in most of the cases is very much active for gully formation and expansion

- The most commonly accepted measures for this spot are physical structures, such as paving with loss stone, diverting water using cutoff drains and reshaping.
- Nevertheless integrated treatment with biological measures will also help in stabilizing the gully head.
- Some creeping plant species can be used for reinforcing the structures constructed

(b) Gully offset

- It is a part of gully area which is located away from the gully embankment and extended to the next land use type
- It is a part which has to be considered in the gully treatment scheme to avoid further expansion of the gully
- In most of the cases these areas are characterized by medium soil depth, moderately wet in the rainy season and dry in the dry season, and with moderate slope
- Micro basin construction, trench and sub soiling are recommended for better performances of crops planted in the area
- Thus the plant species recommended for the treatment of this area are those with moderate tolerance to dryness and wetness.

(c) Gully sidewall

- It is a part of the gully between the gully offset and gully bed
- It is characterized by high slope gradient, shallow soil depth, susceptible to erosion and mass movement, very dry in most of the time due to less water holding capacity.
- Reshaping and hence constructing moisture harvesting structures are the recommended measures to treat gully sidewalls
- As far as farmers/land users are convinced to undertake reshaping, the gully offsets can be converted into potential areas for multiple purposes
- Biological measures can play a pivotal role in rehabilitating this section of the gully
- The species to be selected should have invading characteristics, with light foliage and steam biomass and high tolerance to drought

(d) Gully bed/floor

- It is a part of the gully on top of which the run off flows
- It is occupied with the flow of runoff throughout the rainy season
- This gully parts can be treated in the dry season with physical measures like arc weir, loose stone, and gabion, brushwood and sandbag check-dams.
- These areas are regarded as very wet in most of the year, with deep alluvial soil
- Thus the biological material recommended for this part of the gully should be tolerant to water logging, with high root biomass and, resistant to soil sedimentation and high flow of water
- A lot of biological material which can fit to this condition can be found at the local condition in consultation with the farmers.

It is not only the type of species but also time of planting influences the success in gully rehabilitation. This is directly related to the availability of moisture and the amount of flow in the different sections of the gully. As a result, the general recommendation is to undertake planting on the offset and sidewall immediately when the rain starts. But the gully bed should be planted when the flow reduces and the main rainy season ceases. Unless and otherwise, the planted seedlings and seeds sown will be easily washed away by the running water along the gully.

Having the aforementioned suggestions in mind, the following biological measures can be taken as potential alternatives for gully rehabilitation. They can be combined with physical measures and or be used alone for gully rehabilitation depending on the amount of pick discharge coming from the upper catchment and nature of the gully.

(a) Reinforced bundling (or wattle)

Bundling or wattle is a technique where fresh stems of plants (e.g. elephant and bana grass, green gold, Spanish reed, elderberry, poplar, and willow) are bound together, then horizontally planted (across the gully bed or along the sidewall), and covered by soil. To economize planting material the bundles (also wattles) may be supplemented with other bulky organic matter (filling material) such as dry grass or straw, or the dry stems of plants such as *Acacia saligna*, *Sesbania*, etc.

Reinforced bundling requires that mature poplar or willow stems or truncheons (branches), 70 cm in length, are inserted 20 cm deep next to each other across the gully floor in two rows, spaced 50 cm apart. Downstream buttressing (support) should be provided for stability. The space between the two rows of truncheons should then be filled with bundles consisting of approximately 30% vegetative (fresh) bundling material, and 70% filling material. To prevent the drying out of the bundling material, it should be lightly covered with moist soil.

As soon as the poplar or willow stems have exhibited adequate vertical growth, the space between the stems can again be filled with bundling material. There will thus be an incremental growth in the height of the structure, which will in turn add to the level and amount of siltation. This technique can only be applied when the rainy season has commenced. Through time, the bundles will grow and serve as live check-dam.

Plate 10. Bundles put across the gully bed and supported with popular and willow stems

(b) Layering of vegetative material

Layering is the horizontal planting of fresh stems of plants (e.g. elephant and bana grass, green gold, spanish reed, elderberry, poplar, willow) across the gully floor and or reshaped sidewall, or at the base of gully walls. This technique is applied when a satisfactory level of sedimentation has been achieved. The stems of these plants root very readily, after which shoot growth is initiated. Sedimentation occurs and increases as the shoot growth forms a dense barrier that disturbs and breaks the velocity of the water. This leads to a gradual build-up of the gully floor.

Plate 11. Planting of elephant grass by layering to rehabilitate gully bed

(c) Gully bed plantation

The planting of water-loving or moist tolerant trees, shrubs and grasses such as *Paraserianthes lophantha*, *Salix spp.*, *Acacia melanoxylon*, *Phalaris aquatica*, and *Pennisetum clandestinum*, *Pennisetum riparium*, *Pennisetum purpureum* and green gold grass on the gully bed, adequately spaced, breaks the flow and velocity of water run-off, traps the sediment, and protects the gully bed from erosion. Biomass production already during the second rainy season will be astonishing.

