Part 2

FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF AGRICULTURE

Community-based Participatory Watershed and Rangeland Development: A Guideline

INFOTECHS ON TECHNOLOGIES FOR WATERSHED AND NATURAL RESOURCE DEVELOPMENT FOR MIXED-FARMING AREAS

Editors: Amare Mugoro, Lakew Desta, Tariku Alemu and Alex Schumacher.

Contributors (Alphabetical): Abenet Mengistu, Aklilu Mesfin, Amare Mugoro, Betru Nedesa, Dagnew Menan, Dr. Gizaw Desta, Hailu Hunde, Halake Bente, Hune Nega, Lakew Desta, , Mesfin Brihanu, Nesredin Rube and Tariku Alemu.

Co-contributors: Begashaw Wukaw, Dr. Melesse Temesgen, Hana , Hadia Seied, Ian Campbell, John Relay, Mebratu H/silase, Million Alemayehu, Tedrows G/Egizhabhare, Workineh Fisseha, Yiftusera Yitaye and Yosef Assefa.

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INFO-TECHS ON TECHNOLOGIES FOR WATERSHED AND NATURAL RESOURCE DEVELOPMENT FOR MIXED-FARMING AREAS

A. Introduction

The Info-techs (information on techniques and technologies) or information kits are IEC (Information, Extension and Communication) materials are prepared to assist Development Agents and various experts at *wereda* level as well as other field staffs at different levels for implementation of technologies, to conduct supervisions, monitor and evaluation of performances.

The Info-techs for mixed-farming areas (Highlands) are presented in 13 main categories of technology groups based on technical similarities, purposes, implementation modalities and technical expertise requirement.

The main purpose of the Info-techs part of the guideline is to guide field staff to follow correct and quality oriented technical standards pertaining to local conditions of soils, slopes, vegetation, and rainfall patterns. Info-techs attempt to summarize several aspects related to the interventions, providing information on key design features of the measures. To describe info-tech technology groups and each technology in a consistence way a standard technology description features and procedures are used as much as possible.

The info-tech technology groups are described with a two pager preamble page to give a general overview on the grouped technologies. Similarly, most of the technology are described with ten description features formatted in table form.

The formats used are not in a definitive form and can be adapted and further modified and improved by regions and *wereda*s as necessary, provided that national norms are maintained and followed. Some of the work norms needs revision and the MoA will conduct work norm revision studies for selected technologies in the near future.

The info-techs are based upon the previous watershed guideline and experiences gained from different parts of the country and considered new and modified technologies practically undertaken by various stake holders. The info-techs are developed following a gap assessment and tried to be as brief and descriptive as possible. In this regard they should not be seen as comprehensive and sufficient for all situations. They are simple guidance notes on major activities based on national work norms developed earlier and recommended from experiences. Accordingly, additional technical references and materials (and expertise) should be consulted whenever necessary. Furthermore, additional info-techs could be developed by regions on single measures or combined set of measures proven successful and adapted to specific conditions.

The Info-techs can be used within the context of ongoing projects and programmes on natural resources and watershed development supported by the government and various local and international organizations (PSNP, RLLP, NGOs, GIZ, etc.), the national voluntary participatory community labor efforts and the CALM PforR project watersheds. At *wereda* level the info-techs can be used during field work and training as quick references. They need to be explained to DAs by professional specific technical experts (NRM, water resources, irrigation, livelihood, etc.) and/or used during on-the-job or in-service training.

B. Main features of the Info-techs

Group of technologies: The info-techs are grouped as physical SWC technologies; in-situ physical moisture harvesting – water storages measures; drainage management structures; gully rehabilitation technologies; biological SWC technologies; area closure, rehabilitation of degraded lands and management practices; agroforestry practices; wind erosion control measures; structural water harvesting technologies; SSI technologies - irrigation water application and management; water lifting devices; homestead development and livelihoods; and feeder road constructions.

Size: Summarized in either two or three pages in a single sheet. Some new technologies are presented in three pages and very few in four pages.

Information: The info-techs contain both written and visual information in the form of drawings and pictures. Each technology has a general description of the technology; geographical extent of use or suitability; technical design requirements and procedures; layout and construction procedures; period of implementation across season; planning and mobilization requirements; implementation procedures and approaches; cost elements and work-norms; management and maintenance requirements; acceptability and sustainability, and challenges/limitations as a description feature.

Ready to use (user friendly): As much as possible, a clear explanation on basic design features is provided. In several info-techs, ready-made tables with specifications are also provided together with several drawings. Most info-techs can also be explained to farmers using by enlarging and using the drawings.

Linkages and Flexibility: Most Info-techs also suggest various integration requirements and modifications to standard design necessary to accommodate various local conditions. In this regard, flexibility in design is essential to provide sufficient adaptability to local conditions within the quality standards proposed

Adaptability: The info-techs can be further refined and expanded (or contracted) to accommodate region and *wereda* specific realities. Therefore, they should be seen as guidance for further improvements.

Measures specific: This set of info-techs focusses mainly on single activities although specific references on integration with other measures is often made. In this regard, they should be seen as basic info-techs on the main interventions. However, other info-techs related to a variety of combination of measures or set of measures can also be developed to reflect specific technological approaches for different areas. Some of these info-techs are currently under preparation.

Physical Soil and Water Conservation Technologies

Overview

The main factor attempting against the sustainability of agricultural production is soil and land degradation. Also, of growing importance are the offsite effects of land degradation on increased risks of catastrophic flooding, sedimentations, landslides, etc., and on global climate changes. Although land degradation is affected by soil and climate characteristics, it is mainly due to inappropriate use and management of the natural resources soil and water, generally imposed by social and economic pressures. Among the different land degradation processes, soil water erosion is the major threat to the conservation of soil and water resources. The processes of soil erosion, caused by the interactions of soil, rainfall, slope, vegetation and management, generally result on, or there are caused by unfavourable changes in the soil water balance and in the soil moisture regime. In surface erosion, the soil particles detached by rainfall or running water, are transported by surface flowing water (surface runoff). Mass movements are the gravitational movements of soil material without the aid of running water. The hydrological processes leading to surface or landslide erosion are different, and therefore, soil conservation practices are very appropriate for controlling surface erosion processes may increase erosion danger by mass movements under specific combinations of climate, soil and slope.

Soil conservation can be defined as the proper utilization of the soil resource so as to make possible a high level and sustained production. Soil conservation is to obtain the maximum sustained level of production by maintaining soil loss below a threshold level i.e., the natural rate of soil formation. Different practices have been developed to accomplish soil conservation work, though not all of them are applicable in all contexts. The main functions of physical soil and water conservation measures described in this section are:

a) To modify landscape (slope) – slope correction and ultimately achieve benching

b) To safely evacuate excess water/runoff

c) To reduce runoff impact and increase infiltration and conserve moisture

d) To ease cultivation operation as it is easy to cultivate level than steeper slopes

e) To reduce runoff volume and velocity by increasing surface roughness and act as barriers to soil transport by erosion agents, i.e. runoff water

The soil and water conservation technologies should be appropriately planned to align with overall development and conservation goals and strategies and achieve objectives of multi-functionality on climate adaptation, livelihood and environmental protection. In turn, the technologies should fulfil environmental and economic efficiency. Moreover, the soil and water conservation technologies need to be guided by the community watershed development plan and land use plan.

Physical or mechanical conservation measures: are those practices, which call for the construction of some kinds of earthwork. Physical soil and water conservation measures are also known as structural or engineering measures. They are usually needed to reduce velocity of runoff and retain to assist infiltration of soil and/or dispose-off surplus storm water (runoff) safely. Physical conservation measures are applied as secondary measures when the erosion problem is not mitigated by land use and vegetation cover management measures. In other words physical measures are applied when biological and vegetative measures are not sufficient enough to control erosion. They are only aids to proper land use and land cover using appropriate biological conservation measures. Physical or mechanical protection works are expensive, time consuming and dangerous at times of failure. Thus, they should be considered only where other conservation practices couldn't provide adequate control.

In order to enhance the required functions, the type of soil and water conservation technologies should be carefully identified and selected and properly match with the specific local conditions /niche i.e., soil drainage, soil erodibility, slope gradient and shapes, rainfall characteristics, and the prevailing farming system. Moreover, the specific functions can be met by a combination and integration of the different technologies. Thus, selection and integration of SWC technologies should be supported with detailed spatial information such as topographic, soil and climatic information as well as connectivity of upstream and downstream uses.

For designing and layout of physical SWC measures to determine dimension of structures (i.e. width, depth, freeboard, cross-sectional area); channel gradient, channel lining, shape, length; and spacing (vertical interval and horizontal interval), the following parameters are important:

- Peak discharge in cubic meter per second
- Maximum permissible flow velocity in meter per second
- Erodibility of the soil
- Soil drainage conditions, and
- Land use efficiency of the measures or land lost by physical soil conservation measures to be compensated by improving productivity on bunds.

The physical soil and water conservation measures presented as toolkits are:

1. Level Soil Bund
2. Level Fanya Juu
3. Stone Faced Soil Bund
4. Stone Bund
5. Bench Terracing
6. Hillside Terracing

Name of the Technology	LEVEL SOIL BUNDS (SB)

General Description

Level soil bunds/channel terraces are impermeable structures constructed along the contour and across the slope to reduce velocity of runoff and retain eroded soil and moisture. Consequently, reduces soil erosion and the steady decline of crop yields. Unless provided with spillways, intended to retain all rainfall, and hence, increases the moisture retention capacity of the soil profile.

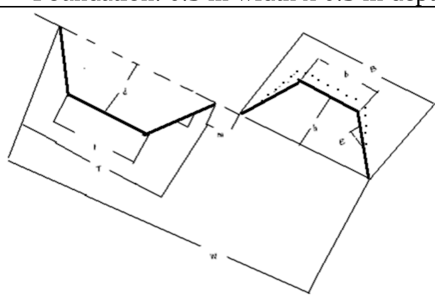
Geographical Extent of Use

The most limiting conditions are rainfall and soil drainage. Suitable mostly in semi-arid and arid areas but also in medium rainfall areas with well drained soils. Commonly practiced in dry and moist and mid altitude/highland areas where moisture conservation is found important. Applied generally on cultivated lands with slopes above 3% and below 15% gradient (See Table below). Can be applied on grazing lands with gentle slopes at wider intervals (up to 5%). Can be applied also within sloping homestead areas combined with cash crops. Several areas also show introduced bunds adapted or adopted from past conservation activities. Local experience is very relevant to assess performance of past activities and suggest modifications as required. Improved designs can be integrated with local ones to add strength to bunds (grass, stones, etc.).

Fig 1. Level SB on farmland with trenches – the land sloping from downwards from left to right

Technical Design Requirements

- Height: 60-70cm up to 100 cm (lower side);
- Total Base width: (height/2) + (0.3-0.5 m);
- Top width: 30-40 cm;
- Foundation: 0.3 m width x 0.3 m depth;
- Grade of soil bank (seal) on upper side: 1 horiz :1.5-2 vert.;
- Bunds need to be spaced staggered for animals to cross;
- Max bund length 60-80 meters.
- Channel can be tied every 5 - 10m to maximize infiltration



T=Top width of trench (80 cm)	t = Bottom width (50 cm)
d=Furrow depth/trench 50 cm	E = Embankment gradient 1 (horiz.): 2 (vert.)
B=Bund width at base (90 cm)	m = Berm (10 cm)
W=Overall width (180 cm)	b = Top width (30 cm)
Height after compaction 50cm	Height before compaction (60 cm)

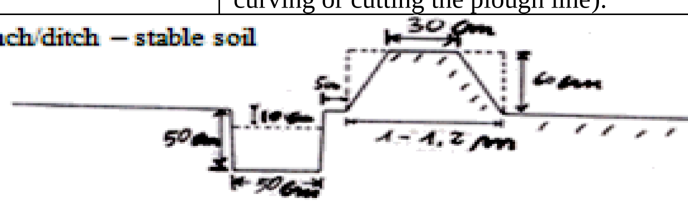
Fig 2. Schematic view and standard cross section of the channel and bund / embankment for conventional soil bund on stable soil

Layout and Construction Procedures

Vertical intervals: follow a flexible and quality-oriented approach:
- Slope 3-8% VI = 1-1.5 m; Slope 8-15% VI = 1-2 m
- Slope 15-20% VI = 1.5-2.5 m (only exceptional cases - reinforced); Depending on the relative soil erodibility, modify VI. Narrow spacing between bunds is recommended for silt and loam and wider for clay and pure sand soil textures. For layout of SWC measures see Annex 2.

Caution: soil bunds > 15% to max 20% only if space reduced and with trench, short bunds - above 15% better apply stone faced or stone bunds) using intervals of Table 1. Layout along the contours using line level; discuss spacing with farmers and in case of lateral slopes try to maintain lines as straight as possible by applying reinforcements on depression points (to avoid curving or cutting the plough line).

a) Profile of bund and collection trench/ditch – stable soil



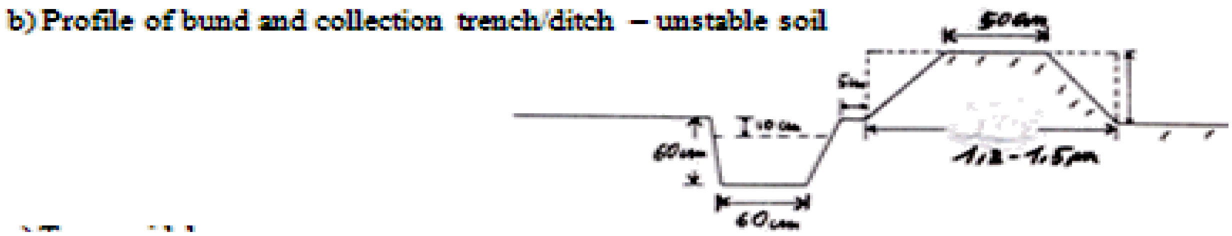


Fig 3. Profile of bund and collection trench/ditch in different soil types

Table on Layout and Vertical Interval (VI) specifications

Ground slope %	Height of bund (m)	Vertical Interval (M)	Horizontal Interval (m)
5	0.5	1	20
10	0.5	1.5	15
15	0.75	2.2	12
20	0.75	2.4	10
25	1	2.5	8
30	1	2.6	8
35	1	2.8	6

Period of Implementation Across Seasons

Only during the dry season and period not interfering with land preparation. However, short showers ease the digging and compaction of the soil as it gets moist than dry.

Planning and Mobilization Requirements

It should be considered as an integral part of the treatment of the community watershed and not in isolation. Assessment of land use, soil, topography and drainage is required to identify and understand integration of SWC measures along the topo-sequence. Discuss/agree with farmers on design and layout and support with on job training, Regular maintenance specifications and mechanisms of maintenance need to be agreed with farmers.

Cost Elements and Work Norm

Layout: One water line level, two range poles graduated in cm and 10 meters of string (three people layout approx 2-3 ha/day). **Work materials:** shovel, pick axes and wooden compactors (the proportion of shovels and pick axes depend on type of soil). **Work norm** is 150 PD/km.

Management and Maintenance

Upgrading soil bund using FJprinciple: Problem with FJis that they overtop easily and break. So in difficult slopes with traverse/lateral gradients it is better to implement soil bunds and stone bunds/stone faced bunds than Fanya Juu. After the 1st or 2nd or 3rd year upgrade the terrace by using the FJ principle (See Figure below). For rapid benching + apply compost to improve infiltration near embankment/raiser. This form of upgrading can be applied at very large scale on existing conserved areas.

Integrate vegetative bund stabilization: using grasses (indigenous and improved) and legume shrubs (Pigeon peas, Sesbania, Acacia Saligna, etc.) in dense rows by direct sowing (15-30 cm) on upper side of bund and berm. Pigeon peas also planted annually. Lower part of the wall can also be stabilized by planting drought resistant plants such as Sisal, Aloes and Euphorbia in dense rows.

Agronomic practices: contour plowing and compost (start first year applying 2-3 m strips above the bunds - where soil is deeper and high moisture).

Grow cash crops along bunds (especially after 1-2 years of composting) in single or wider strips as required. Plant specific crops along bunds to use residual moisture (sunflowers, gourd, tomatoes, cucumbers, etc.).

Control grazing - avoid animals graze between bunds for at least 1 yearr and place bunds in staggered position, do not end a bund in a depression.

Benefits and Acceptability

The advantages of channel soil bunds are that during first year the bunds can accommodate more sediments and water than FJ– thus less prone to breakages. During 2nd and following years the deposited soil and retained moisture enhances productivity. The embankment (nearly 8-10% of area) can serve to grow fodder and generate cash from fodder seeds and fruits.

Limitation

On erodible soils, the channels shortly silted up and require regular maintenance. On less erodible soils, achieving bench formation takes long time. Easily damaged by livestock if it is not accompanied with zero grazing practice and vegetative measures. Bunds can create temporary water logging if not integrated with fertility management. Land lost by the structures, at early years, is a limitation.

Name of the Technology	LEVEL FANYA JUU (FJ)

General Description

Similar to the level soil bunds they are impermeable structures constructed along the contour and across the slope to retain soil and moisture. Contrary to level soil bunds soil is dug from below and put upwards. FJ is a "*Swahili*" language word which means "Throw UP" (See Figure right). The conventional soil bund is inverted in the sense that the channel is dug and the soil for embankment is thrown up slope. Compared to soil bunds it is constructed on gentler slopes (<10%). Depending on the rainfall intensity and nature of the soil FJ bunds can be level or graded. The FJ reduces the velocity of runoff and consequently reduces soil erosion. They are impermeable structures intended to retain rainfall, and hence, increase soil moisture, water availability to plants. FJs benches quicker than soil bunds, less land loss by the structure and not easily crossed by livestock but it is not efficient in conserving moisture and more prone to breakages /overtopping by concentrated runoff.

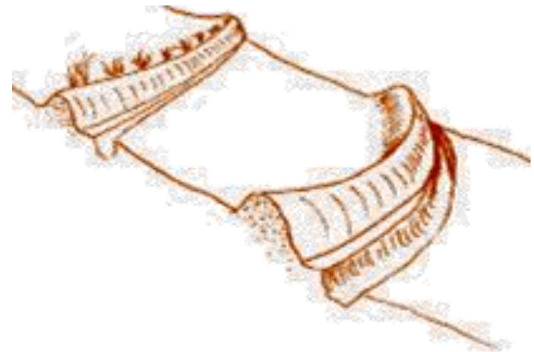


Fig 1. Level FJ with the trench on the lower side and embankment on the upper side

Geographical Extent of Use

Suitable mostly in moist and medium rainfall areas with deep and well drained soils. Can also be practiced in upper ranges of semi-arid conditions, particularly on gentle slopes and well drained soils. FJs are commonly practiced in Ethiopia in several areas following its introduction over 3 decades ago. Applied generally on cultivated lands with slopes above 3% and below 15% gradient. Fanya Juus are best constructed in uniform terrains with deep soils that do not have traverse slopes (depressions). Can be applied on grazing lands with gentle slopes at wider intervals (up to 5%). Can be applied also within sloping homestead areas combined with cash crops.

Technical Design Requirements

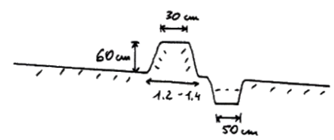
Height: min. 60 cm after compaction; **Base width**: 1-1.2m in stable soils (1 horizontal: 2 vertical) and 1.2-1.5m in unstable soils (1 horiz:1 vertical); **Top width**: 30 cm (stable soil) - 50 cm (unstable soil); **Collection ditch**: 60cm W x 50cm D; **Ties**: placed every 3-6 m interval along channel; **Length of bund**: up to 60 m in most cases, max 80m; FJ need to be staggered to allow animals - to cross fields as required.

Modifications and adaptations to standard design:

a) Combination of FJs and soil bunds and reinforcements within the same contour line to address the problem of slight traverse slopes/depression points.

b) Combination of FJs alternated with soil bunds along the slope. This method is to allow some excess runoff not captured by the FJ to get retained by the upper trench of the soil bund. c) Upgrading of soil bunds using the FJ principle after 2-3 years (see also soil bunds)

Profile of fanya juu bund and collection trench/ditch - stable soil



Profile of fanya juu bund and collection trench/ditch - unstable soil

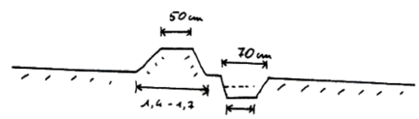


Fig 2. Sections of FJ bunds

Layout and Construction Procedures

Vertical intervals: Flexible and quality-oriented approach. Slope 3-8% VI = 1-1,5m; Slope 8-15% VI = 1-2m; Layout along the contours using line level; poles, string, and three people needed. A-Frame and water-tube-levels are also possible. Depending on relative soil erodibility, modify vertical interval. Discuss spacing with farmers. **Note: Shift to soil bunds in areas with slight traverse slopes of high runoff accumulation and apply stone keys and reinforcements.**

Period of Implementation Across Seasons

Similar to level soil bunds, it will be good if there is some moisture for digging and good compaction. Otherwise, only during the dry season and period not interfering with land preparation.

Planning and Mobilization Requirements

Planning follows community/groups and individual owners' discussions/agreement on layout, spacing and management requirements. Groups of 5-20 households work together to increase efficiency (layout, excavation, shaping, compaction, level check). Integration and connectivity of SWC measures along the topo-sequence require pre-assessment of land use, soil, topography and drainage. Provide on-the-job training. Precise layout and follow-up/adaptations. Discuss and agree with farmers on regular maintenance procedures and mechanisms.

Cost elements and Work Norm
Precise layout along contours (level) using line level; Scratching or removal of grasses from where embankment is to be constructed for better merging/mating and stability; Excavation of ditch or channel, and ties along channel; Embankment building, shaping and compaction (essential); Leveling the top of bund with an A-frame (level bunds). Layout: One water line level, two range poles graduated in cm and 10 meters of string (a team of three people layout approx 2-3 ha/day). Work tools: shovels, pick axes and wooden compactors (the proportion of shovels and pick axes depend on type of soil). Work norm is 250PDs/Km.
Management and Maintenance
Local experience very relevant to assess performance of past activities to suggest modifications. A major opportunity is the application of the FJ principle after standard soil bunds are constructed for not disturbing the upper ditch filled with fertile soil. Integration with vegetative bund stabilization: FJs need the embankment stabilized in the upper side to allow excess water to overtop without creating damage. Grass planted with other shrubs is most suitable. Plants like aloes and sisal combined with more productive shrubs (pigeon peas, etc.) are also recommended on upper and lower side of FJ. Agronomic practices: contour plowing and compost (start 1st year applying 2-3m strips above FJ, where soil is deeper and moisture is high). Grow cash crops along bunds (especially after 1-2 years of composting) in single or wider strips as required. Plant specific crops along bunds to use residual moisture inside ditches (sunflowers, gourd, tomatoes, cucumbers, etc.). Control grazing, staggered position of FJs + same as soil bunds. FJs need to be upgraded to become level terraces - the upgrading should use soil accumulated in the ditch below the bund. Apply cut/carry for grass/legumes growing on bunds (not uprooted). Repair breakages immediately after showers, especially the 1st year. Fully on individuals/groups +/- community (commitment to mgt.). Extension workers/experts/technical support and follow up. Maintaining soil bunds according to FJ principles - see soil bunds as well.
Benefits and Acceptability
The main advantages of FJ derive from its capacity to become a bench terrace in a short number of years. The structure is more acceptable on deep and drained soils under medium rainfall conditions. Moreover, it reduces concentrated runoff and slowly allows infiltrating and recharging the groundwater. However, FJs contribute to increase productivity only if well managed and integrated with soil fertility, particularly, vegetative stabilization and composting.
Limitation
FJ requires intensive maintenance to clean ditches and raise embankments to control overtopping of runoff. In a low drained soil, it causes temporary water logging if not integrated with fertility management practices. If too narrow spaced can take unnecessary space out of production. Limited stability if not integrated with revegetation - regular light maintenance and upgrading.

Name of the Technology: STONE FACED SOIL BUNDS

General Description

Stone faced soil bunds are applicable where there is need to reinforce one or both sides of the embankment with a stone wall or riser. In some instances, the reinforcement may take place only along the depression points to compensate for layout problems and to protect the entire length of the bund. Strengthening of soil bunds with stones throughout their entire length is recommended wherever farmers tend to increase the spacing between structures and stones are available. Stone faced soil bunds can be constructed in all types of soils, except sandy soils. Stones should be available from the field itself or from adjacent areas. Spacing may be slightly wider than for soil bunds, particularly up to 10% on the spacing of soil bund. The dimensions of the stone-faced soil bunds are identical to the stone bund. The difference is on the stone walls placed on one or both sides of the soil bund (See Figure on the right).

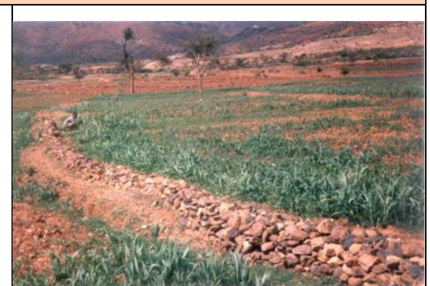


Fig 1. Stone faced soil bund, Ganta Afeshum, Mgulat /Mekedewo CW

Therefore, the bund is larger and stronger. In terms of layout bunds should be level and wing up laterally in order to evacuate excess water. As mentioned for the layout of soil bunds, farmers may want to cross small depression points straight instead of curving up and down hill continuously. In this case the entire bund should be reinforced on both sides, including a stone key.

Geographical Extent of Use

Slope range: The slope range may increase up to 35-40% slope compared to soil bunds alone. However, on such extreme slope range, the spacing between bunds should be guided by standard technical recommendations (relationships between slope, vertical interval and soil depth). Besides, above 30% slope the stone riser of the downstream embankment should have a deep foundation (30cm). Generally, spillways may be required below 8% slope if water logging problems are likely to occur. Suitable mostly in semi-arid and arid areas but also in medium rainfall areas with deep and well drained soils where there are moderately drained soils to avoid water logging and overtopping. Commonly practiced in dry and moist agro-climatic zones/areas under traditional systems. Stone faced soil bund is relatively stable and require less land compared to soil bunds.

Technical Design Requirements

Height: 60 to 100cm (lower side). Total base width: (height/2) + (0.3-0.5 m). Top width: 30-40cm. Foundation: 0.3m width x 0.3m depth. Grade of stone face downside: 1 horizontal: 3 vertical. Grade of stone face upper side: 1 horizontal: 4 vertical. Grade of soil bank (seal) on upper side: 1 horizontal: 1.5-2 vertical. Bunds need to be spaced staggered for animals to cross. Max bund length 60-80 meters. See Figures below and at the back. The design of these bunds is explained in the Figures below.

Types of stone reinforced soil bunds: *a) Single faced protection wall+/- collection trench*: Stones are placed on the downstream side, well inclined to offer maximum resistance (1:2 – 1:3 vert.). A collection trench is dug on the upper stream side of the bund (see Figures a) and b) Right - show stone faced soil bunds (single faced). They are provided with spillways if necessary (spacing, type of soils and type of crops). Stone keys are also applied in depression points if any.

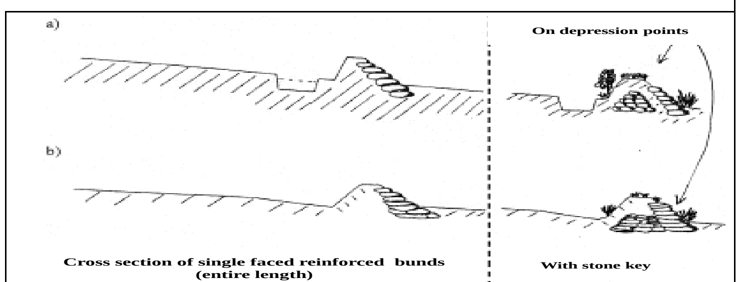
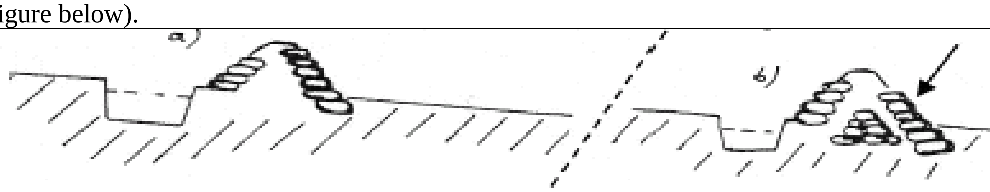


Fig 2. Cross section of single faced stone reinforced bunds (entire length)

Double faced stone/soil bunds +/- collection trench: Both sides are reinforced with stones. This type of bund is rather resistant against excess runoff. Stone keys along depression points within the earthen part of bund should also be applied as required (Figure below).

Fig 3. Double faced stone /soil bunds with a collection trench in uniform terrains (<8% slope)



Double stone faced bunds

This type of reinforcement which

c) Double faced stone/soil bunds without collection trench: Are suitable for gentle and uniform slopes (<8%). The soil embankment is obtained by scratching a wider and shallow layer of top soil. Small ties can be placed at intervals along the upper side of the bund). Double faced stone/soil bund without collection trench

d) "Corner" or lateral stone/soil bunds: This type of corner or lateral bunds differs from those for soil bunds because they are stone faced on both sides and through their entire length (See Figure right). In some instances, if the bend is on one side only these bunds are also called "*Walking Stick bunds*". They are used for moisture retention and are suitable for lateral field boundaries with gentle slopes (<5%) where farmers want to extend their bunds w/o following a precise contour line.

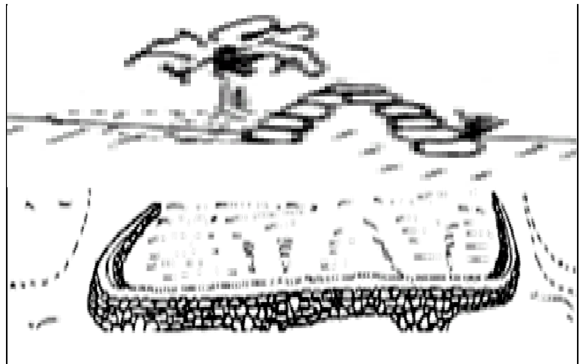


Fig 4. Double face (top) and laterally bending bund (low)

The bunds should then be raised at those corners and strongly reinforced on both sides with stones. The tips of the bunds winging upwards, whilst remaining level, are of decreasing height towards the slope. They may also evacuate excess water through their tips.

Layout and Construction Procedures

Some suggested standards are as follows:
Grade of lower stone face: 1 horiz. To 3 vertical; Grade of upper stone face: based on soil embankment grade; Grade of soil: 1 horiz. to 1.5 vertical on stable soils and 1 horiz. to 2 vertical on unstable soil; Lower stone face riser foundation: 0.3 depth x 0.2 – 0.3 width; Upper stone face riser foundation: 0.2 x 0.2 m; Stone size: 20 cm x 20 cm stones (small and round shape stones not suitable); Top width: 0.4 - 0.5 m; Height: min 0.7 and max 1 m (lower stone face); and Ties: required every 3-6 m

Stone faced bunds can be constructed by digging a foundation for stone blanket. Large stones are then placed in the ditch with the right inclination. Soil then dug from a trench on the upper side and, together with smaller stones is recommended. The rest technical specifications are identical to soil bund. Provision of spillways can be placed at the end, in the middle or in whatever convenient position with its apron at the outlet.

Period of Implementation Across Seasons

Only during the dry season and period not interfering with land preparation.

Planning and Mobilization Requirements

Planning follows community/groups and individual owners' agreement on layout, spacing and management requirements. Groups of 5-20 households work together to increase efficiency (layout, excavation, stone collection, placement, stability).

Cost Elements and Work Norm

250 PD/km (includes from stone collection up to construction).

Management and Maintenance

As for integration and input requirement it is same as for soil bunds except demanding more labour. For management and maintenance, well-constructed bunds require little maintenance, up grading bund height and controlled grazing. Apply cut and carry for grass/legumes growing on bunds (not uprooted), composting and check on stability of stone raiser, apply repairs as damage may occur. Farmers need to get enough training and supervision particularly in shaping and positioning of bunds. Regular maintenance specifications and mechanisms of maintenance need to be agreed with farmers. Tools that help to simplify labor requirement.

Benefits and Acceptability

Less space compared to soil and FJ bunds. The removal of stones from cultivated fields aids more space for plant growth (i.e. de-stoning). The presence of many traditional/indigenous knowledge increases its acceptability.

Limitation

It requires large labor for construction. If stone wall not well constructed require continuous maintenance.

Name of the Technology	STONE BUNDS

General Description

Stone bunds are bunds made of locally available stones or boulders. They are semi-permeable structures unless sealed with soil in their upper side. Stone bunds increase the moisture retention capacity of the soil profile and water availability to plants, and increase the efficiency of fertilizer applications. The stone bund reduces the velocity of runoff and consequently reduces soil erosion and the steady decline in fertility and crop yields. Compared to soil bunds and FJs stone bunds occupy less land, more durable and stable (See photo and Figure below). This is due to bunds with stones can be kept more vertical. The need for channel is less required since the stone is impervious and excess water can make its way through. However, for dry areas need to excavate ditch above the bund with adequate berm. Stone bunds are entry points for application of organic residues or compost, especially in the first 2-3 meters behind the bund where soil is deeper.

Fig 1. Typical stone bund on farmlands, Dire Dawa, Harla, Ejeru CW

Geographical Extent of Use

Stone bunds are more suitable where there is stone and rock outcrop. Stone bunds can be constructed on farmlands and grazing lands. On farmlands for most of the cases stone bunds are laid out and constructed level. If draining of excess water is needed then stone-faced-soil-bunds are essential. The removal of dense stone mulch from cultivated fields aids more space for plant growth (i.e. de-stoning). Suitable mostly in semi-arid and arid areas but also in medium rainfall areas with deep and well drained soils. To increase stability of stone bunds on steeper slopes, it requires reinforcement with vegetative measures. Local experience is very relevant to assess performance of past activities and suggest modifications as required. Improved designs can be integrated with local knowledge to add strength to bunds.

