TRAINING PACKAGE ON BIOPHYSICAL SOIL AND WATER CONSERVATION MEASURES ON HILLSIDES/DEGRADED LAND

PART TWO: TECHNICAL MANUAL FOR FLOOD CONTROL AND DRAINAGE MANAGEMENT STRUCTURES

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1. INTRODUCTION

For the last two decades a lot of soil and water conservation activities have been implemented in the country. Quite impressive and promising results are being achieved in reversing the degradation situation. However compared with the rate of degradation, the efforts made have been unable to completely reverse the situation due to various reasons such as population growth, expansion of agricultural lands, etc. Experts, decision makers and scientists are still frequently tasked with analysing the situation and finding out solutions for this untapped potential for improvement and development.

This particular manual would like to deal with the comprehensive thinking about runoff management. The aim is to provide the general concepts, principles and techniques on how to efficiently and effectively manage the drainage in all agro ecologies following the integrated watershed meant to serve for different purposes. It will indicate how one can safely drain and store the excess run off and utilize for various uses. The word drainage is referring to the system of drains or elimination of unwanted water from the land surface .Therefore the management is the systematic and appropriate way of controlling and utilizing the drains. As the techniques of drainage management is linked to various soil conservation and water harvesting measures, experts/DAs need to refer to this manual together with other training manuals.

Practically, it is not always possible or advisable to protect runoff generation and concentration owing to two reasons. The first reason is that whatever treatments you make to the land, runoff formation is inevitable. The second reason is that runoff formation/generation should be seen as an opportunity, a resource that can be harvested and used in a productive way. Therefore, different alternatives for the productive use of flood waters and different dimensions to how well the flood is exploited should be considered while planning flood-control schemes.

This manual will focus on the drainage management techniques that are directly related to the soil and water conservation measures. All measures are expected to be implemented. The overall purposes of the techniques are to minimize the problems related to water logging and soil erosion and increase the potential for water harvesting both on the surface and sub surface of the land. ***Cutoff drains and Waterways*** are the main drainage management measures identified in the manual to be applied to the watersheds. The layout, design and construction procedures of the measures are indicated in this manual. They are used to safely drain the excess water from the farm land and divert/convey to water harvesting structures (in situ and above ground storage).

For further reference on simple survey tools and methods, slope measurement, and methods to calculate peak runoff rate, please refer a separate document prepared as “Key Tools and Methods for Implementation of SWC Measures’’.

2. MODULE 1: CUT-OFF DRAIN

2.1Concept

Description of cutoff drain

A cut-off drain/diversion ditch is a graded channel constructed to intercept and divert the surface runoff from higher ground/slopes and protect downstream cultivated land, villages, agricultural infrastructures like irrigation headwork and active gully heads. Cut-off drains safely divert the runoff to a natural or artificial waterway, river, or run on areas.

A cut-off drain usually has a larger capacity and steeper gradient than a terrace channel. Cut-off drains are essential for protection of cultivated land against runoff from slopes higher up. Diversions may also be used to control gully erosion, roads and compounds. The catch water drain should not be constructed too close to cut faces of the road as it would increase the danger of land slips.

Purpose of constructing cut-off drain

In dry lands, cut-off drains may be used mainly for the following purposes:

- To divert additional water to cultivated plots;
- To divert additional water to Sediment and Water Storage (SWS) dams and cropped areas inside gullies;
- To divert additional water into reservoirs for irrigation and/or domestic use.

Photo 1: Cut-off drain leading to a waterway

In ***dry areas*** like Konso, Diredawa and Kobo, most farmers use diversion ditches to direct water coming from the upper catchments onto their farmlands.

Photo 2: Runoff directed to farm land

However, in places where there is ***relatively high rainfall***, and in areas with Vertisols, cut-off drains are used to let the excess water drain out from the farmland to the natural or artificial waterway.

Photo 3: Cut-off drain placed on the upper part of cultivated land to protect soil bunds and farm lands from excess runoff

With modified design as it is being practiced in Oromia, the runoff passing through the channel could be recycled in the catchment for ground water recharging through the construction of a series of sink holes in the channel.

Time to construct cut-off drains

Cut-off drains are constructed preferably during the dry seasons and periods not interfering with land preparation and when the conditions are good for stabilizing the structure. If possible, it is good to carry out the construction just before the small rainy season because it stimulates the growth of grasses and immediately becomes stable.

Suitability and agro-ecology

Cut-off drains are most suitable:

- In moist areas of the country with medium to high rainfall.
- In dry areas to protect cultivated lands and irrigation schemes, and divert runoff into run on areas for example reservoirs and farmland.
- Where there are proper waterways, soils with minimum clay content to avoid swelling and cracks and on areas less than 50ha.
- At the foot of a steep hillside under which cultivated fields are exposed.
- Above gully head and gully sides to divert run-off from active gullies.

To achieve effective protection of farmland, the cut-off drains should be constructed between uncultivated and cultivated land. If the farmland area is relatively large and requires a big channel size, cut-off drains could also be constructed in the middle of farm land.

Constructing cut-off drains should be avoided on very steeply slope sites (>50%). However, if climatic and surface conditions allow, an integration of different physical soil and water conservation structures needs to be considered as an alternative to minimize the effect of runoff to downstream areas.

2.2 Design, Layout and Construction

2.2.1 Technical standards and design steps

Cook's method (which is a simplified method that does not require annual rainfall data and rational methods are commonly and practically applicable for the design of cutoff drains (See also the separate background material annexed as "Methods to calculate peak run-off rates for channel design''). For ***smaller catchments <50ha***, using Cook's method is easier and preferable. The Rational method is also good but requires a minimum of 10 years rainfall data**.** Because of its simplicity to calculate for Development Agents (DAs), this background material only focuses on the use of Cook's method in more detail.

Design Steps using Cook's method to determine peak runoff and channel design

Step1:

- To estimate the peak runoff using Cook's method, determining first the role played by ***surface conditions*** (vegetative cover, soil conditions and topography) in the runoff area is important;
- Determine the runoff area from a map or by field survey;
- Determine the summarized value or characteristics of the surface conditions of the runoff area using Table 1;
- Using the summarized value and runoff area you got, read or interpolate the peak runoff from Table 2;

Table 1: Values of summarized characteristics[1]

Vegetative/land cover	Soil conditions	Topography
Forest or thick grass cover 10	Well drained soils e. g. Sand 10	Slope 0-5% 5
Scrub or medium grass cover 15	Moderately pervious soils e.g. Silt 20	Slope5-10% 10
Cultivated land 20	Slightly pervious soil e.g. loam 25	Slope 10-30% 15
Bare or sparse cover 25	Shallow soils with impeded drainage 30	Slope more than 30% 20
	Clay and rock 40	Mountainous 25

[1] *The sum of the three characteristics gives the total catchment characteristic (CC) for a more or less square catchment. For long and narrow catchments, CC equals the sum of the three characteristics multiplied by 0.8 and for broad and short catchment areas; CC equals the sum of the three characteristics multiplied by 1.25 (Source: Guideline for prevention and control of soil erosion in rock work, 2010)*

Example 1: Find the summarized characteristics for a piece of land with the following surface conditions. The land is cultivated, has a loam soil and is on a 35% slope.