Plate 12. Gully bed and sidewall planted with various tree, bush/shrub and grass species

(d) Retaining wall with bamboo-mat

In gully rehabilitation scheme, the difficult part is to control the lateral flows which are coming from farm fields, footpaths, degraded grazing areas and other miscellaneous land use types. To protect the lateral flows and hence mass movement and soil sliding/melting from fragile sidewalls of a gully, retaining walls made out of reed/bamboo mat can be installed along the foot of the sidewall. The mat can be strengthened on the lower side by wooden sticks, possibly using vegetative propagating species like popular, willo and indigenous species.

Truncheons/branches of various species can be layered on the upper part of the mat. This technology facilitates self reshaping of gully and hence rehabilitation.

"Mini" bundles, with or without pegging, are also employed in small soil and moisture pockets. Arundo donax and Hyparrhenia stems consisting of three to four nodes each proved particularly useful for this purpose. Retaining, bundling and pegging commence with the onset of the rainy season.

Plate 13. Protecting gully sidewall using bamboo-mat retaining wall.

Box 4. Successes in protecting gully sidewall

The treatment of Magera gully which is found in Farta woreda, South Gondar zone, has been started in March 2003 as a pilot for IFSP. The Farta woreda office of Agriculture tried three times to rehabilitate the area using conventional approaches: constructing small loose stone check-dams. Unfortunately, all of the attempts failed to serve the purpose. The problem of this particular gully was aggravated due to the lateral flows coming from cultivated fields located left and right of the fragile gully sidewall. Therefore in the beginning agreement was made with the respective land owners to manage the excess flood from their plots either by diverting to the nearby natural streams or by reducing the speed of flow via constructing bunds and planting vetiver and other vegetative materials along the contour of the farm fields. Then after the actual gully has been treated by installing wire gabions to control the head; constructing simple check-dams exclusively from local material (woven reed boxes and mats); and protecting the mass movement from the gully embankment by fixing bamboo/reed mats along the lower part of the sidewall. The physical structures have been integrated with biological measures by planting various species like popular, Spanish red, Green gold, Bana grass, Elephant grass, Kikuyu, etc. on appropriate locations of the gully. Note the massive biomass production in the right picture after the third rainy season (plate 13).

(e) Planting of trees, shrubs and grasses on gully sidewalls

The long-term stabilization of gully sidewalls also requires the establishment of woody perennial plants. Multipurpose trees like *Dodonea angustifolia*, *Acacia saligna*, and *Teline* spp. are recommended for treating reshaped gully sidewalls.

Excellent results have been achieved by planting Bana Grass and Green Gold Grass in rows across the gully slope. Planting of kikuyu around the lower sidewall and crown vetch even on steep side walls have shown interesting results.

(f) Direct sowing or broadcasting

Direct sowing (broadcasting) on gully beds, and into cracks on sidewalls during the rainy season results in an almost immediate cover of these fragile areas. Seeds of *Sesbania sesban, Accacia saligna, Pegeon pea*, common vetch and other can be mixed together and sown on different sections of the gully. To assure an economical use, and to avoid over-planting, seeds should be mixed with dry sand during sowing.

(g) Off-Set Plantations

The gully offset is the area that extends from the top edge of the gully wall up to five meters away. Adequate stabilization is inevitable to prevent the sideway extension of the gully and further encroachment of arable land. Generally, gully offsets are moisture deficient. Thus drought tolerant multi-purpose species of trees, shrubs, grasses, and fodder legumes are suggested for stabilizing this fragile area. Recommended species include: *Lespedeza sericea, Medicago sativa, Coronilla varia, Atriplex nummularia, Teline canariensis and madeirensis, Acacia saligna, Acacia abyssinica, Acacia angustissima, Paraserianthes lophantha, Chamaecytisus palmensis, Grevillia robusta, Sesbania sesban, Lupinus arboreus, Tephrosia vogelli, leucaena leucocephala* and *Tamarix spp* etc.

8. Design Considerations Common for All Check-Dam Types

Proper design of check-dams is very crucial if they are to fulfill their objective. The following points apply when designing the check-dams, regardless of the material used.

- Low check-dams are less likely to fail than high dams. High dams will impound much water and the pressure may lead to seepage and undermining
- A check-dam should have a spillway in the center to discharge water and shoulders on either side to prevent water cutting around. The width and depth of the spillway will be determined by the width of the gully and the discharge rate.
- All check-dams should have properly constructed apron on the downstream side to protect the dam from undercutting.
- For the dams to be effective they must be spaced at a distance that takes into consideration the gradient of the gully and the expected height of the dam
- The check-dam should be properly keyed to the floor and sides of the gully to improve stability. This involves excavation of foundation 0.5 m deep and wide across the gully floor and 0.5 m into the gully sides.
- Construction should start at the upper end to reduce the risk of failure if water enters the gully before all check-dams have been constructed

8.1 Estimation of catchment runoff

In order to design appropriate conservation structures such as check-dams; diversion ditches or waterways, it is important to be able to make an estimate of runoff. Runoff expressed in terms of depth is not convenient to determine the capacity of disposal structures. If you are planning to design a channel or a spillway to discharge a given amount of runoff, then you ought to know how much of the runoff could be accommodated by that channel. Therefore, you have to know what quantity of the water to be conveyed and at what rate. That is the reason why it is compulsory to determine the peak runoff rate.