Technical Design Requirements

Height: 60 to 100 cm (lower side). Total base width: (height/2) + (0.3-0.5 m). Top width: 30-40cm. Foundation: 0.3m width x 0.3m depth. Grade of stone face downside: 1 horizontal: 3 vertical. Grade of stone face upper side: 1 horizontal: 4 vertical. Grade of soil bank (seal) on upper side: 1 horizontal: 1.5-2 vertical. Bunds need to be spaced staggered for animals to cross. Max bund length 60-80 meters. See Figures below and at the back.

$$BW = \text{Base width} = \frac{h}{2} + 30\text{-}50\text{cm (minimum)}$$

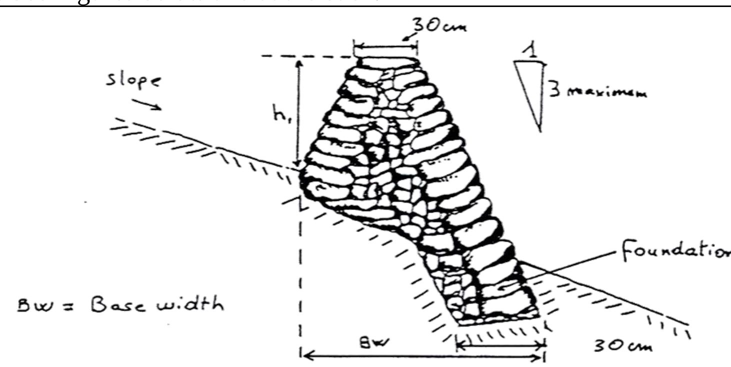


Fig 2. Different sections of a stone bund on cultivated fields

Layout and Construction Procedures

- Work out the gradient of the slope using line level**;**
- Decide the spacing of the stone bunds based on the slope;
- Excavate the foundation, place and build stone walls (larger stone for foundation);
- Continue to build the wall with stones until you reach the desired height;
- Fill voids between walls with smaller stones;
- As much as possible avoid round stones;
- **S**ealing of the upper side with soil as required;
- Reinforcement of depression points;
- Move down to the next bund and repeat the steps;
- Repeat the same in the next bund;
- Stabilization and application of compost;
- Plant the bunds with grasses, fodder legumes and tree to stabilize and make it productive;

– See Figures above and at the back.

Layout and Vertical Interval (VI) specifications

Ground slope %	Height of bund (m)	Vertical Interval (M)	Horizontal Interval (m)
5	0.5	1	20
10	0.5	1.5	15
15	0.75	2.2	12
20	0.75	2.4	10
25	1	2.5	8
30	1	2.6	8
35	1	2.8	6
40	1	2.8	5
50	1.15	2.8	4

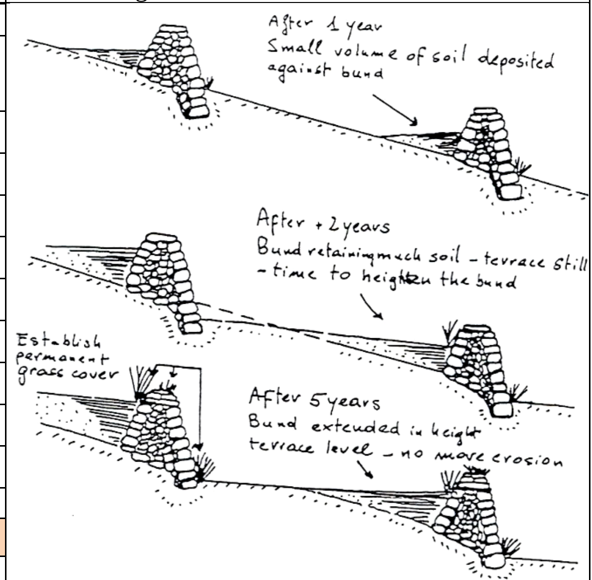


Fig 3. Stone bund with gradual build-up of sediments and benching

Period of Implementation Across Seasons

Only during the dry season and period not interfering with land preparation.

Planning and Mobilization Requirements

Planning follows community/groups and individual owners' discussions/agreement on layout, spacing and management requirements. Groups of 5-20 households work together to increase efficiency (layout, excavation, stone collection, placement, stability). Assessment of land use, soil, topography and drainage is required to identify and understand integration of SWC measures along the topo-sequence. Discuss/agree with farmers on adaptive design and layout and support with on job training, Regular maintenance specifications and mechanisms of maintenance need to be agreed with farmers.

Cost Elements and Work Norm

Laying out along the precise contours (level) using line level, collection of stones, excavation of foundation, placement and building of stone walls (larger stones for foundation and on the lower side), filling of voids between walls with smaller stones, filling of voids between walls with smaller stones and sealing of upper side with soil as required, small stone ties every 5m (optional), reinforcement in depression points. **Work norm is 250 PDs/Km**.

Management and Maintenance

All the management integration requirements mentioned under soil bunds and FJs also needed here. Stone bunds can be reinforced and stabilized further by planting drought resistant plants such as sisal, Aloes and *Euphorbia tirucalli* placed on the lower side and/or upper side of the stone bund. **Agronomic practices:** contour plowing and compost (start first year applying 2-3 m strips above the bunds - where soil is deeper and moisture is higher). **Grow cash crops along bunds** (especially after 1-2 years of composting) in single or wider strips as required. Plant specific crops along bunds to use residual moisture (sunflowers, gourd, tomatoes, cucumbers, etc.) can be applied. **Control grazing** - avoid animals to graze between bunds for at least 1 year and place bunds in staggered position and do not end a bund in a depression point. In some areas farmers practice shifting of terrace but not recommended.

Benefits and Acceptability

Less land required for stone bund compared to soil and FJ bunds. The removal of dense stone mulch from cultivated fields aids more space for plant growth (i.e. de-stoning). Suitable mostly in semi-arid and arid areas but also in medium rainfall areas with deep and well drained soils. Commonly practiced in dry and moist agro-climatic zones/areas under traditional systems. Several areas also show introduced bunds adapted or adopted from past conservation activities. The presence of many traditional/indigenous knowledge increases its acceptability.

Limitation

Stone bunds can create temporary water logging if not integrated with fertility management. If too narrow spaced can take unnecessary space out of production and appearance of some rodents (during colder seasons).

Name of the Technology	BENCH TERRACES

General Description

Bench terraces are a series of level or virtually level strips running across the slope (along the contour lines) at vertical intervals, supported by steep banks or risers. They are suitable for workable soils, sloppy land farms with a considerable depth of soil, labor availability, and for farms which are being intensively cultivated and suitable for high value production systems. In the literature bench terraces are sometimes differentiated from the common and conventional SWC measures in the way i.e. time taken for their make-up.

Fig 1. Bench terrace under construction, Meket Woreda

Excavated bench terraces carried out at one go through cut and fill process are known as “Radical terraces” while the gradually developed terraces through the action of erosion, cultivation operation, and deposition are known as “Progressive terraces”. The purpose of bench terracing are:

a) To reduce soil erosion and instead conserve it (i.e. retain sediment); b) To contribute for maximum moisture retention in the soil – with this respect bench terraces are more relevant for moisture stress areas; c) To ease the cultivation operation; and d) To achieve uniform plant growth over the width of the bench.

Geographical Extent of Use

Bench terraces are particularly suitable in the following areas: i) Where there are relatively deep soils; ii) On slopes not exceeding 25 degrees or 47%; iii) Severe erosion hazards but on sites which are not dissected by gullies; iv) Areas not too stony; v) Areas with small holdings and a dense population; vi) Areas where there are food/land shortages or high unemployment rates or large available casual labour; vii) Areas where crops require impounding water or flood irrigation; and viii) Bench terraces are much more cost-effective if there is potential for growing high-value crops, irrigation and mechanized farming.

Technical Design Requirements

When planning, designing, constructing and managing bench terraces some common terms/terminologies that one needs to be familiarize with are given below: Soil depth; Width of terrace; Terrace riser; Lip; Toe; Drain; Forward sloping; Outward sloping; Backward sloping; Reverse sloping; Inward sloping; Double sloping; Level vs graded terraces; Individual terrace; Continuous terraces; Discontinuous terraces; Transitional terraces; Vertical interval; Height of riser; Riser slope; Cut-depth; Fill height; Dike height; Dike cross-section; Horizontal interval; Width of riser; Width of bench; Cut section; Fill section; Linear length of terraces; Net area of bench terrace; Construction sequence; Progressive versus radical terraces; Developed versus constructed terraces; Excavated versus developed terraces; Layout and surveying procedures; Center-line (non-cut or non-fill); Slope in degree; Slope in percentage; Equipment for surveying; Tools for construction; Use of tractors and bulldozers; Waterways; Manuring; Cost of bench terracing; Top soil treatment; Top soil preservation; Irrigated bench terraces; Rain-fed (Upland bench terraces); Bulk density of the soil; Angle of repose; Percentage of bench; Cross-sectional area of the bench terrace; Reverse height; Outward height; Wider terrace versus narrow terrace; Cultivation of high value crops; etc. For designing bench terraces, consultation of proper manual on the technique is required, however, the following quick steps can be followed.

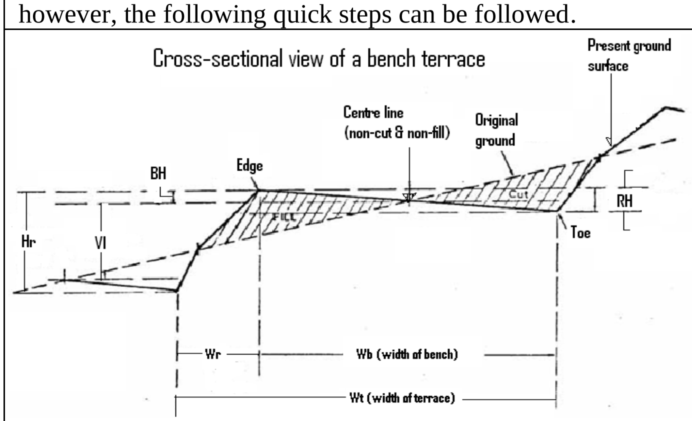


Fig 2. Cross-section view of bench terrace

Fig 3. Bench terracing with stone riser under technical evaluation – Tigray, Fereweyni Woreda

$D = \frac{Wb}{2} \tan \emptyset$ (for level terraces)

$D = \frac{Wb}{2} \tan \emptyset + \frac{RH}{2}$ (for reverse − sloped terraces)

$D = \frac{Wb}{2} \tan \emptyset - \frac{OH}{2}$ (for outward − sloped terraces)

Where; D: depth of cut in m; Wb: width of bench in m; : tangent of the slope angle.

RH : reverse height; OH: Outward height

(viii) **Net Area**: This is the area in benches or flat strips which is used for cultivation. The net area can be calculated by using the following formula:

A =

Where A is net area of benches per ha in m^2; Wt: width of terraces (the sum of the width of the bench and the width of the riser), in m; Wb: width of the bench, in m; When calculating the net area of level terraces, the dyke width should be subtracted.

(ix) **Cross section**: The cross-section can be computed by the

$C_A = \frac{Wb*Hr}{8}$ Where, C_A: Cross-sectional area of the cut triangle, in m^2; Wb: Width of bench, in m;Hr: Height of riser,

The linear length of terraces per hectare can be calculated by the following equation: $L = \frac{10,000}{Wt}$

The linear length of terraces per acre can be calculated by the following equation: $L = \frac{43,560}{Wt}$

L: Linear length of terraces in one hectare, in m; Wt: Width of terrace, in m (where Wt = Wb + Wr).

The volume (V) can be calculated by multiplying the linear length (L) by the cross-sectional area (C_A); $V = L * C_A$; When calculating the volume to be cut and filled it should be noted that only one cross-section is used. This is because the same cross-section is moving down slope to form a terrace.

For level terraces, the following formulas should be used for computing cross-sectional area:

$C_A = \frac{Wb*VI}{8} + DC$ Where, C : cross-section, in square m; Wb : width of bench, in m; VI : vertical interval, in m; DC: Dyke cross-section, in square m (or m^2)

For outward-sloped terrace a modification of the riser height (Hr) is required for calculating cross-section and volume as follows: Hr = VI - OH; Hr: Height of riser; VI: Vertical interval; OH: Outward height (equals width of bench multiplied by 0.03)

Layout and Construction Procedures

Lay out of terraces should include an examination of the site's physical conditions such as slope, soil depth, texture, erosion, presence of rocks, wetness, vegetation cover and present land use. This entails clearing the area, preparing survey equipment, stakes, color ribbons or markers, and deciding on survey methods and sequences. Equipment: the equipment usually consists of: dumpy level, abney level or A-level or A-frame; measuring tape and rod; and soil auger. For level terraces: use contouring or leveling techniques. For upland bench terraces: use graded-contouring techniques. Techniques of layout: i) Setting an up-and-down base-line at the site along a representative slope; ii) Use of centre-line method i.e. a quick calculation of the VI; iii) Use a level to determine and stake the VI of the terraces along the base line. The stakes should be streamlined if there are sharp turns and narrow bottlenecks as these will interfere with future operations. Streamlining the stakes entails extra cuts or fills but is worthwhile in the long run.

Marking stakes: Each contour line of stakes should be marked with a different color ribbon or paint in order to avoid confusion during construction, (e.g. center lines in red, and side lines in yellow or green, etc.).

Construction methods: The cut and fill of the terraces should be done gradually and at an equal pace so that there is neither an excess nor a lack of soil. This principle applies regardless of what kinds of tools are used for the operation. The terrace must be built when the soil is neither too dry nor too wet. Start building the terrace from the top of a hill and proceed down slope.

Tie cord or rope around the stakes to mark each constructed terrace in sequence. The initial cut must be made immediately below the top stakes while the fill work should be started against the bottom stakes. This is done in order to ensure that the correct grade is attained without overcutting. Sometimes, rocks or clods of earth can be placed along the bottom line of the stakes to serve as a foundation before filling. During the filling operation, the soil should be compacted firmly by a beater every 15 cm layer. If the layer of soil fill is thick, the compacting process becomes difficult. Terraces across existing depression areas should be built particularly strong. The edge of a terrace should be built a little higher than planned because of settling. The rate of settling may be as high as 10% of the depth of the fill. Both the reverse and horizontal grades should be checked by a level during construction work and corrections made promptly. The slope of the riser should be shaped to 0.75:1. Waterway shaping should be commenced only after the terraces are cut. Make sure all the terrace outlets are higher than the waterway bottom.

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

Period of Implementation Across Seasons

The terrace must be built when the soil is **neither too dry nor too wet**. Wetter soil condition is to ease the cut and fill/compaction condition, otherwise bench terracing is constructed only during the dry season not interfering with land preparation. Construction shall start and be completed in the dry season.

Planning and Mobilization Requirements

When planning the application of terraces or any soil conservation work farmers or land users should make the final decision through consensus. However, local government authorities or watershed management experts or conservationists should assist the farmers by examining the site and explaining what type of treatments are needed.

Cost Elements and Work Norm

The construction cost can be computed as follows: $C = \frac{V}{T} * R$ where, C : Cost of constructing terraces; V : Volume of cut and fill; T : Output per person-day; R : Wage per person-day, etc. For topsoil preservation, add 40 person-days per hectare for manual labor.

Management and Maintenance

If a small break is neglected, large-scale damage will result. Inspection, protection, maintenance, management and integration requirement is mandatory. Further: i) Periodic inspection and maintenance during and after construction as per standard specifications will be required based on post-construction site conditions; ii) Make any repairs necessary to ensure the measure is operating properly (drainage outlets, risers, etc); vii) Damaged benching and terracing areas shall be repaired immediately and reseeded as soon as possible. Substantial maintenance of the newly planted or seeded vegetation may be required. The lower part of the benched field is planted with perennials such as coffee, Gesho (*Rhamnus pranoides*), and Chat (*Catae dulis*). On the benched field growing high value crops like vegetables, fruits, and root crops are preferable. Making use of the residual moisture green crops of fodder value can be practiced. Farmyard manure and compost is intensively applied. A rotation can be considered to alternate cropping in the catchment in wetter seasons and fallow in the drier ones. Deep ploughing or sub-soiling, green manuring, or compost is needed to improve soil fertility. Soil productivity should be maintained by means of proper crop rotation and the use of fertilizers. B/c there is soil disturbance **top soil treatment** is also crucial element in benching.

Benefits and Acceptability

When population density and intensity of cultivation reach certain thresholds, bench terraces are effective. BT are effective for soil erosion control, better moisture retention, and easy cultivation operation and for practicing intensive/precision agriculture and getting uniform plant growth compared to the conventional terraces. It provides long term increase in productivity. With this regard the naturally occurring slope has to be corrected to artificially made BTs. It has been traditionally practiced in many parts of Ethiopia (to mention are: Konso in the SPNNs; Ankober in Northern Shewa; NadierAdet of Tigri; and Hararge highlands). On small farms situated on gentle slopes, natural terraces, which possess the advantage of being labour-saving, can be employed.

Limitation

It is a labor-intensive technology. Compared to other techniques, it requires high level of technical skill, proper design, layout and construction methods. BTs should not be constructed on the following conditions: a) With sandy or rocky soils, non-cohesive or highly erodible soils, or decomposing rock including other depositional materials; ii) On recently soil-cuts and soil filled up segment – this is because the cut part could be infertile and the fill may have not settled properly; iii) With soft-rock laminations in thin layers oriented so that the strike is approximately parallel to the slope face and the dip approximates the staked slope line; iv) BTs may cause sloughing if too much water infiltrates in the soil and are effective only where suitable runoff outlets are available; and v) Avoid benching, if possible, in areas where there is potential for rock-fall slide problems.

Name of the Technology | **HILLSIDE TERRACE**

General Description

A hillside terrace is a physical structure implemented on hills to conserve soil moisture. It is a structure along the contour where a strip of land, about 1 meter wide, is levelled for tree planting. Hillside terraces are recommended for low rainfall areas, because they help to retain runoff and sediment on steep slope land. When it is applied in moist areas, a slight inclination or slope to one side to safely drain excess runoff and a proper waterway should also be established at the end. It is commonly applied on degraded and grazing hillsides to be rehabilitated or for closure management. Generally, hillside terrace is very costly. Hence, it should be used only if there is a strong justification for its construction. Can be integrated with trenches.

Fig 1. Hillside terracing with trenches, Amhara R., Sekela Woreda

Geographical Extent of Use

Applicable in low rainfall areas and steep hillsides - community closures with steep slopes (max 50%).

Technical Design Requirements

- Stone riser height: 0.75-1 m from ground level;
- Width of terrace = 1.5 m-2 m;
- Foundation = 0.3 m depth x 0.3 m width;
- Grade of stone riser = 1:3 (horizontal : vertical);
- In lower rainfall areas hillside terrace needs to have 5-10% gradient back slope;
- Integration with micro basins or trenches in a regular interval is recommended;
- Stone riser foundation: 0.3-0.4 m depth x 0.3 m width;
- Top width: 0.5 m (0.25 m stone riser and 0.25 m soil);
- Grade of soil bank: 1 horiz: 1.5 (unstable soils) to 2 vertical (stable soil);
- Base width: based upon slope;
- Size/place of trench: 50W x 50cm D x terrace length - placed 0,75-1m above stone wall

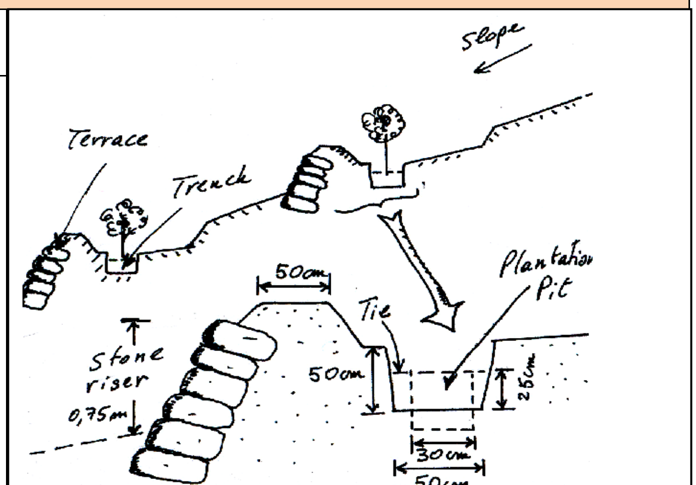


Fig 2. Ideal cross-section of a hillside terrace

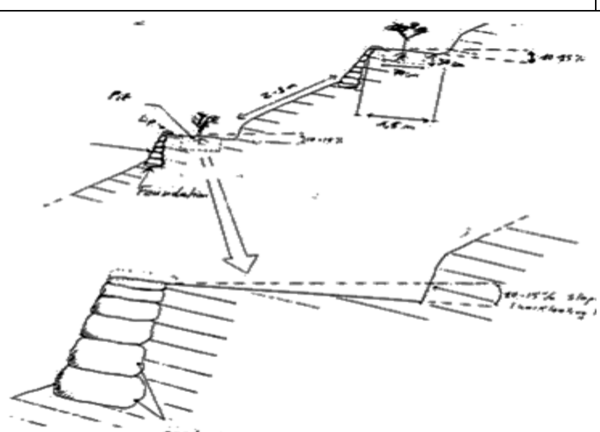


Fig 3. Cut sections of a hillside terrace

- Size/place of ties: within trenches ties are placed at 2-3m intervals based upon plantation requirements and half way the depth of the trench (0.25 m) with 0.6m horiz. length x 0.5 cm width for planting seedlings;
- A 30x30x30 cm plantation pit is placed in the middle of the tie or in front of the trench (between berm and embankment) with lateral spacing depending on tree and shrubs planted (1-3 metres);
- Max length of HTTs: 50-80m. HTTs should wing up laterally, before depression points.

Fig 4. Some modifications to standard designs - see where bigger trenches and small pits for bushes/shrubs are incorporated

Layout and Construction Procedure

Includes: a) Cut and fill of the terrace area; b) Collection of stones from working site; c) Shaping of side of some stones with sledgehammer for better stability and merging; d) Excavation of foundation; placement and building of stone riser; e) Trench excavation above stone riser; f) Placing of excavated soil on hillside embankment; g) Pitting on ties within trenches; and h) Leveling top of the terrace embankment.

Period of Implementation Across Seasons

Mostly during the dry season or after short rainy season for hard soils.

Planning and Mobilization Requirements

Agreements for use rights and management of treated areas (areas shared amongst individuals, groups or managed by community or mixed). See opportunities for land use certificates over closures. Arrange working groups for regular maintenance.

Cost Elements and Work Norm

For **layout**, one water line level, two range poles graduated in cm and 10 meters of string (a team of 3 people layout approx 1ha/day), measuring tape. **Tools**: crow bars, sledge hammers, shovels, and pick axes. Ratio of shovels and pick axes depend on type of soil) shovels and pick axes with handles, wheelbarrow, crow bars, sledgehammer, etc. **Work norm** 250PD/km and 330PD/km with trenches.

Management and Maintenance

i) **C**ontrolled grazing and closure necessary ii**)** In dry areas and shallow soils need to be combined with other in-situ moisture conservation measures (eyebrow basins, etc); iii) Series of trenches (2-3 lines) can be constructed in between HTs (starting 2-3 meters above the terrace; iv) Apply soil and tree management practices; .; v) Fodder, legume and cash crops can be planted with appropriate agronomic standards at the top of the stone raiser or at its toe: using grasses (indigenous such as “sembelete”, “dasho”, others, etc.); vi) + legume shrubs (pigeon peas, Sesebania, acacia Saligna, trilucerne etc.) in rows by direct sowing (15-30 cm); vii) Hillside terraces, like stone bunds, can be stabilized by drought resistant plants such as Sisal, Aloes and Euphorbia tirucalli placed on the lower side of the stone wall; viii) Integration with strong check dams along depression points and small gullies; ; and ix) Fodder and crops growing on terraces should not be uprooted but cut and carried. Develop agreed benefit sharing rules and management arrangements.

Benefits and Acceptability

Useful and suitable for rehabilitating the degraded hills, tree/shrubs planting and very effective in controlling runoff and erosion; ensure protection of downstream fields, play a significant role in replenishing water tables, especially when combined with in-situ moisture conservation (trenches and micro-basins).

Limitation

Hillside terraces can be overtopped - need integration with trenches. Require maintenance if not well constructed and stabilized. Are labor intensive techniques.

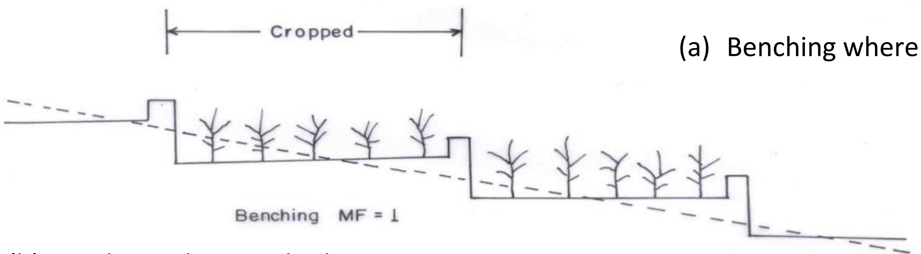
In-Situ Moisture Harvesting Technologies – Physical Soil Moisture Storage

Overview

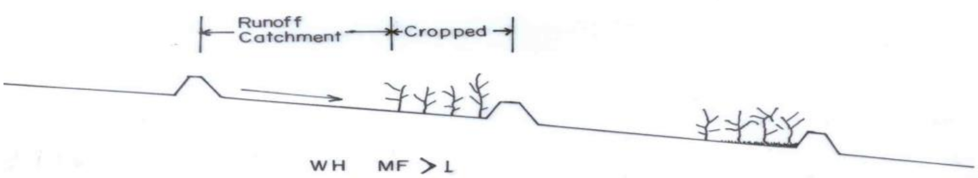
Definition: Rainwater harvesting describes methods of collecting, storing and spreading various forms of runoff from different sources for domestic, agricultural, etc uses. It is a deliberate collection of rainwater from a surface (roof/ground catchment) and its storage (soil and structural) to provide a supply of water.

Basic Concept: RWH is a concept of rainfall concentration that multiplies the amount of rain falling on a cropped area by a factor greater than one. At the same time erosion will be controlled and fertility of the soil is managed. This concept differs from the practice of *Soil and Water Conservation* (SWC) in which there is no rainfall multiplication and concentration. In SWC the multiplying factor (MF) = 1. Examples are Terracing, Benching; Furrow drinking, pitting land surfaces (Figure a). The conceptual model for runoff farming in RWH is indicated in Figure b.

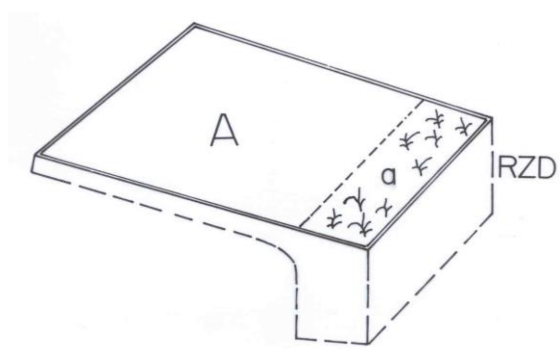
(a) Benching where multiplying Factor



(b) Benching where multiplying Factor >1



Designing Catchment : Cultivated Area Ratio



Conceptual model of micro-catchment runoff farming

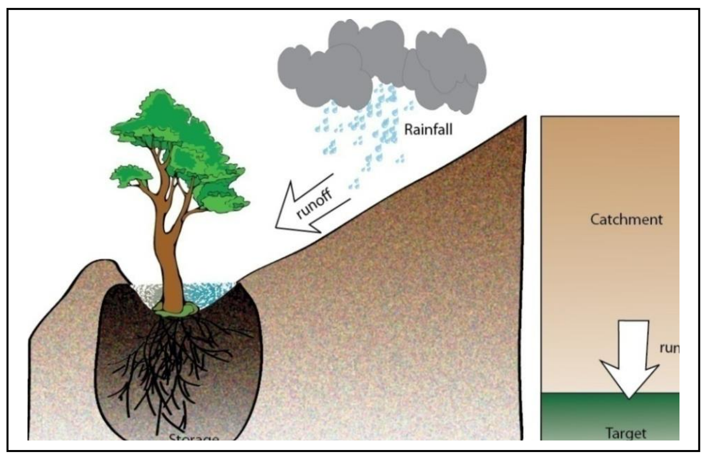
As indicated on the left Figure, "A" is catchment and "a" is cropped area.

Soil properties, and especially physical properties, present a high variability, both vertically and horizontally, and they are submitted to continuous changes under natural conditions, and particularly with the man intervention. The processes of soil degradation start with the degradation of the soil structure, especially of the functional attributes of soil pores to transmit and retain water, and to facilitate root growth. The deterioration of those attributes is manifested through interrelated problems of surface sealing and crusting, soil compaction, impeded root growth, poor drainage, frequent drought, excessive runoff, and accelerated water erosion. Water, that is often the main limiting factor of plant growth, is also the main factor directly or indirectly responsible for soil and land degradation processes. These soil degradation processes ultimately affect the soil water storage capacity of the soil and its recharging capacity to downstream surface water systems.

Soils play a very important role in the hydrological cycle. They are one of the main reservoirs of fresh water, and transform discontinuous and erratic rainfall sources of water into a continuous supply of water to the roots of plants and continuous discharges of water to groundwater, streams and rivers. Integrated approach in the conservation of soil and water is further justified by the close relationship between soil and water quantity and quality.

The soil moisture regime, determined by the changes in soil water content with time, is the main single factor conditioning plant growth and crop production. That will be mainly conditioned by soil properties affecting the capacity and possibilities of infiltration, retention and drainage of rainwater, and the limitations to root growth under the particular rainfall characteristics.

Insitu moisture harvesting systems using physical Soil Storage SWC (RWH) Systems (also micro-catchment runoff farming or 'within-field' water harvesting systems) is a concept of rainfall concentration that multiplies the amount of rain falling on a cropped area by a factor greater than one. Micro-catchments are normally **within-field systems** since runoff comes from within the vicinity of the cropped area, where overland flow harvested from short catchment length and the runoff stored in soil profile (Figure below). In design, a small portion of upslope land is allocated for runoff collection, which is "harvested" and directed to a cultivated area (run-on area or cropped area) down slope. The runoff within a field is directed either to single plants e.g. fruit trees, or to clusters of plants or row crops e.g. maize, sorghum or groundnuts.



Soil Storage SWC (RWH) Systems or Runoff farming for crop production is applied in arid and semi-arid regions where rainfall is either not sufficient to sustain a good crop and pasture growth or where, due to the erratic nature of precipitation, the risk of crop failure is high. RWH can significantly increase plant/fodder production in drought-prone areas by concentrating the rainfall/runoff in parts of the total area. Runoff farming is an ingenious way of improving the productivity of rainfed agriculture in dry regions where conventional methods are unreliable. The method should be considered in regions where rainfall is inadequate or unreliable and normal rainfed farming has become a risky venture.

The goals of Soil Storage SWC (RWH) Systems or Runoff Farming includes:

- Restoring the productivity of crop/range land which suffers from inadequate rainfall.
- Increasing yields of rain-fed farming
- Minimizing the risk in drought prone areas
- Combating desertification by tree cultivation
- Increases adaptation to climate change

Advantages of In-situ Moisture Harvesting or Physical Soil Storage SWC (RWH) Systems:

They are simple in design, low-cost and relatively easy to install since they mostly require just manual labor. Therefore, micro-catchment systems are easily replicable and adaptable. Within-field systems also tend to require less mechanization, relying more on manual labor and animal draught. They also achieve higher runoff efficiency than large scale water harvesting systems, with almost no conveyance losses and plant growth is usually even. Micro-catchment systems carry element of erosion control, thus conserve both water and soil nutrients. Most types of micro-catchment systems can be constructed on almost any slope, including almost level plains, slopes, and there are designs to suit a wide range of crops, trees and fodders.

Limitations of Insitu Moisture Harvesting or Physical Soil Storage SWC (RWH) Systems:

Runoff farming requires relatively large labor inputs and land requirements. It also utilizes more land than conventional rainfed cultivation. The catchment area is sometimes removed from potentially arable land, especially in micro-catchment systems. The catchment area has to be maintained, i.e. kept free of vegetation which requires a relatively high labor input. If overtopping takes place during exceptionally heavy rainstorms, the systems may collapse affecting other crops and structures downhill. Runoff farming requires that crops are planted with relatively wider spacing or structures are spread out, resulting in low crop densities and hence lower yields per unit area, in comparison with conventional rainfed cropping systems.

The major In-Situ Moisture Harvesting Technologies – Physical Soil Moisture Storage Technologies presented here are:

1. Ridges and Tie Ridging
2. Micro Trenches
3. Deep Trenches
4. Micro basins
5. Eyebrow Basins (EBs) or Eyebrow Terraces
6. Herring bones (HBs)
7. Semicircular Bunds
8. Runoff – Run-on Area Bunds/Barrier Lines
9. Runoff – Run-on Strips
10. Percolation Pits

Name of the Technology	RIDGES AND TIE RIDGING

General Description

This method is also known as furrow blocking, furrow damming, furrow diking, and basin listing. Tie ridges are small rectangular series of basins formed within the furrow of cultivated fields mainly to increase surface storage and to allow more time for rainfall to infiltrate the soil. The principle or purpose is to increase surface storage by first making ridges and furrows, then damming the furrows with small mounds, or ties. Making tied ridges manually is time and labor consuming and hence it is usually associated with mechanized farming. There have been some attempts at achieving it with ox-drawn (*Maresha* attached ridge tier) implements, but the system really needs high draught for speed and precision. Either ridging alone or tied ridging has occasionally been practiced using hand labor, but the high labor requirement usually makes this unpopular with subsistence farmers. Hand-made ridges are usually less efficient. They are more likely to depart from a true contour and to have variations in the height of the ridge, both of which will increase the risk of overtopping.

Fig 1. Typical ridge and tie ridging, EARO

The system has been beneficial not only for reducing run-off and soil loss, but also for increasing crop yield. However, during high rainfall years or in years when relatively long periods within the rainy season are very wet, thus, resulting in lower yields.

Geographical Extent of Use

Applicable in cultivation land with gentle slopes. Availability of various cultivation equipment's and the type of soil better mechanization can be adopted to areas where the volume of rainfall is small and variable. It requires a high value of soil storage, usually deep soils with good infiltration and permeability. Suitable mostly in semi-arid and arid parts of the country but also in medium rainfall areas with deep and well drained soils. Commonly practiced in dry and moist weyna dega areas for the growth of trees and support of area closure. Design change based on dryness conditions. If applied on heavy clay soils it could result in erosion or water be lost to evaporation before it is used by plants.

Technical Design Requirements

The design question is when to go for drainage and when to go for storage. Graded ridges alone will usually lead to an increase of surface run-off compared with flat planting, while tied ridges will decrease the run-off and increase the storage. In different seasons either of these two effects may be preferable. The possibility of hedging by tying alternate furrows is also possible. This would reduce the amount of damage by too much run-off or too much retention. In Ethiopia, within the Rift Valley system, oxen drawn ridgers have been developed. Three safety back-ups are required to minimize the risk of damage by erosion:

i) the furrows should be on gentle grade to assist runoff if the ties fail;

ii) the ties should be lower in height than the ridges so that the ties fail along the furrows before the ridges fail down the slope;

iii) There should be a back-up system of conventional graded channels terraces to prevent damage if the ridges do overtop or fail.