Solution: The summarized characteristics for the land are found as follows:

- For cultivated land the value under the first column of Table 1 (vegetative/land cover), for a cultivated land is 20, from the second column of soil conditions (Table 1), you have the value of 25 for loam soils and from the third column of topography you have a value of 20 for a 35% slope. Thus, the summarized characteristics = 20 + 25 + 20 = 65.

Table 2: Runoff values in cubic meters per second

Runoff Area (ha)	**Summarized characteristics of the runoff area**										
	30	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**
2	**0.1**	**0.2**	**0.3**	**0.3**	**0.4**	**0.4**	**0.5**	**0.5**	**0.6**	**0.7**	**0.8**
4	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**1.0**	**1.1**	**1.3**	**1.5**
6	**0.3**	**0.4**	**0.6**	**0.7**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**	**1.9**	**2.1**
8	**0.4**	**0.6**	**0.7**	**0.8**	**1.1**	**1.3**	**1.6**	**1.8**	**2.1**	**2.4**	**2.7**
12	**0.5**	**0.7**	**0.9**	**1.2**	**1.5**	**1.8**	**2.2**	**2.5**	**3.0**	**3.4**	**3.8**
16	**0.6**	**0.8**	**1.1**	**1.4**	**1.8**	**2.3**	**2.7**	**3.1**	**3.7**	**4.2**	**5.0**
20	**0.7**	**1.0**	**1.4**	**1.8**	**2.3**	**2.8**	**3.4**	**4.0**	**4.7**	**5.7**	**6.1**
30	**1.0**	**1.4**	**2.0**	**2.5**	**3.3**	**4.0**	**4.8**	**5.7**	**6.7**	**7.6**	**8.8**
40	**1.1**	**1.5**									
50	**1.2**	**1.8**									

Example 2: Find the runoff to be produced from a catchment with a square runoff area of 20 hectares with the summarized characteristics calculated in the example 1 above.

Solution: To find the runoff, you have to have two pieces of information: the runoff area (from Table 2 above) and the summarized characteristics (from example 1 above). Thus, runoff area = 20 ha, the summarized characteristics is 65.Then read from Table 2 the value corresponding to the value of 20 for runoff area and the value of 65 for summarized characteristics. Therefore, the reading for the runoff from the Table is 4 m^3/sec.
For more examples, see attached exercise.

Step 2: Find out the value of permissible flow velocity.

- Permissible velocity is the velocity of water allowed to flow in a channel without causing ***scour*** in the channel bed and that does not allow ***siltation*** in the channel.
- In constructing the drain, the velocity of water flowing in the drain should not exceed the maximum permissible velocity for the soil type. In this case erosion will not be created.
- The ability of water to cause scouring and erosion varies with the lining material (earth, grass, stone or concrete); and for each of these, there is a maximum permissible velocity above which scouring can occur (Table 3).
- The maximum permissible/allowable velocity is governed by soil type and degree of vegetative/grass cover in the channel.

Table 3: Maximum permissible velocity in channels (m/sec) – Hudson 1981

Surface material	Bare	Good/Medium grass cover	Very good grass cover
Very light silty sand	0.3	0.75	1.5
Light loose sand	0.5	0.9	1.5
Coarse sand	0.75	1.25	1.7
Sandy soil	0.75	1.5	2.0
Loam	.9	1.5	2.1
Firm clay loam	1	1.7	2.3
Stiff clay or stiff gravelly soil	1.5	1.8	2.5
Coarse gravels	1.5	1.8	Unlikely
Shale, hardpan, soft rock, etc.	1.8	2.1	-
Hard cemented conglomerates	2.5	-	-

Step 3: Compute the cross-sectional area of the channel.
The cross-sectional area should be able to accommodate the peak runoff rate (Q_p) and fulfill the permissible flow velocity (V) requirement. It is computed by the following equation:

$$\mathbf{Q_p = Q_c = A \times V \rightarrow V = Q_p / A \rightarrow A = Q_p / V}$$

Where, Q_c = The discharge calculated inside the channel
Q_p = Peak runoff (m^3/s) expected from the catchment not from the channel
V = Maximum permissible velocity (m/s)
A = Cross-sectional area of the drain (m^2)

Step 4: Compute the various dimensions of the channel using Table 4 to suit the area of the cross-section obtained in **Step 3**. The dimensions of the channel are its depth, bottom width and top width. Geometrical formulas used to find the size of the channel for parabolic and trapezoidal shapes is shown in figure 1 below.

Example 3: From table 4 below it is given that the channel depth is 0.5m and the gradient is 0.5%. Therefore, the discharge found from the Table is 0.95 m^3/sec/1 m width of the channel.

Table 4: Discharge in cubic meter per second per width

Depth of channel (m)	**Gradient (%)**		
	1.0	**0.5**	**0.25**
0.3	0.6	0.4	0.25
0.4	0.9	0.65	0.45
0.5	1.3	0.95	0.65
0.6	1.8	1.3	0.95
0.7	2.25	1.7	1.2
0.8	2.8	2.15	1.5
0.9	3.4	2.65	1.8
***Source*: Daniel Danano (1996).**			

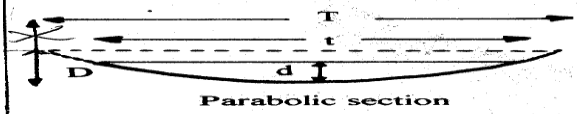
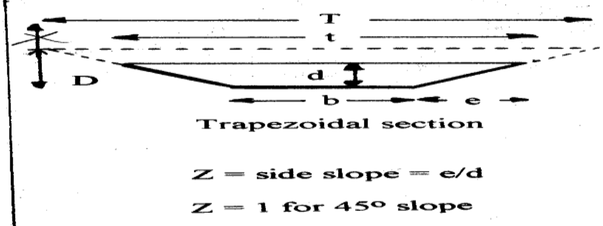
	Area (A)	$2td/3$
	Wetted perimeter (P)	$t + (8d^2/3t)$
	Hydraulic radius (R = A/P)	$t^2d/(1.5t^2 + 4d^2)$ R = approx. $2d/3$
	Top width (t) (T)	$t = 3A/2d$ $T = t(D/d)^{0.5}$
	Area (A)	$bd + Zd^2$
	Wetted Perimeter (P)	$b + 2d\sqrt{1 + Z^2}$
	Hydraulic radius (R = A/P)	$\frac{bd + Zd^2}{b + 2d\sqrt{1 + Z^2}}$
	Top width (t) (T)	$t = b + 2dZ$ $T = b + 2DZ$

Figure 1: Channel cross section, wetted perimeter, hydraulic radius and top width formulae

Note:

- Generally, *d* is one third of *b* if *z* = 45 degree slope. For each soil type, specific degree of slope is needed.
- The channel should have wider bottom width and smaller depth. The lower the depth the channel the lesser the risk.
- It will be best to define first the depth of the channel (50-60 cm is taken as a good depth).
- Parabolic sections are more applicable for waterways and Trapezoid sections for cutoff drains.