In natural catchments, any rainfall is either intercepted by vegetation, infiltrates into the soil, starts moving over the surface as runoff or is lost through evaporation. For a rainfall of a given duration and intensity, the proportion which becomes runoff depends mainly on the cover of vegetation or crop residues, the soil infiltration rate, water content and storage capacity, and the slope of the land.

The reason why the peak runoff rate is used to determine the capacity of channels is to avoid risk of designing low or high capacity channels, rupture and overtopping of dams, overflow of bunds, channels and rainfall multiplier systems. For instance low capacity channel would not be required since it allows overtopping and high capacity channel is not required either, because it entails unnecessary costs.

There are two simple methods used for estimating runoff rate: known as the **Rational formula and Cook's method**. They are both useful and as they will not give exactly the same result they can both be used and the results compared to check on the reliability of the estimate.

A. Rational formula for estimating runoff rate

The rational formula is expressed as follows:

$Q = CIA/360$

Where:

Q = runoff rate (m^3/s)

C = Runoff coefficient (between 0 and 1)

I = Rainfall intensity (mm/hr) = **Rainfall amount over time taken**.

A = Area of the catchment (ha)

While using the above formula, the following points should be noted:

- ***Runoff coefficient*** is the proportion of total rainfall that is expected to become runoff during the design storm. ***Runoff = Rainfall – Infiltration***. It can be determined easily from a table by looking in to the watershed surveying results (Table 4 below).

Table 4: Runoff coefficient values for use with the rational formula

Land use and topography	Soil type		
	Sandy loam	**Clay and silt loam**	**Tight clay**
Cultivated land			
✓ Flat land (0 -5 %)	0.30	0.50	0.60
✓ Rolling land (5 – 10 %)	0.40	0.60	0.70
✓ Hilly land (10 -30 %)	0.52	0.72	0.82
Pasture land			
✓ Flat	0.10	0.30	0.40
✓ Rolling	0.16	0.36	0.55
✓ Hilly	0.22	0.42	0.60
Forest land			
✓ Flat	0.1	0.30	0.40
✓ Rolling	0.25	0.35	0.50
✓ Hilly	0.30	0.50	0.60
Developed areas (villages)			
✓ Flat	0.40	0.55	0.65
✓ Rolling	0.50	0.65	0.80

Source: Hudson, N. 1995.

- ***Rainfall intensity*** value in millimeter per hour for use in rational formula is the highest that can be expected in a 10 year return period for a time equal to the time of concentration of runoff at the outlet of the catchment. This is known as the design storm. The time of concentration is an important concept and assumed that the peak runoff will occur when the storm period lasts just as long as it takes for water from the furthest part of the catchment to reach the outlet. In this way all parts of the catchment are contributing to the runoff at the outlet simultaneously. Time of concentration can be calculated using the following formula: $\mathbf{Tc = 0.0195\ L^{0.77}\ Sg^{-0.385}}$

Where:

Tc = Time of concentration (min)

L = Maximum length of flow (m)

S = Average gradient (m/m)

Once the time of concentration is found, rainfall intensity can be selected from a typical rainfall intensity duration curve for a 10 years frequency (for SWC structures) possibly developed for that particular area.

Time of concentration for small catchments can be also determined using the table below

Table 5: Time of concentration for small catchments

Area (ha)	Time of concentration (minutes)
0.4	1.4
2.0	3.5
4.0	4.0
40	17
200	41
400	75

(Source: Thomas, 1997)

- ***Area*** of a catchment under question which is often called **runoff area** can be measured either from a map or surveyed directly on the field, or usually estimated.

B. Cook’s method for estimating runoff rate

This method was developed by the United States Conservation Service and adapted for African conditions by Prof. Norman Hadson. The method is based on actual measurements of rainfall intensity and runoff rate from small catchments. Here, there are only three factors to be determined; the area of the catchment, the shape of the catchment and the catchment characteristics. The shape of the catchment is relevant because a short wide catchment will generally produce a higher pick runoff than a long narrow catchment of the same size. The catchment characteristic, which is the basis for this method, is determined from observation on the vegetative cover, the soil and the slope. A value is attached to each of these components as shown in Table 6 and the sum of the three figures gives the total catchment characteristic.