- Height of the tie ridge can be 15 - 20 cm within a furrow depth of 20-30cm.
- They are constructed in staggered position along neighboring furrows.
- Row spacing and tying interval could range between 1 and 10m.
- The steeper the slope, the higher the rainfall intensity and the lower the water holding capacity of the soil.
- Row spacing and tying interval dependent on slope of the land, intensity of rainfall and water holding capacity of the soil.
- Training and demonstration is needed on how to insert into the traditional implement

Layout and Construction Procedures

Layout: No much need of surveying equipment as such but need perfect contoured furrows run with oxen or tractor. If tie ridges are to be made by hand then use of A-Frame is advised. Making an implement to form the ridges is straight forward, it is interrupting the ridging process to leave a tie that is difficult. Possibilities are: i) intermittent lifting by hand if the ridger is pulled by tractor or by oxen; ii) automatic lifting devices based on an eccentric wheel; and iii) intermittent hydraulic lift either manual or triggered by rotation of tractor wheels. For any layout of In situ Physical Moisture Harvesting Measures see Annex 2 for technologies.

Period of Implementation Across Seasons

During planting or seeding and also during cultivation operation or harrowing.

Planning and Mobilization Requirements	Cost Elements and Work Norm
All necessary mobilization requirements for tillage and planting. Tied ridges are appreciated on individual plots where use right is secured. As they are meant to maximize moisture on cereal or row crops that are usually annuals, they can even be practiced on rented land effectively. Point breakage by high intensity of rainfall can be checked and repaired during growing seasons.	Implements for building tied ridges are tractors, oxen and ridgers to be trailed by tractor or oxen. For manual labor, hoe, shovels and pick axe with handles. Tie ridging is usually an activity to be performed as a normal cultivation operation. If it has to be done by hand it will take 20 person days per ha. In Ethiopia, *Maresha* attached tie ridging can be carried out by 2 person days per person each having pair of oxen. Staggering of the ties along neighboring furrows is required.

Management and Maintenance

There is a danger of soil erosion if the ridges are overtopped and break so that the water temporarily stored in the depressions is suddenly released. This will not happen if the combination of surface storage plus the amount which infiltrates into the soil surface is less than the storm rainfall. This implies a high value of soil storage, usually deep soils with good infiltration and permeability. In some systems the infiltration is increased either by mulching in the furrow bottoms or by sub soiling or cultivating. Three safety back-ups are required to minimize the risk of damage by erosion are: i) the furrows should be on a gentle grade to assist run-off if the ties fail; ii) the ties should be lower in height than the ridges so that the ties fail along the furrows before the ridges fail down the slope; and iii) there should be a back-up system of conventional graded channel terraces to prevent damage if the ridges do overtop or fail.

Benefits and Acceptability

There is an extensive literature reporting trials of tied ridging in many countries. A few of the reports indicate problems/failures but the great majorities claim outstanding success. In many countries, for low rainfall areas such as the Rift Valley of Ethiopia, Katumani in Kenya; it is reported that substantial increases in sorghum, maize, millet, cotton yield for tied ridging compared with flat planting. It is reported that tied ridging in Tanzania gave higher maize yields not only in low but in high rainfall years as well.

Good potential to improve production exists because of effective moisture conservation. It is also possible to use tied ridges for diverted runoff directed to the cultivated fields other than for rainfall. Farmers in Raya - valley practice tied ridges along their practice of runoff farming i.e. spate irrigation. They are used for annuals, however, when changed to inter-row rainwater harvesting structures tree crops can be grown. See back page for inter-row RWH

Limitation

Hand-made ridges are usually less efficient. They depart from a true contour and to have variations in the height.

Once made during planting it requires little maintenance, however it has to be done for every cropping season.

Name of the Technology	MICRO TRENCHES

General Description

Trenches are pits constructed along the contours with the main purpose of collecting and storing rainfall water to support the growth of trees, shrubs, cash crops and grass or various combinations of those species in moisture stressed areas (350-900 mm rainfall). Trenches can have flexible design, to accommodate the requirements of different species. Therefore, they can suit what the farmer want to grow. Trenches collect and store considerable amount of runoff water, thus vegetation grows faster and vigorous. They protect cultivated fields located downstream from flood and erosion. Part of the water captured by the trenches reaches the underground aquifer. Therefore, water tables are recharged and supply springs and wells with good quality water and for a long period of time (See Photos below). There are various trenches known by shape and size such as circular, square or trapezoidal and small or large.

Geographical Extent of Use

On hillsides where soil at least 50 cm deep and not too rocky (from 5-50% slopes); On abandoned lands that you wish to restore for growing tree/shrubs or other crops; On portions of forest land or closures that should be enriched; On homesteads for growing high value trees or other crops. Do not construct trenches in rocky areas and steep slopes above 50%. Highly suitable in many areas in the highlands to improve closures and plantations. Also relevant in pastoral areas to improve grazing reserves, aerial pasture, etc. Smaller water collection trenches are also applicable in steep and degraded hillsides (max slope 100%) and for community closures. Can be combined with other measures such as hillside terraces, stone bunds, and trenches based upon soil, slope, and surface stoniness. Can also be applied inside large gully areas for tree planting.

Technical Design Requirements

a) It can be constructed to grow 1 or up to 3 trees in each trench. The designs of the trench depend from the type of soil, rainfall, and the type and position of trees; b) Take advantage of the water harvesting effect of the trench by planting 1 fast growing tree and 1 or 2 additional slow growing trees (which require less water); c) Catchment Area/Trench Area ratio CA/TA is 3-5:1 (based on rainfall and tree water requirements) – normally 2-3 meters distance between lines of trenches - ratio can vary depending on dryness; d) Trench with two trees planted on pits dug in two ties; e) Trench with 1 tree planted in a tie and 2 trees on pits dug in front of trench; f) Trench with 2 trees planted in two ties and 1 tree planted in front of the trench; g) They are constructed in staggered position one from another (triangle); h) No of trenches/ha from 800-1200. N.B. For further detail see Pictures below and other references on SWC.

Fig 1. Trenches on gently sloping hillsides and grazing lands- Atsbi Wemberta, Tigray R.

Fig 2. Trenches constructed on farmlands above soil bunds - Atsbi Wemberta, Tigray R.

Layout and Construction Procedures

a) Start from the top of the hill or field; b) Using an A-frame (or other level) the same size of the trench (2,5-3 m long) level the two tips of the frame and then mark the shape of the trench; c) Continue marking more trenches with the A-frame adjacently and below the first one; d) Spacing between two trenches laterally is 25-50 cm; e) After layout dig soil to reach 20-25cm depth x 50cm width x 2,5-3m length; f) Keep some of the good topsoil aside for filling planting pit (s); g) Then dig a 50 x 50 cm wide x 40cm deep pit in the middle of the trench; h) Bottom of the pit should be 10-15 cm deeper than bottom of trench; i) Side ditches may slope towards ties for maximum utilization of light rain showers; j) Demarcate the tie around the pit (10cm from pit border on both sides) and proceed to deepen the collection ditch around the ties up to the required depth of 50cm; k) The embankment is to be shaped level and well compacted; and for more construction sequence and Figures – see Pages 148-150 CBPWD Guideline, 2005). See also Figures below.

Period of Implementation Across Seasons

Mostly during the dry season or after short rainy season for hard soils. One month before rainy season is also good to enable plantation pit to weather.

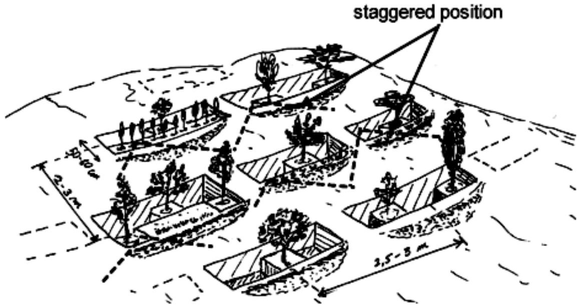


Fig 3. Water collection trenches in the landscape

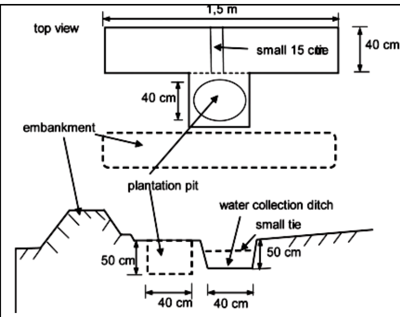


Fig 4. Layout out of an ideal trench

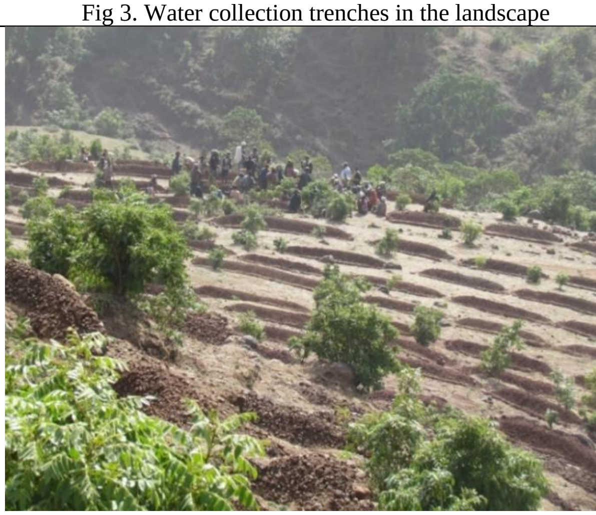


Fig 5. Trenches for groundwater recharging, staggered, Amhara R., Dera Woreda

Fig 6. Recharging pits/trenches, Tigray R. Tahitay Koraro, Maydumu CW

Planning and Mobilization Requirements

Farmer groups and communities are trained in proper layout, design and construction; Make sure community agrees on groups and individual sharing of degraded hillsides; Discuss and decide the different type of trenches to construct based upon what farmers want and what is more appropriate based on type of soils and depth; If technology not introduced test at small scale first. Agreements on use rights and management of treated areas (areas shared amongst individuals, groups or managed by community or mixed). See opportunities for land use certificates in protected areas. Arrange working groups for maintenance.

Cost Elements and Work norm

A-frame level or water hose level linked to 2 poles placed at 3m distance. If not available use the normal water level hooked to a string linked to range poles placed at 5m distance. **Tools**: crow bars, pick axes and shovels (1 crow bar: 2 pick axes: 2 shovels). For all trenches work norm includes excavation of soil, embankment, compaction and digging of plantation pit (s). The work norm is 2 person days per 3 trenches per day. For trenches 5 meters long and 2-3 ties/pits apply 1PD/Trench/Day.

Management and Maintenance

Cut unpalatable grass from trench and surroundings to mulch pits and water collection area. Apply compost into planting pit (s) and water collection ditch. Check distance, size and layout of trenches. If trenches have more than one tree check growth of trees and prune/thin as required. Heavily mulch and apply compost around fodder/cash crop belt. Mulching to continue for at least 2 years and apply compost for multipurpose trenches.

Benefits and Acceptability

Reduction of runoff and sediments. Good for degraded hillsides rehabilitation. Area closure accompanied with trenches results in good regeneration. Good potential to improve degraded hillsides and flat to gently sloping lands - mostly for area closure and multipurpose tree and fodder tree plantations. Good groundwater recharging techniques for replenishment of water table. Already in use in many areas of the Highlands in the Eastern Nile Regions and acceptability is not a problem if planned and implemented as an integral part of community watershed management interventions. Together with other measures trenches can significantly improve watershed rehabilitation, biomass production and recharging of water tables. Can easily be understood /adopted after demonstration.

Limitation

They are labor intensive techniques and can be applied in areas where farmers/communities are willing. Need some 50 cm of top soil to be applied.

Name of the Technology	DEEP TRENCH

General Description

Deep trenches are large and deep pits constructed along the contour with the main purpose of collecting and storing rainfall /runoff water to support the growth of trees, shrubs, cash crops and grass or various combination of those species in moisture stressed areas as well as they are groundwater recharging structure. It is the most appropriate and effective moisture harvesting technologies selected and being practiced in the regions to minimize the prevailing and rapidly escalating land degradation and rehabilitate denuded hillside. Simple or normal trench bund or micro trench that was practiced in the past did not suffice /trap to deal with huge run off created as the result of torrential rainfall with high intensity (rainfall falling in short period of time). Thus, **deep trench + soil bund is discovered** to be the best technology for surface water harvesting and contribute to raise the groundwater table for the use of hand dug wells, shallow wells, irrigation and domestic water supply.

Fig 1. Deep Trench in May Dumu CW, Tigraay, Tahitay Koraro, May Wudmo CW

Geographical Extent of Use

It can be implement in all agroecology to store water in aquifer for later use by excavating wells, diverting perennial rivers and springs. It can also implement in all land use except in farm land that can be affected by water logging problem and part of the excavated farm land will be left to store water and become out of crop production. It is highly suitable in many areas in the highlands to improve closures and plantations on hillsides where It has a soil depth at least 50 cm deep and not too rocky (from15-30% slopes) with possible change of dimensions (Width). In steep slope (>30%) special care/attention is required to reinforce the bund. But not recommended to implement deep trench in cultivated land. Also relevant in pastoral areas to improve pasture land etc.

Technical Design Requirements

The technical requirements are explained from A to D

A) Determination of direct runoff volume: Deep trenches are designed to hold part of the runoff (excess rainfall) from a storm of daily maximum rainfall. The volume of runoff from the design storm is estimated using the Rational Formula, See Annex 1 or simply use the following equation.

Q = 10*C*R*A; Where; Q = Runoff volume in m^3; C = runoff coefficient (from Rational Formula); R = Maximum daily rainfall in mm; and A = Watershed (catchment) area for the particular structure in ha

B) Determination of cross-sectional area and volume of deep trench + bund:

The cross-section of deep trench can be rectangular or trapezoidal (See Figure xx). The size of the deep trench depends up on the soil depth available at the site and workmanship.

In relatively deeper soil, depth of trench is generally fixed at 1m while for shallower soil; depth of trench may reduce to about 0.4 to 0.5m. As far as the length of deep trench is concerned 3m is adopted for convenience of layout and construction. The length of the bund should be between 50 to 100m. In other way it can be also designed (considered the deep trench dimensions) based on the runoff volume you have calculated in the Rational Formula or the above equation.

The horizontal water spread length resulted due to the construction of the bund can be determine at different length of the upstream side using the equation:

Y = S*X/100; Where, Y = height of the bund or water rise at X=0 distance from bund; X = distance from the crest of the bund to the point where Y = 0; and S = Slope of the ground in %.

The size of bund includes its height (Y), top width, side slopes and bottom width. For evaluation of bund size, the height of it is fixed first. Normally, the height is half the vertical interval, with minimum height of 50 cm. This height is required in order that there is sufficient runoff retention capacity on 0.3m effective bund height. Once the height of the bund is determined, the other dimensions such as top width and base width can easily be obtained. The height of bund mainly depends on the land slope, spacing of the bund and expected maximum rainfall intensity of the area. The excavated soil from the deep trench is used to make an embankment on the lower side and a berm of 10 to 25 cm should be left between the embankment and the edge of the channel /trench to prevent the soil from sliding back.

Table Showing vertical interval of two consecutive bunds is on the right side.

Slope ranges in %	Vertical interval, fix bund height, and spacing
3-8%	0.7-1
8-15%,	1-1.2
15- 30%,	1.2-1.7
30-50%,	1.7-2.00

Initially, bund may not be compacted, and allow for compaction a 15 - 20% increase in height required. Therefore, if the design requires a 0.3cm height, the initial construction should be up to 50cm. Low points are to be avoided b/c they are points of frequent failure.

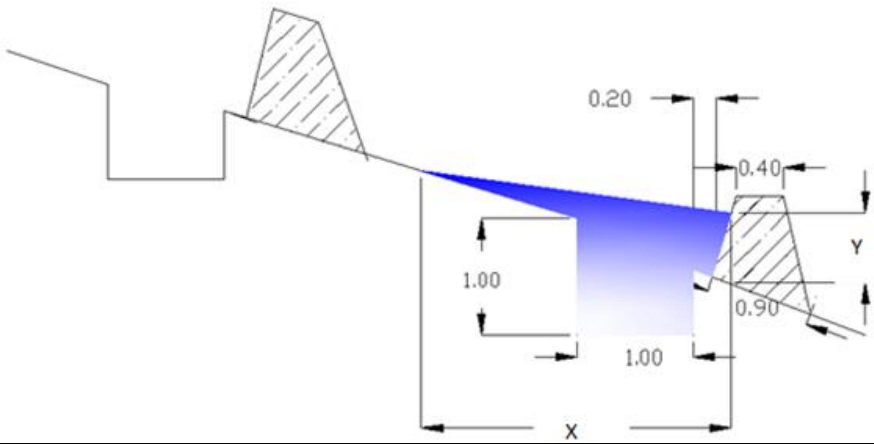


Fig 2. Cross sections showing standard dimensions of soil bund and burrow trench on stable soil, all units are in meter.

Where;
T = Top width of trench (100 cm)
t = Bottom width of trench (100 cm)
d = Depth of excavated trench (100 cm)
E = Embankment gradient 1 (horiz.): 2 (vert.)
B = Width of bund at base (90 cm)
m = Berm (20cm)
W = Overall width (210 cm = 100+20+90)
b = Top width (40 cm)
Y= Total Height of the bund after compaction (50 cm),
Effective height of the bund is (30 cm),

The volume of water spread due to the bund can be calculated considering the ground slope and vertical interval between the two bunds using the formula:
SV = 0.5*X*Y*L;

Where;
SV = storage volume of water spread due to the bund of L meter running length
L = Running length which is the length of the total bund

C) Determination of spacing: Spacing is expressed in terms of horizontal (HI) based on the run off: run on area ratio of the expected excess runoff for deep trench. For soil bund the water surface profile computation to upstream of the bund is crucial in designing the **spacing** between two consecutive deep trench + soil bund. Therefore, The horizontal water spread length resulted due to the construction of the bund can be determined at different length of the upstream side using the following equation:

$$\mathrm{HI} = \frac{\text{Cross sectional area of the deep trench} + \text{Cross sectional area of the bund}}{Effective\ runoff\ depth}$$

$$\mathrm{HI} = \frac{(\mathrm{W} * \mathrm{D}) + (0.5 * \mathrm{X} * \mathrm{Y})}{ER}$$

Where; Y = Effective height of the bund in m
X = water spreading length in m
W = Width of the deep trench in m
D = Depth of the deep trench in m
HI = horizontal interval (spacing) b/n two consecutive deep trench + bund
ER = excess run off depth in m

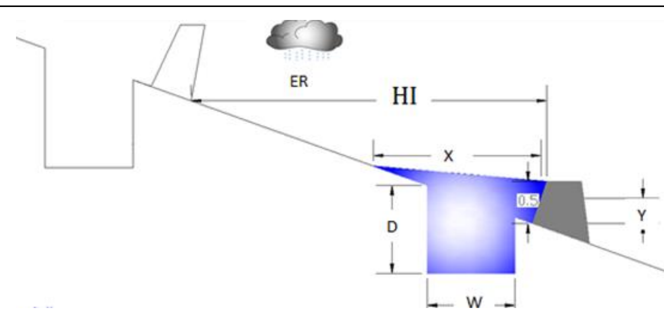


Fig 3. Spacing between two consecutive deep trench + soil bund

D) Determination of number of deep trenches:

To determine the number of deep trench to be constructed in a particular catchment area use the following steps and formulas;

a) Determine the space between two contour deep trench bund in section
b) Determine the length of one row to be constructed in a ha
c) Determine the number of rows expected in a ha and the total number of row for the given catchment area

$$No\ of\ rows(bund)\ in\ 1ha = \frac{width\ of\ the\ area\ in\ m}{spacing\ of\ the\ bund\ in\ m}$$

$$total\ no\ of\ rows(bund) = No\ of\ rows(bund)\ in\ 1ha * total\ area\ in\ ha$$

d) Determine the number of deep trench in one row

$$\text{No of deep trench in one row} = \frac{length\ of\ one\ row}{(tie\ ridg\ length\ + length\ of\ one\ deep\ trench)}$$

e) Determine total number of deep trench to be constructed in a ha

$$\text{number of deep trench in 1ha} = \text{number of deep trench in one row} * \text{total number of rows in 1ha}$$

f) Finally determine number of deep trench constructed in the given total area

$$\text{Total number of deep trench} = \text{number of deep trench in one row} * \text{total number of rows}$$

Or

$$\text{Total number of deep trench} = \text{number of deep trench in 1ha} * \text{total area in ha}$$

Layout and Construction procedures	The layout and construction procedure is as described for the micro trench
Period of Implementation Across Seasons	Mostly during the dry season or after short rainy season for hard soils. One month before rainy season is also good to enable plantation pit to weather.

Planning and Mobilization Requirements

Farmer groups and communities are trained in proper layout, design and construction; Make sure community agrees on groups and individual sharing of degraded hillsides; Discuss and decide the different type of trenches to construct based upon what farmers want and what is more appropriate based on type of soils and depth; If technology not introduced test at small scale first. Agreements on use rights and management of treated areas (areas shared amongst individuals, groups or managed by community or mixed). See opportunities for land use certificates in protected areas. Arrange working groups for maintenance.

Cost Elements and Work Norm	**Management and Maintenance**
A-frame level or water hose level linked to two poles placed at 3 meters distance. If not available use the normal water level hooked to a string linked to range poles placed at 5 meters distance. **Tools**: crow bars, pick axes and shovels (1 crow bar: 2. pick axes: 3 shovels ratio). For all trenches work norm includes excavation of soil, embankment, compaction and digging of plantation pit (s). The work norm is 2 person days per 3 trenches per day. For trenches 5 meters long and 2-3 ties/pits apply 1PD/Trench/Day	Cut unpalatable grass from trench and surroundings to mulch pits and water collection area. Apply compost into planting pit (s) and water collection ditch. Check distance, size and layout of trenches. If trenches have more than one tree check growth of trees and prune/thin as required. Heavily mulch and apply compost around fodder/cash crop belt. Mulching to continue for at least 2 years and apply compost for multipurpose trenches.

Benefits and Acceptability

Reduction of runoff and sediments. Good for degraded hillsides rehabilitation. Area closure accompanied with trenches results in good regeneration. Good potential to improve degraded hillsides and flat to gently sloping lands - mostly for area closure and multipurpose tree and fodder tree plantations. Are also very good groundwater recharging techniques for replenishment of water table. Already in use in many areas of the Highlands in the Eastern Nile Regions and acceptability is not a problem if planned and implemented as an integral part of community watershed management interventions. Together with other measures trenches can significantly improve watershed rehabilitation, biomass production and recharging of water tables. Can easily be understood /adopted after demonstration.

Limitations	They are labor intensive techniques and can be applied in areas where farmers/communities are willing. Need some 50 cm of top soil to be applied.

Name of the Technology	MICRO BASINS (MBS)

General Description

Micro-basins are small circular and stone faced (occasionally sodded) structures for tree planting. MBs are used in order to store precipitation water by collecting surface runoff: low soil ridges optionally supported with stone walls - are constructed in an enclosed shape to form a basin, which helps to prevent the water to further run off. The collected rainwater is then used for direct irrigation or infiltration into the soil to enhance soil moisture and recharge groundwater. Also used for optimization of water use in agriculture, conservation of soil moisture, surface and groundwater recharge. MBs are mostly used for small-scale tree and bush planting in areas with moisture deficit. Each basin consists of a catchment area and an infiltration pit, which serves as the cultivated area.

Fig 1. Scene of use of Microbasins for tree and forage plants

Geographical Extent of Use

Suitable in degraded areas, mostly in semi-arid and medium rainfall areas with stony as well as shallow soils. Commonly practiced in dry and moist areas for the growth of trees and support to plantations in area closure. Applicable in steep and degraded hillsides (max slope 50%) and for community closures. They need to be often combined with other measures such as hillside terraces, stone bunds, etc. Can also be applied inside large gully areas for tree planting. Based upon experience they are not very effective in low rainfall areas (where trenches, eyebrows, etc. are preferred) because of competition for moisture.

Technical Design Requirements

Different design types are possible, including half-moon, V-shaped, diamond-shaped, trapezoidal, as well as contour bund basins. The height of the ridges relies strongly on the slope and the size of the catchment.

Technical standards: i) Diameter: to range from 1 - 1.5 m; ii) Stone riser: 0.2 m; iii) Foundation and height: 0.2 - 0.4 m above ground based on slopes; iv) Plantation pit: 0.4 m diameter x 0.5 m depth; v) Soil sealing: sealed with soil from cut area; vi) Constructed in staggered position between rows and in rather close spacing within row in case of 1 m diameter basins.

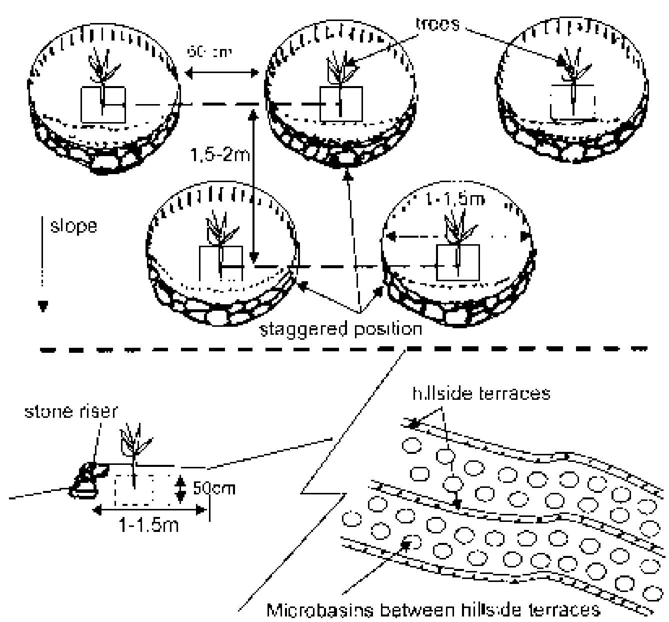


Fig 2. Layout of Microbasins along the contours

Layout and Construction Procedures

Layout: One A-frame or line level (with 5 meters string and two range poles.

Tools: Crow bars, sledge hammers, shovels, and pick axes.

i) Layout in staggered position; ii) Foundation; iii) Placement of stone raiser; iv) Cut and fill and seal required so that the water should not leak unnecessarily; v) Construction of plantation pit.

Planning and Mobilization Requirements

Agreements for use rights and management of treated areas (areas shared amongst individuals, groups or managed by community or mixed). See opportunities for land use certificates. Arrange working groups for regular maintenance.

Period of Implementation Across Seasons

Mostly during the dry season or after short rainy season for hard soils

Cost Elements and Work Norm

Work norm includes digging foundation, placement of stone raiser, cut and fill and sealing and plantation pit activities. The WORK NORM: 1 PD/5 MBs.

Benefits and Acceptability

Simple design and construction; can be applied to even/uneven grounds; and applicable for very small scale (e.g. only for a few trees).

Good potential to improve degraded and steep hillsides - mostly for area closure and multipurpose trees and fodder trees plantations.

When combined with sound moisture conservation (trenches, etc.) and proper management it will contribute to watershed rehabilitation, biomass production and recharging of water tables.

Limitation

Labor intensive; Applied where farmers or communities are willing. Implementation is not mechanized and only applicable to small scale. MBs can be easily overtopped - need integration with hillside terraces.

Require maintenance if not well constructed and stabilized.

Management and Maintenance

Controlled grazing and area closure are necessary or a precondition for micro-basins to control light trampling that will compromise their function. Bunds have to be repaired immediately if they break. The field can be additionally protected from excess water runoff with the construction of a cut-off drain or a retention ditch. Fodder growing on micro-basins should not be uprooted but cut and carried. Few series of staggered lines of micro-basins can be constructed in between hillside terraces (say every 10 - 15 meters) on slopes up to 30% - rows of micro-basins decrease as distance between hillsides decreases, especially > 30% slope. Fodder legumes, shrubs can be planted along the filled area (Pigeon peas, Tree Lucerne, etc.) in smaller planting pits instead of a tree. Manuring pits and mulching (decrease evaporation and enhance growth). Integration with check-dams in depression points and in gullies. Development and extension workers, technicians follow up required to make it productive than remaining idle.

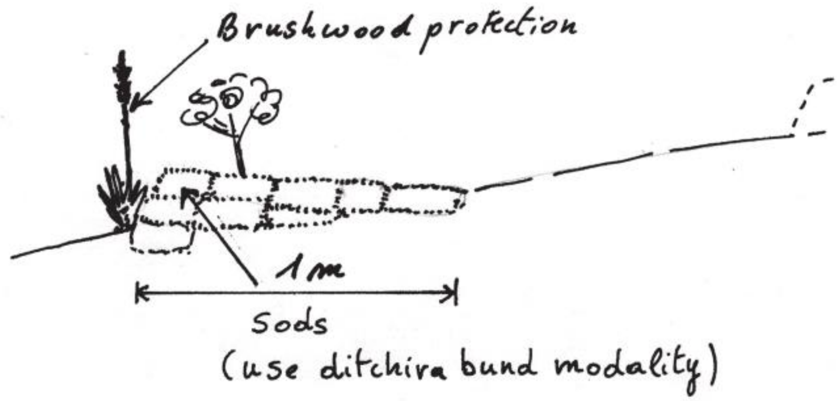


Fig 3. Microbasin constructed with sods in areas without stones (max 20% slope)

Name of the Technology	EYEBROW BASINS (EBS) OR EYEBROW TERRACES

General Description

Eyebrow basins or eyebrow terraces are larger circular and stone faced (occasionally sodded) structures for tree and other species planting. Based upon experience they are effective in low rainfall areas to grow trees and harvest moisture. Can be constructed in slopes above 50% for spot planting. Controls runoff and contribute to recharge of water tables (i.e. groundwater). If laid out and constructed in staggered arrangement significant reduction in runoff can be achieved.

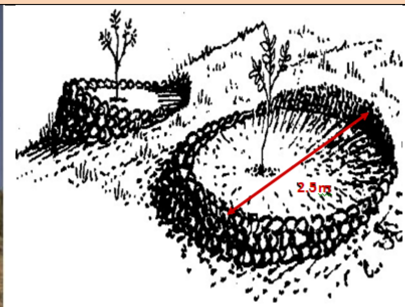


Fig 1. View (left) and layout (right) of Eyebrow Terraces, FAO

Geographical Extent of Use

Suitable in degraded areas, mostly in semi-arid and medium rainfall areas with shallow soils. Commonly practiced in dry as well as moist areas for the growth of trees and support to plantations in area closure. Applicable in steep and degraded hillsides (max slope100%) and for community closures. Can be combined with other measures such as hillside terraces, stone bunds, and trenches based upon soil, slope and stoniness.

Technical Design Requirements

Size of 2.2 - 2.5 m diameter. Stone riser (or stabilized by brushwood or life fence). Foundation of 0.2 m depth. Height 0.4 - 0.6 m. Place larger stones on the back side (lower side) and smaller ones on the upper side so that space is effectively filled. Stone riser sealed with soil excavated from water collection area. Water collection area is dug behind the plantation pit: 1 m width x 1 m length x 20-25 cm depth (lower side). Plantation pit (s) of 50cm depth x 40cm diameter dug between riser and water collection area. Water collection ditch can be placed sideways or in front of plantation pits depending on soil type. The distance between two EBs along the contour as well as consecutive rows of EBs is each 2.5 m. The area occupied by one semi-circular or EB at the runoff to planted area ratio is 4:1 (see the sketching /drawing below) or 10 m^2 to 2.5 m^2. With this kind of spacing there exists 800 EBs per hectare. If trees happen to exist do the terrace around and pass so that the existing bushes/trees will rejuvenate as they get additional soil moisture. Design, layout and Photos are given below.

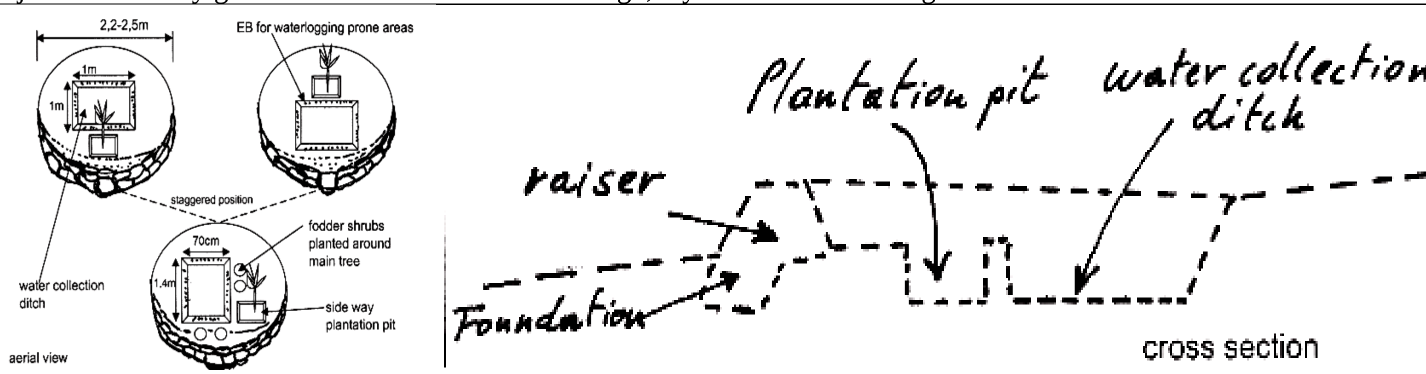


Fig 2. Layout (left) and cross-section view (right) Eyebrow basins

Layout and Construction Procedures

Few series of staggered lines of EBs or Semi-circular bunds can be constructed in between widely spaced hillside terraces (say every 10 - 15 meters) on slopes up to 50% - rows of EBs decrease as distance between hillsides decreases > 50% slope (for example one line of HTs and one of EBs). Two planting pits per eyebrow basin can be arranged.

Period of Implementation Across Seasons

Mostly during the dry season or after short rainy season for hard soils.

Planning and Mobilization Requirements

Agreements on use rights and management of treated areas (areas shared amongst individuals, groups or managed by community or mixed). See opportunities for land use certificates in protected areas. Arrange working groups for maintenance.

Cost Elements and Work Norm
Precise layout using A-frame or other level; Collection of stones from working site; Excavation of foundation and construction of stone riser; Excavation of water collection area, cut and fill, plantation pit and sealing of stone riser. WORK NORM: 2 EB/person day.
Management and Maintenance
a) Control grazing and closure of areas treated with EBs is necessary and is a precondition as even light trampling will compromise their function; b) Fodder legumes shrubs and cash crops (on better soils) can be planted along the filled area (Pigeon peas, Sesbania susban, etc.) in addition to the tree, fodder/cash crops growing on EBs should not be uprooted but cut and carried.; c) Manuring of plantation pits and mulching required (decrease evaporation and enhance growth); d) Integration with strong check dams along depression points and small gullies; e) EBs constructed using sods and stabilized with plants up to 20% slope); f) Can also be planted with a mix of trees, shrubs and cash crops. and g) Multipurpose EBs (tree + fodder + cash crop)
Benefits and Acceptability
Reduction of runoff and sediments. Good for degraded hillsides rehabilitation. Area closure accompanied with EB terraces results in good regeneration. Good potential to improve degraded and steep hillsides - mostly for area closure and multipurpose tree and fodder tree plantations. They are also very good groundwater recharging techniques for replenishment of water table. Together with other measures EBs can significantly improve watershed rehabilitation, biomass production and recharging of water tables. Community acceptance and closure or fencing is important.
Limitation
They are labor intensive techniques and can be applied in areas where farmers/communities are willing. Only applicable to small scale, mainly because their implementation is not easily mechanized. Require maintenance if not well constructed and stabilized.

