TRAINING PACKAGE ON BIOPHYSICAL GULLY CONTROL AND REHABLITATION MEASURES

PART ONE: TECHNICAL MANUAL FOR PHYSICAL GULLY CONTROL AND REHABILITATION MEASURES

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MoA SLM ETHIOPIA
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DEUTSCHE ZUSAMMENARBEIT
Implemented by:
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MODULE 1: CONCEPTS OF SOIL EROSION AND GULLIES

1.1 *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 and
- 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 the land is bare of its natural protective vegetation because of human interventions, 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.

Erosion by water involves three physical processes: - Detachment, Transport and Deposition. Detaching forces include:

- Raindrop/rain splash,
- Flowing water,
- Animal's hooves,
- Human activities such as cultivation operation, and
- Wetting and drying.

Nevertheless the main transporting agents are the rill, gully and stream bank erosion types due to rain.

Detachment due to raindrop/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. The fine materials from the soil are removed and less fertile sands and gravels remain behind. The principal effect of splash erosion is to detach soil and other forms of erosion to transport the detached soil.

The number and size of drops and the velocity of drops determine the impact of raindrops per unit area. A single raindrop may splash wet soil as much as 60cm high and 150cm from the spot where the raindrop hits. Splash erosion is the worst form of water erosion. It gives a start for the other forms of erosion. Continuous bombardment of rainstorm, with millions of raindrops causes damage by hitting the bare soil and converting it into a flowing mud. The factors affecting the direction and distance of soil splash are: presence of wind, land slope and soil surface conditions (vegetative cover and mulches). The velocity of re-flushing (rain drop) is much higher i.e.: 6 – 9m/sec coming and 12 – 18m/sec for going back velocity.

Wash Erosion

Running water causes wash erosion. The erosive power of running water is related to the quantity and velocity of flow. The velocity generally increases with the depth of water. Based on the nature and extent/form of soil removal, wash erosion is classified as: sheet erosion, rill erosion, gully erosion and stream bank erosion.

Sheet erosion

Sheet erosion is the removal of a fairly uniform layer of soil from the land surface. This type of erosion is extremely harmful to the land. It is usually so slow that the farmer is not conscious of its existence. It is common on lands having a gentle slope. Areas where loose, shallow topsoil overlies a tight sub-soil are most susceptible to sheet erosion. The following signs are indicators to detect sheet erosion:- Roots and stones are exposed, deposits of eroded soils laid at the bottoms of sloppy areas, sub soils becomes mixed with topsoil, and crop yields fall gradually.

Rill Erosion

Rill erosion is the removal of soil by running water that lead to forming shallow channels (i.e., less than 30cm depth) - “Maresha”. It can be smoothed out completely by normal cultivation. Rills develop when there is a concentration of run-off water, which, if neglected, grow into large gullies. Hence, it may be regarded as a transition stage between sheet erosion and gully. This progress of rill erosion hinders the movement of farm implements, reduces the actual area under crops and results in declined crop yield. Rill erosion is more serious in soils having loose shallow topsoil.

Gully Erosion

It is an advanced form or stage of rill erosion. Gully erosion is the total removal of soil by running water. Gully channels cannot be smoothed out completely by normal cultivation. It is associated with accelerated and concentrated overland flow.

Stream Bank Erosion

It is under cutting, sliding, slumping, land slide or mass movement from saturated pore water pressure. 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 cover and over-grazing 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.

In summary, the if appropriate measure is not taken timely, erosion hazard could intensify its level of damage that leave the land unproductive. The gravity and stages of disaster are:

- 1st stage- Sheet erosion develops into rill erosion;
- 2nd stage- The rills gain depth and remove the weak material;
- 3rd stage- The water starts to curve and create a hollow at the bottom of the gully;
- 4th stage- When the excavation has become too deep, the steep wall collapses;
- 5th stage- As the problem continues, the head progresses backwards; and
- 6th stage- Then gully formed and its length increases, which eventually leave the land unproductive.

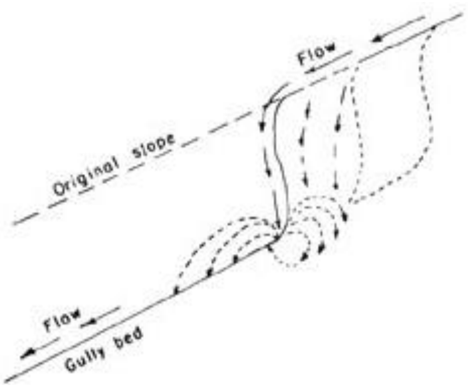

Figure1: Erosion due to rain fall at gully head (Source: Lakew Desta and Belayneh Adugna, March, 2012)

1.2 Concept of Gullies

Gully is a channel created from erosion that comes due to heavy rains falling usually on the upper barren catchment area. Gullies are:

- Intermittent stream channels larger in size than rills. But unlike rills they cannot be obliterated by simple tillage;
- Final stages of uncontrolled surface wash; and
- Visible manifestation of misuse of land that end up in increased denudation of the soil by severe runoff.
- Gullies have different parts that includes heads, beds, off-sets and side walls.

Gully head

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

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 (see photo below);
- 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; and
- Thus the plant species recommended for the treatment of this area are those with moderate tolerance to dryness and wetness.

Gully sidewall

- It is a part of the gully between the gully-offset and gully-bed; (see photo below)
- 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 pivotal role in rehabilitating this section of the gully; and
- The species to be selected should have invading characteristics, with light foliage and steam biomass and high tolerance to drought.

Gully bed/floor

- It is a part of the gully on top of which the run off flows; (see photo below)
- 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 rooting and biomass. It should also be resistant to high soil sedimentation and flow of water (flood pressure); and
- A lot of biological materials, which can fit to this condition, can be found locally by consulting the farmers.

1.3 Consequences of gully formation

There are different negative consequences as a result of gully formation due to severe rain erosion. The impact could be on economic, social and ecological aspects of the areas affected. Among those consequences of gully formation, but not limited to, some are:

- Degradation of the land and loss of the natural resources
- Reduction in crop production and productivities
- Loss of range land that could feed a reasonable number of livestock
- Destruction of infrastructures such as roads, culverts and bridges
- Time wastage to access various social services such as schools and market places due to difficulties to cross
- Serious erosion hazards to downstream neighboring kebeles that has destroy lives
- Drying up of streams and dwindling of irrigation activities
- Increasing food insecurity
- Shortage of drinking water especially during the peak dry seasons
- Threats to adjacent farmlands due to the widening up of the gully offset yaer after year etc.

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MODULE 2: CHECK DAMS

2.1 Concept of check dams

In gully control, physical or structural measures are measures of gully control used to dissipate the energy of runoff and to keep the stability of the gully. Gully control is the technique deployed to rehabilitate the already degraded gully so as to reduce soil and water loses by reducing the runoff. Control structures for large gullies require an engineering design and are expensive. If the stabilization of gully head appears too costly or difficult, it is possible to divert the runoff away from the gully head so that it ceases at least to erode and expand. Otherwise it is possible to place a check dam close to the gully head so that it traps sediment, raise the floor level and submerge the head.

2.2 Definition of check dams

Check dams are an obstruction wall across the bottom of a gully or a small stream. There are different types of physical techniques which can be applied for effective gully treatment. Brushwood check dam, Loose stone check dam, Gabion check dam, Arc weir check dam, Organic gabion box/ bamboo mat check dam, Sediment Storage Dam and Sand bag check dam are the lists of check dams used in gully rehabilitation work. Check dams are made of stone/stone and mortar/stone and galvanized iron/soil filled plastic and galvanized iron/ soil or sand filled bag/ brush bamboo mat/box/ woods or other building material. Structural gully control measures/check dam are mainly an aid to vegetative control measures especially in areas where conditions are not suitable due to less conducive environment. Structural gully control measures are essential for treatment of critical locations, like gully head cuts, entrances of branch gullies and at places where abrupt changes in the gradient occur. One or a combination of the available technology should be used to control the gully.

2.3 Reasons for constructing check dams

Check dams are constructed across the floor of the gully to reduce the channel gradient and then to slow runoff and to trap sediment. Check dams reduce velocity of runoff, reduce erosion, increase silt deposition and prevents the deepening and widening of a gully channel. Run-off during peak flow season is conveyed safely by check dams. If properly used and the runoff flowing to the gully is diverted, check dams can also be used to gradually build up the floor of the gully to its original ground level, or to rehabilitate the gully. Check dams also serve to recharge ground water and give rise to springs at downstream areas. They are mainly used to facilitate the establishment of vegetation in the gully, which will eventually stabilize and protect it from further erosion permanently. Sediments behind a check dam may also be planted with cash crops or trees/shrubs and grasses to generate additional income for the farmers.

2.4 Time of construction of check dams

Check dams should be constructed only during the dry season and in periods not interfering with land preparation and harvesting. The required materials should be available at the right time in the right place and quantity to put in place those structures timely.

2.5 Place of construction of check dams

Check dams are constructed across the gully bed to stop channel/bed erosion. Check dams can be used in different parts of the country or all over the country in different agro-ecologies. For example, silt storage dams (SSD) are common in dry lands areas, Arch weir check dams are suitable all over the country provided stones are available and sand bag check dams are suitable all over the country where soil/sand are available. A combination of different check dams can be used based on the availability of the resource, the type of gullies, the financial capacity and the objectives of the check dams. Commonly, check dams' used to check gullies on highly eroded grazing and cultivated lands and hillsides in consideration of the local experience. Check dams are not suitable for large gullies without catchment treatment and protection (land use). Check dams can be used particularly where local structures are damaged by excess runoff. Check dams can be constructed in a wide range of conditions, such as the following:

- In small gullies serving a larger one
- As stone outlets for traditional or newly constructed bunds or terraces unable to accommodate all run-off
- As a silt trap for water ponds.

2.6 Construction principles of check dams' for gully rehabilitation

To obtain satisfactory results from structural measures, a series of check dams should be constructed for each portion of the gully bed. Series of check dams are less likely to fall as one supports the other. Shorter check dams from are more desirable than high ones. The following principles are crucial for the effective implementations of soil and water conservation measures in general and gully rehabilitation in particular:

- *Ridge to valley:* Gully control practice should start from the top of the gully and proceed downhill to safely handle and protect surface run off.
- *Simple, low cost and less labour demanding for a maximum benefit:* Gully rehabilitation structures/ technologies should be simple to understand and doable by land owners. Labour and cost demand has to be maintained at optimum level to meet its objective and achieve the maximum benefit.
- *Socially accepted and sustainable:* Any conservation structures should get acceptance by the implementers for its sustainability
- *Proper location, design, lay-out and construction procedures:* Structures should be placed at their appropriate place in the landscape, properly designed, and constructed scientifically.
- *Provide short term benefits:* The 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 and water use. For sustainability of enclosures, the surrounding communities must also benefit from cut-and-carry of the grass/resources, collection of dry wood, collection of wild fruits and traditional medicines, apiculture and other activities.
- *Integration of physical measures with biological:* it is very important for sustainability and effective stabilization of the gully.
- *Adopting conservation measures to the local situation:* There is no single approach to gully rehabilitation measure that can be adopted in all situations. Blanket recommendations do not work. Build on traditional practices, local knowledge and experience as far as possible.
- *Active participation of communities especially women:* Involve farmers in identifying priorities, analyzing problems and devising solutions. Encourage group work and strengthen local institutions for these purposes.
- *Stage of erosion:* active gullies with steep gradient require stronger and durable check dams than passive gullies with gentle slopes.
- Characterization of the gully prior to implementations:- Application of the technology is based on the:
  - → The availability of resources
  - → The amount and speed of the run off
  - → The depth and area of the already formed gully etc

- *Repair and maintenance:* Every year, just before the inception of the rainy season and immediately after heavy rain flood, structures need to be checked and maintained. Perhaps one of the possible arrangements for maintenance could be to give responsibility for the owner of the land to regularly maintain the structures and protect structures from livestock and humans trampling effect. If the area is a communal land, arrangement could be done with local landless or other community based organizations to bear such responsibilities.
- *Precaution measures for wild fire:* Care should be taken for unanticipated bush fire!

2.7 Planning of gully control measures

Gully control plan should take in to account the following:

- Maximum retention of rainfall and runoff in the watershed
- Interception and diversion of runoff above the gully area (proper attention should be given to discharge the diverted water into safe outlets and waterways).
- Re-vegetation through allowing regeneration of vegetation or through planting
- Construction of grade stabilization structures to control the channel erosion and encourage sedimentation behind the structure
- Exclusion of all kinds of grazing
- Gully wall filling and reshaping for small and active gullies only

Determine the land use

Soil and topography should be assessed. Methods of assessment and mapping of gully erosion are:

- Direct field observation and measurement
- Using GPS/GIS
- Using Google earth maps
- Combination of all of the above.

Advantages of gully erosion assessment and mapping

- To have an overview of erosion in a particular area/watershed
- To document the extent of damage/severity as a result of gully formation
- To identify the nature of a gully and causes of its formation
- To get relevant information for designing of appropriate measures for gully treatment - niche based intervention
- To discuss/agree with farmers on the design and layout and provide on-the-job training for experts, DAs and community facilitators,
- To perform precise layout adaptations which are critically important for gully control.

2.8 Layout, design and construction of check dams

Check dams can be categorized as temporary and permanent based on their life spans. Temporary check dams include brushwood, bamboo mat and sand bag while permanent check dams are loose stone, arc weir, gabion, sediment storage dam. Retaining wall can also be temporary or permanent based on the material it is made. Both types of check dams are used to facilitate the growth of permanent vegetative cover. The following are procedures (summary points) to be considering in the construction of check dams.

- Proper site selection for the construction of the check dam is essential. It should not be where gullies get very narrow, deep, turning or have steep slopes.
- Proper design should be based on the contour
- Deciding on the type of the structure and spacing between the successive dams
- The effective height of the dam ranges from 1-1.5m excluding foundations.

- Start construction at the upper end to reduce the risk of failure if the water enters the gully before all check dam constructed.

Before starting to construct check dams, the following activities (technical preparations) are essential.

The steps in layouting

- Assessment of the gully is the first steps for check dam construction;
- Determining/design the check points; and
- Finding the contour line where the check dam place is perpendicular to the channel of the gully bed.

Contour lines are horizontal lines across a slope, linking up points of the same elevation. These lines are important for constructing barriers for the interception of surface water flow like bunds, cut-off drains, in soil and water conservation.

Design and construction of check dam

The selection of the type of check dam and the extent to which it can sustains depend on the amount of runoff and the nature/character 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 same. Consideration should then be given to ways of stabilizing the gully head, floor and its 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. Check dams may also be combined with retaining walls parallel to the gully axis in order to prevent the scouring and undermining of the gully banks.

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 structural gully control measures will fail as well. For stability of structures and quick healing the gully head should be reshaped and planted with grass sod. Structural measures are just an aid to vegetative measures. In dry areas where conditions are harsh for vegetative measures, structural measures are the only means and are highly recommended. Check dams need good skills for their design and construction and they may be expensive to implement.