Table 6: Catchment characteristics used for determination of runoff rate by Cook's method

Vegetative cover	Value	Soil conditions	Value	Topography (slope)	Value
Forest or heavy grass	10	Well drained soils e.g. sandy	10	0 -5 %	5
Scrub or medium grass	15	Moderately pervious soils e.g. Silt	20	5 -10 %	10
Cultivated land	20	Slightly pervious soils e.g. loams	25	10 – 30 %	15
Bare or sparse	25	Shallow soils with impeded drainage	30	>30 %	20
		Clay sticky soils and rocky areas	35-40	Mountainous	25

Source: Adapted from Hudson (1955)

Table 7: Runoff Rates (m^3/s) determined for small catchments by Cook's method

Runoff area (ha)	Summarized characteristics											
	25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**
5	*0.2*	*0.3*	*0.4*	*0.5*	*0.7*	*0.9*	*1.1*	*1.3*	*1.5*	*1.7*	*1.9*	*2.1*
10	*0.3*	*0.5*	*0.7*	*0.9*	*1.1*	*1.4*	*1.7*	*2.0*	*2.4*	*2.8*	*3.2*	*3.7*
15	*0.5*	*0.8*	*1.1*	*1.4*	*1.7*	*2.0*	*2.4*	*2.9*	*3.4*	*4.0*	*4.6*	*5.2*
20	*0.6*	*1.0*	*1.4*	*1.8*	*2.2*	*2.7*	*3.2*	*3.8*	*4.4*	*5.1*	*5.8*	*6.5*
30	*0.8*	*1.3*	*1.8*	*2.3*	*2.9*	*3.6*	*4.4*	*5.3*	*6.3*	*7.3*	*8.4*	*9.5*
40	*1.1*	*1.5*	*2.1*	*2.8*	*3.5*	*4.5*	*5.5*	*6.6*	*7.8*	*9.1*	*10.5*	*12.3*
50	*1.2*	*1.8*	*2.5*	*3.5*	*4.6*	*5.8*	*7.1*	*8.5*	*10.0*	*11.6*	*13.3*	*15.1*
75	*1.6*	*2.4*	*3.6*	*4.9*	*6.3*	*8.0*	*9.9*	*11.9*	*14.0*	*16.4*	*18.9*	*21.7*
100	*1.8*	*3.2*	*4.7*	*6.4*	*8.3*	*10.4*	*12.7*	*15.4*	*18.2*	*21.2*	*24.5*	*28.0*

Table 7 above gives the values of runoff rate for different catchment sizes and characteristics. For areas known to experience less intense rainfall, multiply the values obtained from table 7 by 0.75. Since the shape of the catchment affects the time of concentration and hence the design intensity and ultimately the peak runoff, multiply the runoff values obtained from table 7 by 0.8 or 1.25 for the long narrow – and broad short – catchments respectively.

Example 1: Runoff rate estimation – using Cook's method

Runoff from higher ground is causing damage to a farmer's land by creating a gully, and the soil and water conservation officer has been asked to design check-dams which can dissipate the energy of flow. He inspected the catchment and found that the soil is deep and permeable. He estimated the size of the catchment to be 5 ha and noted that there is a mountainous area of about 3 ha of bare land having a well drained soil. Cropland which is well drained and with a slope of 3% occupies 1.5 ha and there is an area of medium grass cover with sandy soil and 8% slope occupying 0.5 ha. He estimated the discharge by Cook's method in the following way.

1. Find the weighted mean catchment characteristic (CC_w) using figures from table 6

	C		
Bare land	3.0 ha x (25 +25+10) = 180		
Cropland	1.5 ha x (20 +10 +5) = 60		
Medium grass	0.5 ha x (15 + 10+10) = 17.5		
Total area	5 ha x CC_w	=	257.5 therefore CC_w = 51.4

2. From table 7, the peak runoff rate Q for a catchment characteristic of 50 is 0.9 m^3/s and for 55 is 1.1 m^3/s. Therefore the value of 51 is equivalent to a peak runoff rate of 0.92 m^3/s. As a result, the Soil and water conservation officer can use this value to design the check-dams to be installed in the gully.

The above calculation may give a different result when a rational formula has been applied. In this case the soil and water conservation officer has to analyze the existing situation and decide to take one of the results. Sometimes the average value of the two can be applied.

8.2 Spacing between check-dams

The spacing of the check-dams should be such that the spillway crest of one check-dam is level with the base of the next check-dam upstream. With this assumption, the spacing between check-dams can be calculated using the following formulae.

(a) Calculating number of check-dams using compensation gradient

$$N.O.C.D. = \frac{a - b}{H}$$

Where, N.O.C.D = Number of check-dams to be constructed in the gully under observation

a = the total vertical distance is calculated according to the average gully channel gradient and the horizontal distance between the first and last check-dam in that portion of the gully bed.

b = the total vertical distance is calculated according to the compensation gradient and horizontal distance between the first and last check-dam in that portion of the gully bed (compensation gradient).

H = the average effective height of the check-dams, excluding foundation, to be constructed in that portion of the gully bed.

The above formula depicts that 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.

Figure 13: shows how to use clinometers, a clinometers' stand and a target in order to find the second check-dam point in a gully bed. 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.