Name of the Technology	HERRING BONES (HBS)

General Description

HBs are small trapezoidal structures (called also A structures) for tree and another species planting. They are suitable for both dry and medium rainfall areas, and medium soil depth. Based upon experience HBs are most effective in medium/low rainfall areas (500 - 900 mm). They can be constructed on slopes < 5% and soils > 50 cm depth.

Geographical Extent of Use

• Suitable mostly in semi-arid and medium rainfall areas.
• Not very common in Ethiopia but has possibility to expand in many areas, including pastoral areas for improving grazing reserves - can support the growth of different species.
• Applicable in gentle slopes (<5%) on small plateaus, on degraded lands (widespread gullies) with portions of gentle slopes (lower sections of community closures, etc.) and homesteads
• Can be often combined/mixed with other measures such as trenches soil and stone bunds, based upon soil, slopes and stoniness.

Fig 1. Herring Bones with two water collections

Technical Design Requirements

- Spacing: the structures are placed 3 m apart (max 4m in very dry places) along the contours and have extended arms conveying water towards the planting area.
- A water collection ditch (1m x 1m x 0.3 m depth at lower side) is dug behind the planting pit (40 cm diameter x 50 cm depth),
- The tips of the extended arms are 2.5-3 m apart (average).
- Embankment: max. Height down slope (0.4 - 0.5 m) and decreases to 20 cm at the end of the side arms.

Layout and construction procedures

Layout: One A-frame. The A frame can directly provide the shape of the HB when laid down at ground level. Water line level not as good as A frame but can be used for marking major contour lines - then proceed with direct assessment by sight and adjusting orientation of HB based on micro slopes.
Tools: shovels and pick axes.

Period of Implementation Across Seasons

Mostly during the dry season or after short rainy season for hard soils.

Cost Elements and Work Norm

Work norm includes precise layout (using A-frame or other level), excavation of collection ditch and planting pit, embankment building and compaction. WORK NORM: 4 HBs/Person day

Planning and Mobilization Requirements

- Depth of soil and slope assessed. Discuss and agree with farmers on species, spacing and integration with other measures as required
- Training on layout and construction (very precise for HB) Precise layout and follow-up/adaptations
- Agreements for use rights and management of treated areas (areas shared amongst individuals, groups or managed by community or mixed). See opportunities for land use certificates in protected areas. Arrange working groups for maintenance.

Management and Maintenance

1. 2 - 3 series of staggered lines of HBs in between bunds (say every 10-15 meters) can be constructed in areas with slopes up to 5% (8% in sandy soils with good percolation).
2. Control grazing and closure of areas treated with HBs necessary.
3. Fodder legumes, shrubs and cash crops can be planted along the embankment (pigeon peas, tree Lucerne, Sesbania, etc.).
4. Manuring of plantation pits and mulching required (decrease evaporation and enhance growth).
5. Integration with trenches and other structures as soon as slopes increase and there is a danger of overtopping.

Benefits and Acceptability

- Good potential to improve degraded areas with gentle slopes - mostly suitable for medium textured and drained soils (sandy loams, sandy clay loams). Can also be planted with a mix of trees, shrubs and cash crops.
- Combined with other measures can significantly improve watershed rehabilitation, biomass production and the recharging of water tables.

Limitation

• HBs are suitable only in gentle slopes - layout is demanding.
• Require maintenance if not well constructed and stabilized.

Name of the Technology	SEMICIRCULAR BUNDS

General Description

Semi-circular bunds (also known as Demi-Lunes or Large Half Moon bunds) are usually earthen bunds in the shape of a semi-circle or a crescent and the tips facing directly up slope. They are created at a spacing that allows sufficient catchment to provide the required runoff water, which accumulates in front of the bund, where plants are grown. They are usually placed in staggered position (see top and land bottom Figures in the right box). These bunds, usually the smaller sizes, are used mainly for the rehabilitation of rangeland or for fodder production, but may also be used for growing trees, shrubs and in some cases field crops (e.g. sorghum). They vary depending on the crop type, soil and the rainfall amount. When it is large, like 0.5 ha food crops such as sorghum or millet can be planted. They are suitable structures to enable cultivation of drought resistant crops in areas with very low rainfall. They also used as water/runoff spreading bunds too. Figure of semi-circular bund in staggered arrangement for forage production is shown in the right box.

Fig 1. Semi-circular bund with sorghum crop

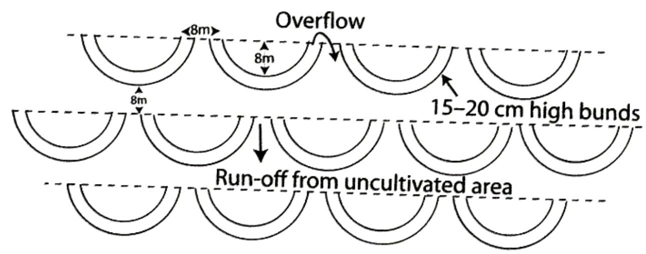


Fig 2. Staggered layout of semicircular bunds

Geographical Extent of Use

Semicircular bunds are suitable for arid and semi-arid areas (rangelands and degraded grazing lands) where annual rainfall ranges about 200 - 750 mm rainfall, deep soils and low slopes (2 - 5%). The land terrain should be even, with topography that is almost flat to gently sloping. The slope could be increased to 10% (see Table 1 below). It can be applied in areas with sandy and sandy loam soils affected by low fertility levels and thin surface crusts that inhibit infiltration and increase runoff.

Table. Minimum height for semi-circular bunds

Radius (M)	Ground slope (%)									
	1	2	3	4	5	6	7	8	9	10
1		Use a height of 20 cm								
2								21	23	25
3						23	26	29	32	35
4				21	25	29	33	37	41	45
5				25	30	35	40	45	50	55
6			23	29	35	41	47	53		
7			26	33	40	47	54			
8		21	29	37	45	53				
9		23	32	41	50	Not recommended				
10		25	35	45	55					

Technical Design Requirements

Two distinct designs are used depending on whether the crop is a tree or a row crop. While the geometry of the bunds is the same, if the crop is cereal the diameter tends to be large and small for the case of a tree. For cereals they can be as large as 40 m diameters and for forage and tree crops their size is less like 6 m or so. The space between tips of consecutive bunds is used for discharging of excess runoff.

The top width of the bunds is usually 10 cm and the height may be uniform where the topography is flat. The side slopes are 1:1 although flatter sides are also possible. As the slope increases, the height is increased accordingly from the tip to the lowest point. The minimum height at the tip is o.1 m. When they are smaller it is suggested that they can be used up to 5% slope similar to eyebrow terrace. Line level, measuring tape, cotton string, and pegs are required.

Layout and Construction Procedures

Steps: i) Design the diameter, spacing and height of the bunds (Figures and, Table 2 below); ii) Stake out a contour line at the top of the field just below the cut-off drain; iii) Cut a string equal to a diameter and a half, marking into three equal parts. With it, mark the tips of a bund, its center and the spacing on the contour; iv) With a peg tied at two ends of the half diameter portion, inscribe the bund below the contour. Similarly, complete the row of bunds on the contour; v) Measure the position of the next row from the bottom of the row above using the calculated spacing. The centers of bunds in this row should vertically line with the mid-point of the space between the bunds in the first row. Repeat until all rows are done; vi) Dig a small trench outside the bund to

Caution:

- Structures are semi-circular bunds 5 -15 meters large, 50 - 75 cm high and with a decreasing height at their tips to evacuate excess water although soils are often permeable enough. Slopes should not exceed 5% and soil depth should be not less than 30 - 50 cm.
- The runon-runoff ratio should be 1:1 to max 1:3 as more runoff can break the embankment. This means a 5 meter diameter half-moon (has 2.5 meters width of cultivated area) will be distant from the next one 2.5 meters; with 3:1 ratio (see Figure xx). Half-moons can be placed one attached to the other (1:1 ratio) as a continuous system. However, the drier the area the higher the ratio between runoff-runon areas.

get soil. Make the bunds in layers of up to 10 cm and compact each until the required height is achieved; vii) Protect bund tips with stones to avoid erosion. If stones are not available, plant a suitable dense grass instead.	• Low moisture demanding crops should be planted such as millet and specific varieties of sorghum. Pulses such as specific drought resistant varieties of beans but also chick peas can be used. • Half-moons can also be planted with pure stands of pigeon peas and other fodder crops mixed with grasses.

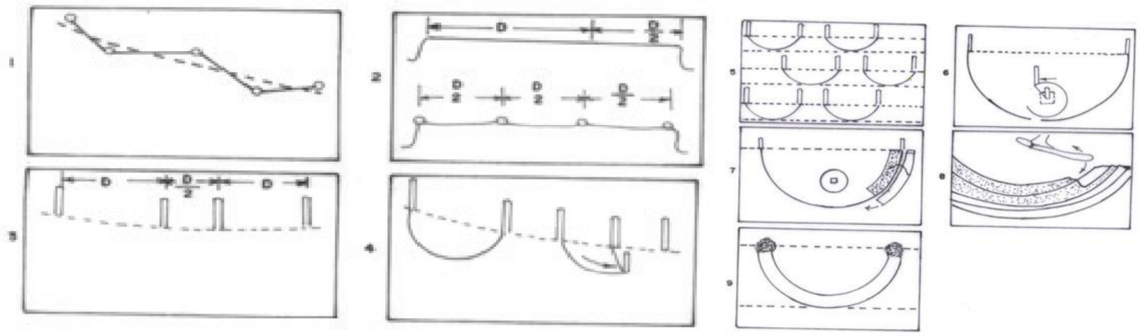


Fig 3. Stepwise layout and construction of semicircular bunds

Period of Implementation Across Seasons	Planning and Mobilization Requirements
Only during the dry season and period not interfering with land preparation. Construction shall start and be completed in the dry season.	Proper site investigation required. All necessary working tools should be mobilized to the site. Community and individual consultation prior to its introduction required. On completion all the necessary site cleanup required.

Cost Elements and Work Norm

Quantities of earthworks for semi-circular micro-catchments is indicated in below Table 2.

Table 2. For work norms, apply 1PD/0.5m^3 earth work volume.

Land Slope	(1) Radius (m)	(2) Length of bund (m)	(3) Impounded area per bund (m^2)	(4) Earth works per bund (m^3)	5) Bunds per ha	(6) Earthworks per ha (m^3)
Design “a” up to 1.0%	6	19	57	2.4	73	175
Design “b” up to 4.0%	10	31	160	13.2	16	210
Design “c” up to 2.0%	20	63	630	26.4	4	105

Management and Maintenance

Where necessary, protect the field from external run off with a cut-off drain at a maximum gradient of 0.25%. Plant a suitable grass on the bunds to avoid erosion. Stone pitching required at the tip of the bund to control scoring by runoff.

Integrated with control grazing and tree/shrubs planting on embankment (pigeon peas, etc) + manure applications.

Benefits and Acceptability

When used for forage, it provides sufficient moisture. If applied correctly it is a very effective technology for the reclamation and rehabilitation of shallow and crusted sandy areas, and changes marginal lands productive. It is usually a zero-runoff system thus reduces erosion significantly. Once the technique is properly sited and demonstrated acceptability is high.

Limitations

It is labor intensive and not effective above 5% slope. Design and layout of large bunds requires careful consideration.

Name of the Technology	RUNOFF RUNON BUNDS /BARRIER LINES

General Description

Runoff - Runon area measures are micro-catchment systems in which surface runoff are collected from a small catchment area with mainly sheet flow over a short distance. These runoff harvesting or runoff farming systems are based on the utilization of surface runoff combined with natural rainfall, to grow crops. In these RWH Systems, the source of runoff is close to the cropped area and is also called as 'within-field' or 'on-farm' microcatchment systems. Runoff water is usually applied to an adjacent agricultural area, where it is either stored in the root zone and used directly by plants, or stored in a small reservoir for later use. The target area may be planted with trees, bushes, or with annual crops. The size of the catchment ranges from a few square meters to around 1000 m. The ratio of catchment (runoff)-to-cultivated area (runon) can range from 1:1 and up to 5:1. The selection of the C/CA ratio and design of structures may be modified taking into consideration farm size and various crop spacing. All the components of the systems are constructed inside farm/rangeland boundaries, and easily maintained and managed by the land users - controlled by the land users.

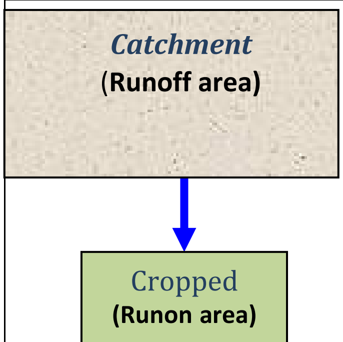


Fig1. Illustration of a runoff-runon area

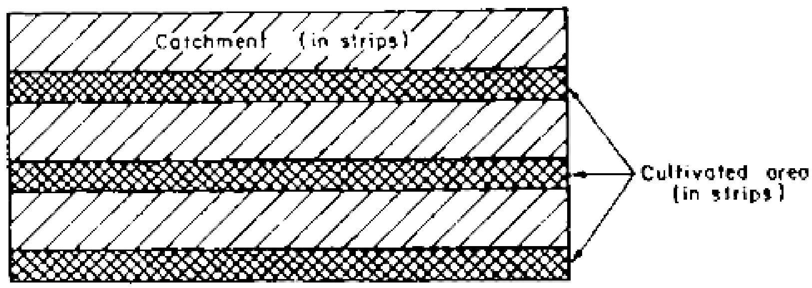


Fig 2. Catchment- Cultivated area ratio of 1:1 - Within Field System

The main characteristics of runoff-runon micro-catchment RWH - sometimes referred to as "within-field-catchment" systems are:
- Overland flow harvested from short catchment length
- Catchment length usually between 1 and 30 meters
- Runoff stored in soil profile
- Ratio catchment: cultivated area usually 1:1 to 3:1
- Normally no provision for overflow
- Plant growth is even

The advantages of runoff-runon microcatchment RWH are
- Simple to design and cheap to install, therefore easily replicable and adaptable.
- Higher runoff efficiency than medium or large-scale water harvesting systems;
  no conveyance losses.
- Includes also erosion control.
- Can also be constructed on almost any slope, including almost level plains

Three most important farm-based runoff-runon micro catchment RWH systems: Small Stone Bunds (SSBs), Narrow Stone Lines (NSLs) along the Contours, and Stone Faced/Soil or Stone Bunds (SFSBs) are described with below with key common features and with detail technical specific descriptions.

Geographical Extent of Use

- SMALL STONE BUNDS WITH RUNON-RUNOFF AREAS: Runoff-runon systems are known and used for different purposes in several dry areas.
- Suitable in dry areas with depleted soils and gentle slopes, crusted and shallow soils and marginal lands used for temporary grazing (Kolla areas).
- Can be easily adapted in moisture stressed areas and agropastoral settings.

- Dry areas with extended degraded grazing lands or rangelands with low productivity and that can be converted into grazing areas.
- **SSBs** can be used to improve long fallows in dry Weyna dega, where such areas exist and can be reclaimed, in combination with agronomic measures such as ley cropping and other measures such as ripping and bunds.
- NSLs can be suitable for pastoral and agropastoral areas to induce better growth of natural grass.
- **SFSBs** mostly suitable in arid areas (Kolla and Berha) but also semi-arid (dry weyna dega) with shallow soils and abandoned or unused areas because of rainfall deficit.

Technical Design, Layout and Construction

SMALL STONE BUNDS WITH RUNOFF - RUNON AREAS

- The system is suitable for shallow soils (<50 cm) and located in marginal areas, with low rainfall (< 400 mm). Most areas used by pastoralist fits this range.
- In slightly higher rainfall ranges (400-600 mm), they are also suitable for marginal areas with soils either shallow and/or with low infiltration rates, or adjacent to gullies.
- In all circumstances they are suitable in areas with slopes ranging from 1 to 5%.
- The minimum area for the construction of a single rainfall multiplier unit should be sufficient to allow the construction of bunds with its planted area and the runoff (catchment area). If the area includes small depressions or gullies, the bunds should wing up before crossing such points. Before the construction of the bunds, the cropped area may be preferably ripped to increase infiltration and encourage biological life.
- Concerning the ratio between runoff area and planted area, it should be estimated according to the amount of rainfall (mean seasonal). The planted area should not exceed 5-10 meters width. Runoff/runon ratios range from 2:1 to 5:1 depending on rainfall and vegetation.
- Since the type of soils is usually shallow, with structural problems (crusts, etc) and limited water storage capacity, excess runoff is expected to occur. For this purpose, bunds should be provided with lateral wings of decreasing height to evacuate excess water and/or side spillways. The bunds wing up laterally for the entire length of the cropped area. Spillway construction follow the same criteria as indicated for soil/stone bunds but often of smaller size due to the smaller size of bunds.
- Suggested dimensions are: height of the bund is 45-60 cm, length 10-50 meters and base width 1-1.5 meters. The bunds have to be staggered alternatively with lateral spacing between bunds of 2 meters to allow overflow.
- The bunds are made out of soil (stable soil, slopes < 3% and rainfall >400 mm) or stone faced (slopes 1-5%, rainfall < 400 mm or above). In case of stone bunds, structures should be sealed with soil on their upper side.

NARROW STONE LINES ALONG THE CONTOURS (STAGGERED ALTERNATIVELY)

- Layout is along the contours, in successive semi-circular lines staggered alternatively.
- Slope should not exceed 3-5%. The soils should be permeable enough to allow sufficient infiltration although this measure is often implemented in areas with crusted and shallow soils, paved with stones. In this respect, stone lines can be easily overtopped by excess runoff. However, it is a cheap method but it is neither an effective erosion control nor an optimal water retention system.
- Stones lines are built with a 30-40 cm height piled in a pyramidal way and are usually 10-40 meters long. Normally, for maximum water retention the two lines are spaced apart 5 to 10 meters.
- If improved grass/legume is planted they should be drought resistant and withstand low fertility levels (fertility building pasture or legume crops). Other biological measures can be applied but farmers may not be willing to invest many resources for a low productivity device.
- Control grazing and cut and carry are required.

STONE FACED/SOIL OR STONE BUNDS WITH RUN-OFF/RUN-ON AREAS (SBRR)

(1) Slope range and type of soils: for slopes < 3-5% and soil depth above hardpan/rocky area of 50 cm or more.

(2) Runoff/runon ratio = ratio of the area yielding runoff (catchment area) and the area receiving runoff (cultivated area) range 0.5-1:1 and 1.5:1 (0.5-1.5 run-off/catchment area and 1 run-on/cultivated areas) for stone faced/soil bunds and stone bunds.

(3) Type of bunds: Stone faced/soil or stone bunds are recommended. There are cases where also soil bunds can be tried (small plots). In case of soil bunds (rare) ratio should not be higher than 0.5-1:1.

(4) Size of the area delimited by two bunds: small catchments will harvest runoff even from shorter storms. Each cultivated area may be delimited by 20-80m long bunds provided with lateral wings of 5-15m width (see the two Figures side by side above).

(5) Layout of bunds: bunds level along the contours and wing up laterally to evacuate excess water. Depression points to be avoided and/or bunds reduced in size and oriented in different directions based on slope.

(6) Construction criteria/phases:

- → Soil bunds: only on slopes < 3% (see standard design);
- → Stone bunds: up to 5% slopes, with strong and large foundation, sealing of the stones is important to reduce the flow of runoff through the bund and facilitate the growth of grass;
- → Stone faced soil bunds: very well compacted and with stone walls placed on both sides of the bund with stable angle. The top of the bund is also planted with dry resistant grass species;
- → Height of the bunds: at least 60-75 cm, length from 25 to 100 m, bottom width 1.5-2 m and top width 30-50 cm. The bund has wings as long as the width of the cultivated area (10-15 meters in the example);

→ Distance between bunds: not exceed 15 to 20 meters within this range of slopes and staggered alternatively. Lateral distance 3-5 meters and protected with lines of stones to evacuate excess runoff (lateral wings should have a decreasing height in order to be the first to evacuate excess runoff).

Period of Implementation Across Seasons	**Cost Elements and Work Norm**
Construction during the dry season, plantation and composting during cropping seasons.	Work norm is same with similar bunds: for Small Stone bunds, Narrow Stone Lines and Stone bunds with runoff-runon measures = 250 PD/km, and for Stone faced/soil and Soil bunds = 150 PD/km are applicable

Management and Maintenance

SSB:

1. In areas developed for fodder crops, first year crop stocks should be cut half their height and the stubble mulched
2. In case of grass/legume pastures, first year reseeding should be allowed and grass cut after grass seeds reach maturity.
3. To improve water holding capacity of the area and encourage fast growth of pasture ripping is recommended (one passage every 1m) followed by 1 ploughing operation.
4. Sowing of drought resistant legume fodder

NSL:

1. Integration is with plantation of drought resistant plants and trees (Acacia species, Parkinsonia aculeata, etc.) at specific intervals (2 m) along the stone lines.
2. Cut and carry and control grazing

SBRR:

a) Provision of spillways with drop/apron may be required in addition to the side wings on bunds (for higher runoff -runon ratio, low infiltration, aggressive rainfall, et.c), particularly in case of soil bunds.
b) Tie-Ridging of the runon (cultivated areas) along the contours is essential for an even distribution of moisture. Every ridge along the contours should be interrupted to allow water to pass through into the next furrow (see Figure 2). Apply compost to increase infiltration every year.
c) Dry resistant trees/shrubs (Acacia species, Aloe sp., Agave sp. etc.) should be planted every 1-2 m along the ditch/berm.
d) Integrated with drought resistant crops (Sorghum, millet, etc.) and legumes.
e) Mulching of crop residues recommended.

Benefits and Acceptability

SSB: 1. In settled agriculture small farmers having difficulties to feed their draught animals or herds are likely to be interested in this measure and take care of the reclaimed areas.

2. This technique may allow to develop large extension of pastures in pastoral and agro-pastoral areas, creating "grazing reserves or fodder banks" to use during drought events and/or to restore cattle conditions before selling them to markets. This activity combined with multipurpose trees planting (aerial pasture, gums, fruits and dyes) such as Zyziphus, Acacia senegal, Neem, etc, can ensure excellent environmental protection and income generation.

NSL: Productivity of grass can improve considerably in areas with stones and with gentle slopes (max 3-5%). If applied over large areas it can control erosion quite significantly and slow down water runoff. Being a semi-permeable or permeable system, it is not considered as efficient as other systems in similar conditions but cheap.

SFSBRR: High potential in agropastoral areas and in drylands with portions of land out of cultivation. This activity may allow large portions of degraded lands to be rehabilitated where cultivation was not considered possible.

Limitation

These systems generally require continuous maintenance with a relatively high labor input.

Name of the Technology	RUNOFF STRIPS

General Description

The technique is similar to contour strip cropping except that alternate strips are here used as runoff catchments. Also known as inter row RWH. The farm is divided into strips along the contour. An upstream strip is used as a catchment, while a downstream strip supports crops (see Photos below). The downstream strip should not be too wide for drier areas and the catchment width is determined in accordance with the amount of runoff water required.

Fig 1. Pictures of runoff strip, final land preparation (left), and during growing field corps (right) - photos in courtesy of ICARDA

Geographical Extent of Use

The technique of runoff strips is suitable in areas where rainfall is low and slopes are gentle. The strips are used to support field crops. Runoff strips are best for field crops such as cereals and legumes. It is common in pastoral areas of Ethiopia.

Technical Design Requirements

Runoff strips based on catchment to cultivated area ratio principle are left purposefully between cropping fields (along the contour) so that runoff flowing down the slope is directed to the cropping field. Sometimes it is difficult for the runoff water to be uniformly distributed for the crops and some grooving required between the runoff and run-on line.

Layout and Construction Procedures

Runoff strips based on catchment to cultivated area ratio principle are left purposefully between cropping fields (along the contour) so that runoff flowing down the slope is directed to the cropping field. Sometimes it is difficult for the runoff water to be uniformly distributed for the crops and some grooving required between the runoff and run-on line.

Fig 2. See the horizontal and spatially dispersed cultivated fields in a runoff-runon principle - Somali Region of Ethiopia. Surface ponds are also noticeable in half-moon crescent shape mostly in the left and upper part of the scene.

Period of Implementation Across Seasons

At the start of the rainy seasons and during sowing/planting.

Planning and Mobilization Requirements
Proper site investigation required. Community and individual consultation prior to its introduction required.
Cost Elements and Work Norm
Working tools and materials: for compacting the catchment part livestock trampling or compacting by machine can be used. Contour layout materials such as line level, meter tape and pegs.
Management and Maintenance
The same cropped strips are cultivated every year. Clearing and compaction may be needed to improve runoff generation/inducement and its distribution by making grooves or corrugations from the catchment to the cropping field. Under good management, continuous cultivation of the cropped strip can build up soil fertility and improve soil structure, making the land more productive. The catchment area can be used for grazing after the crop has been harvested.
Benefits and Acceptability
In dry areas where farmers can set aside a strip of land for runoff generation it can produce crop and forage biomass. The stripping avoids the extra effort needed in the ploughing, seeding, weeding, cultivation, and harvesting, thus optimizing production in a given segment of farm. It requires less farm labor compared to many other RWH measures
Limitation
Since a small ridge is formed during cultivation along the upstream edge of the cropped strip, uniform distribution of runoff across the cropped strip is a potential problem. To overcome this problem it is recommended that the cropped strip should not exceed 2m width, and that water distribution should be helped by good preparation of the strip surface. Difficult to apply in small parcel areas as farmers tend to try the whole field irrespective of the dryness.

Name of the Technology	PERCOLATION PIT

General Description:

A **percolation pit** or sometimes called **percolation pond** is a structure, constructed on any marginal land, pervious soil and with the following objectives: 1. Recharge, augment, replenish the groundwater so that the water can be harvested by digging hand dug wells, shallow wells, and boreholes too; 2. Enhanced groundwater availability for human and livestock use and irrigation; 3. Enhances biomass production through improved water availability in the soil profile as water stored in the upper 1-3 m of the soil profile can sustain vegetative growth. 4. Reduce runoff and subsequently erosion and land degradation. 4. Capturing the runoff by a series of ponds and related structures would retard surface runoff and subsequently avert land degradation.

Fig 1. Function of percolation ponds in capturing runoff and recharing of the groundwater to later be used as springs, streams and hand dug wells.

Fig 2. Function of percolation ponds in the capturing of silts. See the flood mark from the side of the inner pond and feel the water that has soacked instead of being lost as runoff .

Geographical Extent of Use

Suitable in all areas where there is no drainage problem or where the groundwater table is deep and specifically: 1. It is suitable in areas where the ground is pervious

2. Can be constructed on any topography with adequate runoff; in series along waterways, marginal lands and gullies
3. It should be considered only as an element of an integrated watershed development

Technical Design Requirements

Shape: The design of a percolation pond can be circular or trapezoidal. Trapezoidal is when the perviousness of the whole soil profile is uniform. Circular or telescopic is when there is more pervious layer under the top soil layer – See Figure.

Site Selection: On site selection, land use, soil and topography should be assessed; they are more appropriate at the foot slopes and digressional points where runoff can be pulled int. Discussing and agreeing with farmers on design and layout is essential; provide on-the-job training. More specifically, on site selection, it is appropriate to construct percolation pit or percolation pond within shallow waterways where runoff can be directed from left and right of the catchment and can safely surpass it when it gets filled. The spatial location of a percolation pond can be seen in the scene of Figure xx. Abandoned /dried hand-dug wells or shallow wells can be used by renovating and orienting it to percolation pits. At outlets of cutoff drains/water ways and at abandoned quarry sites and depressions. The larger the size the better the recharge of the groundwater. Minimum spacing between two percolation ponds shall be about 50 meters.

Layout: Precise layout and follow-up/adaptations required. The pit can be circular, trapezoidal or take the shape of the available land. To layout, mark the top 0.5m deep pond, again mark the 2.5m pit, and the 1.5m diameter in – See Figure xx. The depth of the percolation pit can be 3m and above.

Construction Work: Dig the first 0.5m deep pond with about 3m diameter. Then dig the 2m deep pit with 2.5m diameter. Next dig the 1.5m diameter pit. Fill the lower portion of the percolation pit which is ≥ 1m depth with gravel of 4cm diameter stone gravel; the next 1m depth with 4cm diameter gravel; the next 50cm depth with 2cm diameter gravel; the next 40cm depth with coarse sand; the next 10 and 50cm depth as seen in the telescopic-shape Figure xx to be left for water storing until it is soaked in.

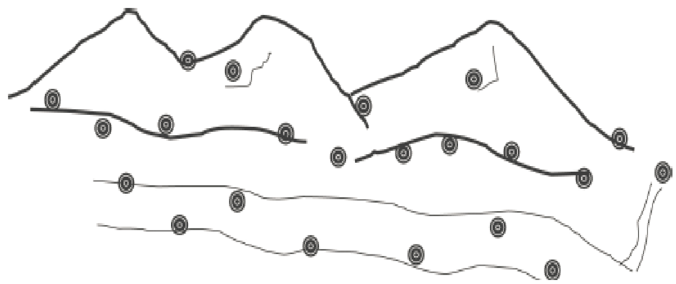


Fig 3. Spatial location of percolation pits, see there are more on footslpe and on gentler grounds than on the hilltop

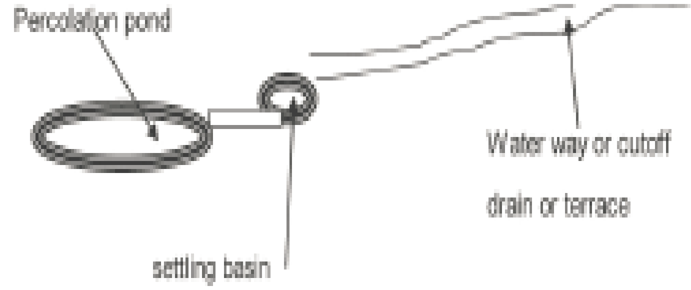


Fig 4.Spatial placement of the waterway /cutoff drain, settling basin and the percolation pond /pit

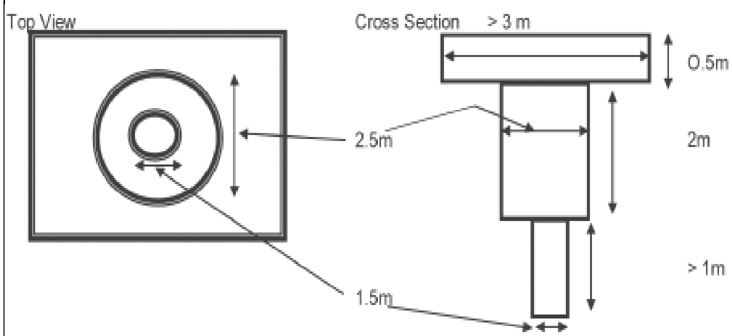


Fig 5. Telescopic percolation pit layout and section /elevation

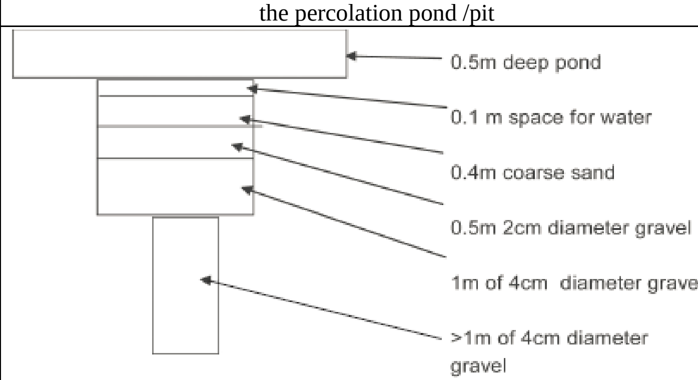


Fig 6. Parts of each section filled with filter materials

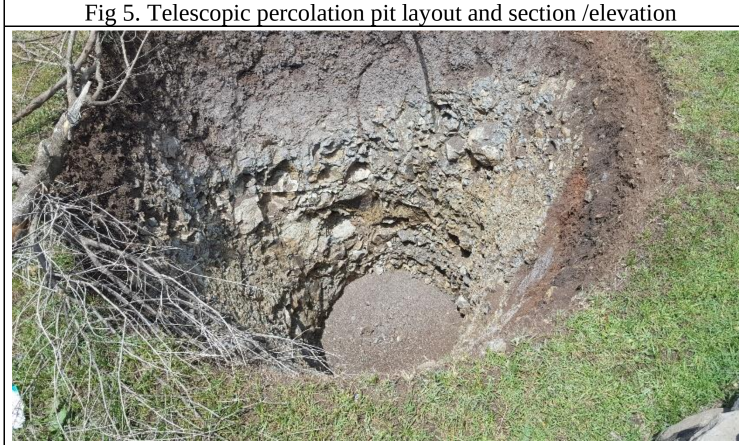


Fig 7. Percolation pit in gravely soil - cascaded in a waterway

Fig 8. Percolation pit within a shallow waterway with soil embankment and stone paved spillway at the middle

Fig 9. Excavation (left), backfilling with small stones and gravel (middle), and placement of coarse sand on top of the gravel

Period of Implementation Across Seasons	Only during the dry season and period not interfering with Agriculture.

Planning and Mobilization Requirements
Farmer groups and communities are trained in proper layout, design and construction; Make sure community agrees on groups and individual sharing of degraded hillsides; Discuss and decide the different type of trenches to construct based upon what farmers want and what is more appropriate based on type of soils and depth; If technology not introduced test at small scale first. Agreements on use rights and management of treated areas (areas shared amongst individuals, groups or managed by community or mixed). See opportunities for land use certificates in protected areas. Arrange working groups for maintenance.
Cost Elements and Work Norm
Tools: crow bars, pick axes and shovels (1 crow bar: 2 pick axes: 2 shovels ratio, 1 crowbar). For all percolation pits work norm includes excavation of soil, carting away the soil and use it for the embankment and its compaction (spillway if it is in the waterways). Work norm is 12 to 15 person days per percolation pit per day including digging, gravel collection, backfilling.
Management and Maintenance
Activities such as spring development, hand dug wells, shallow wells, construction of community ponds, construction of trenches and percolation pits, cutoff drains, and artificial waterways can be integrated and managed along percolation pits. If the top part is sealed with fine sediments then scratching it and removing would be required for temporary fresh runoff storage. Safety during digging, for depths greater than 3m or so is crucial as collapsing walls can cave in.
Benefits and Acceptability
Reduction of runoff and sediments. Good for degraded hillsides rehabilitation. Area closure accompanied with percolation pits results in good regeneration. Good potential to improve degraded hillsides and flat to gently sloping lands. Is also very good for groundwater recharging techniques for replenishment of groundwater and raising the water table. If demonstrated properly, acceptability is not a problem, and should be planned and implemented as an integral part of community watershed management interventions. Together with other measures percolation pits can significantly improve watershed rehabilitation, biomass production and recharging of water tables. Can easily be understood /adopted after demonstration.