Before starting to construct check dams in a gully, experts must calculate and determine the *spacing* between check dams, the design of the *spillway*, *apron* and *side key*. These three elements are critically important to construct a given type of check dams.

Methods of making contour lines in a gully

There are two simple methods/ways of contour making: line level and frame methods.
Line level method: Materials needed in using this method are:

- Two wooden posts of 2m long graduated/marked /at every 10 cm interval, Sprit level /line level, 11m plastic string, Pegs to mark ground every 10m (20 pegs for 100mts), and Three to Four people (Two persons to hold poles at the right angle position to pull the full length of 10m stretched out with optimum tension; one person to read the line level and guide the movable wing person to move up and down the slope till the line level is exactly between the two cross hairs and a third person for making points with pegs).

Procedures in working with line level are:

- Tie the 11m plastic string exactly at10m between the two poles (1m is used to tie)
- Mark the point of start first with peg

- Hold one pole in upright position at the starting point and stretch the full length of 10m string across the slope with optimum tension.
- Put the sprit level at the middle of the string
- Start instructing the movable wing to move up and down slope until it is level
- Put peg at a point of movable side point when it shows level
- Start again from the second contour line marking point
- Proceed across the slope until you finish marking the contour line
- Survey 10 m at a time and in difficult topography only 5m
- Spacing is pre determined through appropriate VI (vertical interval)

Determining the base width, length, height of the check dam, etc based on the gully width
- Determine and design the type of structure (loose stone, gabion, arc weir, ...)

Key elements in layout:
- Soil depth and slope – vegetation cover (remove under most structures except for sodding based),
    - → Traverse (lateral) slopes – avoid swinging lines by applying reinforcements (see bunds),
    - → Use of line level and A-frame,
    - → Staggered position as required,
    - → Safety devices (spillways, outlets, pitch, plates, scours, etc), &
    - → Laying out for check dam placement in the gully using line level

Spacing between check dams

The spacing between two consecutive check dams should be such that the spillway crest of the lower check dam is level with the base of the upper check dam (see figure 1 below). With this assumption, the spacing between check dams can be calculated using the compensation gradient or empirical formula as follows.

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, 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, 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 (figure 1). It is formed when the material carried by flowing water deposited and fills the check dams to the spillway level. Field experience has demonstrated that the compensation gradient of gullies is not more than 3 percent. The first check dam should be constructed on a stable point in the gully such as a rock outcrop, the junction point of the gully to a road, the main stream or river, lake or reservoir. If there is no such a stable point, a counter-dam must be constructed. The distance between the first dam and the counter-dam must be at least two times the effective height of the first check dam.

The points where the ensuing check dams built are determined according to the compensation gradient and the effective height of the check dams. Figure 2: 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.

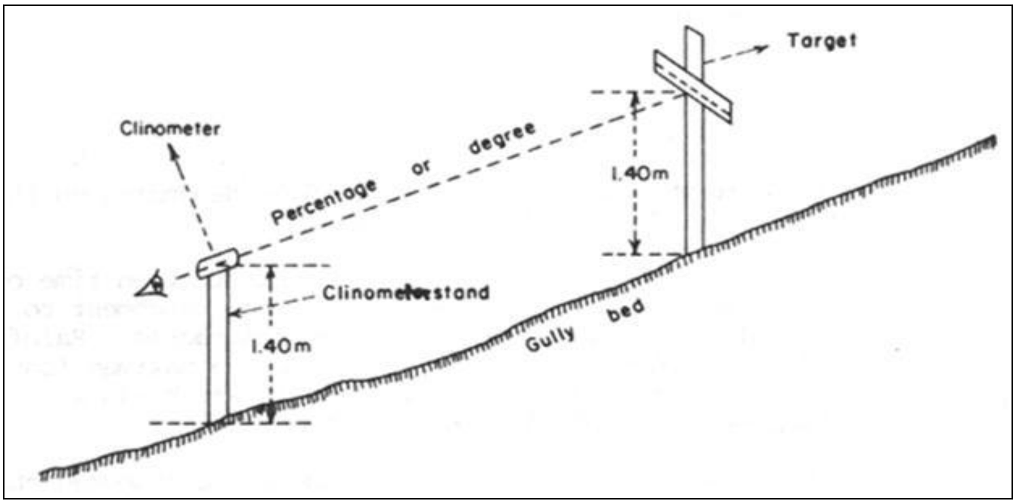

Figure 1: Measuring the gradient of the gully between check dams (Source: http//www.fao.org)

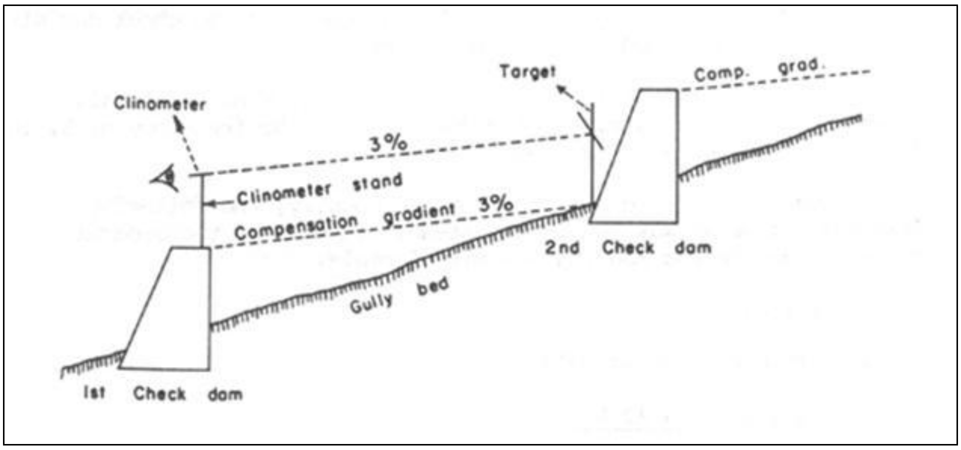

Figure 2: Measuring the compensation gradient between check dams, Source: http//www.fao.org)

Stand at this point marked at the edge of the gully, or if this is impossible, at another position on the same level as the marked one. Since at this point the compensation gradient is measured as three percent, the construction site for the third check dam has been determined. In this way, all the other proposed check dam points can be marked in the gully.
While spacing the check dams, give preference to the narrowest parts of the gully in order to reduce construction costs. In this case, to establish the compensation gradient between the proposed check dams, proportionately increase the foundation depth of the upper check dam when the space between the lower and upper check dam is extended. When the space is shortened, decrease the foundation depth (figure 1). As the foundation depth is increased,

the total height of the check dam (effective height plus foundation depth) should not exceed the permissible, maximum total height.

b) *Calculate spacing between check dams using empirical formulae:*

S = 1.2H/G Where;
S it the spacing in meters (figure 3)
H is the effective height of the check dam (spillway height in m)
G is the gully gradient

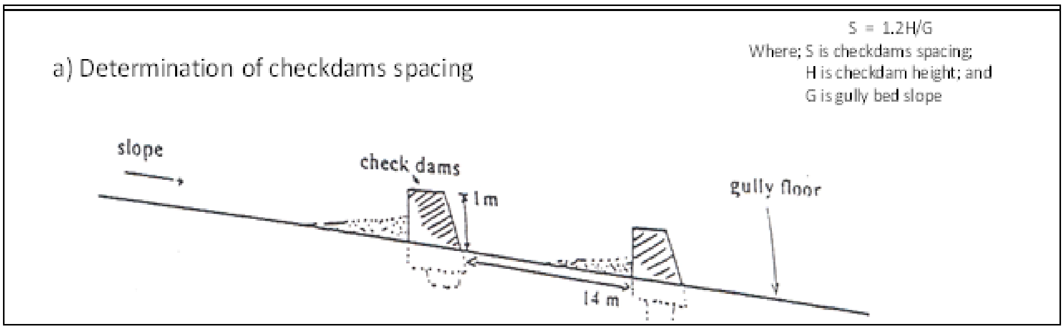

Figure 3: Determination of spacing between check dams (***Source:*** http//www.fao.org.)

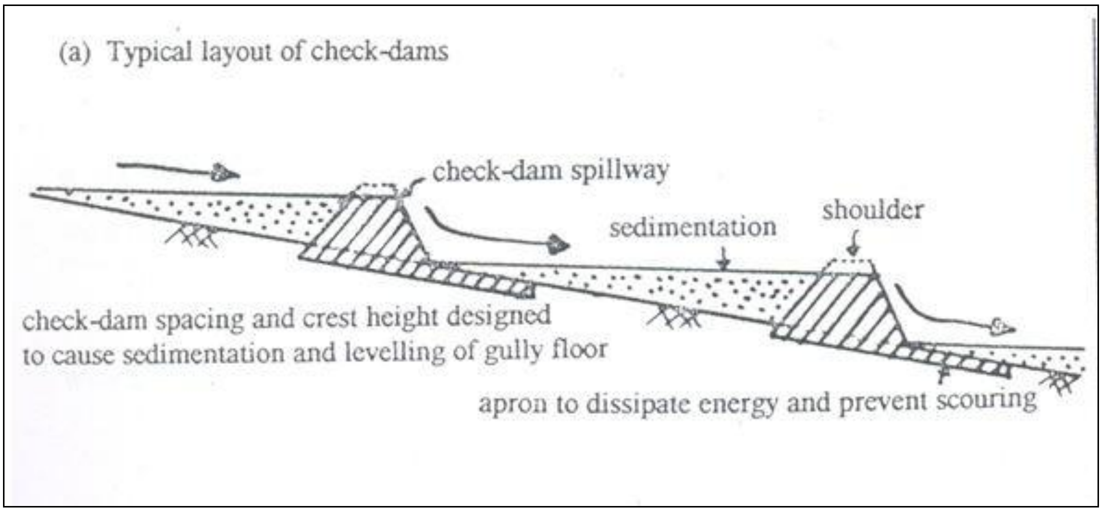

Figure 4: Determination of check dams spacing and the layout (***Source: -*** http//www.fao.org)

Spillway design

Spillway is a part of the check dam used to discharge the runoff properly thus protecting the check dam. It 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. The reason why the peak runoff rate used to determine the capacity of channels is to avoid the 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. It therefore, must be sufficient size to accommodate the maximum flow expected once in ten years. Information provided by local community should be taken as an indicator to help derive a reasonable estimate, which is far superior to a wild guess.

Estimation of catchment runoff is important in order to design appropriate conservation structures. For a rough estimate of a peak flow, the watermarks visible line on the gully banks via debris deposits and this gives a good indication of the magnitude of peak flow and the dimensions required for the spillway. For a better and realistic way of estimation, 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. Spillway (trapezoidal) of check dam with 0.25m free board and 0.25-0.3m permissible depth, width minimum 0.75m and maximum 1.2m (for small catchments) is advisable.

(II) Spillway design using an empirical formula using cooked food:
Q = CLD 3/2
Where:-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(l) = Length of spillway in meters; D(d) = depth of spillway in meters (figure 5)
Q = Maximum discharge of the gully catchment at the proposed check dam point, in cubic meters/second.

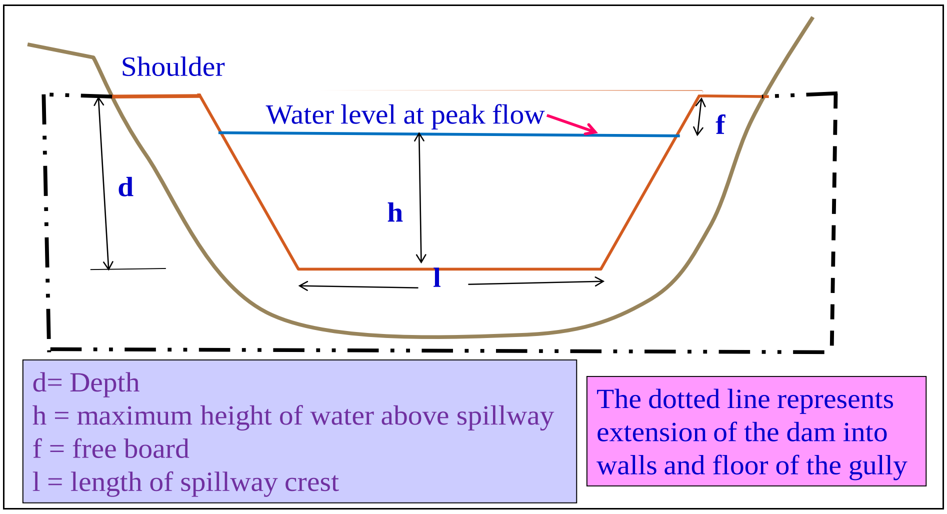

Figure 5: Cross sectional model drawing for water discharge (Source: Belayneh Adugna, 2012)

The energy of the waterfall through the spillway increases with the depth of flow. 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 reduces the splash effect of the falling water on the gully banks.

The shape of a check dam spillway can be trapezoidal (the red line in figure 5 above), rectangular, triangular or parabolic (figure 6). It is preferable to have trapezoidal shaped spillway (as shown in figure 5 above) because this cross-section is stable. Trapezoidal spillway is for loose stone, gabion and cement masonry check dams. Rectangular spillway for brushwood, log (pole), gabion and cement masonry check dams and concave spillway for brushwood and loose stone check dams. Care should be taken not to use small stones at the spillway and the dam crest.

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 9.675m3/second. What are the dimensions of the check dams' spillway?

Solution: The spillway dimensions can be calculated by the spillway formula as follows:
Q = CLD3/2
Q: 9.675 cubic meters/second,
C: 3.0 coefficients 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 0.83/2 = 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.

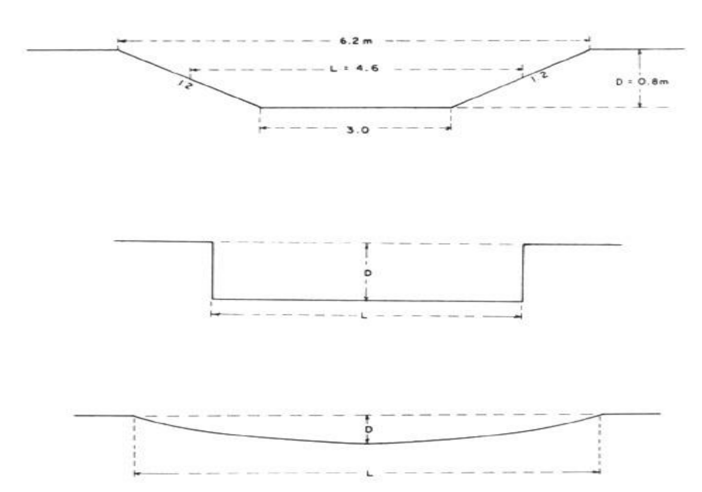

Figure 6: Common spillway forms used for check dams (*Source:-http//www.fao.org)*

Spillway dimensions can also be determined using table 1. 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 in m3/sec. To design the dimensions of the spillway different procedures can be followed.