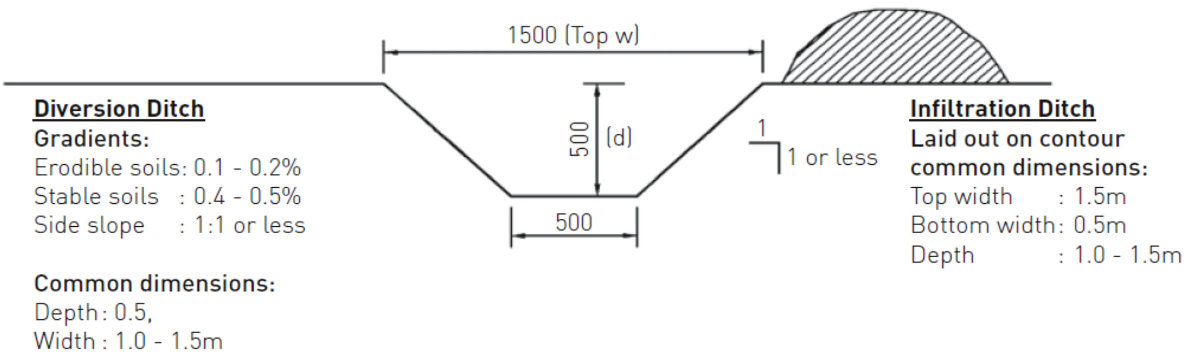


Figure 2: Dimensions for trapezoidal sections of diversion ditch/cut-off drain and infiltration ditch *(Source: Guideline for prevention and control of soil erosion in rock work, 2010)*

Step 5: Determine estimated channel width.

- The width of the channel expressed in meters for a trapezoidal or parabolic section can be calculated by dividing the estimated runoff in cubic meter/second (see Table 2) by the value of the discharge obtained from Table 4 above.

$$\text{Channel width} = \frac{\text{Estimated runoff}}{\text{Discharge of channel}}$$

Example 4: For a 12 ha of land with the following surface condition (cultivated, loam soil on 35% slope and for the channel slope of 1%,if the velocity is 1.5 m/s and the channel depth is 0.5m). Find the width of the channel?

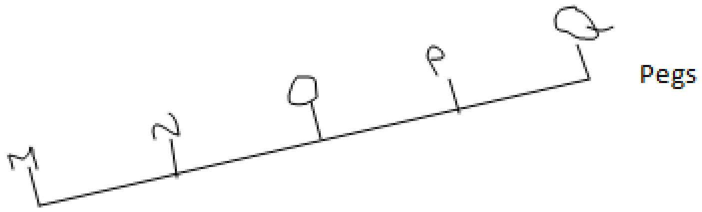
Solution:

- Peak runoff from Table 2= 2.5m^3/sec
- Discharge of the channel from Table 4= 1.3 m^3/sec/m width
- Width of the channel = $\frac{2.5m^3/sec}{1.3\ m^3/sec/m}$ = 1.9m

2.2.2 Layout and construction steps

The layout and construction steps in cut-off drains are as follows:

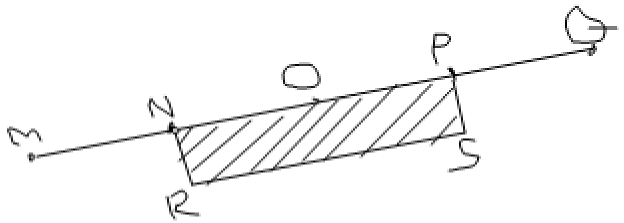
- For laying out cut-off drains a gradient of 0.5—1 percent is recommended. Field trials show that cut-off drains constructed at 2 percent gradient scoured the channel very rapidly.
- Make graded contour and put pegs at an interval of 10 meters. Use this as the center of the channel to be excavated.



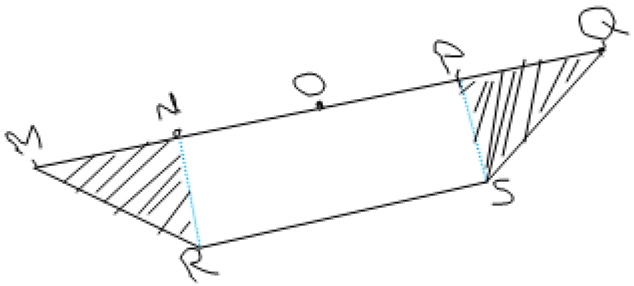
- Take additional pegs and string. O indicates the central peg. Insert four additional pegs on the lower and upper sides to indicate the bottom and top width of the channel.

NO + OP = Bottom width

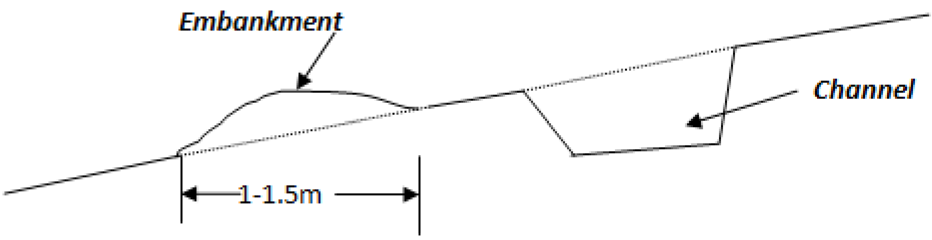
MNOPQ = Top width



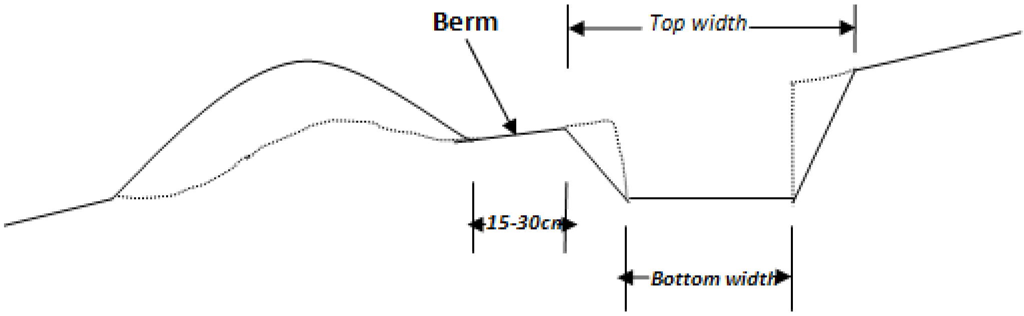
- Start digging out NRSP and then shape the channel by digging out MNR and PQS.