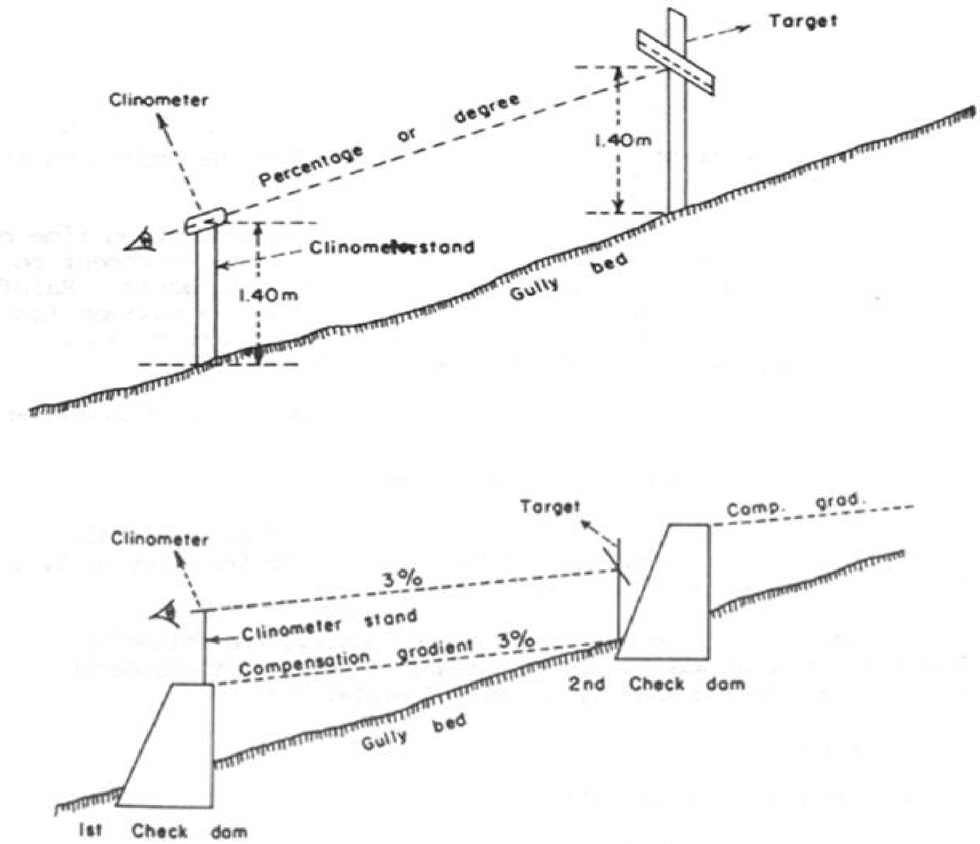


Figure 13: Measuring the gradient of the gully between check-Dams.

(b) The spacing of check-dams can be also determined by using an empirical formula:

S = 1.2H/G

Where;

S it the spacing in meters

H is the effective height of the check-dam (spillway height in m)

G is the gully gradient

Example: What will be the spacing of the check-dam, if the effective dam height is 1.5 m and gully gradient is 15%?

Solution: Using the above empirical formula

Spacing = 1.2x1.5/0.15 = 12 m. This means check-dams will be installed along the gully at each 12m distance.

8.3 Spillway design

The spillway of a check-dam should be designed to convey peak runoff safely. They have to be designed to carry the maximum flow without overtopping or breaching the check-dam. It therefore must be big enough to accommodate the maximum flow expected once in ten years. For a rough estimate of a peak flow, the watermarks visible on the gully banks or debris deposits give a good indication of the magnitude of peak flow and the dimensions required for the spillway. For a better and realistic way, the discharge to be accommodated through the spillway can be calculated using the aforementioned discharge formula and hence the width and depth of the spillway can be estimated using a spillway formula equated below.

$Q = CLD^{3/2}$

C = Coefficient which is 3.0 for loose rock, boulder log and brushwood check-dams; 1.8 for gabion and cement masonry check-dams.

L = Length of spillway in meters; D = depth of spillway in meters

Q = Maximum discharge of the gully catchment at the proposed check-dam point, in cubic meters/second.

Example

The catchment area of a gully (continuous gully) is 15 ha above the point where a loose rock check-dam would be built. The catchment is expected to generate a runoff which amounts $9.675m^3$/second. What are the dimensions of the check-dams's spillway?

The spillway dimensions can be calculated by the spillway formula as follows:

Q = CLD3/2

Q: 9.675 cubic meters/second, as given

C: 3.0 coefficient for rock and brush structures

D: Depth of spillway varies from 0.5 to 1.5 m in general. (0.8 m is tried as shown below).

$9.675 = 3L\ 0.8^{3/2}$

= 3L 0.71

4.54 m = L

The length of the boulder check-dam's spillway is 4.54 m (round 4.6 m), if the depth of the spillway is accepted as 0.8 m.

Spillway dimensions can also be determined using table 8. The depth of the spillway can be determined on the basis of the discharge entering into the gully from the gully catchment upstream and the width of the spillway, which is proportional to the gully bottom width. Note that the numbers in *Italics* in the table below are discharge values.