Limitation	They are labor intensive techniques and can be applied in areas where farmers /communities are willing.

Drainage Management Structures

Overview

An agricultural drainage system is a system by which the water level on or in the soil is controlled or regulated before the frequent water-logging occurs on the soil surface so that agriculture can benefit from the subsequently reduced water levels. The system can be made to ease the flow of water over the soil surface or through the underground, which leads to a distinction between 'surface drainage system' and 'subsurface drainage system' (including the tube well or vertical drainage system). Both types of systems need an internal and field drainage system which lowers the water level in the field and an external or 'main drainage system', which transports the water to the outlet. The main drainage water sources are surface water including rainfall runoff, irrigation water, and sub surface water source or groundwater. By applying various drainage systems, the water coming from the different sources will be removed or disposed-off safely before it creates water-logging and reduces agricultural benefits.

Draining agricultural fields and removing the excess moisture has the following major benefits:

- Controls erosion and hence reclaim and conserve land for agriculture
- Controlled removal of surface water (by keeping the required moisture and removing the excess amount)
- Increases crop yields and vegetation biomass through improving the health of soil
- Reduces the cost of crop production in otherwise waterlogged land
- Prevents structural damage to different infrastructures and residences
- Provides increased aeration in the root zone
- Deepens the root zone in drained soil and etc.

In general terms, soil and water conservation structures can be designed either to retain or discharge runoff. They can also be designed so that part of the runoff is retained but the excess, during heavy storms, is discharged. In areas where there is a risk of water-logging at certain times because of the amount of rainfall, slope of the land and/or properties of the soil, it is usually necessary to design structures to discharge runoff. However, it is a mistake to design structures to discharge runoff if there is no suitable outlet such as a natural waterway, artificial waterway or grassed or forested areas around the vicinity.

Discharging runoff onto a footpath, road or existing gully will simply aggravate the problems of erosion. On large-scale farms it is possible to set aside land for waterways. In densely settled areas this is much more difficult; hence it is compulsory to discuss and agree with the concerned community members. Other factors that must be considered in reaching a decision, besides the availability of a discharge area or waterway, include the soil type, soil depth, land slope, and the risk if any, of retaining water in situ. Soils in higher rainfall areas which are prone to water-logging (because they are shallow or because of the clay content), normally require structures that will drain water.

As mentioned above there are surface and subsurface drainage systems which can be applied on a field to drain excess water/runoff. Some of the technologies particularly, the subsurface techniques are so expensive and difficult to be executed by farmers and other land users. Whereas, the surface drainage systems are relatively cheaper compared to the subsurface techniques, and the working procedures are not as such complex to be understood by communities.

The purpose here is not to elaborate in detail and describe about all drainage systems mentioned; rather it is to concentrate more on surface drainage systems which are usually applied in sloppy and relatively flat lands that have soils with a low or medium infiltration capacity, or in lands with high-intensity rainfalls that exceed the normal infiltration capacity. Properly managing and draining the excess runoff before it devastates the landscape is the joint responsibility of the land users, officials and experts. Implementing different surface drainage control structures like cutoff drains, waterways and graded bunds in all the areas where they are required is therefore should be taken seriously and applied at large scale.

In some parts of Ethiopia, where there is high rainfall, commonly called '*highland areas'* farmers or land users have very much experienced about the risk of water-logging. To mitigate this problem, they have traditional practices of constructing structures which are meant to drain excess runoff. For this purpose, they commonly used to construct traditional drainage furrows above ("*Tekebkeb"*) and within their farmlands (*Feses*). There are some cases where these structures are found helpful in draining the excess runoff and protecting the farmlands. In most cases, the structures are developed into gullies with in very short period of time because of the high gradient level and improper design, layout and construction technique applied by the land owners.

It is clear that currently a due focus is given by concerned professionals and farmers to introduce and adapt various improved drainage control structures like waterways, cutoff drains, and graded bunds which serve to drain surplus runoff. But there is a huge skill and knowledge gap with experts, development agents and farmers about the application and proper installation of these structures. Apart from what is given in the individual info-techs Annexes 1 to 4 can be used.

This guideline includes the technical details of the four major surface drainage structures:

1. Waterway,
2. Cutoff drain,
3. Graded Soil bund
4. Graded Fanya Juu
5. Broad Bed Maker (BBM)

Name of the Technology	WATERWAY

General Description

A waterway is a natural or artificial drainage channel along the steepest slope or in the valley used to discharge runoff. **An artificial waterway is** a drainage structure that can receive and dispose excess runoff from cutoff drains and graded terraces to the natural watercourse, percolation & water harvesting structures. Waterways are needed to conduct runoff safely from hill slopes to valley bottoms where it can join a stream or river. Where there is a natural depression or small valley that is well stabilized with vegetation this may be adequate to take the discharge from diversion ditches or graded terraces, but where there is no such natural waterway, an artificial waterway (drainage way) must be installed. In areas where stone is available the waterways will be paved to protect it from scouring. Whereas, a vegetative waterway can be constructed in areas without stones.

Fig 1. Stone paved waterway

Geographical Extent of Use

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. Traditional drainage ditches and waterways are common in many parts of Ethiopia. The use of grass vegetation in waterways is commonly practiced locally by farmers.

Technical Design Requirements

There are many 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%.
- **Shape**: Choose parabolic cross section for types of waterways as this tends to resemble natural waterway.
- **Size**: The waterway must have sufficient width and depth to accommodate the expected runoff volume. Several small waterways are preferred 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. 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. To dissipate the energy of runoff in the channel, drop structures which could be constructed from stone and wood can be installed a certain distance along the way.

Fig 2. Waterway on sloping land (above)

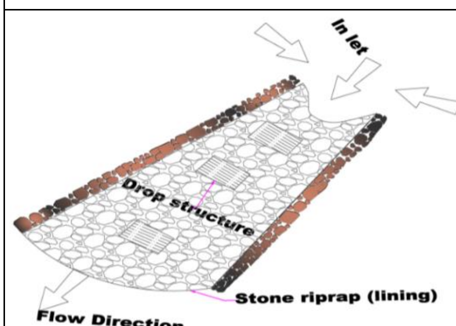


Fig 3. Cross-section of waterway with drop structures (below)

Layout and Construction Procedures

The preliminary position of a waterway should be determined from a reconnaissance field survey. Where possible, the waterway should be located in a natural depression or drainage way. After the waterway has been staked out, construction can start from the lower end by excavating soil from the center and throwing it to each side to form the banks. 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. When constructing waterways, the embankments on both sides have to be compacted very well (upper figure). Sometime, waterways can be constructed in sloping lands where embankment is required on one side only (lower figure).

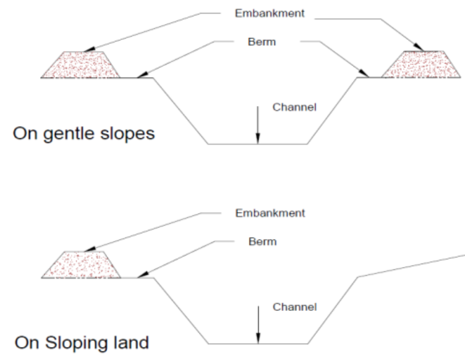


Fig 4. Excavation of waterways on gentle and sloping lands

Period of Implementation Across Seasons

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 cutoff drains. In area where there is an adequate stone for construction of water guide, channel pavement, scour checks and drops structures, both waterway and cutoff drains can be constructed in the same season.

Planning and Mobilization Requirements

The site where the waterway is to be constructed need to be discussed and agreed among community members. To have enough space for the waterway, land users may contribute some patches which require their consent and willingness. The overall construction will be carried out with a shared labor from the community.

Cost Elements and Work Norm:

The work norm for waterway construction includes the following elements:

- Precise layout
- Removal of grasses from place of embankment
- Excavation of soil and preparing channel
- Shaping and compaction of embankment
- Collection and transportation of stones
- Provision of scour checks and drop structures
- Planting with grass and other vegetative materials

The existing experiences in Ethiopia indicate that having the above work norm elements in mind, $1m^3$ vegetative water way requires 1pd ($1m^3$/pd). Whereas, 0.75 m^3 stone paved waterway demands 1pd ($0.75m^3$/pd).

Integration and Management Requirement:

- Waterways need to be linked to graded bunds and cutoff drains. Sinkholes have to be constructed within 4 - 6 m intervals along the channel of the waterway
- 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. Any damage should be repaired immediately.
- Where the cutoff 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.
- Similarly, stabilizing the embankments and planting the channel bed should be considered as an important parameter to keep the stability of the structure.
- Drainage management structures, particularly, waterways have to be integrated with water harvesting schemes. The excess water which is drained by drainage structures need to be harvested in ponds and also allowed to percolate into the groundwater table for recharging.

Benefits and Acceptability:

In areas where cutoff drains, graded bunds and other traditional drainage ditches are constructed, the land users are safeguarded from excessive runoff and able to drain it safely. Community members are well aware of the advantage of constructing waterways. In most cases, they prepare drainage ditches even without expecting technical support from experts/professionals.

Limitation:

- Failure to construct proper waterways to take run-off from roads has led to the formation of many gullies on arable land.
- Because of shortage of land, farmers used to construct deep and narrow waterways. Such dimension may increase the force of the running water and triggers scouring effect and hence gully formation.

Name of the Technology	CUTOFF DRAIN

General Description

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

In the drylands, cutoff drains may be used mainly for the following purpose:

- Protect cultivated land from runoff generated from sparse forest land or degraded grazing land, steep slopes, etc.
- Divert additional water to cultivate plots
- Divert additional water to sediment storage dams and cropped areas
- Divert additional water into reservoirs for irrigation and/or domestic uses (including water supply for livestock).

Fig 1. A well-established grassed cutoff drain

Geographical Extent of Use

Cutoff drains are most suitable in areas where there is medium to high rainfall distribution. They can be also used in dry areas to protect cultivated lands and irrigation schemes, and divert runoff into run-on areas, for example reservoirs and farmlands. The location of a diversion ditch should be determined after checking the outlet conditions, topography, land use, soil type and length of slope. If it is intended to protect cropland against runoff from adjoining non-arable land, it should be constructed at the boundary between the two land uses where there is a slope change. Ditches in this situation are usually referred to as cutoff drains. When diverting water away from the head of a gully, the diversion ditch should be constructed far enough above the gully head so that stable slopes will still exist even if some slopping or sloughing of the gully head takes place.

Technical Design Requirements

The design of any structure to retain or discharge runoff should be based on a reasonable estimate of the volume of runoff (m^3) to be retained or on the peak rate of runoff (m^3/s) to be discharged respectively. Usually the design of graded structures like cutoff drains will be based on the heaviest storm that can be expected in a given period (10 years). Accordingly, in order to prepare a feasible design of a cutoff drain the following steps are required:

- Estimate the runoff rate of the upper catchment using Rational or Cooks methods as described in the annex 1 of this manual,
- Select maximum allowable velocities which can fit to the soil and cover condition of the channel
- Decide the channel gradient which will not bring scouring and allow siltation
- Determine permissible depth of flow, its bottom and top widths
- Check if the dimensions given can accommodate the discharge which is coming into the channel.
- Estimation of catchment runoff is given in Annex 1 of Technologies
- For channel size determination see Annex 4 of Technologies.

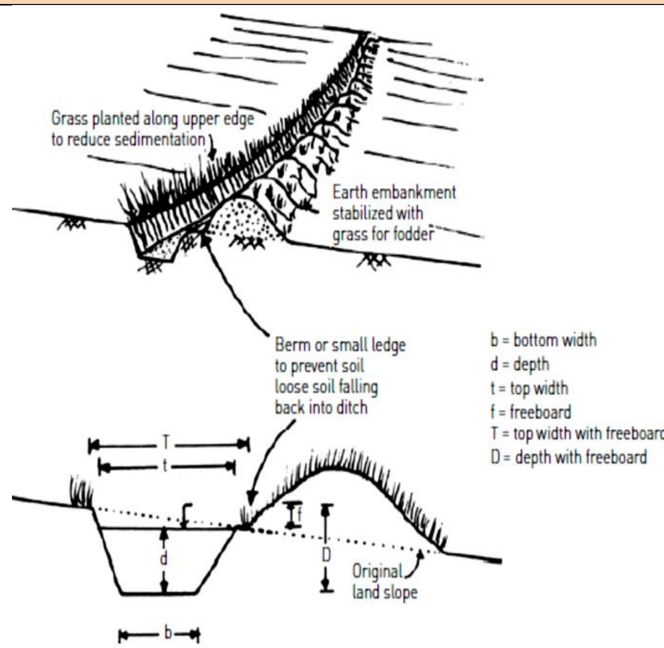


Fig 2. Cross-sectional view of a cutoff drain

Layout and Construction Procedures

- As per the selected channel gradient, lay out graded line.
- While making graded line, put pegs at interval of 10 m along the central line of the drainage channel (through 'o' in the graphics)
- Depending on the width of the channel, **two rows of pegs** should be erected following the graded contour along 'MN' and 'PQ'
- The distance between NO and OP is equal and it gives the bottom width of the channel
- The distance between MN and PQ could also be equal if the same side slope is chosen for both. But if the side slopes are not the same then they are not equal.
- First start digging of a rectangular section (NRSP) whose top width is equal to the bottom width of the channel to the level of the designed depth
- The excavated soil should be through downhill and form a well compacted embankment by leaving 15-30 cm berm space to avoid the moving back of the soil.
- Depending on the side slopes used, shape the sidewall of the channel. When the sidewalls are shaped in a straight inclined line then you have a trapezoidal cross section shown as MRSQ
- After completing the digging of the channel, depth, width and the gradient should be rechecked and corrected if any problem is observed.
- Reinforce properly around the outlet. A good grass cover should be established on the embankment to stabilize it.

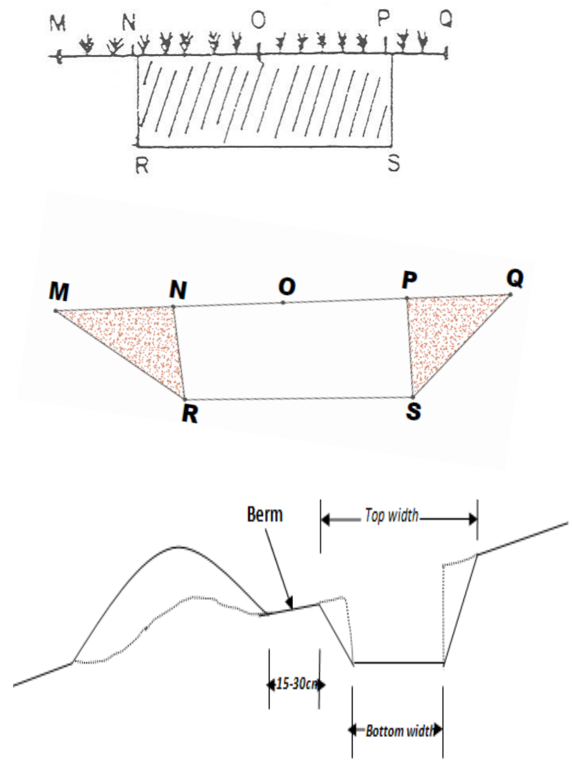


Fig 3. Layout & construction procedures

Period of Implementation Across Seasons

Cutoff drains are constructed preferably during the dry seasons and period 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 stabilizes the channel's embankments.

Planning and Mobilization Requirements

As the cutoff drain may cross several individual and communal ownerships, it is always important to discuss with community members and establish agreement. The community members need to be convinced to contribute labour and materials for the lay-out and construction process.

Cost Elements and Work Norm

The cost elements attached to cutoff drain construction are related to its precise layout, removal of grass from where it is going to be established, excavating soil, shaping and compaction of embankment, provision of scour checks and planting with grasses. The average work norm which is in use in Ethiopia is 0.7m3/pd

Integration and Management Requirement

A cutoff drain should be linked with a waterway (natural/artificial) for safely diverting of the runoff. It requires a regular follow-up and supervision by communities and concerned experts for any maintenance and upgrading if damage happens by any case.

Benefits and Acceptability

Now a-days, community members in many areas have understood the contribution of cutoff drains in managing runoff. Hence, the practice has high acceptability by land users. Consequently, the traditional runoff diversion measures that farmers have been used for years are improving in quality of design and construction.

Limitation

If a cutoff drain breaks because of poor layout and construction, it will have a devastating effect to the downstream areas. Gullies may develop from it.

Name of the Technology	GRADED SOIL BUNDS

General Description

Graded soil bund is similar in description with level soil bund. However, graded soil bund is up to a maximum of 1% inclined against the contour so that excess runoff is allowed to drain to the adjoining natural or artificial waterways. It is also possible and necessary to include tied ridges smaller in height within the channel of the terrace. The stored water in the ties can infiltrate into the soil while any above that height will drained out.

Fig 1. Graded soil bund, water flowing towards the viewer

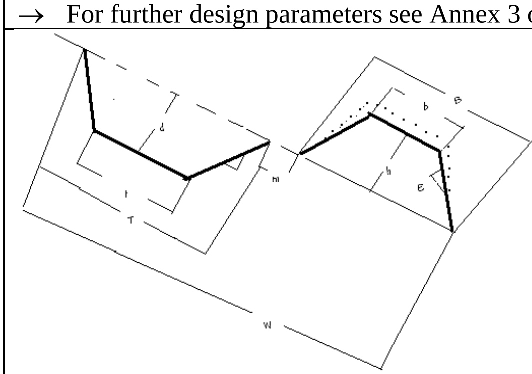
Geographical Extent of Use

Suitable mostly in high rainfall and humid areas of wetter agroecologies and especially where the soil is poorly drained. Overall they can be applied in Wurch, Dega and Wet Weyna Dega areas of the traditional agroecological systems.

→ Local experience is very relevant to assess performance of past activities and suggest modifications as required.
→ Improved designs can be integrated with local ones to add strength to bunds (grass, legumes composting, etc).
→ Applied generally on cultivated lands with slopes above 3%;
→ Homestead areas combined with cash crops. In case of cattle crossings bridge type crossings with stones or wooden structures are needed unlike level bunds where complete blockage is possible.

Technical Design Requirements

→ The artificial or natural WW should be constructed 1 year before GB.
→ The channel is graded up to a maximum of 1% (10cm for every 10m layout of the line level).
→ Height: min. 60 cm after compaction.
→ Base width: 1 - 1.2 m in stable soils (1 H: 2 V) and 1.2 - 1.5 m in unstable soils (1 H :1 V).
→ Top width: 30 cm (stable soil) - 50 cm unstable soil).
→ Channel: shape, depth and width vary with soil, climate and farming system.
→ For further design parameters see Annex 3 of Technologies
→ Channel cross section increases towards the end because of more water concentration e.g. from 25 cm depth and 50 cm width to 50 and 100 cm, respectively.
→ Ties (if appropriate): tie width with dimension as required, placed every 3 - 6 m interval along the channel.



Where:

T = Top width of burrow trench (80 cm)	t = Bottom width (40 cm)
d = Depth of burrow trench (50 cm)	E = Embankment gradient 1 (horiz.): 2 (vert.)
B = Width of bund at base (90 cm)	m = Berm (10 cm)
W = Overall width (180 cm)	b = Top width (30 cm)
Height after compaction (50 cm)	Height before compaction (60 cm)

Fig 2. Schematic view and standard cross section of the channel and bund / embankment for conventional soil bund on stable soil

4. Layout and construction procedures:
Vertical intervals: follow a flexible and quality oriented approach:
- Slope 3-8% VI = 1-1.5 m; Slope 8-15% VI = 1-2m
- Slope 15-20% VI = 1.5-2.5m (only exceptional cases)

Caution: soil bunds > 15% to max 20% only if space reduced and with trench, short bunds - above 15% better apply stone faced or stone bunds). Layout along the contours using line level - discuss spacing with farmers and in case of lateral slopes try to maintain lines as straight as possible by applying reinforcements on depression points (to avoid curving a lot or cutting of plough line).

Fig 3. Graded bunds discharging runoff to central waterway

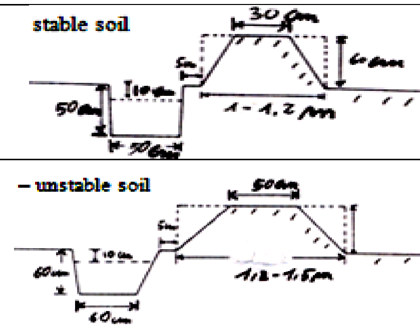


Fig 4. Cross-section of graded soil bunds on different soil type

Layout and Vertical Interval (VI) specifications

Ground slope %	Height of bund (m)	Vertical Interval (M)	Horizontal Interval (m)
5	0.5	1	20
10	0.5	1.5	15
15	0.75	2.2	12
20	0.75	2.4	10
25	1	2.5	8
30	1	2.6	8
35	1	2.8	6
40	1	2.8	5
50	1.15	2.8	4

Period of Implementation Across Seasons

Only during the dry season and period not interfering with land preparation. However, short showers ease the digging and compaction of the soil as it gets moist than hard dry.

Planning and Mobilization Requirements

It should be considered as an integral part of the treatment of the community watershed and not in isolation. Land use, soil and topography assessed. Discuss/agree with farmers on design and layout + on-the-job training.

Cost elements and Work Norm

Layout: One water line level, two range poles graduated in cm and 10 meters of string (a team of three people layout approx 2-3 ha/day). **Work materials:** shovels, pick axes and wooden compactors (the proportion of shovels and pick axes depend on type of soil). **Work norm** is 150 PD/km.

Management and Maintenance

1. Integration with artificial or natural waterways and apron (in case of sharp falls) is a must.
2. Integration with bund stabilization: using grasses (indigenous such as “sembelete”, “dasho”, others, etc.) + legume shrubs (pigeon peas, sebania, acacia saligna, etc.) in dense rows by direct sowing (15-30 cm).
3. Agronomic: contour plowing, composting, start 1st year applying 2-3m strips above bunds-where soil is deep & moisture is higher). Control grazing - avoid animals to graze between bunds for at least 1 year.
4. Grow cash crops along bunds (especially after 1-2 years of composting) in single or wider strips as required. Plant specific crops along bunds to use residual moisture (sunflowers, gourd, tomatoes, cucumbers, etc.).

Upgrading soil bund using FJ principle: Problem with FJ is that they overtop easily and break. So in difficult slopes with traverse/lateral gradients it is better to implement soil bunds and stone bunds/stone faced bunds than FJ. After the 1st or 2nd year upgrade the terrace by using the FJ principle (See Figure below). For rapid benching + apply compost to improve infiltration near embankment/raiser. This form of upgrading can be applied at very large scale on existing conserved areas. **Integrate bund stabilization:** using grasses (indigenous and improved) etc.) + Legume shrubs (Pigeon peas, Sebania, Acacia saligna, etc.) in dense rows by direct sowing (15-30 cm) on upper side of bund and berm. Pigeon peas also planted annually. Lower part of the wall can also be stabilized by planting drought resistant plants such as Sisal, Aloes and Euphorbia tirucally in thick rows. **Agronomic practices:** contour plowing and compost (start first year applying 2-3 m strips above the bunds - where soil is deeper and high moisture). **Grow cash crops along bunds** (especially after 1-2 years of composting) in single or wider strips as required. Plant specific crops along bunds to use residual moisture (sunflowers, gourd, tomatoes, cucumbers, etc.). **Control grazing** - avoid animals graze between bunds for at least 1 yr and place bunds in staggered position, do not end a bund in a depression.

Benefits and Acceptability

The advantages of channel soil bunds are that during first year the bunds can accommodate more sediments and water than FJ – thus less prone to breakages. During 2nd and following years good deposited soil is not taken from upper level for upgrading. Rather for rapid benching maintaining FJ principle. Cropping close to the embankment is also facilitated (less space out of crop production).

Limitation

Bunds can create temporary water logging if not integrated with fertility management. Limited stability if not integrated with vegetation.

Name of the Technology	GRADED FANYA JUU (FJ) BUNDS

General Description

A graded *FJ* bund is similar in description with level *FJ* bund except the fact that it is made graded to drain excess water. Graded FJ bund is an embankment or a structure made of soil and constructed being slightly graded sideways, with a gradient of 0.25% up to a maximum of 1% towards a waterway. Graded *FJ* bunds have to be combined with graded drainage ditches (trenches), which will be located on the lower side of the *FJ bunds (“Throw uphill” in Swahili language)*. The purpose of having a gradient is for surplus runoff to be safely drained if the retention of the bund is not sufficient. Graded *FJ* bunds retain normal amount of runoff in their basins, but they can drain excess runoff at a non-erosive velocity.

Geographical Extent of Use

Graded *FJ* bunds are suitable mostly for high rainfall and humid areas of wetter agro ecologies with the daily rainfall exceeds 75mm and especially where runoff is excess and the soil is poorly drained or where heavy impermeable soils are existing. Like level FJ, graded *FJ* are also best constructed in uniform terrains with deep soils that do not have traverse slopes (depressions). Generally, graded bunds can be applied on cultivated lands with slopes above 3% and within sloping homestead areas combined with cash crops.

Technical Design Requirements

- The artificial or natural waterway should be constructed one year before the graded *Graded FJ* bund.
- The channel is graded up to a maximum of 1%
- Height: min. 60 cm after compaction.
- Base width: 1-1.2 m in stable soils (1 horiz: 2 vertical) and 1.2-1.6 m in unstable soils (1: 1).
- Top width: 30 cm (stable soil) - 50 cm (unstable soil).
- Channel: shape, depth and width vary with soil, climate and farming system.
- Channel cross section increases towards the end because of more water concentration
- Ties (if appropriate): tie width with dimension as required, placed every 3-6 m interval along the channel.

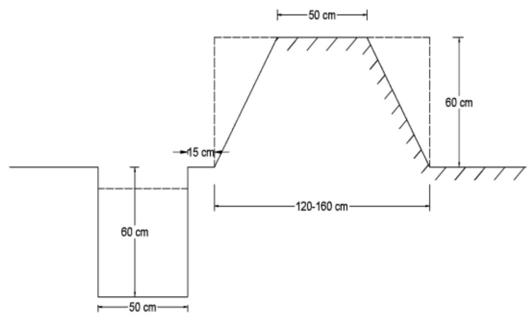


Fig 1. Channel cross-section

Layout and Construction Procedures

- ☞ It is very important that graded *FJ* bunds are properly laid out and surveyed before the construction takes place.
- ☞ Before making decisions to construct graded *FJ terraces*, care should be taken that there is proper outlet.
- ☞ The laying out and construction of graded *FJ* bunds always starts from the outlet.
- ☞ The length of a graded *FJ* bund should not exceed 200 meters,
- ☞ Vertical intervals: follow a flexible and quality oriented approach
- Slope 3-8% VI = 1-1.5 m
- Slope 8-15% VI = 1-2 m
- Slope 15-30% VI = 1.5-2.5 m
- Layout along the contours but with 1% gradient using line level
- It is important to make proper link and stone pitching of the area where *FJ* bund meets the waterway.

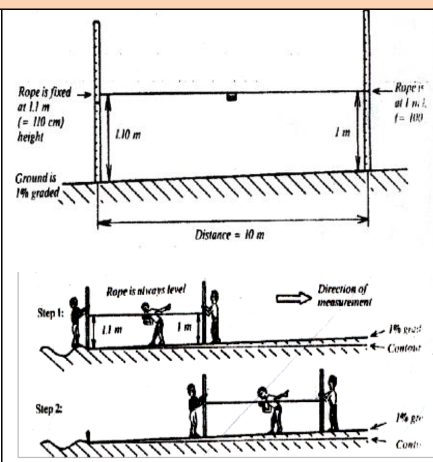


Fig 2. Layout procedures

Period of implementation Across Seasons	Planning and Mobilization Requirements
• Graded *FJ* bunds should be constructed during the dry season after land users/farmers completed harvesting and before beginning the next field preparation operations • The construction of graded *FJ* bunds has to be completed before the onset of the rain to give time for the soil to be compacted and stabilized.	The layout, surveying and construction phases of soil bunds require proper planning of the available labor force and materials. The concerned professionals in collaboration with the land users have to prepare a clear action plan indicating the description of tasks to be accomplished, implementation period and required budget and logistic.

Cost Elements and Work Norm	Integration and Management Requirement
• Precise layout along contours with 1% gradient using line level, • Scratching or removal of grasses from where embankment is constructed for better merging & stability, • Excavation of the channel, and ties along channel (if necessary), • Embankment building, shaping and compaction (essential), • Leveling and compacting the top of bund until the required stability is achieved. • In general, to construct 1 km of graded *FJ* bund, about 250 pd is required (250 pd/km). If it is a soil bund the norm will reduce to 150 pd/km. But, these are average values which need to be verified according to the specific local situations.	☞ Graded *FJ* bunds need to be upgraded and regularly maintained, especially in the 1st year. Every farmer (land owner) is responsible for carrying out continuous maintenance on the graded *FJ* bunds of his/her own land. Bunds have to be increased annually until graded bench terrace is developed. ☞ Newly constructed *FJ* bunds should be stabilized with vegetative materials during the first rainy season and protected from livestock. Generally, a creeping type of vegetation is most suitable for this purpose, but care has to be taken that it is too prolific and interferes with farming activities.

Benefits and Acceptability:	Limitation
Graded *FJ* bunds are found beneficial for growing crops in areas where there is excess runoff and water logging. As a conservation structure, it maintains soil moisture and protects the soil from erosion. In many parts of Ethiopia, the technology is being well accepted by the land users and is becoming a common practice for soil and water resource management.	• If the gradient of graded bund is high, there will be a danger for the channel/bund embankment to be scoured. On the other hand, there will be siltation on the channel and flow will be blocked and hence overtopping occurs when the channel gradient is below the minimum limit. • It requires regular maintenance if not integrated with vegetation

Name of the Technology	BROAD BED MAKER (BBM) FOR VERTISOLS MANAGEMENT

General Description

Vertisols (heavy black clay soils) cover some 43 million hectares comprising 19% of total land area in sub-Saharan Africa. The importance of vertisols for agricultural development is unquestionable. However, most of the vertisols suffer from excess water and poor workability and are also underutilized, hence largely used for dry season grazing. Potentially, vertisols are productive soils but they are not easy to cultivate due to their poor internal drainage and resultant flooding and water logging during the wet season which contribute for lower crop yields.

To overcome these problems various technologies have been tried across the East African countries, particularly in Ethiopia. Among those technologies, the use of Broad Bed Maker (BBM) is a common practice very well-known by farmers. The BBM (Ethiopian case) is a type of plough that was developed from the traditional dual oxen-drawn plough, *the Maresha*, in order to more efficiently make raised seed beds and furrows at the time of seed covering-thus reducing waterlogging and encouraging early planting of improved crop varieties which could then be followed by a second crop in the same growing season (where it is possible). In Ethiopia, manually prepared broad beds have been used since the 16th Century. Currently, animal drawn and tractor mounted BBM technologies are being utilized to facilitate surface drainage and increase productivity of farm plots. See the manual BBM making (right).

Geographical Extent of Use

Experience from different countries (India, Australia and Ethiopia), show that the proper knowledge and management of vertisols has resulted in increased yields. Hence the proper application of the BBM technology for vertisols is believed to increase productivity and food security levels within the farming community. The BBM became the center piece of a technology package that evolved to contain some key elements-namely a plough to improve the effectiveness and efficiency of traditional drainage practices and resource conservation, improved (high yielding but less water tolerant) seeds, fertilizer, herbicides and pesticides, credit for the plough and/or inputs, and training on how to use the package. With this combination in mind, the BBM technology can be used for different soils and various agro-ecological zones.

Layout and Construction Procedures

- There are various prototypes of BBM for preparing raised beds. The one which is indicated on the Fig (right, top) is I-Bar BBM - used in Ethiopia and proved working.
- All raised bed construction must include appropriate surface drains. The amount of extra water running from raised beds is not trivial and there are responsibilities that farmers must abide by with respect to the safe disposal from their land.
- The layout of raised beds and their associated drains is thus important for 2 reasons: the safe disposal of excess water; and the operational efficiency of farming.
- The prime objective of constructing raised beds is to drain excess water from the root zones of crops and pastures. Success requires that this be achieved with certainty to remove the risk of production.
- One of the necessities to properly achieve the above objective is to undertake elevation surveys. Precision contour surveys are thus essential on low slope areas in order to detect the dominant direction of slope. On higher slope countries, that may not be needed because the slope direction is much less likely to be altered by minor elevation changes.
- The excess water to be drained out has to be stored for later use by constructing a pond nearby. Hence combining drainage management with water harvesting should get the attention of farmers and practitioners – Fig (right bottom).

Gully Rehabilitation Technologies

Overview

Gully formation: Gully erosion is the erosion process whereby water concentrates in narrow channels and over short periods removes the soil. Gully erosion produces channels larger than rills. As the volume of concentrated water increases and attains more velocity on slopes, it enlarges the rills into gullies. Gully can also originate from any depression such as cattle trails, footpaths, cart tracks, and traditional furrows and indicates neglect of land over long period of time. Gullies are more frequently found on bush and grasslands than on cultivated lands because rills on cultivated lands are removed by plowing and other recurrent cultivation measures. However, these rills continue to enlarge on grazing lands and forest areas. Nowadays, even in cultivated areas, the number and size of gullies are increasing due to several factors of which traditional ditches, which farmers are constructing for draining excess moisture and runoff are the main ones. Gullies are mostly initiated during unique erosive storms. Once such gullies are formed, they tend to become further enlarged in subsequent rainfall seasons.

Figure: Typical gully erosion (land devastation) in highlands of Ethiopia

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

Gully development stages: After its initial incision, a gully usually extends backwards and sideways through the development of secondary gullies. Gully erosion is caused by head-ward advance, upstream migration of secondary nick points, widening of the gully channel by slumping and mass soil movement, and deepening by mobilizing or transporting sediments from the gully floor. Generally, a gully develops in three distinct stages; waterfall erosion around gully head; channel erosion along the gully bed; and landslide erosion on gully banks. Correct gully control measures must be determined according to these forms of gully erosion, gully development stages and locations.

Gully treatment: As gully control can be an expensive undertaking, *prevention is always better than cure*. Gully formation is often a symptom of land misuse and can be prevented by good land husbandry according to land capability. Planning of any infrastructural development should take into consideration the safe disposal of the runoff water. In gully control, the following three methods must be applied in order of priority:

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

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

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

In some areas, the first and/or second methods may be sufficient to stabilize small or incipient gullies. In some other areas which receive large rains, all three methods may have to be used for successful gully control. Runoff control is the first, foremost and effective way of gully control. If runoff entering a gully can be controlled, then it is possible to grow vegetation in the gully. Stabilization of gullies involves the use of appropriate structural and vegetative measures around the head, floor and sides of the gully. Once gullies have begun to form, however, they must be treated as soon as possible, to minimize further damage and restore stability. There are a multitude of physical and biological techniques which can be applied for effective gully treatment. The combination of the two measures (bio-physical approach) is the best solution for effective gully control and for productive use of the gully area. The construction of gully physical structures will be followed by the establishment of biological measures. The natural regeneration which is coming after the gullies are protected and enclosed should also be considered in the overall rehabilitation scheme.