- Dig out the bottom width to the level of the designed depth and throw the excavated soil downhill and form a well compacted embankment (1 to 1.5m) at the lower side by leaving 15-30cm berm space to avoid the moving back of the soil.



First:



Second:

- Construct **scour checks**. **Scour checks** are constructed to reduce the velocity of the water. The use of scour checks is very effective in controlling channel scour on cut-off drains, with gradients exceeding one percent and waterways of gradient exceeding 4 percent (results of field trials).They hold back the silt carried by the water-flow and provide a series of stretches with gentle gradients interrupted by small "waterfalls". Scour checks are usually constructed of natural stones or with wooden stakes. The level of the scour check must be a minimum of 20cm below the edge of the carriageway in order to avoid the water flow being diverted out of the side drains. The interval at which scour checks are constructed depends on the gradient. Place scour checks at least 20m before the outlet at interval of 2-4m to slowdown runoff velocity.

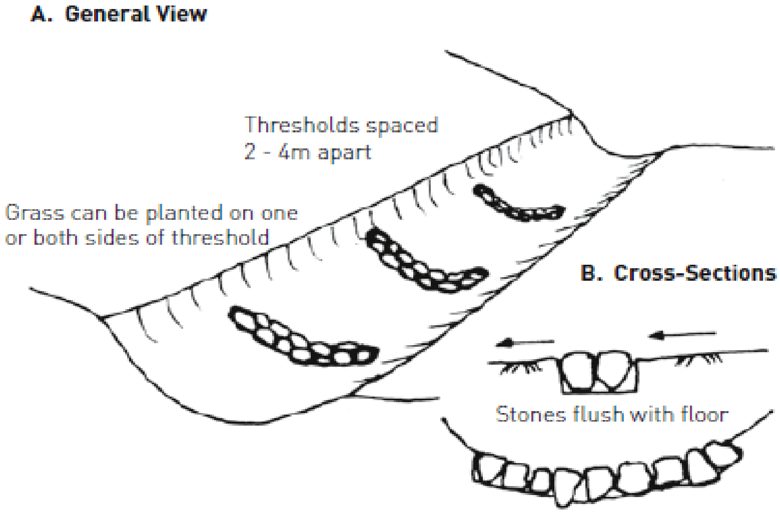


Figure 3: Scour checks constructed in the channel *(Source: Guideline for prevention and control of soil erosion in rock work, 2010)*

Stabilization: Reinforce the outlet properly with different materials, preferably stones. If stones are not available sufficiently, wooden materials, grasses will be used. If elevation difference between the cut off drain and waterway is big, it should be reinforced and provided with drop structures.

→ Plantation of grass, alloy and sisal on the embankment, the berm and the upper side of the channel is needed to prevent the soil entering the channel (see figure 4).

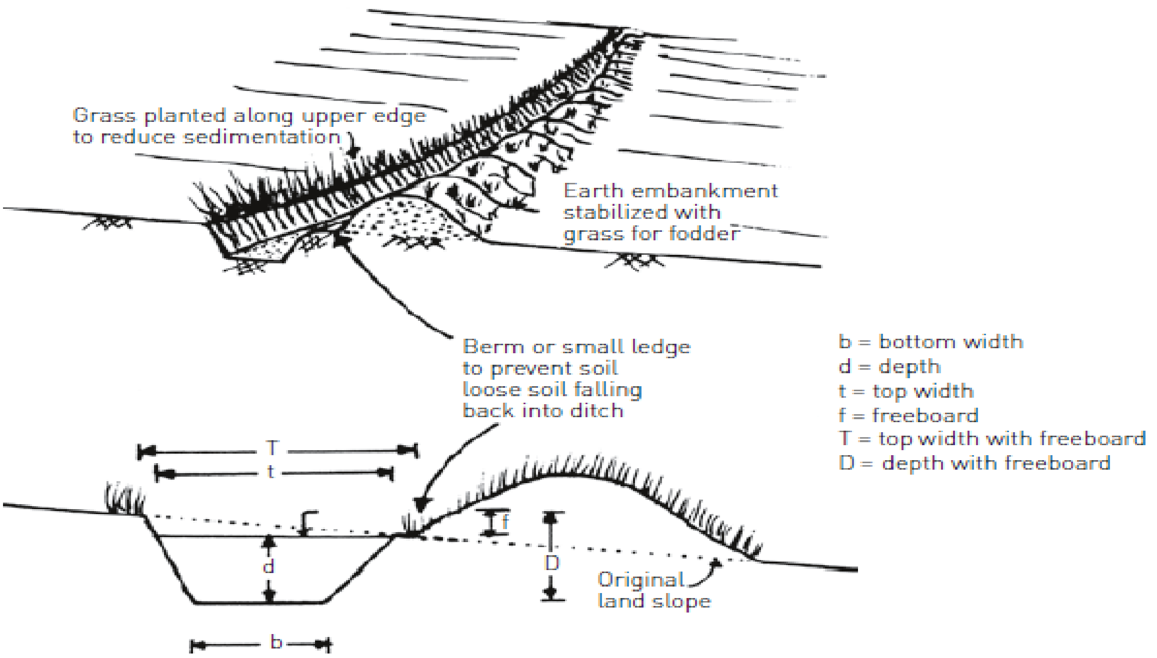


Figure 4: Stabilization with grass *(Source: Guideline for prevention and control of soil erosion in rock work, 2010)*

→ **Sink holes**: for the purpose of recycling runoff within the watershed, sink holes of 1-1.4m diameter and 1-1.5m depth need to be constructed along the channel with 6-8m spacing. Protect the inlet and outlet from scoring. Field practice has shown that it requires frequent de-silting.

Work norm: The manpower requirement (work norm) for construction of cut-off drains is 0.7 M^3/Person day.

Tools/equipments required: Pegs, String, Shovel, and Level.