Table 1: Depth of spillway required for different widths and discharges

	Average width of spillway (m)						
Depth 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
0.30	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
0.60	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

Apron

Aprons are structures to be constructed on the downstream side of the check dams. It is designed to dissipate the energy of falling water passing through the spillway and/or to protect the dam from undercutting. 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 should be filled with gravel. In conditions when the spillway height is high, apron can be constructed from gabion box filled with stone or steps using stone and mortar.

An apron may also be built below the ground surface. In this case, it will form basin, which when filled with water, will function as a water cushion and dissipate the energy of water falling on it.

Apron should have a 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. An apron with a minimum of 1 m length towards water flow should be constructed. A sill, about 15 cm high, should be constructed on the lower end of the apron to reduce the speed of the water and keep some water on the apron that serve as a blanket. The apron should be built at least 50 cm wider than the spillway opening on both sides (total width 1.5-2m) (figure 7).

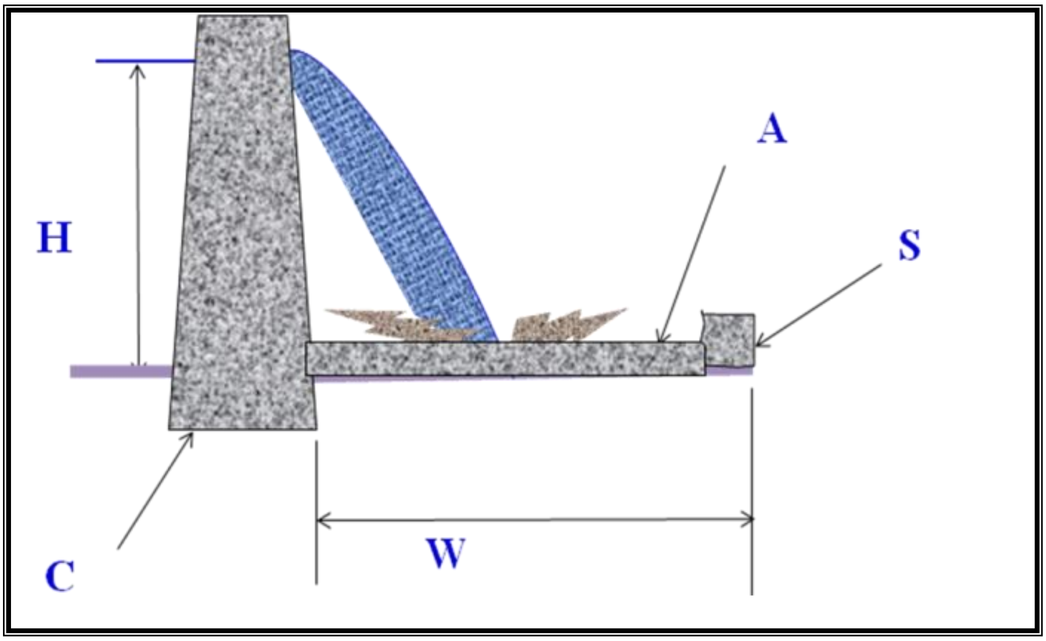

Figure 7: Design and types of Apron: above ground and flush apron (Source: Belayneh Adugna, 2012)

Where A = Apron;
S = Sill;
W = Apron width;
C = Check dam; and
H = dam Height

Side key

The other thing to be considered is the side key of the check dam. Key is a part of the check dam which helps to strengthen the resistivity of the constructed check dams against the force/pressure of erosion. The check dam key should be properly keyed across its base and up the abutments, to the crest elevation. It should extend to about 0.5 to 1m on each side of the gully wall during constructions (figure 8).

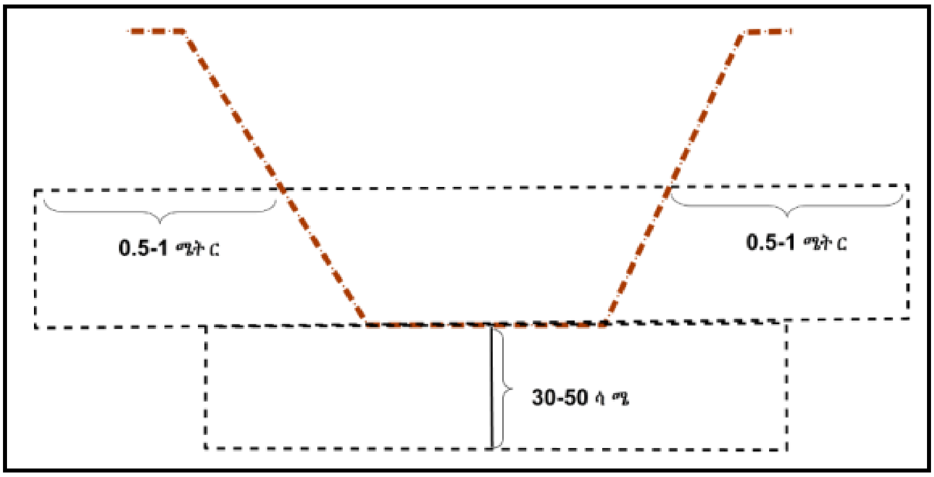

Figure 8: Drawing that shows foundation depth and length of side key

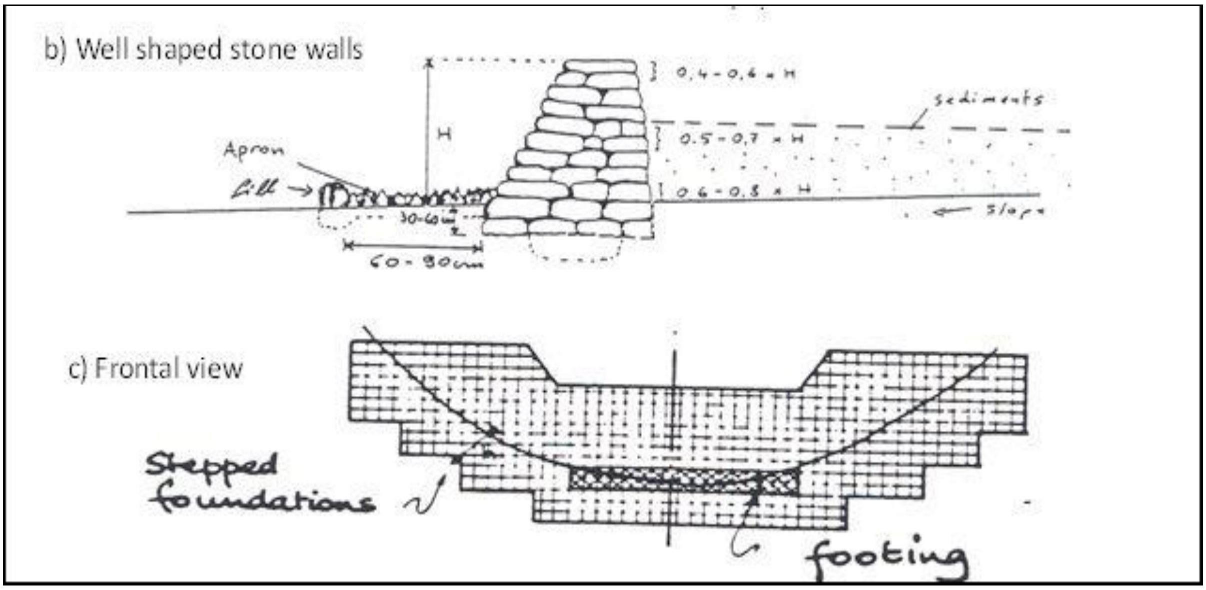

Figure 9: Shape of the check dam (b) and steps of the foundation (c) (***Source:-*** http//www.fao.org)

How to sustain check dams (Management, integration and utilization requirement)?

The sustainability of treated check dams is a function of layout, construction standards, nature of the soil, altitude of the treated gullies, proper follow up of the farmers, integration of physical with biological conservation measures, insensitivity of the rainfall, catchment treatment and protection. For a sustainability of check dam the following are important:

- Appropriate spacing during construction
- Well founded basement, side key and apron as per the standards
- Appropriate position and capacity of spillway with maximum runoff
- Supported with gully reshaping and retaining wall structures
- Integration of the physical with biological measures (Gully sides should be planted with rows of grass and possibly re-enforced with sisal plantations along the upper and/or lower side of the dam).
- Upgrading or rising of the check dam as necessary
- Fertility improvement (compost, etc) within 1-2 years
- Use of quality construction materials and its appropriate mix (sand and cement)

- Protection/closing the area from human and/livestock traffic for quick recovery of vegetation (avoiding farming or grazing right up to the head or sides of the gully and never allow traffic in a gully is very crucial).
- Repair damaged check dams especially during rainy seasons to avoid further damage and eventual collapse (Maintenance for structural measures must be continued for at least two years after the treatment year).
- Train, participate and empower farmers to take part from site selection and construction of check dams up to the protection and maintenance.
- Training and awareness creation to improve the knowledge and skill of farmers should also be considered.
- Proper application of use concept or management plan prior to any rehabilitation activities in gullies is critically important.
- Application of proper construction procedure following standards,
- Closing the area from free grazing and establishment of buffer zones
- Organizing community in user groups, establishing functional byelaws under legalized watershed associations and so on.

What are the common mistakes?

- The base of the check dam is often built too 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 deep (keying) as per the recommendations;
- Spillways are not built with a proper shape (parabolic/trapezoidal) and dimension. Spill ways should be built with 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;
- Construction of check dams with organic box, loose stone, plastic bag etc in places where there is no sufficient soil depth;
- Inappropriate construction of check dams (side key, spillway, shaping, filling of gabion box and apron);
- Failure to complete the work: half measures do not offer the required protection and are a waste of time and resources;
- Poor soil and water conservation measure considerations for upper catchment treatment;
- Use of loose stone, plastic bag, bamboo box etc check dams for very large gullies;
- Poor integration between physical and biological measures;
- Poor regular maintenance and protection; and
- Lack of sense of ownership and accountability

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PHYSICAL GULLY REHABILITATION MEASURES

MODULE 3: GABION CHECK DAM

3.1 Concepts and purpose of Gabion check dam

Galvanized Gabion check dams are rectangular boxes varying in size and are mostly made of galvanized steel wire woven in to mesh. The boxes are tied together with wire and then filled with either small stone or plastic filled soil materials. The same principle is followed with wire gabion boxes, lined with plastic sheeting and filled with soil. Then they are placed across the gully as building blocks. Gabions are filled in situ and as they are very heavy they will not be washed away provided they have been correctly installed. Gabions may be laid in courses like large bricks to form bank revetment, etc. 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.

3.2 Reasons for construction of Gabion check dams

Gabion check dam is tough and long lasting dam provided that the wire has been well galvanized. Furthermore they are somewhat flexible and can be installed where the surface is uneven. Once in placed and properly anchored, gabion check dam can resist even strong floods and last for longer. Gabion check dams combined with gabion retaining walls can be used to stabilize landslides in the upper portions of the gully. They can also be used to stabilize roadsides, embankments, river banks etc.

3.3 Place of construction of Gabion check dams

Gabion check dams are suitable in all agro ecology where gullies are formed and extended. Gabion can be constructed with stone in area where stone is available. In areas where stones are not available it can also be made with soil/sand filled bags together with plantations. Installing gabions is not a substitute for land misuse and, if the land is denuded, installing gabions will not solve the problem unless vegetation cover restored.

Gabion check dams are commonly used to check large gullies on highly eroded grazing and cultivated lands and hillsides combined with catchment treatment and protection. Gabion could be used in a wide range of conditions: to treat big gullies, to construct retaining walls on gully/river banks, to make fords for access roads and to strengthen irrigation structures.

3.4 Design and construction of Gabion check dams

Following the excavation of the foundation each gabion box should be laid into two gabion boxes at a time to improve the strength of this check dams. A good foundation must have sufficient strength to withstand the weight of the structure and prevent sliding/bulging. It should be tight enough and uplift must be reduced as much as possible. It should also not be damaged by overflow discharge and outlet discharge. After sediments have been deposited behind the structure, it is possible to raise the spillway height by adding additional gabion boxes. The spillway is always having lower height than the side key (Figure 1 left). 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 1 here under. When suitable soil condition do not exist, sidewall reinforcement is required.

Table1: 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

Technical standard and construction procedures

- Gabion check dam construction starts from ridge and proceeds to bottom;
- After digging the foundation, a layer of box gabions are placed vertically. Gabions need to be closed by using large spanners (closers). Similar diameter have to be wired together with binding wire;
- Gabions should be constructed on spots where the soil depth is higher, preferably in a wider part of the gully next to series of loose stone check dams;
- Stones to be used for filling the gabions should be hard and of sufficient in size and should be placed tightly together so that no large voids are created that could give space for water to flow through and eventually result in sinking of the dam. To avoid this, the bigger stones should be put along the sides of the gabion box while the smaller ones are filled in the middle, and finish a top layer with large stones;
- When using gabion box which are two meters long, after one-third is full, place five parallel ties between their inner and outer sides. Five more are placed when the boxes are two-thirds full. Four corner ties are also placed;
- After overfilling a box gabion slightly to allow for subsequent settlement, a lid is laced with binding wire to the top of all the sides. The lid must be stretched to fit exactly to the sides,
- If there is more than one layer of boxes in a gabion check dam, the ones in the upper layer must be laced to those below. A strong inter-connection of all units is an important feature of the technique. Therefore, it is essential that the lacing is done correctly;
- When a gabion check dam has three layers and is no higher than three meters, place a "binding box gabion" in the middle or top layer;
- The space behind the dam and wing walls should be filled with soil excavated for the foundation and from the gully bed;

- The depth of the foundation is equal to one-half of the effective height of the dam, which means that the foundation depth is one-third of the dam's total height. The foundation is longer than the spillway. The foundation depth (key trench) should not be less than 50 cm;
- Wings should enter at least 50 cm into each side of the gully and they should be protected against flash water by wing walls. The angle between the wing and wing wall is 0 to 45 degrees. The height of a wing wall is equal to the depth of the spillway;
- Construct apron from downstream side of the structure with a foundation of 30cm;
- It is neither necessary nor economical to build a series of gabion check-dams to control channel erosion along the gully beds. However should only be used if no other cheaper method will suffice; and
- Gabion check dams are built by placing the galvanized wire boxes across gullies, "usually not higher than 1.5 m spillway height" in the first year.

After following the above steps and procedures the scheme of gabion is presented below in figure 1 right.