Table 8: Depth of spillway required for different widths and discharges

Depth of spillway (m)	**Average width of spillway (m)**						
	0.6	**1.2**	**1.8**	**2.4**	**3.0**	**3.6**	**4.8**
0.15	*0.05*	*0.1*	*0.15*	*0.2*	*0.25*	*0.3*	*0.35*
0.3	*0.1*	*0.25*	*0.4*	*0.5*	*0.6*	*0.75*	*0.9*
0.45	*0.2*	*0.5*	*0.7*	*0.9*	*1.2*	*1.4*	*1.5*
0.6	*0.35*	*0.7*	*1.1*	*1.5*	*1.8*	*2.2*	*2.5*
0.75	*0.6*	*1.5*	*2.0*	*2.7*	*3.3*	*3.9*	*4.7*

Source Wenner, 1984

Example: Find the depth /height/ of a check-dam dam if the runoff entering into the gully is 1.5m^3/s; assume the spillway width of 2.4 meters.

Solution: From the table above you find that when the discharge is 1.5m^3/s and the spillway width is 2.4 meters, the depth of spillway is 0.6 meters.

The energy of the waterfall through the spillway increases with the depth of flow. Therefore, a spillway with greater length relative to the depth is more desirable. Generally, a spillway should be designed that its length should not be greater than the gully width at the dam sight. This will reduced the splash effect of the falling water on the gully banks.

The shape of a check-dam spillway can be trapezoidal, rectangular, triangular or parabolic. It is preferable to have trapezoidal shaped spillway (as shown in figure 14) because this cross-section is stable. Rectangular spillway can be used for gabion structures and in small check-dams if the stones to be used are stable. Care is also to be taken not to use small stones at the spillway and the dam crest.

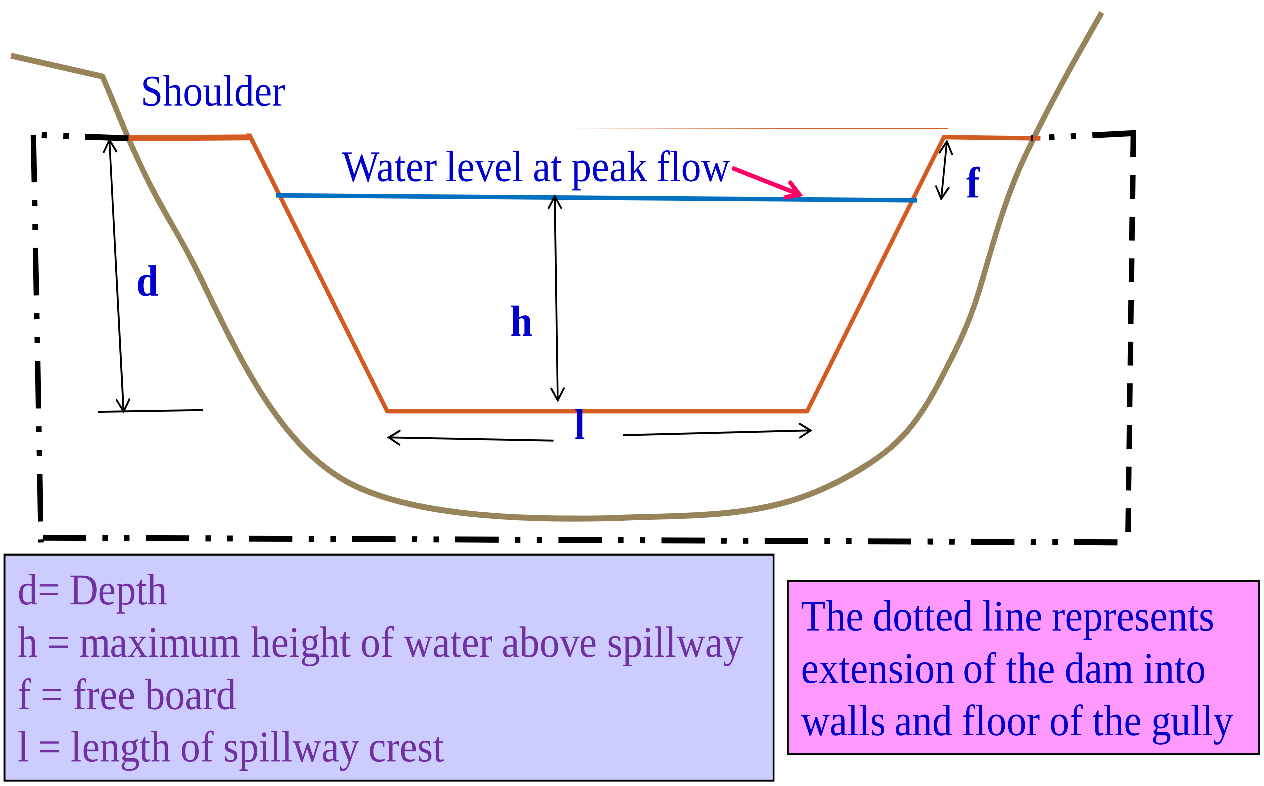


Figure 14: A pictorial representation of a typical trapezoidal spillway

8.4 Apron

An apron is to be designed such that it dissipates the energy of falling water passing through the spillway. It can be made from stone riprap, strong enough to withstand pressure of falling water and a surface wash. To prevent surface wash the voids between the stone riprap is to be filled with gravel. In conditions when the spillway height is big, the apron can be constructed from gabion box filled with stone.