2.3 Management and Maintenance

Cut-off drains require special attention and maintenance for proper management of the channel surface. The following are important issues to be considered in order to properly manage and maintain cut-off drains.

- Remove deposited soils regularly and undertaking proper maintenance.
- Continuously follow up after heavy rain and storms.
- Repair small damages immediately.
- Check for the beginning of scouring in the bed and damage in the embankment. This needs to be upgraded from time to time.
- Due attention to the outlet should be given because it is susceptible to damage and there is high volume and velocity of water to its susceptibility.

2.4 Major issues not to forget and common mistakes

Major issues not to forget:

Don’t forget:

- To get agreement with the community.
- To check whether disposal areas, especially whenever gullies are used as a disposal, are well protected and stabilised in advance.

- To start layout from the outlet point.
- To follow construction procedures.
- To compact and stabilize embankments with multipurpose grasses and trees.
- To check the bed gradient after construction.

Photo 4: A cut-off drain (Left) and area rehabilitated by enclosures. Natural vegetation regeneration after enclosures (right)

Common mistakes:

The following are the common mistakes during the design, lay out, construction and maintenance of cut-off drains that we should take care to avoid.

- Designing cut-off drains with less focus on the outlet conditions, topography, and kind of land use and soil type.
- Either under-designed or silted up cut-off drains/waterways could be a cause of severe erosion by an incoming flood as it undermines them.
- Doing layout and construction in parallel.
- Not maintaining the standard width of the berm.
- Failure to keep the intended bed gradient
- Trying to construct cut-off drain without having a safe disposal area.
- Loose compaction of the embankment.
- Absence of scour checks, drop structures and sink holes.
- Less focus on maintenance and management.

References

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3. MODULE 2: WATERWAYS

3.1 Concept

Description of Waterway

A waterway is a natural or artificial drainage channel that collects water from cut-off drains, on-farm graded structures, water storage structures and leads down the slope and safely is disposes of in an outlet. There are two common types of waterways: Vegetative and Paved Waterways.
A vegetative waterway can be constructed in areas without stones. The main advantage of a vegetative waterway is that it can be constructed for both very small and large size catchments, thus accommodating individual or communal needs for drainage and use of excess run-off.

A paved waterway is suitable in steeper terrains and areas with a large amount of stones.

Purpose of Constructing Waterways

Waterways are constructed to conduct excess run-off safely from hill slopes to valley bottoms where it can join a stream or river. Waterways also help to reduce soil erosion and gully formation.

Where there is a natural depression or small valley that is well stabilized with vegetation, this may be adequate to take the discharge from diversion ditches or graded terraces, but where there is no such natural waterway, an artificial waterway (drainage way) must be installed.

Photo 5: Waterways for disposing discharge coming from cutoff drains and graded terraces (Photo , 2004)

Time to Construct Waterways

Waterways are constructed only during the dry seasons. In order to assure their stabilization, they need to be constructed one or two seasons before the construction of cut-off drains. In area where there is adequate stone for construction of a water guide, channel pavement, scour checks and drops structures, both water way and cut-off drains can be constructed in the same season.

Suitability and agro-ecology

Waterways are applicable in all agro-climatic conditions, particularly in moist areas and areas prone to water logging. They are constructed following depressions or natural waterways and farm boundaries. Waterways are linked to graded bunds and cut-off drains in cultivated areas.

Photo 6: A waterway constructed to convey runoff from terraces and cut-off drains

3.2 Design, Layout and Construction

3.2.1Technical standards and design steps

Main factors to be considered in designing vegetative or paved waterways:

- **Slope**: The slope of a waterway is normally the slope of the land at right angles to the contour. Vegetative waterways are recommended for slopes <10% and stone paved waterways can be implemented up to 20-25% of slope. If the slope is greater than 25%, we have to apply a combination of different soil and water conservation structures like drop structures.

- **Shape**: Choose parabolic cross sections for types of waterways as these tend to resemble natural waterways.

- **Size**: The waterway must have sufficient width and depth to accommodate the expected runoff volume. Several small waterways are preferred (1-5 ha drainage area) than one very large one, and the waterways should be close enough to each other to avoid the terraces being excessively long.

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

- **Channel roughness:** The rougher the surface over which water flows, the greater the resistance to flow. The velocity of water in a channel can be reduced by making it wider and shallower (i.e. lowering the hydraulic radius) or by making the surface rougher. Hence, the value of allowable channel velocity varies depending on the surface materials and cover conditions (see Table 2). One of the ways of making the surface rougher is by planting grasses. A tall grass will provide more resistance to flow than a short one, although the resistance will be lowered if it is pushed over and flattened during heavy run-off. A rough stone surface will provide more resistance than a smooth concrete surface. The importance of the roughness factor (known as Manning's n) is presented further in Table 5.

Table 5: Manning's roughness coefficient (n) – Hudson 1981

A	Channels free from vegetation	n
	Uniform cross-section, regular alignment, free from pebbles and vegetation in fine sedimentary soils	0.016
	Uniform cross-section, regular alignment free, from pebbles and vegetation in clay soils or hard pan	0.018
	Small variation in cross section, fairly irregular alignment, few stones, thin grass at edges, in sandy and clay soils, also newly cleaned, ploughed and harrowed	0.0225
	Irregular alignment, pebbles on bottom, in gravelly soil or shale, with jagged banks or vegetation	0.025
	Irregular section and alignment, scattered rocks and loose gravel on bottom, or considerable weeds on sloping banks, or in gravelly material up to 150 mm	0.03
	Eroded irregular channels, channels blasted in rock	0.03
B	**Vegetated channels**	
	Short grass (50-150 mm)	0.03-0.06
	Medium grass (150-250 mm)	0.03-0.085
	Long grass (250-600 mm)	0.04-0.15
C	**Natural stream channels**	
	Clean and straight	0.025-0.03
	Winding, with pools	0.033-0.04
	Very weedy, winding and overgrown	0.075-0.15

Table 6: Maximum permissible velocity in channels (m/sec) – Hudson 1981

Surface material	Bare	Good/Medium grass cover	Very good grass cover
Very light silty sand	0.3	0.75	1.5
Light loose sand	0.5	0.9	1.5
Coarse sand	0.75	1.25	1.7
Sandy soil	0.75	1.5	2.0
Firm clay loam	1	1.7	2.3
Stiff clay or stiff gravelly soil	1.5	1.8	2.5
Coarse gravels	1.5	1.8	Unlikely
Shale, hardpan, soft rock, etc.	1.8	2.1	-
Hard cemented conglomerates	2.5	-	-

Note: Permissible velocity is the velocity of water allowed to flow in a channel without causing ***scour*** in the channel bed and that does not allow ***siltation*** in the channel.