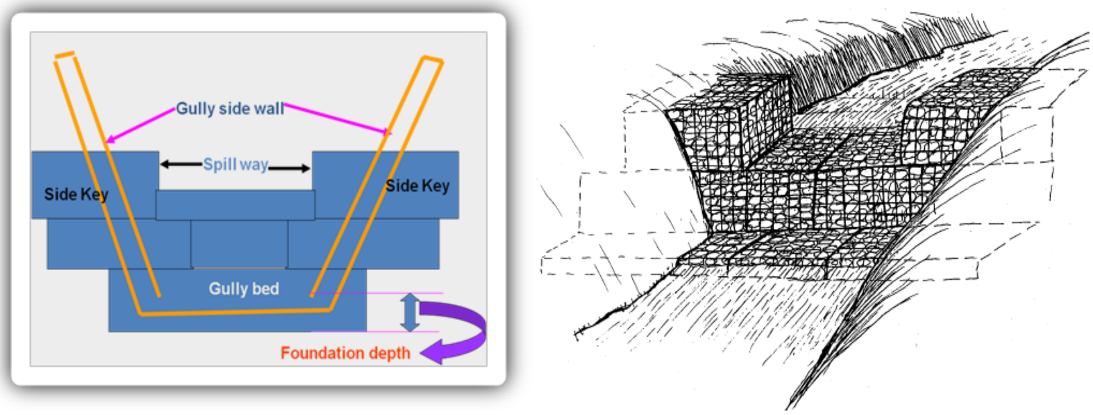

Figure 1: Scheme of the gabion check dam (*Source: Belayneh Adugna, GIZ-SLM, 2012 (left) and http//www.fao.org. Basic Gully treatment measures (right))*

Work norm and norm elements

The work norm includes stone collection, foundations/key excavation and proper placement of gabion boxes, stones and drop/apron structures. Work norm is 0.25 m3/PD.

Minimum surveying and tools requirements
Layout: One water line level, one range graduated in cm and 10 meters of string.
Tools: Shovels pick axes, crow bars and sledgehammer.

Reasons for failures in gabion check dams

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. Poor regular protection and maintenance is also the other factor.

How to sustain the constructed Gabion check dam (Management and integration requirements)?

The sustainability of the gabion check dam depends on catchment treatment, layout and design, construction standards, and proper follow up and integration with biological conservation. Provision of appropriate knowledge and necessary skill for the farmers has great importance for the sustainability of the structure and the watershed in general. Some of the important activities that need to be considered for the sustainability of check dam are:

- The gabion check dams, similar to other check dams, require proper regular follow-up and maintenance work through group of people sharing the gully area;
- Upgrading or rising of the gabion check dam may be required;
- Supplementary measures such as integrating with plantation, reshaping and stabilization of gully sides should be performed as required; and
- Plug the scouring places with jut bag and other local material after every run off, until it is fully sediment to the reservoir level is essential.

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MODULE 4: SAND BAG CHECK DAMS

4.1 Definition and purpose of sand bag check dam

Sand bag check dams are temporary check dams constructed by filling the sand in the bags and piling them across large rills or small gullies up until the desired height levels. The bags are piled up usually to a maximum of 3 – 4 layers to form a small check dam. The bags used for the purpose are either used jute or polyethylene bags (50 kg).

4.2 Place of construction of Sand bag check dams

Sand bag check dams are suitable alternative technologies for every agro-ecology all over the country provided stones, wood and other materials are not available in the area to use other types of check dams. It is commonly used to check rills and small gullies on temporary basis. It is a very good technology for the gully head control. Nevertheless, it is not suitable for the treatment of large gullies.

4.3 Layout and construction steps of sand bag check dam

Fill bags with sand up until a little space left after tying to enable it to fully lay and touch with high surface area. White clay or termite mound soils “Kuyisa” can also be used instead of sand as they are also less erodible and can stay intact in flood water.

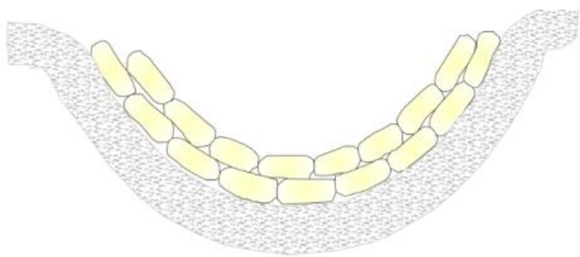

Figure 1. Sand bag check dam (Source: GFA-Amhara, Jan 2013)

While piling up, water the sacks first to make them wet, which in turn will help to avoid easy sliding of the sand bags (Figure 1).

Pile up sand filled bags to a height of 1m. Construct a side key of 0.5m on each side of the gully wall.

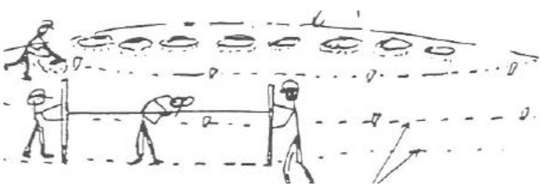

Figure 2: Lay outing and pegging (Source: MOARD, Jan 2005)

Construct trapezoidal/parabolic shaped spillway with 0.25 – 0.5 m permissible depth and 0.25 m free board; and width 0.5 – 1.2 m. The spillway depth depends on the expected flow.

Support piled up sand bag check-dams, on the downstream side, with brush wood structure or wooden poles to avoid easy washing away of the dam.

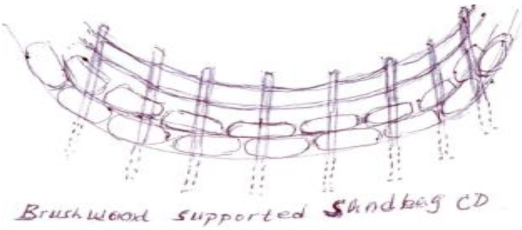

Figure 4: Sand bag supported by wooden poles on the downstream side of the gully

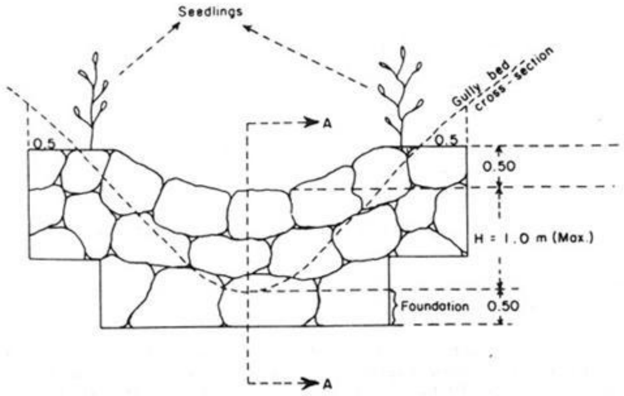

*Figure 3: Design of the key & foundation (*Source: MOARD, Jan 2005)

Work norm and norm elements

The work norm includes proper placement of sand bag check dams, soil filling inside the bag, compaction and tying. Work norm is 0.5 m3/PD.

Minimum surveying and tools required

Layout: One water line level, one range graduated in cm and 10 meters of string.
Hand tools: Shovels, plastic bags or jute sacks, pick axes, crow bars and sledgehammer.

4.4 Management and maintenance of sand bag check dams

- The combination of this technology with other relatively stronger structures (for example gabions) is an important consideration to be made for better efficiency and durability.
- Sand bag check dams can also be combined with brushwood check dams of single-row or double row.
- As soon as an adequate degree of sedimentation has been deposited, appropriate biological measures should be taken so as to strengthen, and eventually replace the "sisal made sack", which would rot over time.
- As a result, the expansion, deepening and elongation of gullies will be reduced and gully beds and sidewalls would be converted into productive areas.
- It is necessary to enlarge the size of the check dam width and minimize the height whenever the volume of water that comes from upstream catchment is high.
- Regular visit and maintenance of plastic bag check dams especially after heavy floods is very important at initial period of constructions.
- The reshaping of gully banks is also important to manage and maintain plastic bag check dams.
- Establish buffer zones and/or closure areas with committed community owned watershed associations.

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MODULE 5: LOOSE STONE CHECK DAMS

5.1 Purpose of Loose Stone Check dam

Loose stone check dam is an obstruction wall across the bottom of a gully or a small stream constructed for the purpose of reducing the velocity of runoff, encourage siltation and prevention the deepening and widening of a gully channel.

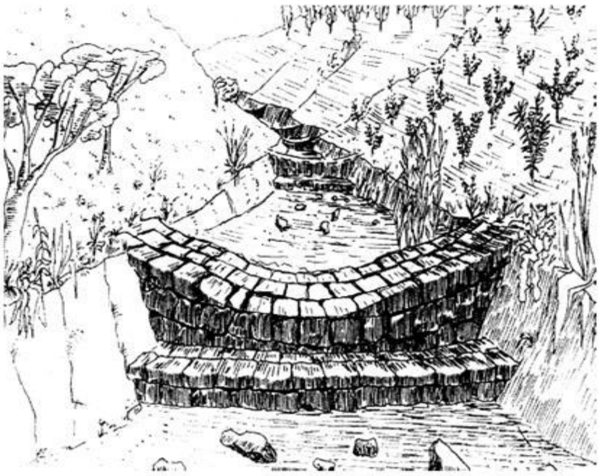
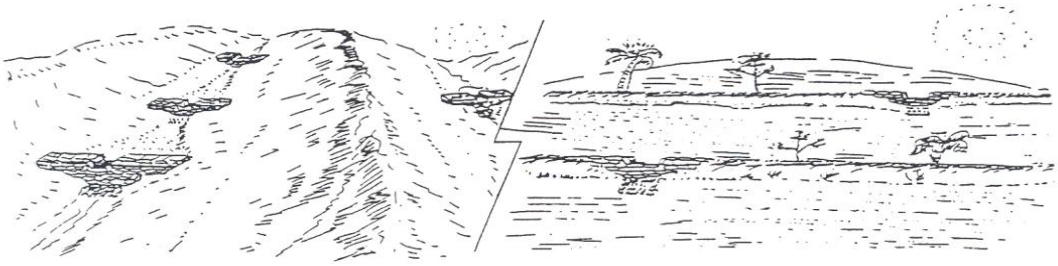


Figure1: Typical Loose Stone Check dam
(*Source***:** *MOARD, Jan 2005)*

5.2 Place of construction of loose stone check dams

Loose stone check dams are suitable all over the country provided stones are available. It is commonly used to check gullies on highly eroded grazing and cultivated lands and hillsides. It is not suitable for large gullies without catchment treatment and protection measures. Loose stone check dams could be constructed in a wide range of conditions:

- In small gullies serving a large one;
- As stone outlets for traditional or newly constructed bunds or terraces unable to accommodate all runoff (Figure 2); and
- As a silt trap before a water pond (water harvesting structure).



a) In small gullies b) As outlets for bunds/terraces

Figure2: Loose stone check dams' perspective View (Source: MOARD, Jan 2005).

5.3 Layout and construction steps to follow

Collection of stones necessary for the construction of the check dam.

Peg and tie a string marking base width of 1m- 3.5m on the floor across the gully bed (Figure 3).

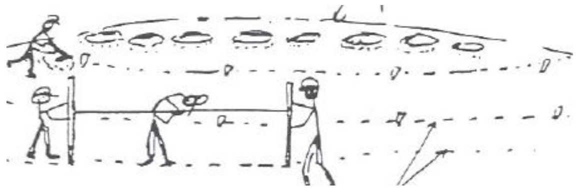


Figure 3: Layouting and pegging (Source: MOARD,Jan 2005).

Construct the loose stone to a height of 1m excluding the foundation (Figure 5).

Place stones in such a way that they interlock easily and form a denser structure. If small stones are to be used they should be placed in the inner parts and the outer surface should be covered with large stones to strengthen the dams (Figure 6).

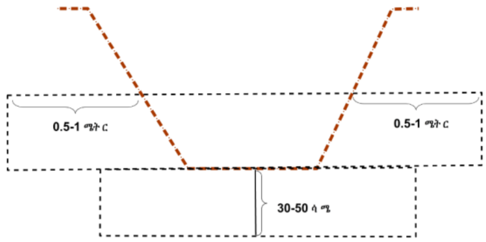


Figure 4: Schematic representations of foundation and side keys Source: GFA-Amhara (Jan 2013)

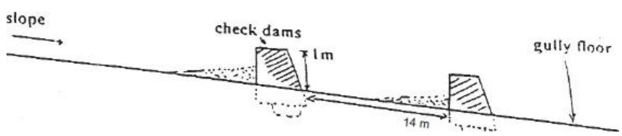


Figure 5: Determination of spacing between check dams (Source: http//www.fao.org)

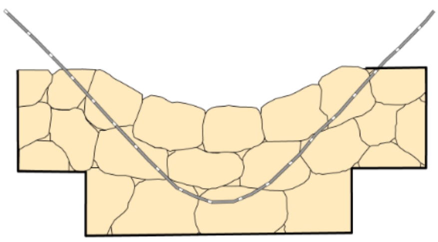


Figure 6: Design of foundation & spillway Source: GFA-Amhara (Jan 2013)

Construct a side key of 0.5 to 1m on each side of the gully wall (see Figure 7).

Construct a trapezoidal/parabolic shaped spillway with 0.25 – 0.5 m permissible depth and 0.25 m free board; and width 0.5 – 1.2 m. The spillway depth depends on the expected flow.

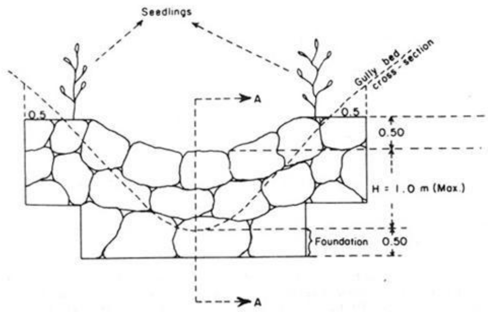


Figure 7**:** Design of the key & foundation Source: MOARD (Jan 2005)

Construct apron on the downstream side of the check dam to protect the dam from undercutting. The apron should be placed in an excavation of about 0.3 – 0.5 m to ensure stability and prevent wash away (Figure 8).

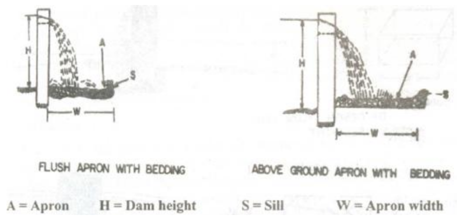


Figure 8: Side view of a check dam with its apron showing the effective height, apron width and sill (Source: Daniel Danano et al. 2001)

Apron length should be at least 1.5 times the effective height of the check dam and as wide as the gully bed. For gullies with slopes more than 15% the apron length should be 1.8 times the height of the dam.
Construct a sill of about 15 cm on the lower end of the apron.

Construct drop structures before the apron (ladder placed stones between the spill way and apron) in places where there is a steep slope of above 15% (Figure 9).