Integrated gully development practices: To obtain satisfactory results from physical and biological measures, it is vital to understand the nature of the whole gully system/network in the catchment and properly diagnosis the different parts in the gully section: the gully bed, gully sidewall and gully offset. Overall, stabilized watershed slopes are the best assurance for the continued functioning of gully control structures. Therefore, attention must always be given to keeping the gully catchment well vegetated. If this fails, the biophysical gully control measures which are executed with huge investment will fail as well. Accordingly, the rest of this section is dedicated to basic gully treatment measures. Some of the most common physical and biological gully treatment measures which have been proven for their effectiveness are explained with elaborations using pictures and graphics for more in-depth understanding. The selection of type of gully measures rely on gully geomorphology and erosive nature of the flow. The gully rehabilitation technologies presented as info-techs are:

1. Brushwood Checkdam
2. Bamboo-Mat Checkdam
3. Sandbag Checkdam
4. Loose-Stone Checkdam
5. Gabion Checkdam
6. Arc-Weir Checkdam
7. Sediment Storage Dam (SSD)
8. Gully Wall Reshaping
9. Gully Re-Vegetation
10. River Bank-Stabilization, and
11. Development Of Green Corridors (GCs)

Name of the Technology	BRUSHWOOD CHECK-DAM

General Description

Brushwood check-dams made of posts and brushes are placed across the gully. The main objective of brushwood check-dams is to hold fine material carried by flowing water in the gully and stabilize active small gullies. Brushwood check-dams are temporary structures and should not be used to treat ongoing problems such as concentrated run-off from roads or cultivated fields. They can be employed in connection with land use changes such as reforestation or improved range management until vegetative and slope treatment measures become effective. It can be constructed by vegetative materials and twigs. Plant species which can easily grow vegetative through cuttings are ideal for the purpose.

Fig 1. Review discussion after construction completion

Geographical Extent of Use

Brush wood check-dams are suitable or applicable for all land use type and agro-ecologies. 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, not deeper than one meter. However, it is not suitable for gullies which are large enough and have high pick runoff rate. In the gullies which are large enough and have high pick runoff rate, the utilization of brush wood check-dams is very limited.

Technical Design Requirements

- In areas where the soil in the gully is deep enough, brushwood check-dams can be used if proper construction is assured.
- The gradient of the gully channel may vary from 5 to 12 percent, but the gully catchment area should not be as such huge which produces high amount of runoff volume.
- 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 brushwood check-dam can be used where the flow of runoff is less than 0.5 m^3/sec. Whereas, double row is used in gullies having runoff rate of up to 1 m3/sec.
- Whatever sort is used, the spillway crest of the dam must be kept lower than the ends (on both sides), allowing water to flow over the dam rather than around it.
- The maximum height of the dam is one meter from the ground (effective height).
- Before construction begins, wooden poles and branches required should be prepared. The specific locations in a gully where brushwood check-dams can be constructed (wider portions) have to be identified.

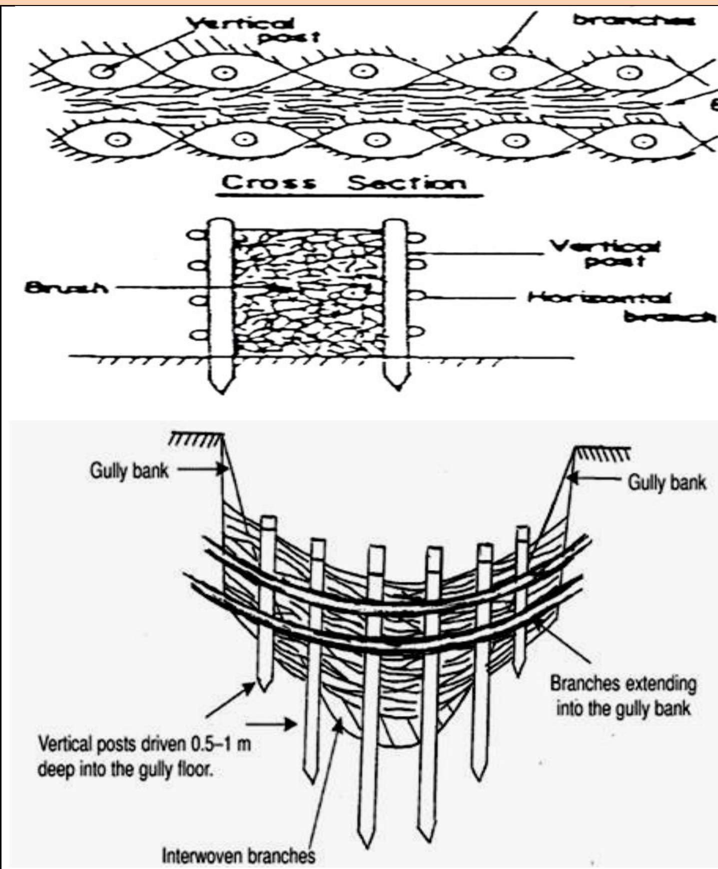


Fig 2. Cross-section of double row (above) and side view of single row (lower) brush wood check-dams

Layout and Construction Procedures

→ ***Single row check-dams:***

- Live posts of diameter 8 – 10 cm should be used
- Thicker branches are used as vertical posts driven in to the soil to about 50 cm - 1 m (1/3 to 1/2 of the post length) depth and spaced about 30 to 50 cm apart. The posts will have a length of 1 – 2 m.
- The space between the posts will depend upon the height of the check-dam. The higher the dam, the closer will be the distance between the posts.
- Thin branches will be interwoven with the vertical posts

→ ***Double-row brushwood check-dams***

- *Two rows of posts, 5 -10 cm in diameter and 1 - 2 m in length are placed into the holes, across the floor of the gully to a depth of 0.5 – 0.6 m. The spacing between the posts is 0.5 m.*
- *Brushwood or branches are packed between the posts.*
- *The height of the posts in the center should not exceed the height of the spillway otherwise the flow will be blocked and water may be forced to move to the gully sides.*

→ ***Other specifications for brushwood check-dams***

- The choice for post brush check-dam must be made after careful examination of material availability in the near vicinity.
- Brush wood check-dams particularly single rowed ones can be strengthened with bamboo mat or sand filled bags on the upstream part to serve as a shock absorber and to dissipate the runoff energy during pick flows.
- Any tree or shrub species can be used as posts. But the wooden posts should be rot resistance and termite proof
- To avoid the brushwood being removed by flowing water, it is necessary to fix the brushwood and twigs/branches together with rope, wire or nail.
- The ends of interlink materials should enter at least 50 cm into the sides of the gully.

Fig 3. Brushwood checkdam, single row, Amhara

Fig 3. Brushwood checkdam, double row, Sudan, Dindir, Jaldokra

Period of Implementation Across Season

If vegetative propagating species 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.

Planning and Mobilization

Brushwood check-dams require a lot of wooden poles and branches. Labor is also required for excavation and fixing the materials. Therefore, timely planning and mobilizing the community is mandatory.

Benefits and Acceptability

Brushwood check-dams can be used to stabilize and reclaim small and medium gullies. The construction techniques are simple to be easily taken up by local people. As such check-dam are effective and simple to be constructed by using local materials, farmers in many areas have accepted the practices and are regularly using the techniques for rehabilitation purpose.

Integration and Management Requirement

Brush wood check-dams have to be constructed in combination with other types of check-dams. The integration of biological gully rehabilitation measures (vegetative measures) with brushwood check-dams facilitates the stability of the structures and provides income generating opportunities to farmers.

Cost elements and Work Norm

The cost parameter for brushwood check-dam includes labor required to prepare the pit for the poles, interweaving of branches, preparation of apron, etc. 1 pd is required for 3 linear meters (3Lm/pd) for double row and 5Lm/PD if it is single row. The materials cost has to be added on top labour cost.

Limitation

Not applicable in large gullies and in areas where there is shortage of vegetative materials

Name of the Technology	BAMBOO-MAT CHECK-DAM

General Description

"Bamboo-Mat ('organic gabion boxes') check-dams are made from locally available bamboo and reed strips, which are woven and tied together to form cubic, permeable boxes to be filled with stone. The organic gabions are placed across gully floors, and buttressed downstream for stability. The characteristic of the specific location determines the height and the width of the organic gabion check-dam, and consequently the number and size of bamboo mats to be utilized for – See Fig on the right side.

Once the bamboo mat check-dam is installed across a gully bed, the velocity of the run-off is reduced, and sedimentation creates a favorable environment for the establishment of permanent biological structures. Accordingly, appropriate vegetative structures are put in place so as to strengthen and finally replace the "organic" gabion/bamboo-mat that rots over time.

Fig 1. Bamboo-mat checkdam

Geographical Extent of Use

The following issues should be 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;
- Thechnically, 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;
- Ideal to treat gullies in private lands since the labor demand can be covered by family members.

Layout and Construction Procedures

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 not less than 1m on the floor across the gully bed.
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 of the gully and continue down to reduce the risk of failure.
Support and strengthen boxes with wooden poles/sticks pegged in on the lower and upper parts of the bamboo-mat check-dam
Construct trapezoidal/parabolic shaped spillway with appropriate dimensions of depth, width and freeboard (please refer annexes (4 & 6).

Fig 2. Bamboo-mat checkdam under construction

Period of Implementation Across Season

Bamboo-mat check-dams have to be constructed towards the end of the dry season. Excessive dryness will cause the box to be damaged and hence the soil in the box will be washed away. To overcome such challenges, it is always important to construct bamboo-mat check-dams so that there will not be long period until the rain starts.

Planning and Mobilization Requirements

Bamboo-mat check-dams are cheaper in terms of cost and the techniques to be applied are easy for the farmers to understand. But the bamboo/reed sticks need to be collected from community members/land users. Accordingly, community members have to plan together and contribute for labor and cash.

Integration and Management Requirement

In areas where bamboo, reed and other materials are growing, bamboo-mat check-dam is a good option for gully treatment. It does not need complex knowledge and skill. Therefore, farmers can use their own local knowledge to implement this technology.

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 respective owners who have land on both sides of the gully in order 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 (vital for other types of check-dams too).

Thick poplar and willow stems are also stuck into the soil filled the in organic boxes. This helps to quickly stabilize the soil in the 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.

If bamboo-mat check-dams are constructed in suitable areas, and regularly manged and maintained, it could contribute for reclamation of a gully and even for water harvesting in the gully bed. If the objective is to harvest water and hold moisture in the gully, the interior part of the bamboo-mat can be covred with plastic sheet.

Fig 3. Effect of bamboo-mat checkdam in rains

Fig 4. Bamboo mat checkdam can be staggered with plastic gabion

Cost Elements and Work Norm

The work norm includes foundations/key excavation and proper placement of organic gabion boxes, soil filling inside the boxes, compaction and tying. The average wok norm estimated for these check-dam types is 1m^3 /PD (1 person can execute 1m^3 per day).

Limitation

The bamboo-mat can be easily destroyed by runoff coming with boulders. Because of excessive drying and thawing, the bamboo-mat can rot and the whole check-dam can collapse.

Name of the Technology	SANDBAG CHECKDAM

General Description

Sandbag check-dams are temporary structures constructed by filling the sand in 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 of 50 -100 kg.

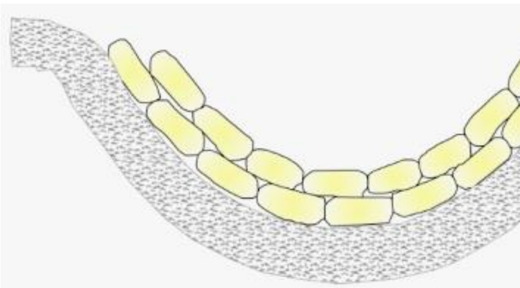
Fig 1. Sand bag checkdam

Geographical Extent of Use

Sandbag check-dams are suitable alternative technologies for every agroecology of many areas 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 large 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.

Technical Design Requirements

- Fill bags with sand up until a little space left after tying to enable it to fully lay and touch the ground and/or the other soil/sand filled bag with high surface area.
- White clay or termite mound soils can also be used instead of sand as they are also less erodible and can stay intact in flood water.
- While piling up, water the sacks first to make them wet, which in turn will help to avoid easy sliding of the sand bags.
- Peg and tie a string marking base width of 1 - 3.5m on the floor across the gully bed
- Pile up sand filled bags to a height of 1m
- Construct a side key of 0.5m on each side of the gully wall
- Construct trapezoidal/parabolic shaped spillway with appropriate permissible depth, width and add free board. The different dimensions of the spillway depend on the expected flow coming through the gully.
- Support piled up sandbag check-dams, on the downstream side, with brushwood structure or wooden poles to avoid easy dismantling of the sandbags.
- Wooden nails can also be used to have a good connection of the sandbag with the gully floor and sidewall.



Arrangement of sand bags in a gully

Fig 2. Sand bag checkdam ready for gully side reshaping

Fig 3. Cascaded sand bag checkdam

Period of Implementation Across Season	Planning and Mobilization Requirements
Sandbag check-dams have to be constructed towards the end of the dry season. Excessive dryness will cause the sandbag to be damaged and create openings in which the runoff will enter into the bag and wash the soil/sand in it. Hence, it is always important to adjust the time so that the rain starts soon and the check-dam is covered with sediment immediately.	Sandbag check-dams are cheaper in terms of cost and the techniques to be applied are easy for the farmers to understand. But the sacks/plastic bags need to be purchased from the local market or they have to be supplied. Consequently, community members have to plan together and contribute for labor and cash.

Integration and Management Requirement
The combination of this technology with other relatively stronger structures (for example, gabion check-dams) is an important consideration to be made for better efficiency and durability. Sandbag 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 these check-dams especially after heavy floods is very important at initial period of construction. The reshaping of gully banks is also important to manage and maintain sandbag/plastic bag check dams.

Cost Elements and Work Norm	Limitation
The work norm includes proper placement of sandbag check-dams, soil filling inside the bag, compaction and tying. Taking all parameters together, 1 PD can cover on average 0.5 m^3 per working day (05m^3/PD).	Sandbag/plastic bag check dams are susceptible to runoff which carries boulders and they cannot be used in large and deep gullies

Name of the Technology	LOOSE STONE CHECK-DAM

General Description

Loose stone check-dam is a structure made of relatively small rocks and placed across the gully or small stream, which reduces the velocity of runoff and prevents the deepening and widening of the gully. Sediments accumulated behind this check-dam could be planted with crops or trees/shrubs, grasses and thus provide additional income to the farmer. The main purpose here is to stabilize and rehabilitate gullies and convert into productive land.

Fig 1. Typical illustration of loose stone check-dams

Geographical Extent of Use

Loose stone check-dams can be applied in any situation provided stones are available. It is more suitable and preferable on stable soils with less sliding/swelling or cracking behavior. 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 other protection measures. Loose stone check-dams could be constructed in a wide range of conditions:

In small gullies serving a large one in a gully network;

As stone outlets for traditional or newly constructed bunds or terraces which are unable to accommodate all runoff; and as a silt trap before a water pond (water harvesting structure)

Technical Design Requirements

- Bottom key and foundation; 0.5 m deep
- Side key: 0.5 – 1 m on each side
- Height: 1 – 1.5 m excluding the foundation, mostly 1 m is sufficing to avoid failures
- Base width: 1 m – 3. 5 m
- Spill way (trapezoidal/parabolic): 0.25 – 0.5 m permissible depth and 0.25 m free board; and width of 0.5 – 1.2 m.
- Apron length should be at least 1.5 times of the effective height of the check-dam and as wide as the gully bed.
- The apron should be placed in an excavation of about 0.3 – 0.5 m to ensure stability and prevent wash away. A sill of about 15 cm should be constructed on the lower end of the apron.
- Proper spacing between the successive dams should be ensured (For successive checkdam spacing refer Annex 7 of Technologies)

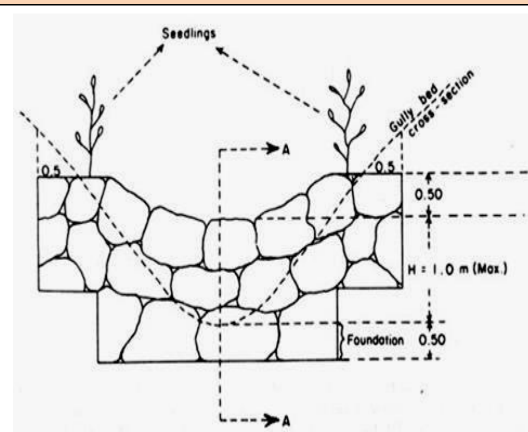


Fig 2. Cross-sectional view of loose stone check-dams

Layout and Construction Procedures

- Identify appropriate location in the gully where the bed slope is < 5 %, soil depth > 50 cm and relatively wider locations of the gully. Cross-sections of gullies where the reservoir level requirement is not more than 1.5 meter is appropriate. Avoid locations where the gully is meandering/turning
- Collect stones necessary for the construction of the check dam.
- Peg and tie a string marking base width on the floor across the gully bed
- Excavate the foundation and place stones such that they interlock easily
- Construct the loose stone to a height of 1 – 1.5 m excluding the foundation. Construct a side key and a parabolic spillway
- Construct apron on the downstream side of the check dam to protect the dam from undercutting and include a sill on the lower end of the apron.

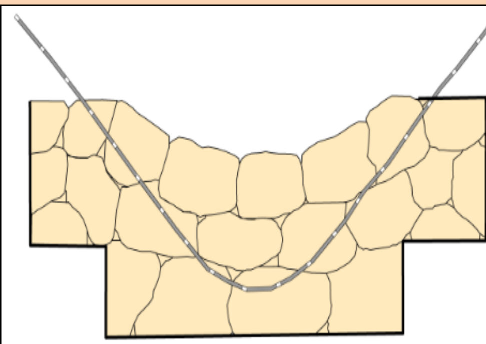


Fig 3. Cross-section view of stone check-dam

Period of Implementation Across Season

The appropriate construction time for loose stone check-dam is during the dry season and period not interfering with land preparation. But, minor maintenance works can also be handled during rainy season too.

Planning and Mobilization Requirements

Planning for check-dam construction follows community/groups and individual owners' discussions/agreement on site selection and management requirements. The collection of stone and the whole construction process demands mobilizing of the available local labor.

Integration and Management Requirement

- Loose stone check-dams require regular follow-up and maintenance.
- Upgrading or rising of the check-dam may be required after one year
- Gully protection/closure is important for quick recovery of vegetation.
- Check-dams are integrated with plantation, reshaping and stabilization of gully sides.
- It is important to plug the scouring places with jut bag after every runoff, until it is fully sedimented up to the reservoir level
- Covering the upstream wall and the crest with bamboo-mat stabilizes it.

Fig 4. Check-dams integrated with plantation and upstream stabilized

Cost Elements and Work Norm

The work norm involves:

- Stone collection and excavation of foundations/key and apron
- Proper placement of check-dams and drop/apron structures.

All the norm elements together require 0.5 m^3/PD

Fig 5. Farmers field day on gully treatment measures

Benefits and Acceptability

- Reduced erosion and accumulated soil sediments used for re-vegetation
- Gullies could be reclaimed for production of trees (including fruits) and crops.
- Gullies control run-off and conserve moisture in the soil that give rise for springs at downstream sites.
- In Ethiopia, large tract of farmlands and grazing areas are reclaimed with the application of loose stone check-dams.
- Because of its low cost (only local labor) and relatively its simplicity during construction, most land users are experienced with the measure.
- The size and volume of work varies as per the size of the gully and availability of stone nearby. Hence, farmers can construct any size of a loose stone check-dam as per their labor capacity and availability of stone material. Gradually, the size of the check-dam can increase through regular maintenance and upgrading.

Limitation

- Stone check-dams are effective to plug small gullies and are not very convenient for large gullies.
- They are constructed only in places where there is stone.
- Loose stone check-dams are not effective for moisture harvesting as the water passes through the voids/openings

Name of the Technology	GABION CHECK-DAM

General Description

Gabions are rectangular boxes of varying sizes and are mostly made of galvanized steel wire woven into mesh. The boxes are tied together with wire and then filled with either stone or soil material and placed 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. The purpose is to stabilize and rehabilitate gullies and convert gullies into productive land.

The main advantages of gabion check-dams are that they are tough and long lasting provided that the wire has been well galvanized. Furthermore, they are somewhat flexible and can be installed where the surface is uneven. They can be used to stabilize gully sides, gully heads, roadside embankments, river banks and even landslips.

Fig 1. Typical stabilized Gabion check-dam, Farta W.

Geographical Extent of Use

Gabion check-dams are suitable in all kinds of agro-ecologies where gullies are formed and extended. Gabions 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 check-dam 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.

Design Considerations

- Gabion check-dams are built usually not higher than 1.5 m spillway height in the first year. After sediments have been deposited behind the structure, it is possible to raise the spillway height by adding additional gabion boxes. The foundation, apron, side key and spillway are the important parameters to be considered during designing of gabion check-dams.

The sele ctio	Gabion size (m^3)	2.5 mm wire (kg) Net	3.5 mm wire (kg) Frame	Tying wire (kg)	Share of each size during
1.	2 x 1 x 1	12.0	2.3	0.6	60
2.	2 x 1 x	8.5	1.7	0.5	20
3.	1 x 1 x 1	7.0	1.5	0.4	15
4.	1 x 1 x	3.4	0.9	0.3	5

- If stone is not available in close proximity, the gabion boxes can be matted (covered) in the inner part with plastic sheet and then filled with soil material. This will serve the purpose of stone filled gabion check-dam if properly constructed following design specifications (see picture on the right).

Fig 2. Gabion check-dam construction - stone filled, Amhara R., Farta Woreda, Alekt Wenz CW

Fig 3. Gabion check-dam construction - soil filled

Layout and Construction Procedures

- The foundation depth (key trench) should not be less than 30 - 50 cm
- The foundation width is 1m and the structure should be plugged 0.5 - 1 meter to each side of the gully wall /abutment/ right up to the height of the dam.
- Construct apron from downstream side of the structure with a foundation of 30cm from a dry stone or with a gabion box with a width of 1.5 times the reservoir level.
- The spillway should be adequate to allow the peak flows, without overtopping the dam (see annex 6 for details).
- Stones to be used for filling the gabions should be, hard and of sufficient size and should be placed tightly together
- Gabions should be constructed on spots where the soil depth is higher, preferably in a wider part of the gully next after a series of loose stone check-dams
- It is neither necessary nor economical to build a series of gabion check-dams to control channel erosion along the gully beds.
- Gabions need to be closed by using large spanners (closers) and should be wired together
- 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.

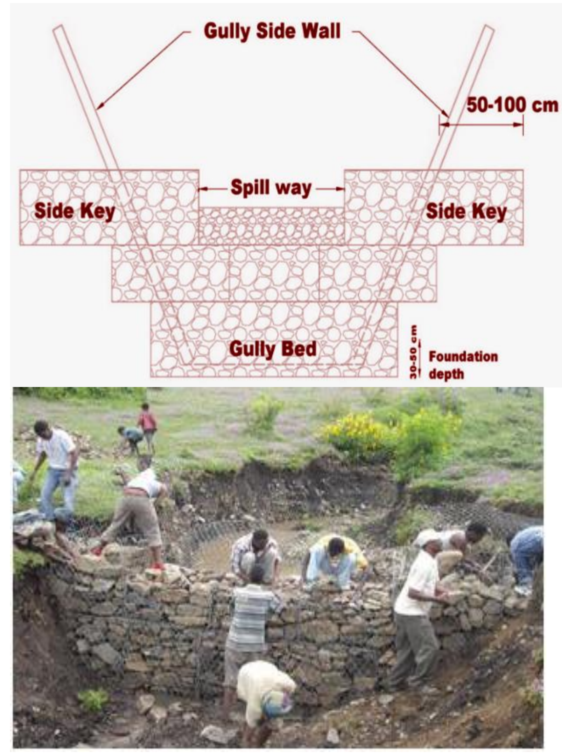


Fig 4. Gabion check-dam construction and cross-sectional view

Period of Implementation Across Season

The construction of gabion check-dam is labor demanding. Therefore, the construction time should fit to the slack periods of the farmers so that they can avail labor as required. The preparation of various sizes of gabion boxes, tie wire and closing equipment should be prepared in time in order to ensure smooth implementation process during the actual work. There may be small maintenance works that could be undertaken during the rainy season.

Planning and Mobilization Requirements

The collection of stone and the whole construction process demands mobilizing of the available local labor. As a result, the community members: those who have land around the gully and those who will be getting direct and indirect benefit from the rehabilitation work shall discuss together and agree on the labor contribution. To manage the rehabilitation work efficiently, a community-based gully rehabilitation action plan needs to be prepared and communicated to all concerned.

Cost elements and Work Norm

The work norm includes stone collection, foundations/key excavation and proper placement of gabion boxes, stones filling and construction of drop/apron structures. The placement of stones in the gabion box requires skill and experience. Hence the overall work norm is $0.25m^3$/PD. In terms of labor, gabion structure is expensive. Cost of materials (gabion box and tie-wire) have to be considered here.

Integration and Management Requirement

The gabion structures are stronger compared to other types of check-dams. But their effectiveness depends on the overall upper catchment treatment and integration of technologies in a gully. In this regard, planting the gully sections with appropriate species is vital for successful rehabilitation of a gully.

Benefits and Acceptability

The gabion check-dams are beneficial particularly for rehabilitating medium and large gullies. As such check-dams are going to be constructed in locations where there is a good pounding area upstream, patches of lands can be created on which economical crops and vegetation can be planted. The contribution of gabion-check-dams for recharging streams and water harvesting in a gully is also an important benefit to be considered.

Limitation

- The major limitation of these types of check-dams is their high cost in relation to the gabion boxes which cannot be afforded by small holder farmers.
- On the other side, if such structures are destroyed by runoff (running water in the gully) the damage could be even worse than before treatment.

Name of the Technology	ARC-WEIR CHECK-DAM

General Description

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

Fig 1. Arc-weir structure made up of cemented stone wall in horseshoe shape, Amhara R., Farta Woreda

Geographical Extent of Use

Arc weir check-dams are suitable for all locations 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. Proper site selection for the construction of the dam i.e. constructing the dam in a narrow, deep, and steep place of gullies is vital. The dams must not be constructed on points where there is fragile soils and 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.

Design and Construction Specifications

- A formwork is prepared across the gully bed on the site where it is appropriate to construct arc-weir check-dam
- Foundation depth should not be less than 50cm. It actually depends up on the compactness of the underneath soil.
- Excavation for plugging in to the sidewall should not be less than 1m.
- The shape of the foundation is in an arc concaved to the stream flow
- The mortar ratio for the foundation is 1:4 for cement and sand respectively while it is 1:6 for the superstructure
- Plastering of the arc-weir, from the upstream is indispensable with mortar ratio of 1:3.
- Pointing is enough for the downstream face.
- The width of the foundation is 60-80 cm and gets narrower towards the upper end.
- The apron is in a form of steps at a height and width of 40 cm each.
- The number of steps depends up on the reservoir level.
- The spillway has a shape of an arc
- Lining from upstream side is important to avoid piping.
- Plugging of leakage after the very first runoff up until it fills with sediment is essential.
- 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 about 45 degrees. The wing walls can be constructed out of dry masonry.
- The upstream face of the dam is vertical, whereas its downstream face inclination is about 20 percent
- The stones to be used in constructing masonry check-dams must be hard enough to withstand abrasion, non-disintegrating, and resistant to weathering. Watering is necessary until it finishes its curing period.

Fig 2. Foundation work for Arc-weir check-dam

Fig 3. Construction completed Arc-weir checkdam

Layout of Arc-weir Check-dam

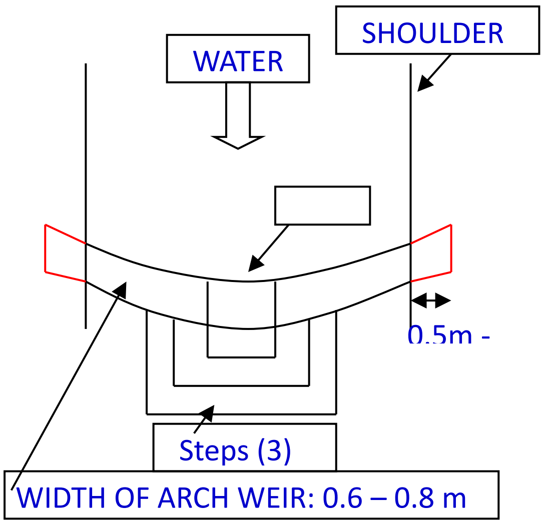


Fig 4. Sketch layout of Arc-weir check-dam


Fig5. Stabilized Arc-weir check-dam

Basic Requirement to Avoid Failure

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 and base

Below standards of height, width, and length of the dam;

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 behind causes instability and piping underneath or around the structure;

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;

Failure to water the arc-weir structure until it completes its curing period

Poor regular protection and maintenance. The life and effectiveness of control measures is extended by regular maintenance.

Constructing arcweir or other types of check-dams with out upper catchement ttreatment will cuase a lose of efforts and resources.

Poor integration between physical and biological measures.

Cost Elements and Work Norm:

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. From experience, the work norm to be used for arc-weir check-dam construction is $0.5m^3$/PD Cost of materials has to be calculated separately.

Integration and Management Requirements

The strength and contribution of arc-weir structures depend on the site selection for construction, integration with biological measures, and overall catchment treatment. Hence, proper planning with a full participation of community members is paramount important. The harvested water needs to be planned for appropriate utilization.

Benefits and Acceptability

Arc-weir check-dam has comparative advantages like;

It is a strong structure and can be built relatively higher;

It is good for building on the bedrock (no excavation); and efficient for water harvesting in a gully/stream

It needs less stone compared to a gabion check-dam with similar volume; and

Hence, it is acceptable by the local community as far as it is well combined with other income generating options.

Limitation

Arc-weir check-dam 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);

The structure needs watering after construction; and

Not suitable for large gullies without catchment treatment and protection.

Name of the Technology	SEDIMENT STORAGE DAM (SSD)

General Description

Sediment/soil storage dams (SS dam) are water harvesting and conservation systems that convert unproductive, large and active gullies into productive areas (fertile cultivated or fodder producing areas, mixed plantations, and fruit tree orchards).
SS dams are stone-faced (soil filled) earth dams constructed across medium/large size gullies to trap sediments, collect water and divert excess runoff. SS dams accommodate the runoff generated by the catchment located above the gully. The structures are often constructed in series along the gully. It is just like creating a land that does not exist before treatment.
Contribute significantly to protect cultivated lands, arrest gully expansion and recharge water tables
Particularly in low rainfall areas, it can be used to change vast and long gullies to productive areas and provide opportunities to carry out cultivation practices.

Fig 1. Sediment storage dam

Geographical Extent of Use

- SS dams are applicable in highly eroded gully areas in all land uses.
- Not suitable for large gullies without catchment treatment and protection.
- Very important for production of cash and staple crops, introduction of fruit trees, vegetables and other valuable vegetation and biomass in gullies, etc.
- SS dams can be easily introduced in dry-land areas, particularly where local structures are damaged by excess runoff

Technical Design Requirements

Site selection:

- Inside gullies and natural depressions that you wish to convert into productive fields.
- Below catchments with less than 40 ha maximum, because of the increased costs to construct larger structures.
- The site should allow the maximum formation of a cropped field area (wide portions of a given gully are preferred to narrow and deep portions).
- One side of the gully needs to have suitable hard structure to put the spillway (stony areas, very hard pans, etc).
- When suitable soil conditions do not exist, reinforcement of spillway is required (riprap and drop structures).
- Select appropriate site in a gully where SS dam can be constructed
- 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.
- Determine the dimensions and volume of the structure: they are selected based on the area of the catchment, the width of the gully and its depth.
- Use the following criteria to approximately estimate the dimensions of the SS dam (simplified for trapezoidal design).

  - Height = H,
  - Base width = BW,
  - Top width = TW,
  - Top length = TL,
  - Bottom length = BL

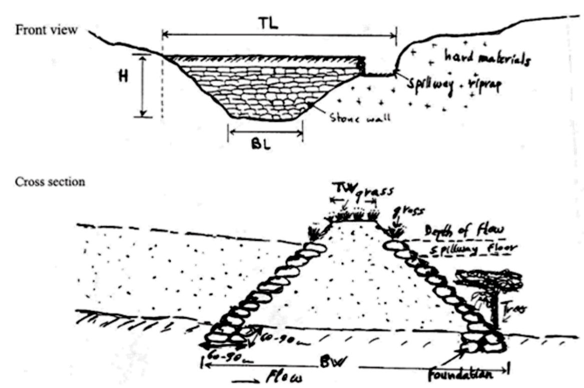


Fig 2. Section view of SSD

- 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

Construction Procedures

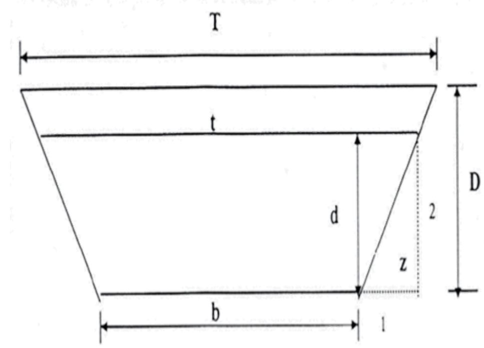
- Scrape and **remove grass and vegetation from the whole bottom width and** sides of the gully where the dam is to be constructed.
- Proceed with construction of the **key & foundation of the downstream wall** (called riser or lower retention wall) in front of the structure.
- Make this key & foundation 60-90cm deep and start filling it with large stones.
- 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 as ladder-shaped.
- Fill space between stone lines with soil and compact. 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.).

Fig 3. Sand bag in Meket Woreda

Spillway Design and Construction

- 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 is 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.
- 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 and its shape is trapezoidal.
- The dimensions of the spillway have been computed based on "safe standards" and are presented as can be seen in the table below

Catchment area in Ha	Medium/low runoff coefficient (0.4)	High runoff coefficient (0.7)	Depth of flow(d)	Total depth (D)
2	08	1,1	0,30	0,70
3	09	1,4	0,30	0,70
4	09	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
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



Volume of SS-Dam

V1 = Volume of embankment earth/stone work (m^3) = (H x (TW+BW) x (TL+BL))/4

V2 = Volume of spillway earth work = Length SP (equivalent to BW) x base width of SP (see table) x total depth of channel (see table)

V = V1 + V2 = Total volume of earth work (including foundation)

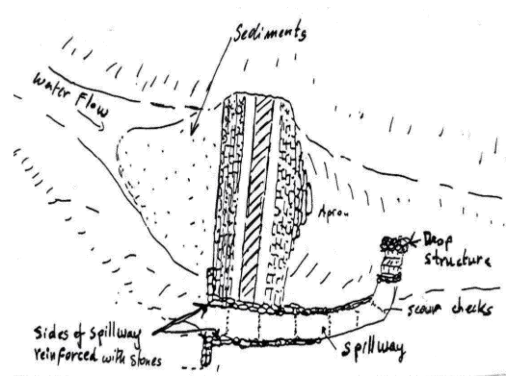


Fig 4. Aerial view of SS dam and spillway

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

Benefits and Acceptability

SS dams can create cultivable lands with good soil moisture and nutrients. It is important to encourage farmers to use these lands appropriately. Introducing high value crops along with SS dams to needy farmers should be taken seriously – as SS dams can become a "food insurance".