- **Rainfall data:** to determine the peak discharge using the rational method (see also annex on "method of calculating peak run off rates for channel design"), a minimum of 10 years rainfall data of the area should be available. Rain fall intensity of the area is derived from the maximum/design daily rainfall of a given return period.

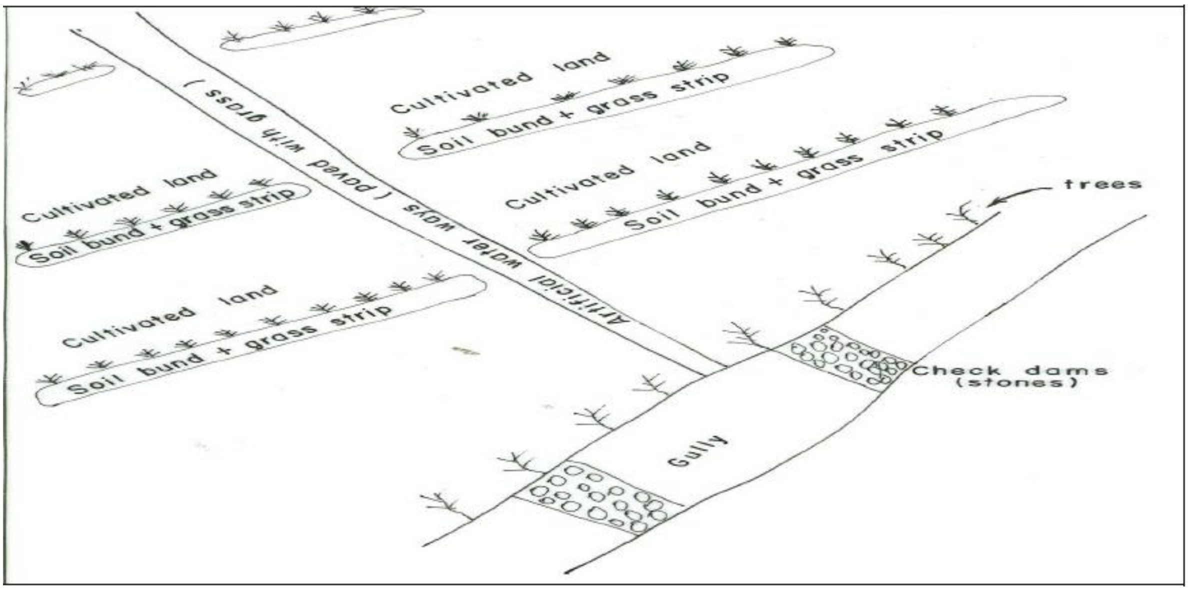


Figure 5: Technical Drawing

Design steps:
Step1: Determine the drainage area (catchment area) that yields runoff to be safely conveyed by the waterway.
Step 2: Determine the peak runoff (volume of flow) using the rational method. Here, use assistance from woreda experts in the calculation of the peak runoff. The dimension of a waterway depends on the expected discharge calculated in cubic meters per second. The estimate of discharge should be based on the peak flow at the outlet end of the waterway rather than the amount expected at the inlet, which is usually less.

- The discharge rate (Q) can be calculated as follows:

$$Q = KIA/3.6$$

Q= the peak runoff rate/the designed discharge (m3/sec)
K= the runoff coefficient
I = rainfall intensity (cm/hr)
A= the runoff producing area (ha)

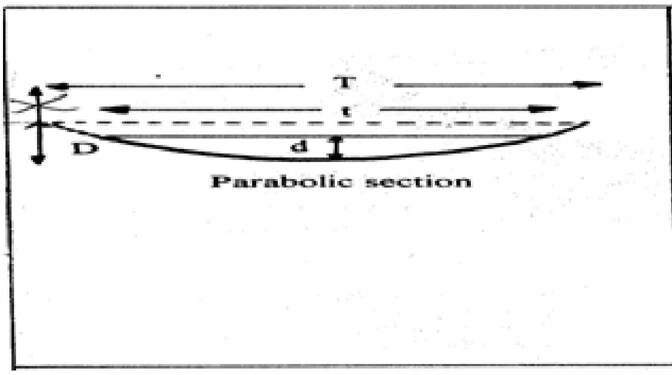
- Use the following table to find **K** value for different land cover and range of slope

Table 7: Values of Runoff Coefficient

Land Use/Cover	Runoff Coefficient (K)		
	Slope (0-5%)	**Slope (5-10%)**	**Slope (10-30%)**
CULTIVATE LAND			
Open Sandy loam	0.25-0.30	0.4	0.52
Clay and silt loam	0.5	0.6	0.72
Tight Clay	0.6	0.7	0.82
PASTURES			
Dense cover	0.1	0.16	0.22
Medium cover	0.3	0.36	0.42
Open pastures	0.4	0.55	0.6
FOREST/WOODLAND			
Dense cover	0.1	0.25	0.3
Medium cover	0.3	0.3	0.5
Scattered	0.4	0.5	0.6

- *In order to determine peak flow and to fix flow depth and bottom width using Rational method, read the separate material prepared for woreda experts.*

Step 3: Determine the width in meters of water way from Table 4 having measured slope of the waterway. For parabolic section take the design width **(w) = A/0.67d**; where **d** is the design depth; **A** is the cross-sectional area of the channel calculated as **A = Q/v;** Q = the peak runoff rate/the designed discharge (m3/sec).



Area (A)	2td/3
Wetted perimeter (P)	$t + (8d^2/3t)$
Hydraulic radius (R = A/P)	$t^2d/(1.5t^2 + 4d^2)$ R = approx. 2d/3
Top width (t) (T)	t = 3A/2d $T = t(D/d)^{0.5}$

Figure 6: Channel cross section, wetted perimeter, hydraulic radius and top width formulae for parabolic section
(For more practical examples, please see Waterway Exercise in the Training Package).

Table 8: Relationship between drainage area and width of waterway

Drainage/ Runoff Area (Ha)	Width of the waterway(m)		
	Slope (0-5%)	Slope (6-12%)	Slope (13-25%)
1	1.5	1.5	1.5
2	1.5	2	2.5
5	2	3	4.5
10	3	6	9
15	3.5	8	12
20	4.5	12	18

Step 4: From the table showing relationship between depth and width (Table 5), determine depth in meters. For parabolic section take the design depth **(d) = 1.5r**; Here, **r** is the hydraulic radius calculated as $\mathbf{r = (vn/s^{0.5})^{1.5}}$ and v = maximum permissible velocity (see Table 6), n = Manning's roughness coefficient (see Table 5), and s = slope.