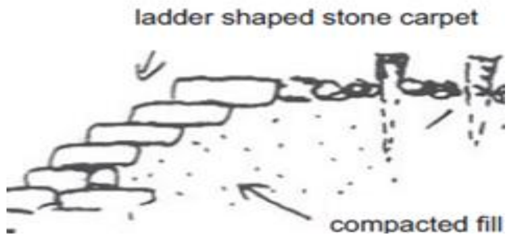


Figure 9: Drop structures constructed before apron (Source: MOARD, Jan 2005).

Work Norms
0.5 M3/Person-day. The work norm includes stone collection, foundations/key excavation and proper placement of stones and drop/apron structures.

Tools/equipments
One water line level, one range graduated in cm and 10 meters of string for lay out and shovels, pick axes, crow bars and sledgehammer.

5.4 Maintenance of loose stone check dam

- Loose stone check dams should be strengthened by covering the upstream wall and the crest with bamboo/red-mat. This helps for better durability of the structure.
- It is important to plug the scouring places with jut bag after every run off, until it is fully sedimented up to the reservoir level

- Upgrading or rising up of the effective height of original loose stone check dam may be required depending on the level of siltation during the rainy season and the depth of the gully.
- Gully sides should be reshaped and planted with rows of grasses, possibly reinforced with plants such as Sisal, Euphorbia, etc, placed along the upper and/or lower side of the check dam.
- Gully protection/closure is important for quick recovery of vegetation and sustainability of loose stone check dams.

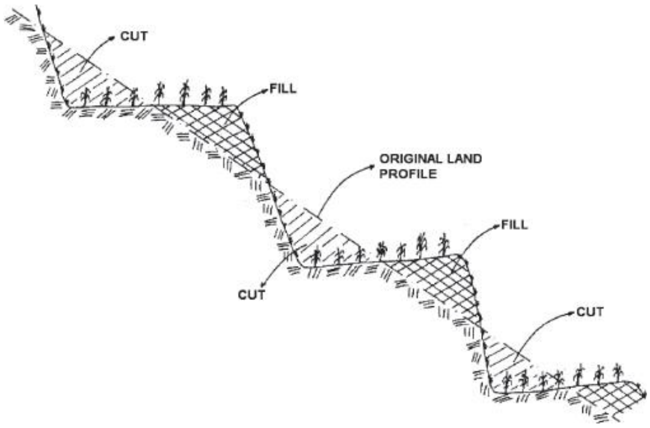


Figure 10: Gully sides reshaped and planted with rows of grasses
Source: MOARD (Jan 2005)

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MODULE 6: ARC WEIR CHECK DAMS

6.1 Definition of Arc Weir Check Dams

Arc-weir is a structure made up of stones connected with mortar of cement and sand (arc cemented walls in horseshoe shape) constructed across the gully. The stones to be used in constructing masonry check dams must be hard enough to withstand abrasion, non-disintegrating, and resistant to weathering.

6.2 Purposes of Arc weir check dams

The main purpose of the dam is to hold fine and coarse material carried by flowing water in the gully or torrent. Besides, arc weir check dam can also serve as a night storage pond in conditions when the water in the gully is not enough to irrigate the downstream plots. From technical and economic point of view it is not necessary to build masonry check dams to control channel erosion in every gully. However, it is one of the options in gully control/reclamation. The technology is very ideal particularly in gullies where it is important to harvest water to use for further irrigation and domestic use.
In general controlling gullies using arc weirs check dams have the following advantages:

- Strong structures;
- It can be built relatively higher;
- It is good for building on the bedrock (no excavation);
- It is good for efficient water harvesting for biological treatment;
- It needs less stone compared to a gabion check-dam with similar volume; and
- Adaptability to local knowledge.

However, it has also some disadvantages:

- It needs cement and special tools for masonry;
- It needs experienced masons/builders;
- It requires regular shapes of stones (sometimes difficult to get in the highlands);
- Structure needs watering after construction; and
- Not suitable for large gullies without catchment treatment and protection.

6.3 Place of construction of Arc weir check dams

Arc weir check dams are suitable all over the country where there is stone and sand in proximity to the construction site. Commonly it is used to check large gullies on highly eroded grazing and cultivated lands and hillsides combined with catchment treatment and protection. It is also constructed in area of considerable local experience exists.

6.4 Design and construction of Arc weir check dams

Points to be considered in the design of technical standards and construction steps in arc weir dam construction:

- Proper site selection for the construction of the dam i.e. constructing the dam in narrow, deep, and steep places of gullies. The dams must not be constructed on points where there is mass movement of soil blocks. They should be built on a gully bed or torrent channel's stable points just below the sliding area to hold debris and material as well as to stop the movement of soil blocks. Nevertheless, in gullies which are relatively wider and having deep soil, either gabion or loose stone check dams will be appropriate in terms of overall efficiency;
- Proper design and measurement in a place where arc weir is constructed;
- The foundation of the first dam must be dug to a durable layer below, such as solid rock. If there is no solid layer, the foundation must be dug at least one m deep, and reinforced, concrete layer at least 20 cm thick must be constructed;
- The stones must be piled behind the mouth of the aqueduct. If possible, the space behind the dam should be filled to the spillway with soil excavated for the foundation and from the gully bed;
- Gravel should be filled in the foundation;
- The mortar ratio for the foundation is 1 to 4 cement and sand, respectively, while for the superstructure it is 1to 6 cement and sand, respectively;
- Plastering is indispensable from the upstream face with mortar ratio of 1 to 3 cement and sand, respectively;
- Wing walls should be built behind the wings of the dam to protect them against flash water. The angle between the wing and wing wall is 30 to 45 degrees. The space behind the wings should be filled with soil. The height of the wing walls is equal to the depth of the spillway. The construction of wing walls is dry rock work;
- The apron is constructed stepwise at the back of the dam. The number of steps depends up on the reservoir level (the higher the effective height of the arc weir check dam the higher the number of the steps) figure 1;
- Constructing apron in a form of steps at a height and width of 40 cm each;
- Lining from upstream side, is important to avoid piping;
- Adequate spillway should be provided for safe disposal of water;
- The height of the dam should be between 1-1.5m excluding foundation;
- The upstream face of the dam is vertical, whereas its downstream face inclination is 20 percent (1:1/5 ratio); and
- Watering is necessary until it finishes its curing period.

Arch weirs should be constructed on spots where the soil depth is lower and where there is strong foundation. The foundation actually depends up on the compactness of the underneath soil. Otherwise, the structure is very susceptible to damage as a result of runoff coming with boulders. When properly constructed, it is highly resistant to greater water pressure. Sample structure developed is presented as follow in figure 1.

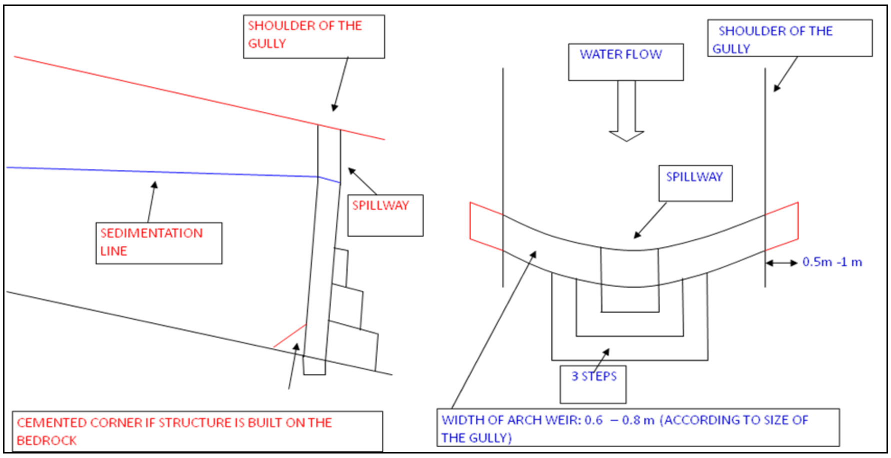

Figure 1: Design of Arc weir Source: Belayneh Adugna (GIZ-SLM) (2012)

Work norms and norm elements
The work norm includes stone collection, foundations/key excavation and proper placement of gravel at the foundation, proper mix of sand and cement, stones and drop/apron structures. Work norms of Arc weir check dams is 0.5 m3/Person Day

Minimum surveying and tools requirements
Layout: One water line level, one range graduated in cm and 10 meters of string.
Tools: Shovels, pick axes, crow bars and sledgehammer.

6.5 Reasons for failure of constructed Arc weir check dams

Gully control can be tedious and expensive where executed measures do not seem to work. 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 arc weir schemes:

- Loose foundation due to wrong site selection;
- Absence of proper key locking to the wall/base of the gullies;
- Below standards of height, width, and length of the dam;
- Inclination problem of the dam;
- Compaction problem on structures that use soil;
- Un-proper designed of runoff disposing structures;
- 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;
- Structures are sometimes made too high and the water which ponds causes instability of the soil and piping underneath or around the structure;
- Poor attention to respect quality standards (too high or too low);
- 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;
- Poor regular protection and maintenance. The structure must be protected from free grazing and other damaging things. Moreover, 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; and
- Poor integration between physical and biological measures.

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MODULE 7: BAMBOO MAT CHECK DAMS

7.1 Definition and purpose of bamboo mat check dam

Bamboo mat check dam is a temporary dam that is placed across gully floors, which is buttressed down, to minimize the speed of water flow, allow siltation and reduce erosion hazard. Bamboo check dams are "organic" gabion boxes, which are made from locally available bamboo or reed grass strips, that are woven and tied together to form cubic permeable boxes. The boxes are filled with stones or soils to making the check dams. In order to avoid the washing away of the soil at the early stages of sedimentation, plastic sheets and leaves from the false banana (*Ensete ventricosem*) are placed inside the box to cover the holes of the mat. The size and nature of gullies determines the number and size of the organic gabion boxes that is required for the construction work.

7.2 Place of construction of bamboo mat check dams

The following are issues considered when selecting the technology for a specific site in a gully:

- More applicable technology for the highland areas where there is enough supply of bamboo and reed grass;
- There is no agro-ecological limitation to implement the technology. The prerequisites are only the availability of materials, the nature of the gully and the characteristics of the upper catchment;
- The technology is applied in all land use types (farmlands and grazing lands) where only smaller/medium gullies exist;
- Good to limit the application of this measure to gullies having a maximum slope range of up to 20% to avoid the frequent destruction and maintenance of the boxes by the runoff water;
- Well suited in gullies where there is deep soil to find a proper foundation to install the boxes properly;
- Good option in areas where there are no big stones or boulders coming from the upper catchment;
- Easily adapted by any farmer/land user as there is no complexity in the design and do not need a special workmanship; and

- Ideal to treat gullies in private lands since the labor demand can be covered by the family members.

7.3 Construction steps to follow for bamboo mat check dam

Layout and construction steps:

- Make organic gabion box out of locally available materials such as using sticks/branches of bamboo, reed, popular and willow.
- Peg and tie a string marking base width of 1m on the floor across the gully bed (Fig 1 below).

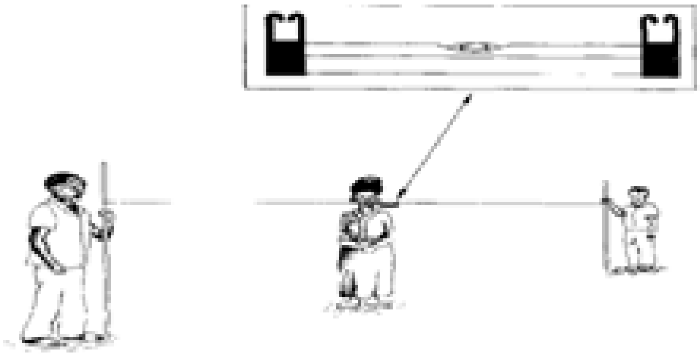

Figure 1: Shows lay outing of contour lines in the field Source: http://www.fao.org/docrep/U3160E/u3160e0a.htm)

- Calculate and determine the spacing between the check dams and continue the lay out and pegging in the gully (figure 2)

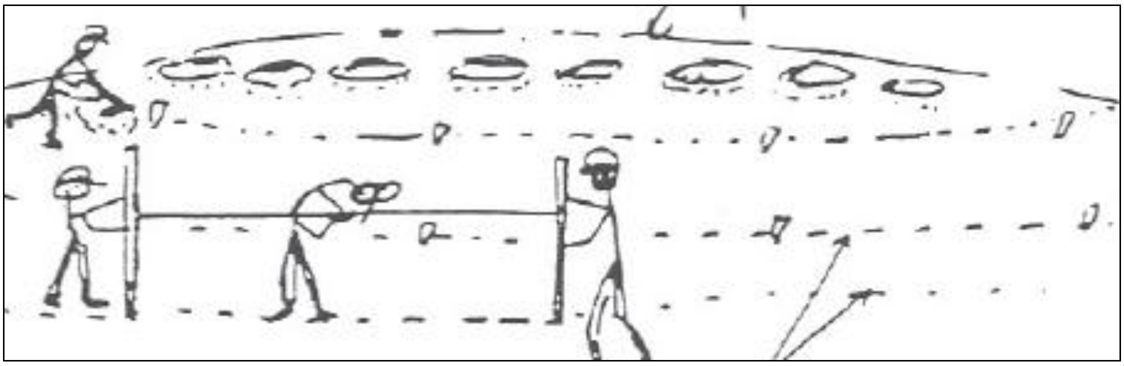

Figure 2: Lay outing using line levels and pegging Source: Daniel Danano et al., 2001

- Dig and remove the top soil to lay the foundation for the construction of bamboo mat check dam
- Place "organic" bamboo boxes across gully floors and buttress downstream for stability.
- Then, fill the boxes with sand, soil and/or stone materials to a height of 1m excluding the foundation.
- Construction should start at the upper end and continue down to reduce the risk of failure.

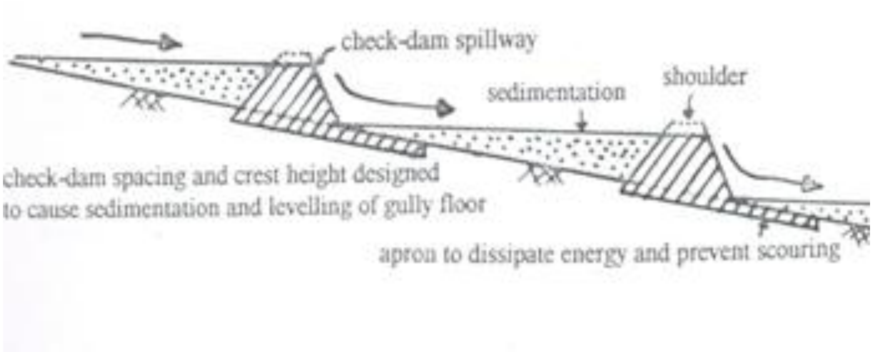

Figure 3: Determination of check dams spacing and the layout Source: http//www.fao.org

- Assume the crest of the lower check dam is level with the floor of the upper (1m VI(vertical interval))
- Construct a side key of 0.5m on each side of the gully wall.