SS dams provide opportunities for income generation to small land holders and landless. It is a drought proof activity - even when rainfall is low SS dams collect sufficient moisture. It also promotes fertility management (compost preparation, etc) and contributes to watershed protection, raise water table, etc. Generally, farmers in many areas have understood the advantage of constructing SS dams. As a result, land users in many parts of Ethiopia are constructing SS-dams by combining their labour and local resources.

Integration and Management Requirement

Construction of SS dams should be taken as part of a sub-watershed treatment. Then construction shall come simultaneously or preferably after closure and treatment of fragile/unstable parts of the catchment with various soil and water conservation measures.

Smaller gullies feeding into the main one where SS dams are placed should be also treated with check-dams. This activity is integrated with re-vegetation of gully sides after sedimentation is completed. Application of compost in the sediment deposition area shall be considered.

Cost Elements and Work Norm

The work norm elements for SS dam construction include:
Site clearing
Excavation for the super structure and the spillway
Embankement/dam building with stone and/or soil
Drop structures and spillway construction
Generally, 0.5m3/pd is required for the proper construction of a sediment storage dam (SS-dam).

Limitation

The technology requires a huge labor and is very difficult to be covered by a family labor.

Needs maintenance and if destruction happens because of poor follow-up the damage could be very expensive.

Name of the Technology	GULLY WALL RESHAPING

General Description

Gully wall reshaping is cutting off steep slopes of active gully flanks in to gentle slope (minimum at 45-degree slope), up to two-third of the total depth of the gully and constructing small trenches along contours for re-vegetating slanted part of the gully walls and beds.
If the gully is wide and has meandering nature with huge accumulation of runoff flowing down, cutoff soils and soil materials can be washed away by runoff water and requires constructing of retaining walls, to protect disturbed (not yet stabilized) soils and soil materials and newly created sidewalls of the reshaped gully.
The main purposes of gully wall reshaping are:
Modification of the unstable gully sides 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 reshaped gully area for plantations and cultivation and makes the land productive.

Fig 1. Reshaped Gully with retaining wall

Geographical Extent of Use

Gully wall reshaping is a suitable technology for all agro-climatic conditions. This measure is common in small and medium gullies. Traditional and recently introduced gully reshaping and re-vegetation efforts are found in different areas with promising results. Combined with other watershed rehabilitation efforts, this measure is highly suitable to reclaim gullies and to change them into productive use. Reshaping can be used for treatment of gullies of different dimensions if properly integrated with other gully rehabilitation measures. In dry areas it needs to be always combined with physical measures.

Technical Procedures to be Followed

- → Control and/or divert the flow above the gully head
- → Construct supporting check-dams and retaining walls, if it is necessary
- → Control the gully head and the side banks by cutting & filling
- → The soil should be well compacted
- → The filling operation should be done before the rains
- → After reshaping, moisture harvesting structures can be constructed to hold moisture and to make it suitable for growing of trees
- → To protect it from erosion, densely growing plants should be planted or seeded immediately
- → Protecting livestock interference and apply cut and carry system.

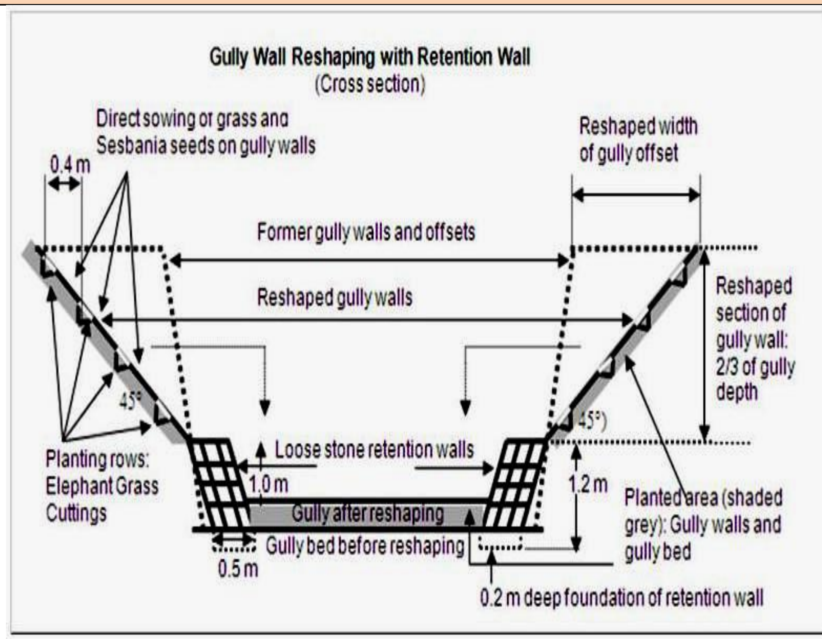


Fig 2. Cross-section of Gully wall reshaping with retention wall

Layout and Construction Procedures

- → Make a contour line along the bottom of the gully side wall for constructing the retaining wall,
- → The reshaping of the steep gully sides should be 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.
- → Following contour lines construct trenches, micro-basins, along the reshaped gully sidewall.
- → The gully edges adjacent to the fields should be stabilized with deep and strong rooting trees and vegetation (Sisal, Acacias, etc) to impede the widening of the gully

Fig 3. Reshaped Gully with contour lines constructed

Period of Implementation Across Seasons

- → The reshaping and filling operation should be done before the rains
- → The entire work of shaping and filling should be done in one operation

Planning and Mobilization Requirements

The reshaping and filling of gullies should be planned as part and parcel of the overall gully rehabilitation scheme of an area. Gully reshaping and filling requires buffering of some patches around. The size of the gully buffer areas (to be protected from further disturbance), management practices to be employed, use of collective labor, type of benefits generated from treated gullies, and equitable sharing should be discussed with community members or land owners ahead and hence common understanding should be established. The excavation and soil moving tasks need to mobilize a significant labor and hand tools.

Cost Elements and Work Norm

The work norm for gully sidewall reshaping is 1 m^3/PD and includes excavation, soil moving and filling, shaping and compaction. In addition, to construct retaining wall 1 pd is required for every 5-linear meter (5 m/PD).

Fig 4. Reshaped Gully with local material retaining wall

Integration and Management Requirement

- → Exclude cattle throughout the year and introduce cut and carry system.
- → Leave a minimum of three to five meters buffer zone (offset) to avoid livestock and human interference for better and quick rehabilitation of a treated gully.
- → Gully wall reshaping needs to be combined with other physical measures (check-dams, retaining wall and moisture harvesting structures, particularly in dry areas) and biological practices.
- → Re-vegetation activity should consider plant species that could stabilize the gully and bring immediate benefit to the farmers and improve their livelihoods
- → The gully sides should be planted with a mixture of creeping and drought resistance grasses, trees and shrubs. In gullies where pore water pressure/piping is the main cause, plant gully sides with water loving plant species.

Benefits and Acceptability

The technique is relatively cheaper compared to other gully rehabilitation measures. Once it is understood by farmers, it can be carried out by family labour and can be an ideal solution to reclaim small gullies before they are turned to be bigger.

Limitations

It is not easy to be successful by this method if applied in large gullies. Even in medium and small gullies, the reshaped area can be eroded by runoff coming from laterals (if not diverted or protected ahead). In most cases, the use of this technique is limited in areas where there is shortage of rainfall. In some cases, subsoils may not be suitable to grow plants. Reshaping is labour consuming and hence the reshaped are has to be planted with economical crops for the task to be rewarding for communities.

Name of the Technology	GULLY REVEGITATON - USE OF VEGETATION (BIOLOGICAL CONSERVATION) FOR GULLY CONTROL

General Description

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

Fig 1. Biological stabilization of physically treated gully

Geographical Extent of Use

The survival rate of plantation in the gully area is directly related to the general agro-climatic conditions and specifically to the availability of moisture during dry seasons and amount of water flow in the different sections of the gully during the peak rainy seasons. The choices of species as per the agroecology and different situation in the gully are also parameters which determine its successful rehabilitation. If these factors are considered or can be controlled, biological measures can be applied anywhere as far as planting space, soil and moisture are available. Vegetative control can be executed everywhere in the country with a due focus of selecting appropriate tree, grass and shrub/bush species which can be compatible to the planting location prepared.

Technical Considerations

- Identification of the specific characters of different parts of the gully which is supposed to be treated with biological measures is crucially important.
- Conservationists and farmers should properly assess the soil and moisture conditions in the gully head, gully floor/bed, gully sidewall and gully offset/gully buffer zone.
- Practically speaking, these different locations of a gully do have different soil and hydrological characteristics which determines the type of species of grass, shrubs/bushes and trees to be planted.
- The type of planting material to be used should be seriously considered based on the specific situation of the gully.
- Once the characters are identified seedlings which are appropriate to be planted in that particular site should be produced with enough amount ahead of the planting time.
- Inclusion of indigenous species that performs well in the identified characteristics of the gully parts is very much important.

Fig 2. Different parts of a gully need different time for planting

- Any part of the gully treated with biological measures should comprise of three components; grass, legume shrubs and trees in a form of story.
- If possible, it is advisable to establish nurseries nearby/ inside the area to be treated.

Characterizing the Different Parts of a Gully for Biological Conservation

Gully Head	Gully Offset	Gully Sidewall	Gully Bed
• It is the upper part of the gully through which most of the runoff enters to the gully • Very much active for gully formation and expansion • Paving with loss stone, diverting water using cutoff drains and reshaping can be applied to control. • Combination with biological measures help creeping plant species can be used for reinforcing the head.	• It is located away from the gully embankment and extended to the next land use type • Are characterized by medium soil depth, moderately wet in the rainy season and dry in the dry season, and with moderate slope • Micro basin, trench and sub soiling are recommended for better performances of plants to be established • Thus, the plant species recommended for the treatment of this area are those with moderate tolerance to dryness and wetness.	• It is a part of the gully between the gully offset and gully bed • It is characterized by high slope gradient, shallow soil depth, susceptible to erosion and mass movement, very dry in most of the time due to less water holding capacity. • Reshaping and hence constructing moisture harvesting structures are the recommended measures to treat this gully part • Biological measures can play a pivotal role in rehabilitating this section of the gully • The species to be selected should have invading characteristics, with light foliage and steam biomass and high tolerance to drought.	• It is a part of the gully on top of which the run off flows • It can be treated with physical measures like arc weir, loose stone, and gabion, brushwood and sandbag check-dams. • It is regarded as very wet in most of the year, with deep alluvial soil • The biological material recommended for this part of the gully should be tolerant to water logging, with high root biomass, resistant to soil sedimentation and high flow of water.

Environmental Benefits of Vegetative Gully Control

- Provides plant cover for the land and prevent direct impact of raindrops (splash erosion);
- Increases soil roughness, which further reduces the velocity of surface runoff and henceforth the soil erosion;
- Reduces surface runoff, which facilitates infiltration rates and enhance in-situ water conservation;
- Better helps deposition of silt by reducing and protecting the soil particles from being washed away;
- Prevents soil erosion and thereby enhance effectiveness of physical control measures when it is applied properly;
- Increases soil organic matter and thereby improves soil properties and soil fertility levels,
- Provides protection against scouring and minimizes expansion of the gully due to further erosion risk; and
- Helps to retain water/subsurface reservoirs and increases the soil recharging capacity or contributes to general soil moisture in the vicinity in a sustainable manner,
- Reduce pollution, contribute for clean environment and serve for biodiversity/ecosystem reservation.

Economic Benefits

- On top of the soil and water conservation, biological gully conservation provides valuable by-products for the livelihood of the farmers.
- Production of planting material for fruits, vegetables, fibers, medicinal plants, consumable goods, and others;
- Source of forage/fodder, fuel wood, wooden poles, bio-degradable materials for compost making and preparation of organic fertilizer etc;
- Income generations from the sale of various biomass, vegetables, fruits, planting materials, etc;
- Suitable for apiculture and other livelihood options; and
- Serve as a research and ecotourism/recreational site/place, etc.

Cost Elements and Work Norm

The cost of vegetative gully control measure is related to seedling production, transporting of seedlings/seeds, and preparation of planting pits, actual planting and sowing of seeds.
Experience in Ethiopia show that to cover 1 ha of gully area, about 500 pd is required (500 PD/ha).

Integration and Management

In the location of a gully where the force of runoff is high, it is important to install physical structures. Gully reshaping and strengthening sidewalls with retaining wall is also important to be considered. The necessary tending operations should also be done regularly. Protecting the gully from free grazing and practicing cut and carry system are important conditions for maintaining the overall health of the gully under rehabilitation.

Name of the Technology	RIVER-BANK STABILIZATION

General Description

Stream /river erosion is the scouring of soil material from the stream/river bed and cutting of the stream/river-banks by the force of running water. River-bank erosion is often increased by the removal of vegetation, overgrazing and/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 side and depositing sand and silt loads on the other. The damage manifolds during flush floods.

In terms of the area affected, stream-bank erosion is a small problem, but its significance increases when other factors are considered. Land subject to surface erosion is only partly damaged, but land lost by river-bank erosion is completely and irretrievably lost, and what is more, the bottom lands of valley floors are nearly always valuable and highly productive. River-bank erosion may also threaten roads and bridges with much more serious economic consequences than the value of the lost land. Considered as a source of sediment polluting the stream, river-bank erosion is important because all the soil goes directly into the stream with no possibility of any of it being trapped or filtered out.

Fig 1. River bank stabilization through vegetation

Fig 2. River side stabilization using stone riprap

Geographical Extent of Use

The phenomena is occurring everywhere if no watershed management actions or more specifically, erosion control measures are not taken properly in time. The extent of the problem is more severe in downstream areas and fragile environments. Hence, integrated river-bank stabilization techniques need to be applied with due attention from all concerned.

Stabilization Techniques

If stream-bank or shoreline is severely eroded, it is important to stabilize the soil to promote plant growth. There are three general approaches to be considered for steam-bank stabilization: Live planting, bioengineering, and hard armoring. The best technique will depend on the existing situation—the size and location of the stream or shoreline, and the cause and severity of the erosion. In many cases, the best approach is to use a combination of techniques. Before attempting any stream-bank stabilization activity, one needs to discuss with the surrounding community and need to get permits from the concerned bodies.

Live Planting

River-banks can be stabilized or prevented from erosion problems by planting appropriate types of vegetation, then allowing nature to heal itself. Costs of this approach are relatively low, and communities can implement this approach on their own. A small investment of time and money can prevent a serious erosion problem that in the future could be very expensive to correct.

Trees, shrubs and grasses can be used to stabilize the stream-banks. This technique may require protection from flowing water (using stakes and erosion control matting) during root establishment. Side-bank reshaping through removal of soil to reduce the slope of the steep banks to a more stable angle is important to be integrated where it is applicable. In addition, the selection of planting materials which can be adapted to the existing situation is important to be considered.

Fig 3. Physical / biological stabilized

Bioengineering Techniques

Bioengineering technique relies on a combination of structural components and plant material to produce a dense stand of vegetation that serves as a "living system" to protect stream-banks and shorelines. This technique works to stabilize many, but not all, erosion problems. One challenge in bioengineering is protecting the bank from erosion until the vegetation becomes established. This could take one to two years. There are a number of structural components available to provide temporary protection while the plant growth becomes established:

Vegetated geo-grids: These are alternating live branch cuttings and compacted soil layers wrapped in geo-textile fabric to rebuild and vegetate eroded banks.

Brush mattress: Live branch cuttings covering entire stream bank and secured in place.

Tree revetments: Row of cut trees (usually vegetative propagating types) anchored to the toe of the bank. It is used in conjunction with native plants to trap sediment and encourage plant growth.

Fig 4. Brush mattress

Fig 4. Tree revetments

Hard Armoring

- Hard armoring includes a variety of techniques including rock riprap (large stones placed along the slope of a stream-bank or shoreline) and gabions (rock-filled wire baskets placed along a stream-bank or shoreline).
- Hard armoring typically involves grading the bank to a gentler slope. If done properly, these techniques provide very good protection and will work in severe situations where bioengineering will not perform. However, hard armoring techniques can be relatively expensive, and may require professional assistance.
- These techniques are often used in situations where less expensive, more environmentally friendly and aesthetically pleasing alternatives would have been successful.
- The technique requires good design and construction.
- In some conditions it can reduce or eliminate the need for bank sloping by creating vertical wall.

Fig 6. Hard armoring

Cost Elements and Work Norm

The work norm includes stone collection, foundations/key excavation, rock riprap and Gabion wok, hard armoring, live planting, foundation work, mix of sand and cement, stones and drop/apron structures, etc. The work norm to be used for river bank stabilization depends on the different activities, and cost of materials has to be calculated separately.

Integration Requirement and Management

As described above, there are several techniques to be applied in order to stabilize river-banks. Each of the techniques need knowledge and experience and requires investments in terms of time and resources. There is no absolute technology which can be applied as a remedy to control stream-bank erosion. Rather, all possible technologies need to be implemented in an integrated manner. The rehabilitation of the upper catchment is also an important parameter to be considered which will have a significant influence in reducing the possible disaster. Once, the river-banks are well established, there should be regular monitoring and continuous maintenance by the surrounding communities and the concerned professional and administrative bodies.

Name of the Technology	DEVELOPMENT OF GREEN CORRIDORS (GCS) ALONG STREAMS, GULLIES, AND ROADS

General description

Green Corridor is an area of habitat connecting multifunctional landscapes/or land uses as well as wildlife populations or two or more fragmented habitats separated by human activities or structures (such as roads, agriculture development, settlements, logging, physically treated river banks). Green corridors (GCs) can provide additional ecosystem products and services; control soil erosion and protect rivers and roads from the erosion, can serve as windbreak, control flooding. Furthermore, connecting two or more land uses or landcovers using green corridors can increase the resilience against climate change adverse impact in addition to flow of ecosystem services from one system to the other. In most cases green corridors are linear features. The length and width can be determined on the basis of the land form/shape where the corridor is established.

Problems it can address: soil erosion by wind and water can be minimized/halted. Provision of goods (such as fire and construction materials, fodder) and services (such as modification of microclimates, carbon sequestration, stepping stones for birds, ecotourism can be developed, etc.) can be enhanced.

Fig 1. Type of GCs along streams and roads
https://conservationcorridor.org/the-science-of-corridors/

The purpose of establishing GC is a) to create connectivity so that ecosystem service and goods flow is enhanced; b) soil and water conserved and erosion is controlled, c) life span of roads is increases and speed of surface flow during rainy season is minimized so that neighboring land uses are protected for possible flooding, d) rivers and river banks are protected to carry water during most of the year, e) carbon stock in both soil and vegetation is increased.

Geographical Extent of Use

Can be implemented in all agroecology, land use, socioeconomic situations.
Areas or situations where it is effective: it can be applied in most landuse but can be effective if implemented along rivers including streams, gulley, roads and between two important or critical ecosystems such as forests with wetlands, or forests with another forest area or connecting one micro watershed with another micro watersheds

Technical Design Requirements

Composition and structure of green corridors

Green corridors can be constructed using trees, shrubs, grasses, and any other non-invasive plant species suitable for a particular agroecology. Species selection for trees and shrubs should be based on a Technical Handbook produced by Azene Bekel-Tessema 1993, and Tree seed zones of Ethiopia by (Aalbaek 1993), among others. All species, preferably, should be indigenous.

Whenever possible priority should be given to multipurpose trees and shrubs species. As much as possible monoculture should be avoided in order to increase diversity in a landscape.

The shape of the green corridor follows the shape of the stream or the road. The width of the corridors is proposed to be 25 to 55 meters from the edge of stream bank, two times the depth of the gully side and 25 meters from roadside (Right Figure). Length can be as long as the length of streams/gully/road found in a given micro-watershed. Depending on the consultation and consensus the width can be increased to a desired size.

Fig 2. GCs along the roads and walking lanes

Green corridors development /establishment needs suitable site for effective return in social, environmental and economical outcomes or benefits. Connectivity rules the operation or it is a must. Therefore, intervention type should be supported by technical feasibility but determined through consultation with the stakeholders. Principles of no-harm to social and environment should be applied.

Layout and Construction Procedures

Common mistakes during construction:

To gain maximum benefits the construction of GCs it can be started from the higher towards lower slope connecting different multifunctional land uses in the watershed.

Following the streams, gullies and roads it is important to map or identify the land uses. One may encounter cropland, grazing land, degraded or barren land or sometimes settlements.

1. Dedicate certain land from the stream bank for non-agriculture practices to protect banks from erosion
2. In the croplands and grazing lands green corridors should be developed using agroforestry and Silvopasture technologies respectively (spacing between trees/shrubs can be 10 m by 10 m so that farmers can practice agriculture)

Land use/Land cover	Intervention type	Recommended spacing (m*m)
Crop land	Agro forestry combined with climate smart agriculture	10 *10
Grassland	Silvopasture combined with grassland improvement	10*10
Forest/tress/shrubs	Enrichment planting/area closure/forest protection (management plan)	TBD on site
Bare land/degraded land	Afforestation/reforestation	2*2
Wetlands (seasonal or permanent)	Protection (wetland management plan) using grass and other low shrubs planting	

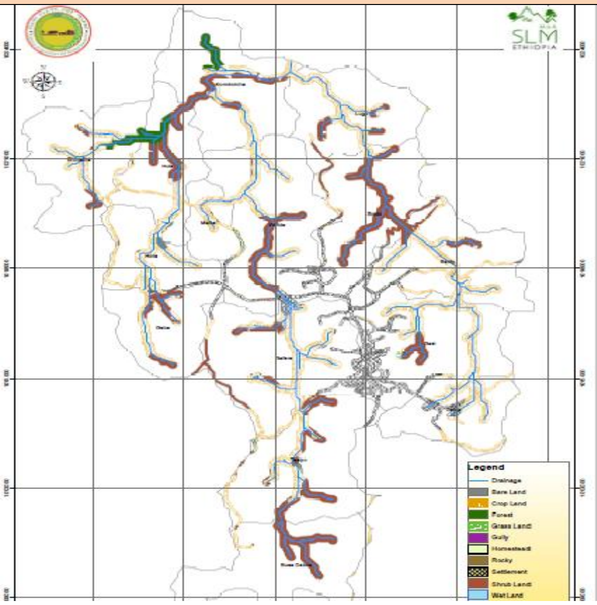


Fig 3. GIS assisted GC layout

3. On degraded lands it is preferable to afforest/reforest with indigenous trees or shrub species (2m by 2m). economically important tree or shrubs can be prioritized wherever applicable
4. If wetlands or swampy areas are encountered no plantation is required in that specific part. However, suitable grass and shrub species could be planted around the wetland to protect the wetland from silt and sand.
5. When shrubs/woodlands/forests resources are encountered it is necessary to manage the resources
6. Make sure that community footpaths used for different purposes are maintained or should not be affected by the GCs. Rather, aim protecting such footpaths from erosion and further degradation

Period of Implementation Across Seasons

The establishment and management of the green corridors is similar to the Soil fertility management and biological soil conservation, Agro-forestry, forage development and forestry infotecs described in the CBPWDG.

Planning and Mobilization Requirements

Planning is participatory and bottom-up. Planning should be part of the multiyear or annual plan of a micro-watershed plan. GCs should be one item in the planning format and should be part of discussion during problem identification, socio-economic survey/analysis, biophysical survey and preparation of the annual plan action. Sufficient consultation with the community should be made. Community buyin is key for success. Hence, as long as the GC is established within the community watershed separate or different mobilization is NOT required. It should be done at the same time when other priority intervetnions are identified and applied. For assessment of gully erosion use Annex 5 of Technologies. Amount of seed needed, seedlings to produce and plant and replant should be estimated after the intervention area is assessed during the biophysical survey.

Technical preparedness needed: Multidisciplinary approach is key for success; hence multidisciplinary team is required. The plants to be used for GCs should not affect the growth of crops and other vegetations. Moreover, the moisture regime and water availability are expected to improve through time. Therefore, proper guidance on development of structures such as water harvesting infrastructures and combining with the GC, particularly GCs along roads is required from the multidisciplinary team. Therefore, infrastructure engineer should be part of the team. Likewise, forage experts, foresters, range land management expert, and socio-economist should be part of the team during the identification and preparation of plans.

Cost Elements and Work Norm
All worknorms and costs for the establishment of GCs is as per the seedling collection, production, pitting, and planting stated in the Biological soil and water conservation, agro-forestry, and other agro-silvi-pastoral practices. Worknorms would be monetized based on local wage rates.
Management and Maintenance
Operations are listed under section 8 above. Approaches and methods are similar to the establishment of GCs will be governed by the principles and frameworks which are agreed and incorporated in the CBPWDG. **Management practices**: Tress/shrub nursery techniques and nursery management expertise is required. Sufficient training for the forman and nursery workers is required. Limited capacity building on plantation, plantation management and forest/tree protection (from insects, fire and disease) is required. GCs will improve production and productivity if properly managed. Planting by itself will not bring the desired result. Follow up activities such as weeding, pruning and thinning will make the plant to grow faster and vigor. Green corridors provide room for combining different technologies such as community infrastructure, roadside water harvesting, homestead development and livelihood, among others. Hence GC establishment requires multidisciplinary team. Since GC connects multifunctional landuse/landscape proper design is important. The planning should be based on facts. **Ownership, management and Institution** Green corridors will be owned either by individula land holder or by community. Green corridors that passes fhrough the private land shall be the property of the landholders, whereas that passes through communal lands shall be ownened by community. Technical support shoud be provided by technical experts mentioned above from Woreda and Kebele. Management of green corridors shall be the responsibility of owners. Technical support to the owners should be provided from the Woreda or Kebele technical staff. Mangement plan for green corridors per major wtaershed should be prepapred. Reseource from green corridors shall be utilized as per the management plan. Watershed User Associations (WUAs) are an appropriate institution to be responsible and accountable for making GCs successful. GCs should be should be clearly indicated in their bylaws. Woreda Watershed team should provide the necessary support to the WUAs. Development Agents need to provide the necessary support to the associations. Additionally, justice institutions should provide sufficient support to the WUAs for effective implementation of their bylaws.
Benefits and Acceptability
The road including footpaths and streams as well as streams in most of the watershed (except forested regions) are not protected. As a result, huge amounts of soils are eroded. Additionally, rapid runoff has destroyed substantial croplands. Establishing the GCs will provide protection of crops and downstream settlements from unexpected flooding. On the other hand, water flow can be regulated. Moisture availability in the soil and water flow in the streams and rivers shall increase from time to time. **GCs establishment shall support the country to implement Climate Resilient Green Economy strategy, Biodiversity conservation strategy, and support to ensure food and water security.** The communities are expected to respond positively since its impact on water availability will be better compared with baseline. The technology does not require significantly different skills and knowledge from what the community know but what is required is doing things a bit differently. In a way it is a combination of different technologies. It can be scaled-up including urban centers. The technology is simple and practical. Its social, environmental and economic benefits make the technology innovative. Its contribution to climate change adaptation and mitigation can be easily assessed and documented.
Limitation
In the absence of proper landuse and clear regulations on road, gully and stream banks protection its success may be limited. However, such limitations can be mitigated by putting the right bylaws. Seedlings at the early stage might be affected by lack of water and in some cases by frost. Communities should aware of such circumstances and take the necessary actions.

Biological Soil and water Conservation, Soil Fertility Management and Conservation Agriculture

Overview

Suitable cultural practices such as maintenance of vegetation cover on the land, addition of organic manures, green manures, and the use of bio-fertilizers, conservation tillage and application of appropriate soil conservation practices are essential components of soil conservation and sustainable soil fertility management practices. Poor cultural practices like over cultivation (destruction of soil structure), cultivating along the slope, cultivating to the edges of dissected lands (e.g. gullies), cutting drainage furrows straight along steep slopes, continuous depletion of soil organic matter and organic residues/vegetation cover are the major factors causing/aggravating soil erosion and depletion of soil nutrients. These practices led to the irreversible land degradation problems including the depletion of soil nutrients, diminishing of crop yields and frequent crop failure. Maintenance of soil vegetation cover and/or residues and soil fertility should be considered as essential practice to sustain soil fertility and agricultural productivity as well as ecological stability. The management practices must maximize vegetation cover on the land and the recycling of nutrients within the soil profile and within the farm, and it must minimize soil erosion and nutrient losses due to natural processes and poor management practices. High biological activity in the soil is an essential element in soil management program and is required to ensure the diversity of fauna and flora of the micro-organisms to sustain soil productivity. Thus, this thematic area of the guideline deals with a wide range of technologies pertaining to biological soil conservation, soil fertility management and conservation agriculture to prevent/minimize soil erosion, maintain and/or increase soil fertility and productivity mainly through proper soil and crop management practices with the basic principles of prevention in contrast to curative methods. Each technology is described following established standard format that depicts general description, purpose and benefits, agroecology, design and method of application, complementarities and integration opportunities, acceptability and sustainability and finally constraints and limitations. The ranges of technologies described under this thematic area are:

Biological Soil Conservation, Soil Fertility Management and Conservation Agriculture Technologies

1. Contour Cultivation and Planting
2. Crop Rotation
3. Intercropping
4. Strip Cropping
5. Ley Cropping
6. Integration of Forage Production into Farming System
7. Grass Strips Along the Contours
8. Hedgerows of Shrubs /Grasses
9. Stabilization of Physical Structures
10. Compost Making
11. Fertilization and Manuring
12. Mulching and Crop Residue Management
13. Cover /Green Manure Crops
14. Acid Soil Management and Liming
15. Reclamation of salt affected soils
16. Conservation Tillage
17. Berken plow

Name of Technology	CONTOUR CULTIVATION AND PLANTING
General description	**Purpose and Benefits**
Contour cultivation and planting is a practice of plowing the land and planting crops along a contour line as opposed to along the slope. It is applicable on relatively short slopes up to about 8 percent steepness with fairly stable soils. By planting across the slope, rather than up and down a hill, the contour ridges slow or stop the downhill flow of water. Water is held in between these contours, thus reducing water erosion and increasing soil moisture. Performing cultivation and planting on the contour was found to reduce soil loss on steep slopes by up to 50 percent compared with cultivation up-and-down a slope. In dry areas, contour cultivation can be adjusted to standard ridge and furrow system to make it effective in controlling soil erosion and moisture conservation. Ridging is a widely used tillage practice for soil and moisture conservation in dry areas. The most effective way to reduce soil erosion and conserve soil moisture is minimizing the rate of runoff on the surface of the land. Contour farming is most effective when used in conjunction with such practices as strip cropping, terracing, and water diversion. This practice should only be used on well-drained soils; if applied to clay soils, water-logging is likely to occur.	Contour cultivation and planting on gentle slopes can considerably reduce soil erosion and hence can reduce costs otherwise required for soil conservation. In dry areas the practice increases the rate of infiltration and moisture content of the soil and when combined with other moisture conservation practices its contribution to sustain and increase moisture in moisture stress areas is very high. Tie ridging is the most effective tillage method used for conserving soil and moisture and for increasing crop yields in semi-arid areas. Greater storage of water and more effective erosion control can be achieved by connecting the ridges with cross ties over the intervening furrows, thereby forming a series of rectangular depressions which fill with water during rain. The practice has been proved to reduce fertilizer loss, as well as to increase crop yields and reduce erosion.

Agroecology

Contour cultivation and planting is very suitable for moisture stress areas as it conserves moisture for the crops in addition to soil conservation. In high rainfall areas the contour cultivation and planting should be graded to drain the water out of the field

Design and Method of Application

Farming operations should begin on the contour baselines and proceed both up and down the slope in a parallel pattern until patterns meet. Plowing forms a series of furrows close to each other; each furrow helps to retain water. If the furrow is to be effective, its longitudinal slope should not be more than 3 per cent. The directions to be followed should be staked out to keep cultivation and planting on the right contour line and to prevent the buildup of water that otherwise causes danger of erosion. Maximum furrow capacity will be obtained by wide and adequately deep Plowing. The earth from the furrow should be turned downhill to form a “plug”.

In inclined ridging, a series of parallel ridges are produced from one end of the field to the other. This method is recommended when the slope, greater than 3 per cent, no longer permits plowing on the flat. The erosion control action of the ridge is greater than that of contour plowing since ridges have a greater water retention capacity. The ridge may follow the contour line (contour ridging) or be slightly inclined to contour lines if there is a danger of overflowing. In low-rainfall areas, contour ridges may be tied by clods of earth at intervals of 3-15 m, which ensures total infiltration and increases the soil’s water reserve.

Fig 1. Contour cultivation and planting

Complementarities and Integration Opportunities	Management Requirements
Contour cultivation and planting is compatible with many conservation and land management practices such as strip cropping, crop rotation, terracing, tie-ridging. Farmers are encouraged to use additional soil and water conservation techniques to supplement the former in order to yield the best results. Such supplements include	It is always necessary to closely monitor the situation of the field. Depending on the soil type and rainfall conditions there could be a danger of overtopping of the furrow by excessive water that causes breakage in the furrows and down wash of

strip cropping, use of cover crops, grass strips and building terraces among others. Strip cropping is good for long and steeper slopes while irregular slopes need more than a single key contour line. Other techniques to include are growing vegetative barriers across the slope, residue management, and mulching to protect the soil.	the soil, fertilizer and planted seeds. Therefore, there is a need to closely and regularly supervise the field to prevent such repercussion and to take corrective measures duly.
Acceptability and Sustainability	**Constraints and Limitations**
The practice of contour cultivation and planting is not common in traditional farming system in most places except in some places like Hararghe highlands where farmers are growing Chat along the contour and grow sorghum/maize in between the hedges of Chat**.** The Hararghe farmers are also making contour furrows and planting the sweet potatoes and other crops along the contour. Similar practice exists in hoe culture areas in the SNNPR and other regions for root crops and other high value crops. But the practice of contour cultivation and planting is not common for cereals grown in the field. In the recent days row planting is advised for increased crop yield and hence the practice is initiated in many places. This initiative is hoped to widen its scope for contour cultivation and planting in the future. Also as the practice of contour terracing is expanding from time to time in Ethiopia, it is very likely that the practice of contour cultivation and planting expands along with the contour terracing practices in the future.	The major constraint is lack of adequate awareness and knowledge among the farmers about the socio economic and ecological benefits of the practice to adopt and regularly exercise the practice. Farmers are solely guided by traditional knowledge and are in short of awareness and knowledge to adopt and exercise the practice on regular basis. Therefore, the extension system should be first well equipped with the necessary knowledge and skill on the subject. Then the practice should be demonstrated practically in the field in different areas depending on the local conditions. This gradually allows the farming communities internalize the value and benefits of the practice to ensure its adoption and expansion. Contour cultivation and planting in high rainfall areas may cause water-logging especially on heavy clay soils entailing negative impact on crop growth and yields.