An apron may also be built below the ground surface. In this case, it will form a basin which when filled with water, will function as a water cushion and dissipate the energy of water falling on it. The apron should have length of 1.5 times the height of the check-dam. For gullies with slope more than 15% the apron length should be 1.8 times the height of the dam. Apron should be placed in an excavation of about 0.3 – 0.5 m to ensure stability and prevent wash away. A sill, about 15 cm high should be constructed on the lower end of the apron. The apron should be built at least 50 cm wider than the spillway opening on both sides.

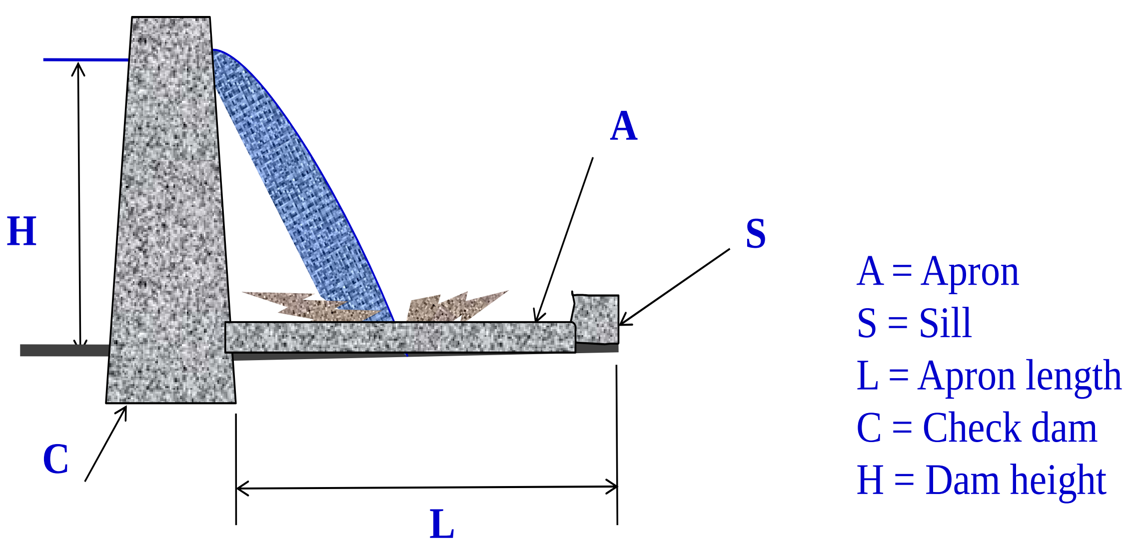


Figure 15: Waterfall passing through the spillway and falling on the apron

8.5 Work norm for check-dams

Different measures/structures used for gully treatment have got work norms based on their difficulty and easiness during implementation. These work norms are included under the revised soil and water conservation work norms prepared by the Ministry of Agriculture (MoA) in 2004. Table 9 below shows the work norms for some selected gully treatment measures as per the MoA and some field experiences from various projects.

Table 9: Work norms for gully treatment structures

S/N	Type of activity	Unit	Norm
1	Gabion check-dam	m^3/pd	0.25
2	Loose stone check-dam	m^3/pd	0.5
3	Arc weir check-dam	m^3/pd	0.5
4	Sandbag check-dam	m^3/pd	0.5
5	Brushwood check-dam	Lm/pd	3
6	Bamboo mat check-dam	m^3/pd	1
7	Gully reshaping	m^3/pd	1
8	Retaining wall construction	Lm/pd	5
9	Stone collection and transport	m^3/pd	0.5

9. Reasons for Failure in Gully Rehabilitation

Gully control can be tedious where executed measures do not seem to work. Failure in control brings losses of material, time, money and sometimes makes the gully erosion even worse. Actually, failure can be avoided if appropriate measures are taken and proper techniques are applied. From experience, the following problems can be taken as the major reasons for the failure of most of the gully rehabilitation schemes in Amhara region if not all over in the country.

- Poor consideration for upper catchment treatment
- Poor installation of check-dams which is related to lack of keying the check-dam to the floor and sidewalls of the gully
- Lack of apron. If there is no apron, water falling from the check-dam spillway erodes the area below and undermines the structure. If the apron is not keyed or secured into the gully, it will be washed away.
- Lack of spillway. The check-dam tends to impede the flow of water. This leads to the water exerting pressure on the dam which can weaken it. A spillway will discharge the runoff thus protecting the check-dam.
- Poor maintenance. The life and effectiveness of control measures is extended by regular maintenance. Any shortcomings in the control structures should be corrected before they

develop into serious problems. Any grass, shrub/bush and tree planted which dies should be replaced.

- Improper spacing of check-dams. Proper spacing is crucial if the check-dams are to serve their purpose. Inappropriate and irregular spacing of the check-dams may lead to their being washed away.
- Failure to complete the work. In some instances the gully rehabilitation schemes may not be completed because of various reasons. Half measures do not offer the required protection and are a waste of time and resources.
- Structures are sometimes made too high and the water which ponds causes instability of the soil and piping underneath or around the structure.
- Poor integration between physical and biological measures.