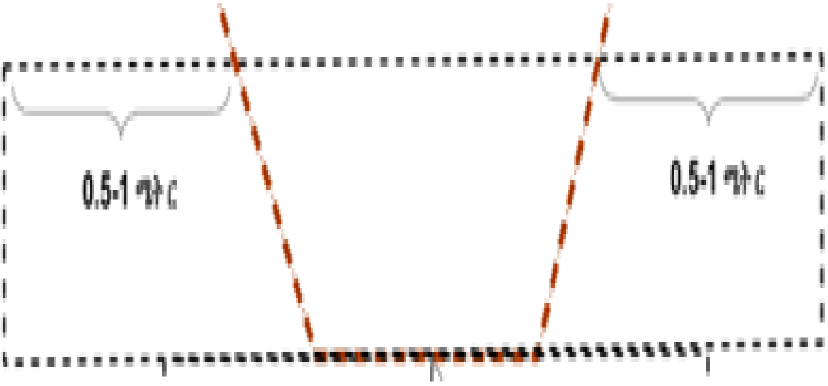

Figure 4: Schematic representations of foundations Source: GFA-Amhara, (Jan 2013)

- Support and strengthen boxes with wooden poles/sticks pegged in 40 cm spacing on the lower and upper parts of the bamboo mat check dam for better durability;
- Construct trapezoidal/parabolic shaped spillway with 0.25 – 0.5 m permissible depth and 0.25 m free board; and width 0.5 – 1.2 m. The spillway depth depends on the expected flow;

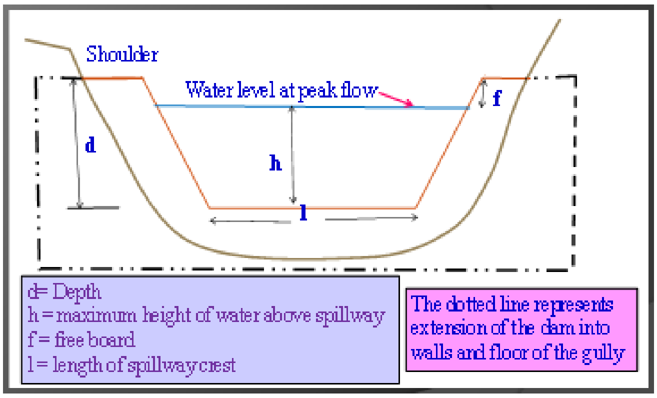

Figure 2: shows the trapezoidal/parabolic shaped spillway Source: - Belayneh Adugna, 2012

Work norm and norm elements
The work norm includes foundations/key excavation and proper placement of organic gabion boxes, soil filling inside the boxes, compaction and tying. Work norm is 0.5 m3/PD.

Tools required
Shovels pick axes, crow bars, sledgehammer, water line level, one range graduated in cm and 10 meters of string.

7.4 Management and maintenance of bamboo check dams

Bamboo mat check dams can provide long term benefits to the community if they are managed with care and timely repaired and maintained. In this connection, an accepted and appropriate mechanism should be in place in consultation with the beneficiary communities before engaging directly on the construction of such physical structures. Perhaps one of the possible arrangements for maintenance could be to give responsibility for the owner of the land to regularly maintain and protect the structures from livestock trampling. If the area is a communal land, arrangement could be done with local landless or other community based organizations to provide such responsibilities. Every year, just before the inception of the rainy season and immediately after heavy rains, structures need to be checked and maintained.

Thick poplar and willow stems are also stuck into the soil filled in organic boxes. This helps to quickly stabilize the soil in organic boxes due to rooting after two years, the latest. This is one of the options in areas where there is no stone nearby the construction sites.

The sediment deposited also creates a favorable medium for the establishment of vegetation cover. Apparently, the vegetation cover permanently replaces the temporary bamboo check dams or organic gabion boxes that decompose over time.

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MODULE 8: BRUSH WOOD CHECK DAMS

8.1 Definition of brushwood check dams

Brushwood check dams are temporary structures constructed with tree branches and poles/posts across the gully to check silt and moisture for the rehabilitation of gullies. It can be constructed by vegetative materials and twigs. Plant species which can easily grow vegetatively through cuttings are ideal for the purpose (figure 1). Brush wood check dams can also be constructed together with sand bag for better sedimentation.

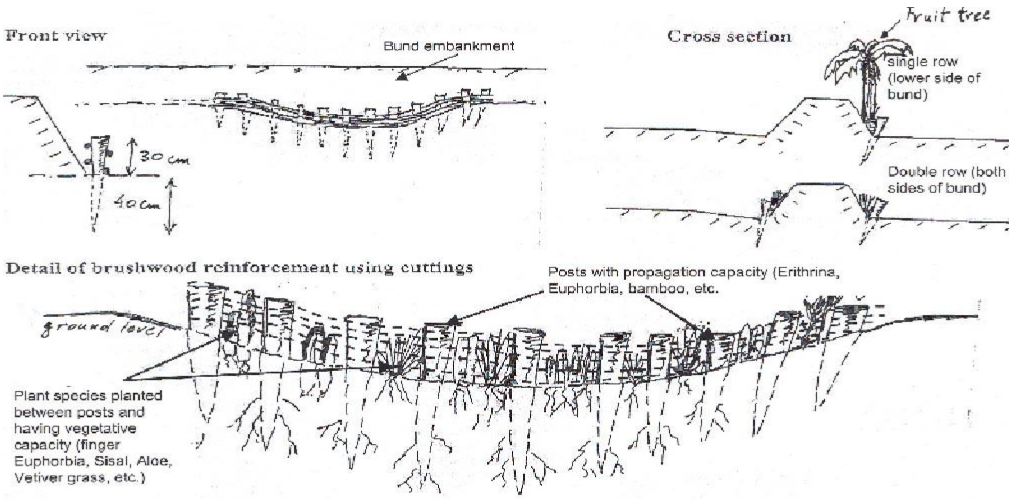

Figure 3: Reinforcing bunds along depression points *Source: http//www.fao.org.*

8.2 Purpose of construction of brush wood check dams

The main objective of brushwood check dams, as in other check dams, is to hold fine materials such as silt carried by flowing water in the gully. Brushwood check dams should be maintained until the time the gully floor gradually build up to its original ground level and re-vegetation measures are effectively established.

8.3 Period of construction of brush wood check dams

If sprouting species (Salix, poplar,…) are selected as post and interlink materials, brushwood check dams can be constructed when the soil in the gully is wet or during early rainy season. If poles of non sprouting species are used as strips and interlink materials, brushwood check dams can be constructed during any time of the dry season.

8.4 Place of construction of brush wood check dams

Brush wood check dams are suitable or applicable for all land use type and agro-ecology. It is suitable from dry-weyna dega to dega zones. In drier places it needs to be combined with stone check dams. It is also recommended along farm boundaries affected by small gullies. These types of structures are possibly constructed where there is sufficient wood resource and gully control is worth compared to conservation of woody materials. The structure can stabilize small gully heads, no deeper than one meter. However, it is not suitable for gullies which are long enough and have high pick run-off rate. Brushwood check dams are also ideal to stabilize conservation structures such as bunds, sediment storage bunds, check dams, bench terraces, road sides, etc.

8.5 How to construct brush wood check dam?

Brushwood check dams are plugged in small gullies of depth less than 2m and width between 2-3 meters. It stabilizes small gullies with channel gradient of 5 to 12% across the gully. 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.

Single row brush wood check dam

This check dams can be used where the flow of runoff is less than 0.5 m3/sec. The 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). Thicker branches are used as vertical posts buried into the soil to about 50 cm -1 m (1/3 to 1/2 of the post length) 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. Practically single row brushwood check dam can be used together with sand/soil bag depending on availability of resources. Figure 2 below is the ideal representation of single brush wood structure.

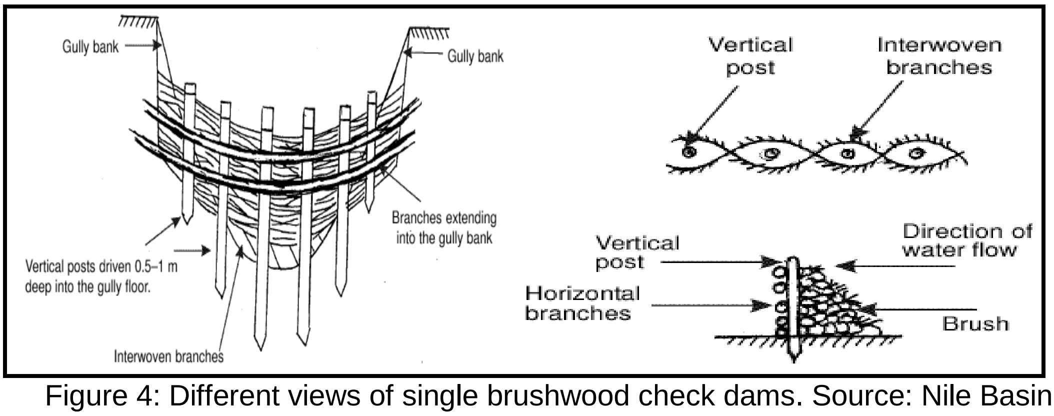

Figure 4: Different views of single brushwood check dams. Source: Nile Basin Initiative (2012) and Belayneh Adugna (GIZ-SLM) (2012)

Double row brushwood check dams

This type of brushwood check dam is suited where the flow of runoff is less than 1 m3/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 two rows are 0.5 - 0.75 m far apart. The spacing between the posts is 0.5 m (figure 3). The height of the posts in the centre 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. Brushwood or branches are packed between the posts and the height of the posts in the centre should be lower than those at the sides.

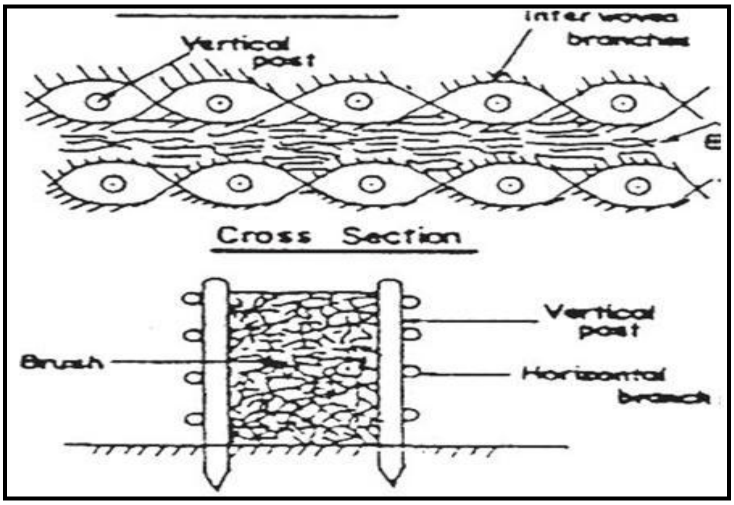

Figure 5: Double row brush wood check dam

Source: Nile Basin Initiative, GIZ-SLM

Construction procedures and Technical Specifications of Brushwood Check Dams

- Straight branches with a diameter of 3-8 cm are ideal. Thicker branches are used as vertical posts. Their height (effective height) depends on the height of particular gully but not exceeding 1m above ground. Vertical posts are driven into the soil at least 50-60 cm depth/ depth of about 1/3 to 1/2 of the post length. The posts should lean to the upper stream side for better resistance and stability. Thinner branches are interwoven alternatively through the posts and are used to form a wall that reduce the runoff effect and improve sedimentation. The ends of interlink materials should enter up to 50 cm into the sides of the gully;
- It is necessary to fix the brushwood parts with string, wire or nail to minimize the risk of being removed by flood water;
- Brushwood check dams should be combined with planting of multipurpose plant species
- Posts/poles that propagate vegetatively (eg bamboo, Erythrina, etc.) are best and should be used wherever available. The Brushwood should be reinforced with plants such as Sisal, finger Euphorbia and Aloe placed along the upper plus lower side of the check dam;
- The spillway form is either concave or rectangular and the side should be locked properly;
- Spacing of the check dams: A simple rule of thumb for spacing between two consecutive dams is 1m vertical interval (VI) which is leveling the base of upper check dam with top of lower check dam. Another approach is to use the same calculation for stone check dam and divide by two/three;
- 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; and
- Brushwood check dams needs frequent maintenance until the time it is stabilized properly

- Brushwood check dams is not applicable in large gullies and in areas with limited vegetative materials or very far from treated sites.

8.6 Other specifications for brushwood check-dams

- Brushwood check dam's 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. In this structure bamboo can be used instead of the branches interwoven into the poles/posts;
- Any tree or shrub species, such as alnus, pine, bamboo, salix, poplar, etc., 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;
- 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;
- 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.

Work norm and norm elements

The work norm includes branches and poles collection, key excavation and proper placement of brushwood check dam, proper spillway. Work norm is 1PD[1]/3 linier meter.

Minimum tools requirements

Farm tools sufficient (matchetes, small hatchets, axe, crow bars and sledgehammer and hooks) some crow bars or hard wood sticks to plant posts and plants.

8.7 Reasons for failures of brushwood check dams

Common problems are:

- Failure to embed the brushwood check dam to a sufficient depth in the floor of the gully bed
- Presence of termite and rot damaging the post and interwoven branches/sticks
- Use of poles off the standards (too high or too low)
- Poor use nailing and support of brushwood check dam structures
- Poor integration between brushwood and biological measures
- Poor regular protection and maintenance
- Limited technical support of Experts and development agents
- Free grazing problems on areas treated.

[1] PD stands for person day (person per day)

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MODULE 9: GULLY WALL RE-SHAPPING

9.1 Meaning of Gully Wall Reshaping

Gully wall reshaping is the cutting off steep slopes of active gully sides into gentle slope and constructing small trenches along contours for re-vegetating of slanted part of the gully walls and beds. While reshaping, cutting of the steep gully wall is done at 45% slope (1 horizontal: 1 vertical) to the level about two-third of the total depth of the gully is covered (Figure 1).

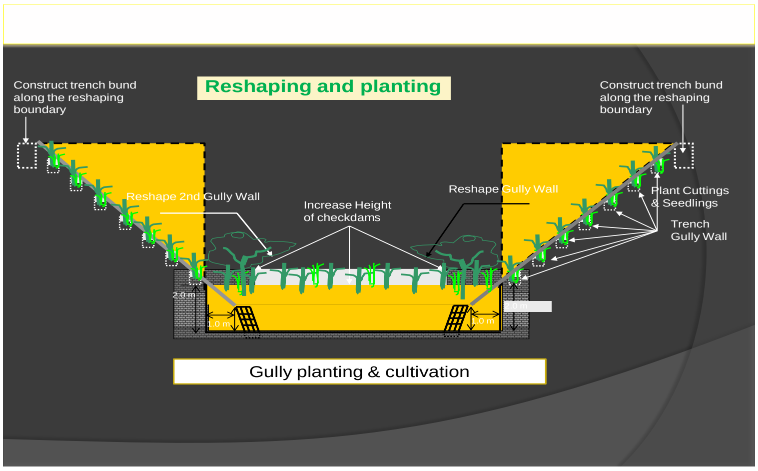

Figure 1: Basic gully re-shaping and re-vegetation Source: Markos Wondie & Wondie Kebede (Sep 2012)

Gully wall re-shaping is commonly used for small gullies. Gullies are divided into three based on size (Table 1).