Table 9: Relationship between depth (m) of waterway and width (m)

Width in meters	Depth in meters
0-3.0	0.3
4.0-6.0	0.4
More than 6	0.5

3.2.2 Layout and construction steps

Layout: Where possible, the waterway should be located in a natural depression or drainage way. Thus, follow natural waterway to determine length and width. However, in case where there are no natural depressions to dispose of the runoff, there should be a simple field survey that can assist us to choose the appropriate artificial waterway. This can be done through intensive discussions with landowners and adjacent villagers.

Required tools: Shovels, Hoes, Pick axe, Crowbars, Level, and Pegs.

Work norm: The manpower requirement (work norm) for construction of vegetative waterways is 1 personday/1M^3 and for paved waterways is 1 personday/0.75M^3 earth/stone work.

Construction steps:

- After the waterway has been staked out, construction can start from the lower end by excavating soil from the centre and throwing it to each side to form the banks.
- As soon as digging is complete, the waterway should be lined by planting a suitable spreading grass, or with stone or a combination of grass and stone.
- The process of excavation may expose less fertile sub-soil and, if so, it is advisable to use manure and mulch to ensure quick establishment of the grass. See each step in figure 7 below.

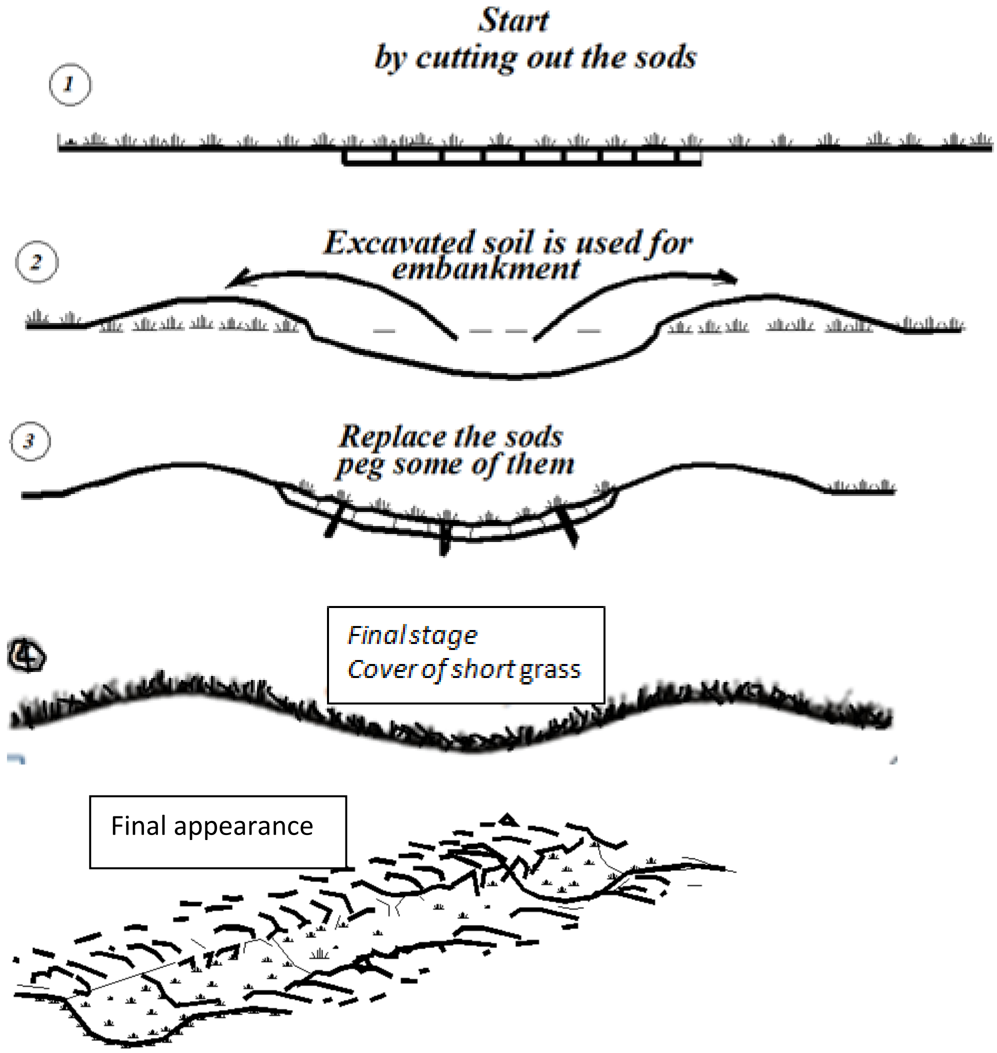


Figure 7: Grassed waterway construction steps *(Source: Guideline for prevention and control of soil erosion in rock work, 2010)*

Note that: Parabolic sections are more applicable for waterways as shown in figure 8 below.

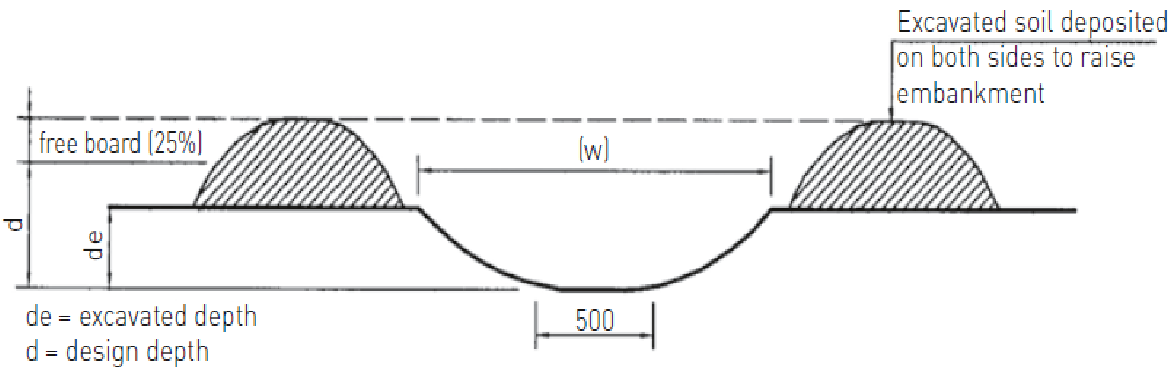


Figure 8: Parabolic section of waterway *(Source: Guideline for prevention and control of soil erosion in rock work, 2010)*

- ***For vegetative waterways:*** place stone or brushwood Checks-drop-aprons (CDAs) every 20m (slope <5%), 10m (slope 5-10%) and 5 m (slopes 10-25%) (See Figure 9 below).