10. Maintenance and Utilization of a Rehabilitated Gully

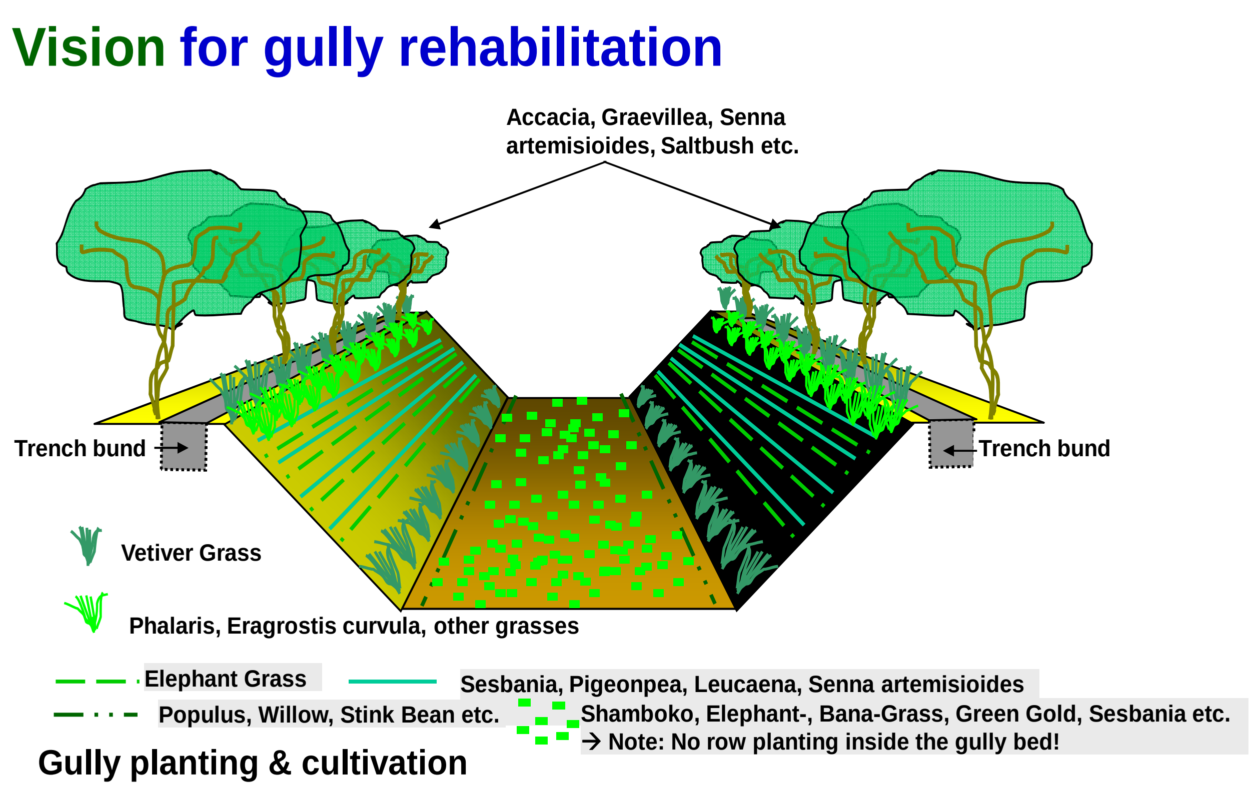
Maintenance of gully control structures is a very important point worth to be emphasized. Treated gullies should be checked regularly and the healing process monitored closely. Structures built in the gully for stabilization purpose should be observed for damage especially during rainy seasons and after heavy storms. Damaged check-dams should be repaired immediately to avoid further damage and the eventual collapse.

The use of gully will depend on whether it has been established to a protected waterway or the water has been diverted and the gully stabilized for other uses. Under the condition when the water is discharged through the gully after the necessary stabilization activities have been undertaken, the side of the gully can be used for growing of grass or fodder. But in conditions when the gully is not used as a waterway, it can be used for growing horticultural crops or plants such as banana or other fruit trees. Wide gullies can have tree planted on the side slopes provided they are not too steep.

The other important issue for sustainable gully rehabilitation scheme is the identification of users and development of a use concept or management plan. In most cases, gullies are crossing different land uses owned by many land users. Therefore, before treatment of gullies, the users should be identified and the boundaries should be clearly demarcated, the gully rehabilitation process should be objective oriented and responsibilities of owners in managing, maintaining and utilizing the gully and its produces should be elaborated and agreed upon.

Experiences have shown that most of the gully rehabilitation efforts are made accidentally without having clear purposes. As a result, it is common to see gullies with a huge biomass, mostly of one species (*Sesbania sesban or Elephant grass*) but not harvested and after all owners are not known. This has forced the community members into conflict and hence destruction of the whole endeavor. In view of this fact, the identification of gully owners and demarcation of their boundary, development of a management plan and formulating user's agreement (on maintenance and proper utilization of the gully) should come before any treatment effort. It is always crucial to remember that before deciding to undertake gully control measures one has to plan first for what purpose the gully is intended to be used after treatment and then try to take measures relevant to the future strategy.

Box 5. Vision for gully rehabilitation



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