Table 1: Classification of gully based on depth and area coverage

Gully classes	Gully depth (m)	Gully drainage area (ha)
Small gully	< 1.5	< 10
Medium Gully	1.5 to 3	10 to 30
Large gully	> 3	> 30

Source: GIZ-SLM

9.2 Purpose of gully wall reshaping

The main purposes of gully wall reshaping are:

- Modification of the landscape (slope) and reduce severe erosion;
- Stabilization of gullies quickly especially if the surface water is diverted and livestock are kept out; and
- Help to use the filled gully area for plantations and cultivation and makes the land productive, i.e., it converts gullies into productive units when combined with leveling and re-vegetation.

9.3 Where do we construct gully wall reshaping?

- Gully wall reshaping is a suitable technology for all agro-climatic conditions. Steep gully heads and gully banks are parts of the gully that are shaped into a gentler slope;
- Gully wall reshaping needs to be combined with other physical measures in dry areas especially if it has to be followed by re-vegetations;
- Gully wall reshaping also requires considerable skills and provision of planting materials. Compost making, half-moon and eyebrow basins are crucial to support the growth of trees in dry areas; and
- However, it is difficult to apply this technology in areas under 600mm rainfall, unless supported by irrigation.

9.4 Technical standards, design and construction steps to follow in gully wall reshaping

Re-shaping and filling

- Divert in the first place the excess runoff into another stable drainage line or treat the upper catchment area (Figure 2).
- Reshaping should be implemented by shaping the gully sides into series of small steps or micro-benches (every 0.75-1m distance).

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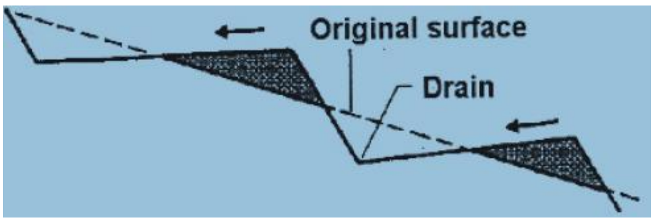

Figure 2: Cutting and filling of gully wall *Source: MOARD (Jan 2005).*

- Control the gully head and the side banks by cutting & filling. The reshaping of the steep gully sides is done in one to one proportion (1 horizontal:1 vertical minimum) by cutting the soil at 45 degree and filling to make it suitable for planting (Figure 2 & 3).

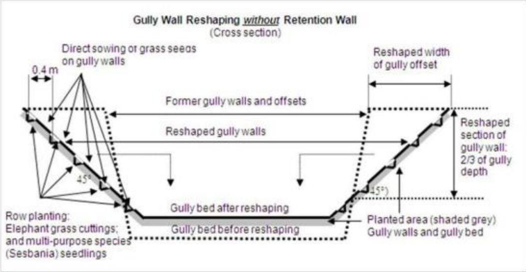

Figure 3: Micro-benches after reshaping
Source: Belayneh Adugna and Getachew Bayafers (August 2012).

- Gully heads can be stabilized by means of stepped stone carpets, brushwood layering or a combination of both (Figure 4).

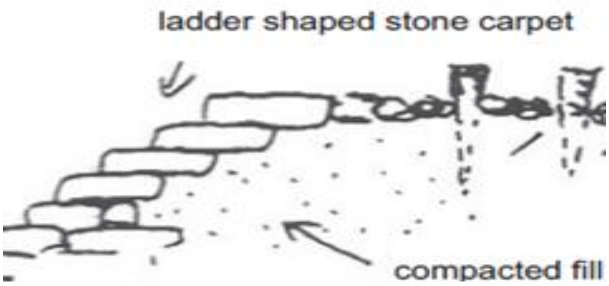

Figure 4: stepped stone carpets *Source: MOARD (Jan 2005).*

- Using stepped stone carpet is more appropriate for dry areas because of less intensity of rainfall.

- The stepped stone carpet comes after the construction of semi-circular shape at the gully head, moving backwards and filling empty space with soil and small stones until reaching the gully edge (Figure 5). However, trenching along the re-shaped gully wall was proven to be much more stable than micro-benching/making small steps.

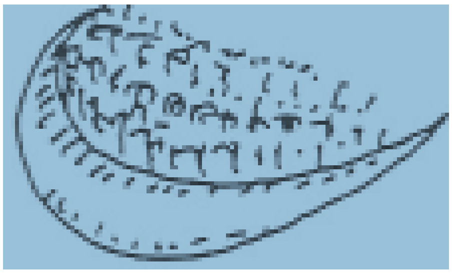

Figure 5: Semi-Circular Structure
Source: MOARD (Jan 2005).

9.5 Re-vegetation

- Plant gully sides with creeping and drought resistant grasses plus trees and shrubs. Elephant grass, Vetiver, Rhodes, Buffle grass, etc, and native grasses appropriate for the area are recommended. For trees/shrubs Sesbania sesban and Acacia species (Saligna for example) are good species. Others such as Sisal, Euphorbia and Erithryna can also be planted (Figure 6).

Figure 6: Vetiver planting for its massive roots and biomass *Source: MOARD (Jan 2005).*

- Trees and shrubs should be planted with a number ranging between 3-4/m² and 6/m² for dense vegetation cover.
- Grass should be planted in dense rows along the steps on simply reshaped gully sides. Close growing crops could also help to better control gullies from erosion hazards quicker. Grasses and annual crops such as teff, oats or barley used to provide a quick cover (Figure 7).

Figure 7: Grass planted in dense rows for better vegetation cover *Source: MOARD (Jan 2005).*

- The gully edges adjacent to the fields should be stabilized with strong rooting trees and vegetation (Sisal, Acacias, etc) to impede the widening of the gully and clumping (Figure 8).

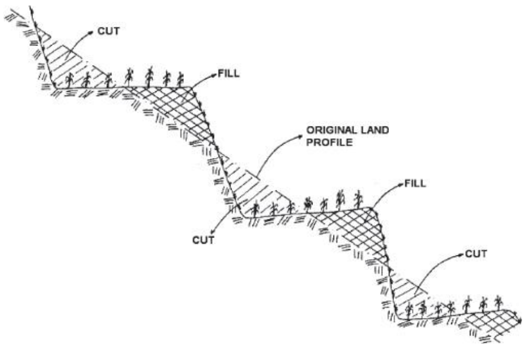

Figure 8: gully wall re-shaping and re-vegetation *Source: MOARD (Jan 2005).*

- Re-vegetation of a gully is often combined with physical structures such as check dams, SS dams, bunds, etc. (Figure 9).

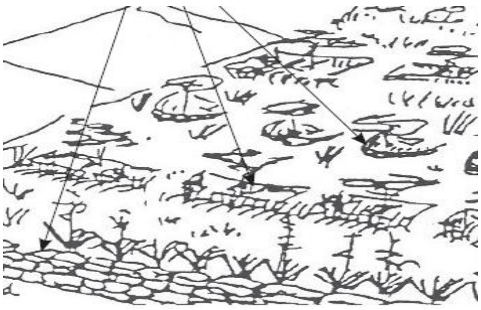

Figure 9**:** combined with physical
Source: MOARD (Jan 2005).

What norms and tools needed for gully wall re-shaping?

- Norms: The work norm includes excavation, soil moving and filling, shaping and compaction and it requires about 500PD/ha of gully area.
- Tools: spade, shovel or plow (on cultivated lands).

9.6 Management and maintenance of gully wall re-shaped

- Exclude the cattle throughout the year and introduce the cut and carry system. Protection of the reshaped area from livestock interference is mandatory (Figure 10).

Figure 10**:** cut and carry system *Source: MOARD (Jan 2005).*

- Divert water from the battered gully area during the time when grass or closely seeded crops are establishing. This will avoid/minimize the washing
- Leave a minimum of five meters buffer zone to avoid livestock and human interference for better and quick rehabilitation of a treated gully.

away and improve the quick recovery.

- Re-vegetation activity should consider plant species that could bring immediate benefit to the farmers and improve their livelihoods.
- The gully sides should be planted with both a mixture of creeping and drought resistance grasses, trees and shrubs.

9.7 Issues that should not be forgotten in gully wall re-shaping

- The practicability of gully wall re-shaping depends on its size and amount of fill needed to restore the gully to its desired shape.
- During excavation work for reshaping, the top soil (top 20-25cm) should be separated from the subsoil and it should finally be re-spread over the reshaped fill area (over the sub-soil). This helps to ensure the rapid establishment of vegetations.
- Application of gully wall re-shaping should be in areas where there is above 600mm of rainfall or should be supported by supplementary irrigation (Figure 11).

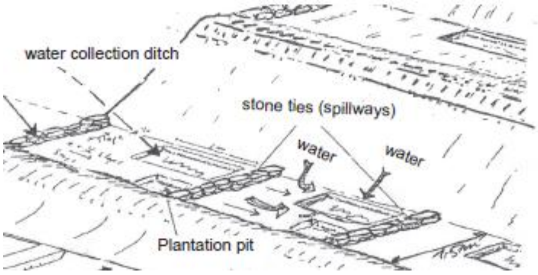

Figure 11**:** supplementary irrigation for dry areas using water collection ditch *Source: MOARD (Jan 2005).*

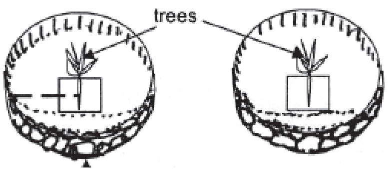

Figure 12: Eye-Brow Basins
Source: MOARD (Jan 2005).

- Compost-making, half-moon and eyebrow basins are essential to support growth of trees and enhance fertilities (Figure 12).
- Use of gully re-shaping for those other than small discontinuous gullies is not that recommended.

9.8 Common mistakes in gully wall re-shaping

- Use of the technology in areas where there is less than 600mm of rainfall without supplementary irrigation;
- Poor integration between physical and biological measures;
- Poor regular maintenance and protection; and
- Poor consideration for upper catchment treatment & sense of ownership/accountability.

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MODULE 10: RETENTION WALL

10.1 Concepts of gully retention wall

A retention wall is a structure or walls made up of stone filled gabion, bamboo mat/ stone/ sand or soil filled bag/wood poles lean against the gully wall. The wall can be temporary (for the case of bamboo mat, dry wood post and /soil/sand filled bags) or a relatively permanent structure when it is made up of stone/gabion. If bamboo is used, the mat need to be strengthened on the lower side by wooden poles and sticks, possibly using vegetative propagation techniques for plant species such as popular, willow and other species. Generally, when properly constructed, together with biological measure, retention wall is highly resistant to greater water pressure. Cutting down the slope of the gully sides (gully reshaping) must be performed before planting the gully side with vegetation. Creeping grass or quick growing legumes are often the best. Shrubs planted 20 cm apart in rows and 50 cm between rows are very effective in slowing down water flow in the gully.

10.2 Purpose of construction of retention wall

Retaining walls is installed along the foot of the sidewall to protect widening of the gully due to mass movement. This can also be better controlled by combining the structures of retaining wall with gully wall reshaping together. Construction of trenches and percolation pits along the gully offset is also proven to minimize gully side erosion from lateral runoff. In summary, retention wall has the following purposes:

- It protects gully sides and head wall movement/slides;
- It converts gully beds and sidewalls into productive areas;
- It provides livestock forage, and fire wood (immediate benefits to farmers) besides reinforcement of the physical structures; and
- Vegetative cover permanently replaces the temporary "organic" gabion that putrefies over time.

10.3 Period of construction of retention wall

Similar to other structures, reshaping and construction of retention walls should be completed before the rainy season to improve the stability of the reshaped soil and so as reduce the run off effect of the rain. It is only required when gully walls are reshaped shortly before the rainy season. Retaining, bundling and pegging can also commence with the onset of the rainy season.

10.4 Place of construction of retention wall

Retention wall are suitable all over the country provided that gabion/bamboo/stones/sand or soil/wood pole are available. There is no agro-ecological limitation to implement the technology. Commonly it is used to protecting sidewall of the gully everywhere. It is applicable in areas where the characteristics of gullies are wider in terms of area, having deep soil or shallow. It is also applied in all land use types (farmlands, grazing lands and others) where only smaller/medium gullies exist. Usually it can be used together with other check dams.

10.5 Site selection, layout and design of retention wall

Retention wall is not independent structure standing alone. This structure mostly used together with gully reshaping and other check dams. The following are part of the site selection; lay out, design and construction procedures:

Site selection for retaining wall construction

- The head is one of the sites/places that needs to be constructed with the different retaining wall materials to reduce the head cut by reducing the energy or speed of runoff; and
- The meandering and curvature places are the sites for constructing retaining wall to reduce water pressure and scouring effect.

Layout

- Assessment of the gully is the first steps for retaining wall construction. Jallo, ranging pole, string, water level/sprit level and meter tap are the lists of assessment tools and three to four persons are involved to assess the gullies;
- Determining/design the check points;
- Finding the counter line where the retaining wall place is perpendicular to the channel of the gully bed;
- Determining the wall base width based on the gully width; and
- Design the type of the retaining wall structure.

Construction procedure for retaining wall

- Excavation of the foundation for gabion/stone with depth ranges from 30-50cm;
- Digging of the land for installation (pole and bamboo mat);
- Proceed with construction of the key & foundation of the downstream wall (called riser or lower retention wall) in front of the structure;
- Erect retention walls with care following the correct H:BW ratio;
- Use a rope and a water level placed across the entire gully to adjust the position of the stones of the retention wall (straight level);
- The retention walls are then carefully constructed ladder-shaped;
- Constructing the side wall stepwise forward for gabion/stone;
- Fill space between stone lines/the structure and all the part of the gully with soil and compact it. Soil is taken from reshaping the gully or (if not suitable) nearby suitable site;

- Constructing the side wall tilted in ward for bamboo mat;
- Reshaping/slanting the side by cutting;
- Plantation of the side/offset of the gully; and
- Truncheons/branches of various species can be layered on the upper part of the mat if the structure is made of bamboo. This technology facilitates self reshaping of gully and eventually the rehabilitation. "Mini" bundles, with or without pegging, are also used in places where there is soil and moisture. Arundo donax and Hyparrhenia stems, each consisting of three to four nodes, proved particularly useful for this purpose.

Norms and requirements

- The work norm requires bamboo mats, stone collection, sand/soil bag and proper placement of wall, proper foundation and proper spillway. The work norm is 5 meters per person per day (m/pd).
- Minimum surveying and tools requirements

Norm: The work norm includes gully reshaping, foundations/key excavation and proper placement of bamboo mat/stone /gabion/sand bag and planting the side with vegetation.
Tools: Shovels, pick axes, crow bars and sledgehammer.