Figure 9: Check-Drop-Apron with wood posts and stones for vegetative waterways *(Source: CBPWD guideline, 2005)*

- ***For paved waterway:*** place stone or wooden pegs **checks-drop-aprons** at 1 meter vertical interval. The apron length should be equal to the height of drop. The height of checks-drop-aprons should be 0.3-0.5m.

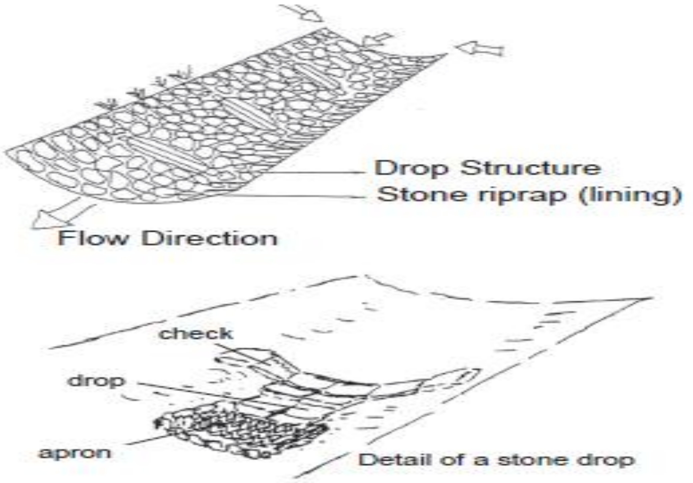


Figure 10: Stone paved waterway design *(Source: CBPWD guideline, 2005)*

- **Excavation**:

➢ **For vegetative waterways**: excavated soil piled and compacted on one side of waterway (thrown downhill) if the channel is constructed on sloping land. However, this soil could be piled and compacted on both sides of waterway (thrown to both sides) if the land is level (see Figure 6).

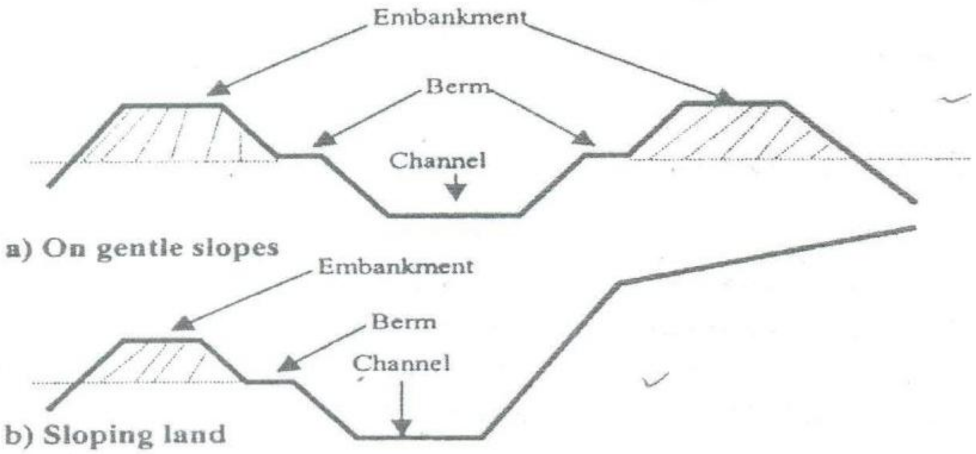


Figure 6: Vegetative Waterway *(Source: Daniel, Betru, Diribu, & Berhanu, 2001)*

➢ **For Stone Paved Waterways (SPW):** pile and excavated soil and place flat heavy stones at the bottom - fill with smaller stone on the space between large ones.

- **Sink holes**: for the purpose of recycling runoff with in the watershed, sink holes of 1-1.4m diameter and 1-1.5m depth need to be constructed along the waterway below every slope change point of lateral drainage terraces. Protect the inlet and outlet from scoring. Field practice has shown that it requires frequent de-silting.

- **Stabilization**: Local grass - sods - dry straws lines buried into the ground during first year.

Remark: Take care not to disturb the already existing stabilized natural waterways unless and otherwise small work of reshaping the inlet and the course is required.

Photo 7: A small stone paved waterway along boundary

Photo 8: A natural waterway stabilized by stone riprap and farm check dams

3.3 Management and Maintenance

- Maintenance is important and the waterway should be inspected after every heavy storm, especially during the first year while the vegetative cover is being established.
- The waterways should be wide, sloping downhill and should never be reduced in width as a result of tillage.
- Never use the waterway as a road and for grazing livestock.
- Any damage should be repaired immediately.

- The inlet, outlet, sidewall should regularly be checked to ensure that no erosion is taking place.
- Adjacent households should work together during and after construction for proper maintenance of waterway channels.
- Periodically reseed or replant bare areas in the waterways.
- Maintenance is needed for cutting the grass along and inside waterways, for preparing the stone paving or for improving drop structures.
- If an active gully is observed, additional measures like check dams should be integrated in the maintenance work.

3.4 Major issues not to forget and common mistakes

Issues not to forget:

Don't forget to:

- establish the grass cover immediately after marking out and constructing the waterway.
- water the planted grass cover to help root initiation.
- establish and protect the vegetation lining the waterway to a distance of at least one metre either side of the banks.
- be sure that the existing natural water course is not disturbed.
- **re-check** the depth, width and the gradient when the digging of the channel is completed**.**
- have several small waterways rather than one very large one, and the waterways should be close enough to each other to avoid the terraces being excessively long.
- re-use the top soil to ensure quick establishment of the grass if the process of excavation may expose less fertile sub-soil.
- plant or sod the outlet. Experiences and field trials conducted in many places in Ethiopia showed that outlets planted with the **local grass** performed fairly well in forming stable outlet. **Sodded outlets** were also seen to be efficient in stabilizing.

Common mistakes:

The following mistakes are often made:

- Not marking the center of the waterway before starting the excavation work will lead to the creation of unnecessary irregularities.
- Failure to construct proper waterways to take run-off from roads has led to the formation of many gullies on arable land. This means that where the cut-off drains/waterways are either under designed or silted up, they could be a cause of severe erosion by an incoming flood as it undermines them. Thus, this fact calls for the proper design and maintenance of the channel.
- Using the waterway as a road and for grazing livestock.
- Focusing on the inlet rather than the outlet to estimate the discharge of the waterway.
- Use of small and sliding stones to pave the outlet which are easily washed away.
- Scouring of waterways while connecting with cut-off drains or graded structures.
- Not de-silting regularly waterways and sink holes damages the shape of parabolic structure and makes water to flow sideways.
- Not avoiding conditions that aggravate gullying while letting cut-off drains or graded terraces into a waterway.
- Not maintaining standard width of the berm.
- Loose of compaction of the embankment.

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