Management and maintenance of retention walls

Retention wall can provide long term benefits to the community if they are managed with care and appropriate maintenance is done timely. In this connection, an accepted and appropriate mechanism should be in place in consultation with the beneficiary communities before engaging directly on the construction of such physical structures. This is important because retaining wall especially made of wood pole in particular and physical structures in general can easily lose their strength due to the effect of flood, human and livestock disturbances.

The main management and maintenance practices for retention wall are:

- The treated area must be closed from free grazing, footpaths and cattle trafficking lines;
- Formation of user groups and empowering communities;
- Economically valuable trees may be planted in gaps to enhance production and productivities;
- People should be allowed to cut and carry/use grass; and
- Close follow up and maintenance should be performed.

The above management interventions are primarily the responsibility of the land user/or the user association, with technical advice from DAs and Experts.

Reasons for failures of constructed Retaining wall

The causes for the failures of retention walls are similar with the other check dams. From experience, the following problems can be taken as the major reasons for the failure of the structure.

- Absence of proper foundation;
- Inclination problem of the wall;
- Problem in re-shaping the side of the gully;
- Lack of enforcing structures (wooden pole);
- Lack of sense of ownership and accountability;
- Absence of follow up, protection and maintenance, and so on.

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MODULE 11: SEDIMENT STORAGE DAMS

11.1 What is sediment storage dam (SS dam)?

Sediment storage dam is stone-faced earth dams constructed across medium/large size gullies. It is also constructed using gabion structures. The structure has stone made steps in front and back of the dam and well excavated and plastered at the side of the gully. As opposed to the other check dams, SSD is constructed with well compacted soil forms the inner dam body while well shaped stones and gabion structures form the outer part. The structure sometimes called soil storage & overflow dams. If properly used and the runoff flowing to the gully is diverted, check dams can be used to gradually build up the floor of the gully to its original ground level or to rehabilitate the gully.

The other point that makes SSDs different from other types of check dams is that it is very big in size and can store water as a surface pond until the space/volume is overtaken by the incoming sediment. It can also be constructed from downstream side to upwards. This is depending on the sediment yield that is harvested. Reclaimed gully can be used to grow high value fruit trees and other crops just to make use of the moisture and fertile soil accumulated by the structures.

11.2 Purpose of sediment storage dams (SSDs)

It is a type of physical gully rehabilitation structure used to trap sediments, collect water and divert excess runoff. SSDs are water harvesting and conservation systems that convert large and active unproductive gullies into productive areas. The development of SSDs should be combined with check dams and reshaping techniques to help control flood, stabilize gullies and restore the disrupted hydrological balances in catchments. Series of sediment storage dams in a cascaded arrangement can also recharge the groundwater for later use through hand dug wells and springs.

In general SSD has a potential to:

- provide multiple benefits such as sediment storage for re-vegetation, water harvesting structure to give springs at downstream sites, reduce the speed of runoff and divert excess runoff for irrigation and others;
- integrate physical and biological gully control measures as part of watershed development; and
- opportunity for the poor due to creation of land that does not exist before.

11.3 Sites for the construction of sediment storage dams

Sediment storage is more useful in dry and degraded areas. Traditional structures similar to SS dams are common in several parts of dry lands of Ethiopia (Dire Dawa,Tigray/Erob, Wollo, Hararghe, etc). In other areas, it is possible to start in small scale and develop local interest of needy farmers in highly eroded gully areas in all land use types. Introducing high value crops on lands reclaimed can assist the effort. However, it is not suitable for large gullies without catchment treatment and protection. SSD, similar to other check dams, are effective to plug in small gullies and it is not very easy for large gullies. This structure is applicable only where stones are available.

11.4 Layouts, design and construction of SSD

Site Selection is the first step to consider before construction of the SSD

- Consider gullies and natural depressions that you wish to convert into productive fields;
- Consider catchments with less than 40 ha (maximum hectare). This is because of the increased costs for larger structures of SSD;
- The site should allow the maximum formation of a cropped field area. Hence, wider portions in a given gully are preferable than narrow and deep portions;
- A gully with one side of it is suitable hard structure to put the spillway (stony areas, limestone, very hard pans and soft rocks); and
- When suitable soil conditions do not exist, reinforcement of spillway is required (riprap and drop structures).

Estimate the size of the structure

Apply the following criteria to approximately estimate the dimensions of the SSD (for simplifications and use a trapezoidal design).

- With a meter tape and a graduated long pole (5-7 m) measure the base width and length, height and top width and length of the structure;
- Select the best placement of the spillway. Estimate spillway construction standards (see figure 1 below) including gradient and length;
- Dimensions and volume of the structure: they are selected based on the area of the catchment, the width of the gully and especially its depth (table 1).

Table 1: Estimation of size of sedment storage dam

H	BW	TW
H < 2m	H: BW is 1:2-2.5	TW = 1.5m
H = 2-3.5m	H: BW is 1: 2.5-3	TW = 1,5m
H = 3.5-5m	H: BW is 1: 3	TW = 3 m

BL = Bottom length
BW = Base width
H = Height
TL = Top length

TW = Top width
V1 = Volume of embankment earth/stone work (m³) = H x (TW+BW) x (TL+BL)/4
V2 = Volume of spillway (SP) earth work = Length SP (equivalent to BW) x base width of SP x total depth of channel
V1 + V2 = Total volume of earth work (including foundation)

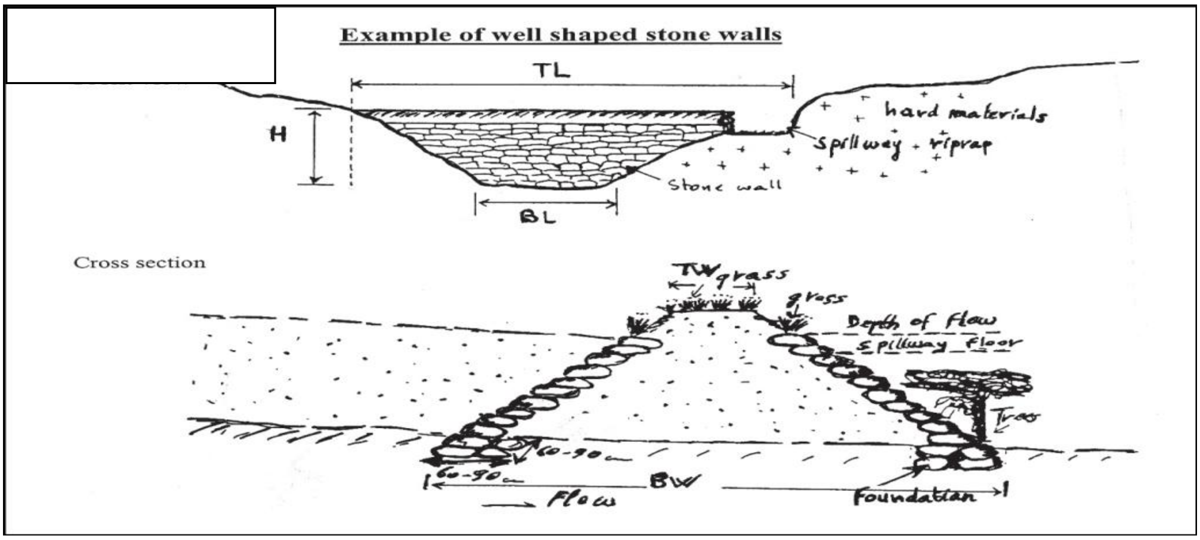

Figure 1: How to measure spillway and how to construct SSD below Source: BoA, 2003

Construction standards and phases: The steps to follow

- Scrape and remove grass and vegetation from the whole bottom width and sides of the gully where the dam is to be constructed (structural continuity);
- Put pegs & tie strings at the corner of bed and top width;
- Proceed with the construction of the key & foundation of the downstream wall (called riser or lower retention wall) in front of the structure;
- Large flat stones used for the key foundation, side keys (abutments) and retention walls. Make this key & foundation 60-90cm deep x 100cm large and start filling it with large stones;
- Fill the space between stones with small stones. The first 2-3 lines of large stones inside the foundation inclined 10-20% uphill (stability of foundation);
- Erect retention walls with care following the correct height to base width ratio;
- Use a rope and a water level placed across the entire gully to adjust the position of the stones of the retention wall (straight level);
- The retention walls are then carefully constructed ladder-shaped;
- Fill space between stone lines with soil and compact it. Soil is taken from reshaping the gully or (if not suitable) nearby suitable site and spillway canal. Compaction should be carefully done by repeated passes of oxen over the piled layers of soil (use oxen-pulled compactors-rollers or manual compactors such as buckets filled with heavy soil & stones, wood beams, etc.);
- Ridge to bottom approach;
- Proper choice of materials for construction;
- Dig and construct the foundations key as per the standard;
- Complete the construction of the structures properly (aprons, reinforced plates, etc). These are structures to be constructed on the downstream side to protect the dam from undercutting;
- Quality approach – fulfill required height and width (compromising can cost dearly);
- Anchor structures (see gully control) as required;
- Compactions and check of level on top of the structures;

- The dam dimensions could vary based on estimation of catchment area and run-off when designing the size and spillway of a check-dam structure. It has a trapezoid shape wider at the foundation and narrower at the top (figure 1 above).

Spillway design and construction

Construction of the spillway helps to reduce the scouring effect of the water or facilitate flushing of deposited sediments during periods of flood flow. Points to be consider in designing and constructions of the spillway are:

- Start digging the spillway at the desired height (see total height of the structure and deduct the total depth of the spillway = maximum permissible depth of the flow (d) + free board);
- Length of spillway equivalent to base width of dam or more;
- Slope of the spillway is 0.4-0.8% and outlet with drop structure and apron if necessary;
- Construct the spillway at the appropriate side (hard materials) of the gully;
- If both sides are of hard materials, construct the spillway at the side which is facing the direction of the water flow;
- Similar to an earth dam consideration of spillway on either side is required. The size of the spillway is determined by the catchment area and runoff estimations;
- The side of the spillway looking towards the dam should be stone faced & reinforced (figure 2) which has trapezoidal shape;
- The dimensions of the spillway (table 2) has been computed based on “safe standards” for rainfall intensity of 100-150 mm/hour.

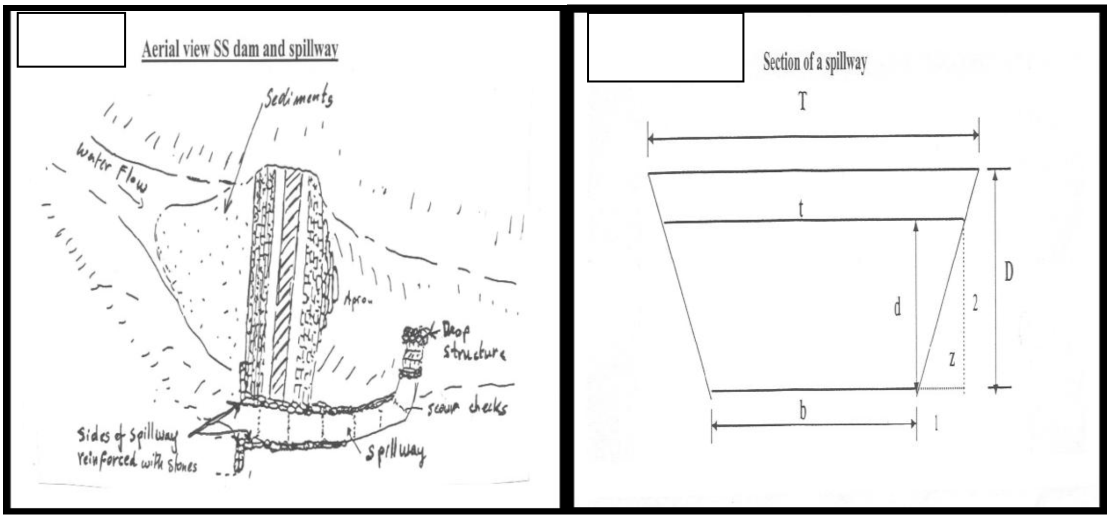

Figure 6: Aerial View of SSD and Spill way (left) and layout of spillway (right) Source: BoA, 2003

Table 2: Sediment Storage and Overflow earth dams (SS Dams)

Catchment Area	Base Width (b)		Depth of Flow	Total Depth
	Medium to low runoff coefficient (0.4)	High runoff coefficient (0.7)		
2	0.8	1.1	0.30	0.70
3	0.9	1.4	0.30	0.70
4	0.9	1.4	0.35	0.75
5	1.0	1.6	0.35	0.80
6	1.0	1.6	0.40	0.90
8	1.0	1.8	0.50	1.00
10	1.0	2.1	0.55	1.05
12	1.0	2.2	0.60	1.10

Catchment Area	Base Width (b)		Depth of Flow	Total Depth
	Medium to low runoff coefficient (0.4)	High runoff coefficient (0.7)		
14	1.1	2.5	0.60	1.20
16	1.1	2.7	0.60	1.20
18	1.1	2.8	0.60	1.20
20	1.2	3.2	0.60	1.20
24	1.6	3.6	0.60	1.20
28	2.0	4.4	0.65	1.25
32	2.3	5.1	0.70	1.30
36	2.7	5.5	0.70	1.30
40	3.2	6.1	0.75	1.35
45	3.7	7.0	0.75	1.35
50	4.2	7.8	0.75	1.35
60	5.1	9.6	0.75	1.35
70	6.1	11.3	0.75	1.40
80	7.1	13.0	0.75	1.45
80	8.1	14.8	0.75	1.50
100	9.1	16.5	0.75	1.50

Tools and requirements
Layout: One water line level, one range graduated in cm and 10 meters of string.
Tools: Shovels pick axes, crow bars and sledgehammer.

11.5 Management and maintenance of SSD)

Gully control can be tedious where executed measures do not seem to work. Failure in proper completion brings losses of material, time, and money and sometimes makes the gully erosion even worse. The causes for the failures of sediment storage dams are similar with the other check dams. From experience, to sustain the constructed SSD, the following are some of the important measure to be practiced:

- The SSD requires proper regular follow-up and maintenance work through group of people sharing the gully area. Maintenance of key should be considered during and after the rainy season (undertake all repairs after first heavy rains);
- Gully protection/closure is important for quick recovery of vegetation through agreement of community/group members;
- Moisture plot management is important;
- Upgrading or rising of the check may also be required;
- Supplementary measures integrated with plantation on sediments and stabilization of gully sides should be performed as required. Gully sides should be reshaped and planted with rows of grasses possibly reinforced with plants such as Sisal, Euphorbia, etc, placed along the upper and/or lower side of the check dam; and
- It is very much important to plug the scouring places with jut bag after every run off, until it sediment up to the reservoir level.

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