Name of Technology	CROP ROTATION

General Description

Crop rotation is a practice of growing different crops one after the other on the same piece of land. Crop rotation is one of the oldest practices known to man for soil fertility restoration and pest/ disease control. It is well known that different crops are not equally susceptible to the same kind of pests or diseases. Growing the same crop year after year provides an opportunity for pests to multiply and outbreak virulently after two or three years of continuous cultivation, eventually leading to serious loss of crop yield. The same problem holds true for weed infestation. Crop rotation in addition to fertility restoration and soil and water conservation is a popular traditional practice of controlling diseases, pests, rodents and weeds infestation. Moreover, plants of the same crop develop their root system at the same depth of soil profile and thus the proliferation of the root systems in the same depth results in a strong competition for moisture and nutrients. If the same crop is grown on the same land year after year, the soil nutrient in that layer decreases sharply and the crop yield consequently declines.

Agroecology

Rotations are integral part of Ethiopian farming systems and are practiced in all agro ecological zones but the intensity and regularity is decreasing in favor of growing similar crops of high economic significance year after year. Thus, sound rotations that grant optimal economic and ecological benefits are needed and should be integrated into regular agricultural extension and land management practices. Under Ethiopian dry land conditions, crop rotations should consider the integration and optimization of livestock production by incorporating legumes (grasses, shrubs and trees) as part of the rotation.

Purpose and Benefits

When different crops are rotated, the depletion of soil nutrients and decline of crop yields are not as serious as when the same crop is grown year after year. Different crops have different characteristics that enable them to exploit the soil moisture and nutrients at different depths that contribute to higher crop yield. Crops also differ in terms of their effect on the soil; some crops restore or build fertility of the soil while others deplete fertility. The improvement of plant cover and soil structure through sound crop rotations substantially reduces the effect of runoff and the rate of soil loss.

Design and Method of Application

It is often recommended to rotate legumes with cereal crops because of their contrasting nature in terms of improving soil ferity, soil conservation and resistance to various pests and diseases. Therefore, specification for application should be formulated by technical staff in close consultation with farmers in view of optimizing the benefits from crop rotation by introducing more innovative methods of application from both socio-economic and ecological benefits perspectives. Existing cropping patterns offer ample scope for improvement in terms of optimizing the sequence of crops, their arrangement and sowing dates. In this respect, accessibility to improved varieties of legumes possibly inoculated with highly efficient strains of rhizobia might help to improve fertility of the soil and crop yields. In all circumstances legumes need to be rotated with cereals.

Management Requirements

In order to optimize the benefits of crop rotation it is necessary to control livestock interference. The crop residues should be maintained in the field and incorporated into the soil to gradually build soil organic matter and soil fertility. In areas getting bimodal rains, cover/green manure crops can be grown during Belg (small rain) and be incorporated into the soil at the onset of big rain to provide additional soil fertility management and soil conservation measures.

Complementarities and Integration Opportunities

Crop rotation can be integrated with various land management and soil fertility and productivity improvement technologies to optimize its economic and ecological benefits. Fertilizer application, manuring, etc. are also compatible and can be integrated. Wherever possible, existing rotations should be improved by integrating soil organic matter management techniques such as crop residue management, green manuring, mulching and various other techniques described in other InfoTech for soil fertility management. Crop rotation can also be integrated with other agronomic practices such as intercropping and double cropping based upon the available moisture and the crop water requirements. Soil organic matter management through the application of compost and other methods combined with moisture conservation are compatible in moisture deficit areas to optimize both economic and ecological benefits from the system. Ley cropping is also best practice to be encouraged in crop rotation practices.

Acceptability and Sustainability

The technology is commonly practiced in many parts of Ethiopia and farmers know well the benefits of the practice. However, the ecological and economic benefits from the practice could be sub-optimal simply because of the inadequate skills and knowledge of the most compatible crops, patterns and the best methods of arrangements of the crops in the field and management practices. In order to ensure wider acceptance and sustainability of the practice, it is then suggested that improved rotations practically demonstrated wherever possible to the land userswith an entire set of additional measures to improve yields of the main crops and optimize the overall benefits.

Constraints and Limitations
Improved rotations may be difficult to apply with low value or low yield crops especially in highly populated area where the size of land holding is very much limited. In these areas farmers prefer to keep growing cereal crops such as wheat and barley year after year instead of rotating with legume crops. The reason being farmers get (by many folds) higher yield from the cereal crops than the legume crops, especially when supported by better inputs. This constraint can be overcome by materializing and exploiting the existing complimentarily and integration opportunities of the technology.

Name of Technology	INTERCROPPING

General Description

Intercropping is a practice of growing two or more crops simultaneously in the same plot in a fixed pattern in one season. The various leaf arrangements of different plants allow light to be better intercepted over time. The contrasting patterns of root growth, which utilize different soil layers, optimize the use of available soil moisture and nutrients. Mixed stands protect the soil surface more effectively than pure stands. In areas where row crops such as maize and sorghum cultivated, the area remains exposed to erosive forces and the soil is subject to soil erosion. Moreover, the stalks of these crops are often removed for various purposes, thus there is very little return of nutrients to the soil. To contrast this nutrient mining system, suitable legume species (chickpeas, cowpeas, beans, green gram, pigeon peas, soybeans, forage legumes, etc.) should be planted in the spaces left between rows.

Fig . Examples of intercropping

Purpose and Benefits

The aim of intercropping is to increase crop production and provide protection to the soil against erosive forces. Overall output per unit area can be much greater from intercrops than single crops and chances of total crop losses are lower than in pure stands. Different planting times and different length of growing periods spreads the labor requirement of planting and harvesting, but also allows mid- season change of plan according to the rain in the early part of the season. Some intercropping would also be advantageous to control incidence of pests because of crop diversity (host of different predators).

Agroecology

Applicable to most of the agro climatic conditions and often practiced in Ethiopia in mid altitudes where the amount of annual rainfall ranges between 700-1200 mm. In moisture deficit areas, the practice seems to be more feasible for row crops such as maize and sorghum, or cotton. In low rainfall areas it needs to be integrated with soil and moisture conservation (tie-ridging, etc.) measures. In higher altitudes above 2500 m.a.s.l it is less practiced and the range of crops and possible combinations are very rare.

Design and Method of Application

To maximize the overall output of the intercrops, the arrangement of the different species in intercropping and the type of species to be mixed should take into consideration better use of the resources such as solar energy, soil moisture and nutrients from the outset. Often the different species with contrasting canopy and root system are combined to minimize competition between the crops and to maximize the output from each crop and the total combined crop yields. In most cases farmers want to minimize the reduction of yield from the main crop. Then, adjustment to the sowing dates should be made to minimize competition between the main crop and the legume (companion crop). In this regard, companion crops should be sown 2 to 3weeks after the main crop.

Complementarities and Integration Opportunities

Legumes are highly compatible with non-legume crops as they are enriching the soil, especially if parts of the legume plants are deliberately incorporated into the soil. Intercropping integrates well with a number of soil fertility management practices and moisture conservation measures. If applied together with conservation measures and stabilization of structures,it contributes to the control of soil erosion. The system should be integrated with rainfall multiplier systems and various moisture conservation techniques in dry areas to increase water availability and thus reduce competition. The use of organic and inorganic fertilization to compensate for some competition might be advisable.

Management Requirements

It is necessary to closely monitor the competition between the main crop and companion crop and take necessary measures to minimize the competition of companion crop on the main crop to minimize the effect on the main crop yield. Weed and pest infestation should also be monitored to take corrective measures to reduce or control the damage otherwise caused by the infestation. In dry areas, where moisture limitation overrides, it is necessary to be always cautious and use water harvesting techniques for supplementary irrigation.

Acceptability and Sustainability

The technology is commonly practiced in many parts of Ethiopia especially where row crops such as maize and sorghum are grown; that means farmers know well the benefits of the practice. However, the ecological and economic benefits from the practice could be sub-optimal simply because of the inadequate skills and knowledge of the most compatible crops, patterns and the best

Constraints and Limitations

The major constraint in Ethiopian condition is lack of scientific skills to support farmers to optimize their benefits from intercropping and mixed cropping systems. Farmers are solely guided by traditional knowledge and are in short of modern technologies to optimize the overall benefits from

methods of arrangements of the crops and management practices. In order to ensure wider acceptance and sustainability of the practice, it is necessary to address the constraints indicated above and secure commitments of the responsible technical and managerial staffs to achieving the maximum expected benefits from the system.	the practice. Common limiting factors in crop production and optimization of yields are light, water, oxygen (in waterlogged soils), temperature, or any one of the essential nutrients. If these limitations are corrected then the overall benefits from intercropping could be guaranteed.

Name of Technology	STRIP CROPPING

General Description

Strip cropping is a cropping practice where strips of two or more crops are alternately established on a contour, or it is a system of establishing more than one crop in alternate strips following a contour pattern for the purpose of erosion control, crop diversification and control of diseases associated with the use of single crops. This cropping system is designed as a defense mechanism against soil erosion in areas where the cropping system is dominated by row/sparsely grown crops that expose the ground to erosive forces. Crops are sown in strips following row planting techniques, one being a soil depleting crop and the other soil conserving/fertility restoring crop. If the main crop is maize or sorghum, the second crop can be a legume (e.g. beans, cowpea, chickpea, etc.) that forms good groundcover. In this case, maize is regarded as soil depleting/degrading crop while the legume is soil conserving crop. Erosion is largely limited to the cereal row-crops and the soil removed from these strips is trapped in the next strips, down slope, planted with the legume-row soil conserving crops.

Purpose and Benefits

This measure is intended to control soil erosion and if well designed can effectively conserve soil on slopes<5% and is best suited to well drained soils. This practice is useful for soil conservation on slopes <5% without additional conservation structures and needs to be combined with other conservation measures above such range.

Agroecology

The practice can be applied to most of agro ecological zones on gentle slopes, particularly in areas where sparely grown crops such as maize and sorghum cultivated. Different forms of strip cropping exist in some areas but rarely done in an organized way. This practice can be adapted if strips are developed using flexible modalities and do not follow rigid patterns of distances.

Design and Method of Application

Strip width vary with the degree of erosion hazard but are generally between5, 10, 15 and 20m with narrower strips on steep slopes and wider strips on gentle slopes. Planting technique is traditional except that it is along the contour. To increase effectiveness of the strip cropping for erosion control, the density of the legume crops should be higher than under normal conditions. However, on steeper slopes it may be necessary to add grass buffer strips of 2 to 4 m wide, placed at 10 to 20 m interval.

Complementarities and Integration Opportunities

The potential to increase productivity results from the combined effects of soil conservation and soil fertility improvement as well as from the value of the crops chosen for strip cropping. Integration with grass strips and other moisture conservation structures can reduce runoff and increase moisture conservation in moisture stress areas resulting in higher production. In general, integration of other moisture conservation, soil fertility improvement and suitable agronomic measures are recommended for optimization of both the economic and ecological benefits.

Management Requirements

When legumes are harvested, residues and roots should be left on the field and eventually incorporated. The protection of livestock interference is the major and most important aspect to optimize the ecological and economic benefits from the practice.

Acceptability and Sustainability

Indeed, this technology can grant both ecological and economic advantages if properly designed and the right type of legume species used. Therefore, its level of acceptability and sustainability depends on the competence and commitment of technical staffs providing the technical supports in particular and effectiveness of the agricultural extension system in general.

Constraints and Limitations

The practice is not traditionally well known by farmers in Ethiopia and farmers could be reluctant to adopt it. However, the integration of appropriate moisture conservation in moistures stress areas and soil fertility management techniques in general can encourage farmers to adopt the practice from practical benefits demonstrated.

Name of Technology	LEY CROPPING

General description

Ley cropping is a cropping system in which legume-based pastures are rotated with food crops. Legume based pastures are grown on fallow lands for a few years to improve fertility of the soil and thus the yields of subsequent crops (mainly cereals).The establishment of dense, productive forage crops during the fallow period (1-3 years) provides a thick ground cover, supply forage of good quality after the rainy season, prevent soil erosion, restore soil fertility quicker than bare (and overgrazed) fallow, increase the water holding capacity of the soil and have a beneficial effect on future crop yields.

Fig 1. Ley cropping

Agroecology

The technology is suitable under most agro-climatic conditions and for cultivated lands left fallow for a few years. Fallow lands are common in parts of Ethiopia above 2500 masl. The practice also exists in lower altitudes with shallow soils where cultivated lands are left to rest for some time to restore soil fertility and productivity.

Design and Method of Application

A suitable pasture legume that can grow relatively fast and produce dense biomass and ground cover is sown after lightly cultivating the fallow lands. The legume seeds can be sown by broadcasting or in rows especially following contour lines to better control the run off. The legume seeds can be planted in mix stands with suitable grass species such as Setaria or native grass in medium altitudes. In case of mixed pasture, two-third legume seed is mixed with one-third of grass. The introduction of ley pastures into fallow lands can be either with annual or perennial species, depending on the length of the fallow period. In moisture deficit areas, the following legume crops are recommended:-Siratro (Macroptiliumuncinatum), Lablab purpureous (Lablab), Stylosantheshamata (VaranoSylo), and Desmodiumuncinatum. In higher altitudes with better moisture conditions:-Lupins (lupinus album),Vetch, Clovers (Trifolium sp.) and Alfa-Alfa (Medicago sativa) are recommended.

Purpose and Benefits

The main purpose of ley cropping is to restore fertility and productivity of lands depleted as result of mono cropping, particularly in cereal crop production system. The legume based pastures are highly nutritious that can be used either for small scale animal fattening and/or dairy farming accruing a lot of economic returns that complements other incomes and optimizes the overall income of the households. According to research results, Lablab and some clovers are capable of leaving 30 to 60 kg N/ha in the top 20 cm of the soil profile only through their root system. Therefore, the introduction of legume based pastures has multiple advantages over the traditional. Moreover, the residues from the foliage and root system improve soil fertility and productivity and helps farmers to optimize the subsequent crop yields.

Complementarities and Integration Opportunities

Leys will be very effective if combined with the closure of cultivated plots and cut and carry practice of the fodder from leys.Soil fertility management and soil conservation measures such as stubble mulching before the return of the main crops can be integrated to optimize the benefits. A very effective supplementary measure is ripping of fallow land and sowing of mixture of grass/ legume along the ripped lines to optimize the benefits of soil conservation and soil fertility improvement. Legume shrubs can also be planted in rows along ley lines (pigeon peas and Sesbania in moisture stressed areas and Tree lucerne in high rainfall/altitude areas.

Management Requirements

The most important management to optimize the benefits of ley cropping is the control of livestock interference. Probably we need to know that the introduced legumes are capable of nitrogen fixing from the atmosphere. Otherwise, inoculation of the area with nitrogen fixing bacteria known as rhizobium could be a requirement. Mixing the suitable grass species with the legumes will give higher benefits of soil conservation, soil fertility and productivity improvement and in terms of providing balanced diets to the livestock. To optimize the nutrition benefits of the pasture leys knowing the right time of harvesting is critically important that should be done at heading/before flowering.

Constraints and Limitations

Free grazing and uncontrolled livestock management system is the major constraint to the promotion and expansion of the practice. Lack of experienced and skilled personnel committed to demonstrate the benefits of the technology is another major constraint to the promotion and exploitation of the ecological and economic benefits of this wonderful technology. The inadequacy of suitable planting materials also may hinder the promotion and expansion of the technology.

Name of Technology	INTEGRATION OF FORAGE PRODUCTION INTO FARMING SYSTEMS

General Description

The integration of forage production into farming system refers to the growing of forage crops (legume and grass pastures) in combination with food crops in different forms for both ecological and economic purposes. In Ethiopia growing of food legumes with food crops in the form of mixed, intercropping or crop rotation is very common in many parts of the country. But the integration of forage pastures in food cropping system is not very common. Nowadays, there is serious shortage of livestock feed, particularly in the highlands due to the conversion of many grazing lands to croplands with the increase in population pressure and demand for cultivation land. Therefore, the integration of forage production into farming system is one of the best ways of reducing shortage of livestock feed and ensuring the co-existence of crops and livestock while also increasing sustainability and productivity of the farming system.

Fig 1. Forage production at homesteads, on conservation structures and around gullies

Purpose and Benefits

Forage pastures have superior nature of biomass (foliage and root system) production compared to food legumes. Therefore, they provide more biomass for livestock production, vegetation cover for the land and soil conservation. The higher biomass (foliage and root biomass) production, in addition to soil conservation has immense effect on soil fertility improvement because of the incorporation of foliage and root system into the soil. Integration of different crops also avails better opportunity of controlling pests, diseases and weeds with minimum or nil costs in addition to optimization of productivity.

Agroecology

Integration of forage production into farming system is feasible in all agro ecological zones where mixed farming (livestock and crop production) system is practiced. Suitable forage species should be identified and integrated to the farming system in different forms suiting the farm households in a given agro ecological zones. Intercropping of food legumes with maize/sorghum is extensively practiced in the most densely populated areas of Southern Nations and Nationalities Peoples Regional State. In Afar Region, farmers using irrigation in the lower Awash intercrop haricot beans between maize or sorghum grown in rows)and the practice is common in many low land farming areas.

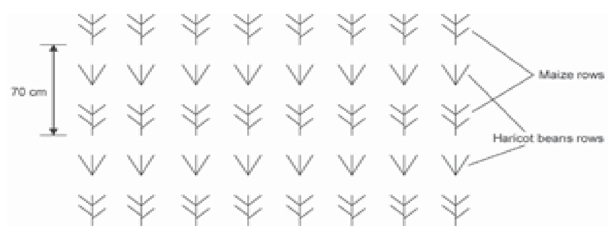


Fig 2. Layout of forage development

Design and Method of Application

There are a number of ways of integrating forage pastures into farming system. This includes rotation of the forage pastures with food crops, mixed or intercropping with food crops or even planting of forage on farm boundaries. **Sequential cropping with food crops:** is possible in areas where conditions for plant growth exist beyond the duration of one early maturing crop. Short duration forage and food crops can befitted sequentially within the same year. Fast growing forage can be planted and harvested early to derive good quality feed. This is especially in areas where land is a constraint and high cropping intensity limits natural pasture during the cropping period. Fodder from the subsequent food crop will then be available after harvest for the dry season.

Intercropping (Mixed cropping):-The crops may be grown in separate rows or in a more mixture stand. Selection of appropriate crops should be made which will result in a minimum competition effect between the inter-crops and one or both crops should have a complementary effect to the other. Legume based pastures also can be grown on farm boundaries, on conservation structures, at homesteads and in gullies.

Complementarities and Integration Opportunities	Management Requirements
As land is becoming the main constraint in the Ethiopian highlands, it is unlikely that small holder farmers can grow separate stands of forage crops for the foreseeable future. Also there is huge complementarity between forage pastures and food crops as the integration of the two saves a lot of resources while optimizing the overall economic returns. The integration of pasture production into food crops somehow addresses the shortage of land to separately grow pastures for livestock feed, at the same time it reduces the labor and time required for land preparation for separate pasture production. An example of intercropping in the highlands involves growing of wheat in association with clovers to increase both the quantity and quality of livestock feed available without affecting the wheat grain yield. Farmers should be technically supported to optimize the complementarities and benefits from the association by using more productive forages species and integration of income generation practices like small scale animal fattening and dairy farm.	Although the integration of forage into food crops grants a lot of multiple benefits, it is important to gradually adapt the most beneficial methods of integration for optimal benefits from practical learning and experiences gained in the process of implementation over the years. While the above ground biomass is used for livestock feed, the root systems and the residue left above the ground should be incorporated into the soil to improve fertility of the soil for the subsequent crops. Thus, there is a need of protecting the area from livestock interference and cut and carry system should be employed for using the products at all times.

Acceptability and Sustainability	Constraints and Limitations
The technology is highly feasible particularly in Ethiopian highlands where shortage of grazing lands is pressurizing the people to adopt suitable practice that can overcome the shortage of feed for livestock. If the practice of mixed farming (livestock and crop production) system should sustain in the highlands, one of the most feasible ways of sustaining the system is the integration of forage production into farming system. But to make the system more attractive and acceptable to the farmers, it is crucial to know appropriate species and methods of integration that can optimize the overall benefits from the integration.	The availability of suitable forage species is one of the major factors limiting the initiation and expansion of the practice. This might be one of the major constraints in adopting integration of crop legume mixtures. As free grazing system is a major threat to almost all land management and natural resources development interventions, the technical service providers should help the communities in developing effective community bylaws to ensure safe protection against livestock damage.

Name of Technology	GRAS STRIPS ALONG THE CONTOURS	
General description	**Purpose and Benefits**	**Agroecology**
Grass strips are vegetative barriers made of grass planted in narrow strips of 0.5 to 1 meters width laid out along the contour. Grass strips are known to be more effective in controlling soil loss than water compared to the physical structures, because while soil particles are filtered out and left behind or within the strip, the water gradually passes through the grass strips. Grass strips control erosion rather effectively ingentleslopesbutabove5-8%slopetheir effectiveness decreases. Grass strips can replace physical structures effectively usually up to 8% slopes. Above those ranges they should be combined with physical structures or hedgerows of shrubs/grasses.	The adoption of grass strips minimizes the area of farmlands otherwise occupied by mechanical structures. It also reduces the costs required for constructing the structures. Under favorable environmental conditions and with controlled free grazing system grass strips are more stable and while contributing to protect soils against erosion they also provide valuable biomass meant to increase animal feed or used for different purposes (e.g. roofing, mulching, etc.). Grass strips also cause less interference than terraces and can be easily crossed by oxen and ploughs.	Grass strips are applicable in most of agro ecological zones where the amount of rainfall allows the establishment of dense grass strips. The potential for establishing effective grass strips is higher in medium to high rain fall areas.Grass strips are most feasible in warm and moist areas and less suitable for cooler and drier areas where the growth of the grass is limited by climatic conditions. There are grass strips in various parts of the country, often in the form of buffer strips, left uncultivated eventually filling up with spontaneous grass.

Design and Methods of Application

Layout: - grass strips are established along the contours. Grass strips are established at a 1m vertical interval, i.e. at 3% slope, the distance between two strips is 33 m and decrease to 7 m at 15% slope. For slopes up to 15% they may be planted alternatively with bunds (one grass strip/one bund). The width varies from 0.5m to1m, depending on the density of the plants in the strip. In dry areas, grass strips should not be established on slopes > 8%. For conservation purposes a width of 0.8-1m is recommended (Figure2). Seed bed preparation is performed at the on-set of rains and planting during the early rains to allow seedlings exposed to long rains for better survival and establishment. The strip is established by broad casting or sowing the seeds. When vegetative materials like root splits or stem cuttings used, planting is done in two or three lines. The middle row can be sown with a legume to improve the nutritive value of grasses. If broadcasting is the method used, grass seeds can be mixed with the legume seeds and broadcast in the strip.

Type of grass species: -grass species should be perennial and persistent, compete with and suppress weeds, provide good ground cover, slow down the water flow and hence conserve the soil and moisture. Besides, they should provide valuable fodder or other materials used by farmers. They should not be aggressive on adjacent crops and act as weeds. There are a number of grass species that can be effective in grass strips, such as Rhodes, Andropogon, Setaria, Phalaris, Vetiver, etc. But also native grasses, which may be more adaptable to local conditions and tolerant to drought, can be used. Besides, the advantage of using native grass species is that land users are familiar with the purpose and management of such grasses. Regarding legumes, species such as Stylo, Sirato, Desmodium for drier areas. Clovers and Medicagospecies are used for higher areas. However some grass species are aggressive with rhizoma and stolons which rapidly colonize the surroundings.

Planting technique:-for direct sowing a fine seedbed preparation is required. Generally, 0.5-1.5 cm depth is the optimum for most species. When planted manually, rows are opened with a stick at the desired spacing and seed is drilled in to the row. Seeds are covered with a thin layer of soil and pressed hard to the soil. Before planting, seeds should be checked for their germination. Alternately, root splits and/or grass cuttings or seedlings are planted in lines/rows. Spacing between the seedlings/splits should not be wider than 5 cm to guarantee continuous and effective grass strips.

Preparation of the root splits:-the grass is cut at about12cm above the ground, and then the clump is uprooted and transported to the planting site. At the time of planting, the handling of planting materials is very important. At planting, the clump is split into pieces including 2 to 3 tillers in each to ensure a good establishment (figure 1). Legume seeds are sown in the middle row. Planting should be carried out at the onset of rainfall, when the soil is not too wet or too dry. Planting should always ensure good soil-seed/seedling contact by pressing the sides of planting material to the soil.

Harvesting of grasses:-depend on their use and characteristics. Some grass should be cut frequently and at a young stage, other at flowering or tillering time etc. If used as forage usually the first harvest is after 3-4 months from establishment, before flowering by cutting the grass at 10-15 cm above the ground.

Figure 1. Splitting grass from clumps

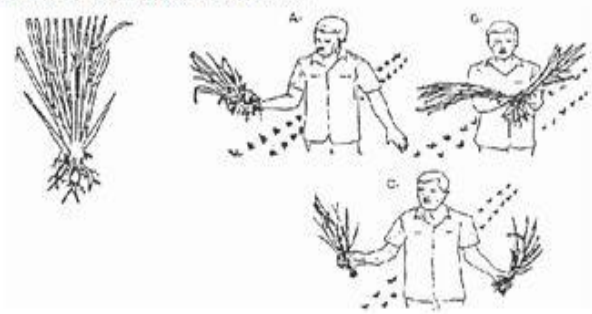
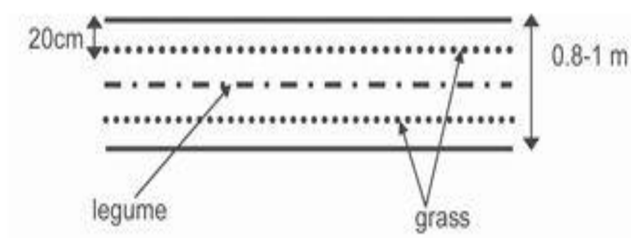


Figure 2. Grass strip (aerial view)



Complementarities and Integration Opportunities

Grass strips can be integrated with lines of legume shrubs such as pigeon peas, Sesbania, Tree lucerne and Acacia saligna planted in alternative dense rows. They can also be integrated with physical soil conservation structures alternatively in 8-15%slopes.Abovesuch range, grass strips are better replaced by physical structures.

Management requirement

Grass strips should be entirely protected from livestock interference. i.e. the farmlands treated with grass strips should be closed from livestock interference at all times. There may be a need of replanting the gaps in case of seedlings or seeds failure during the establishment of the grass strips for optimal erosion control. Too frequent cutting or over exploitation of the grasses may weaken the vigor of the grasses for effective erosion control. Therefore, lenience at harvesting and using the grass is advisable to maintain the vigor and persistence of the grasses.

Acceptability and Sustainability	Constraints and Limitations
Acceptability and sustainability of the technology depends on the effectiveness of the technology in achieving the intended objectives. If the design and method of application is properly implemented and the selected species are of good quality and providing high biomass for livestock the target beneficiaries will readily adopt the technology.	Although they are good enough to control loss of soil, they are less effective in controlling the loss of water as they provide little storage capacity. Therefore, in moisture stress areas where the major interest is on moisture conservation the physical structures are more appropriate. In high rainfall areas they can retard themovement/velocityofwaterand enhance infiltration rate; but may not offer much resistance against erosive rainstorms, particularly during the early stage of establishment as the new shoots are not yet well developed. Besides, they are easily overgrazed and damaged by animals.

Name of Technology	Hedgerows of Shrubs/Grasses

General Description

Hedgerows can be defined as narrow rows of dense vegetation with sufficient height above the ground. Hedgerow can be formed from grasses or shrubs. Therefore, hedgerows can be called: hedgerows of grasses, hedgerows of shrubs/trees, or specifically, hedgerows of Leucaena, hedgerows of Sesbania, hedgerows of Vetiver grass, etc. When tall grasses are planted in close spacing in line/row, they form hedges that can be barrier to animals, wind, runoff or other forces the hedge is intended to prevent. This hedge can, therefore, be termed as hedgerows of grass.

Fig 1. Various type of hedgerows

Purpose and Benefits

Vegetative hedges were found to be effective in filtering out the soil and build up natural terraces. If hedges are placed along the contour at correct vertical interval and dense enough to filter out the soil particles, far more land on steep slopes can be safely brought under cultivation. The growth and regrowth of hedgerows shrubs may be cut several times a year depending on the growth factors (e.g. soil fertility & water) and stored safely under shade after drying in the sun. Then the material is used for green manuring or livestock feed. The dried material can be used for livestock feed in combination with grass hay or crop residues. Its use can substantially increase the digestibility and intake of feed, and hence improve livestock productivity.

Design and Method of Application

For effective soil erosion control, the plants and branches in the hedgerows should be fairly dense and compact. To this effect, the hedges should be established in double rows of 30-40 cm spacing between the rows and about 20 cm between the seedlings in each row, in a staggered pattern. The double hedgerows are more effective in controlling soil erosion than single hedgerow, because in the double hedgerows, the force of the runoff that could not be checked by the first row could be checked by the second row. The double hedgerows are suitable for enhancing faster bench terrace formation, because the space in the double hedgerows allows collection and accumulation of straws, crop residues and other trashes which block the openings in the hedgerows and facilitate faster deposition and accumulation of soil above the hedgerows.

Agroecology

The establishment of the species and effective performance of the hedgerows is expected in areas receiving adequate amount of rainfall (more than 800mm). However, there is a strong need of combining the water harvesting or moisture conservation techniques and adaptable species with the practices in order to optimize the ecological and economic benefits of the hedgerows in dry areas.

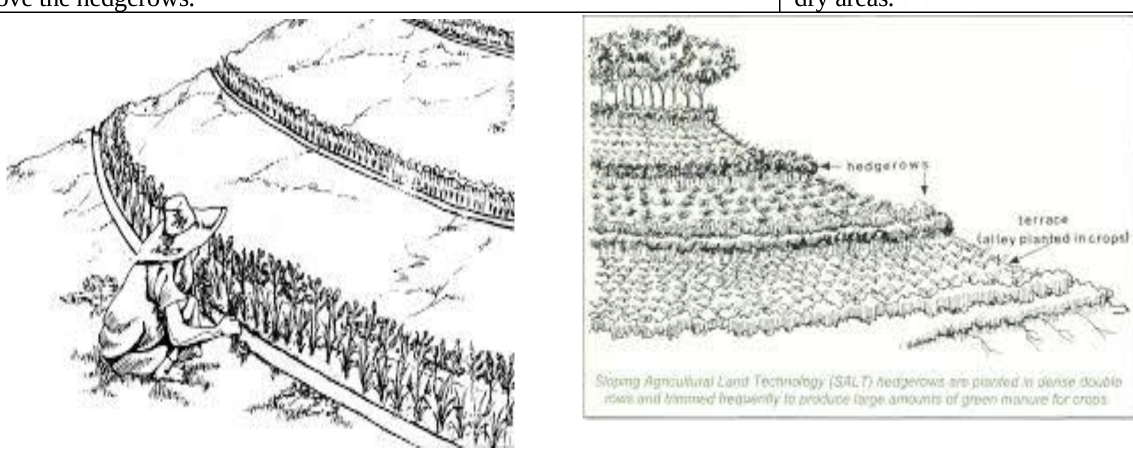


Fig 2. Method of establishing double hedgerows of shrubs

Complementarities and Integration Opportunities	
Hedgerows of shrubs and/or grasses can be integrated with a number of activities. It can be combined with various soil conservation measures when it cannot fully control soil erosion on its own. Similarly in moisture stress areas it should be integrated with moisture conservation measures to improve the moisture condition of the soil. The multipurpose shrub or grass species enable harvesting considerable amount of livestock feed that can be used for the integration of small scale animal fattening or dairy farm. When the shrub species used for the hedgerows are leguminous species, the foliage harvested from the hedgerows can be used for soil fertility improvement by incorporating into the soil. Applying the foliage in the form of mulch also has the benefit of controlling soil erosion from heavy raindrops.	
Management Requirements	**Acceptability and Sustainability**
The seedlings in the hedgerows are first cut when they reach a basal diameter, over 6 cm, just at about 10-15 cm height above the lowest branching. Such low cutting stimulates strong branching from the bottom resulting in the formation of denser/closer branches. The permanent height for regular hedgerows cutting is about 70 cm from the ground. Trimming the hedges to a height of 30-50cm prevents them from seeding, makes them thicken up, and thereby increases their effectiveness in filtering out soil particles. Periodical pruning/cutting of the hedgerows is necessary during cropping season to avoid shading of the companion crop. Pruning intensity varies with shrub or tree species. Fast growing plants, such as Leucaena, Sesbania and Gliricidia, require pruning every five to six weeks during cropping when growing conditions are optimal. Too low or too frequent cutting causes dieback; that is, certain percentage of the leaves should be maintained on the plants at every cutting in order to guarantee continuity of the photosynthesis and hence persistence of the plants.	The practice is not common in our country and the acceptance and sustainability could be low at initial stage. But after the community is well aware of its ecological and economic benefits it is very likely that its acceptability and sustainability increases over the years.. The hedgerows of shrubs and grasses such as elephant grass are very effective in controlling soil erosion on steep slopes when properly designed and established. While structures on steep slopes may collapse, hedgerows of shrubs or grasses are not likely to collapse and hence can be very effective in controlling soil erosion. Genuine and skillful technical supports that lead to the realization of the above merits of the technology can increase the popularity and acceptance of the technology.
Constraints and Limitations	
The major constraint in the adoption and promotion of this technology and other new technologies in our country is lack or inadequate skill and knowledge to properly design and establish correctly the hedgerows that can effectively control soil erosion. In moisture stress areas, it could be difficult to establish hedgerows that can effectively control soil erosion and produce enough biomass for economic benefits without supplementary irrigation or moisture conservation.	

Name of Technology	STABILIZATION OF PHYSICAL STRUCTURES

General Description

Stabilization refers to the planting of grass, shrub and tree species in different combinations on the physical structures such as soil bunds, trenches, check dams, SS dams, etc, in order to increase their stability and resistance against rain drops splash effect, runoff and other inferences. Physical structures are prone to the impacts of mechanical actions such as raindrops, gravity, etc. and subject to destruction unless they are stabilized by vegetative measures. Hence, planting of suitable plant species on the structures stabilizes them with their root system and the biomass and/or canopy above the ground protects the structures from erosive rain drops.

Purpose and Benefits

Stabilization of the structures makes the surface area occupied by the structures productive. Stabilized structures would need less maintenance and damages are less likely to occur, even during heavy rainstorms. Trees or shrubs help to demarcate farm and homestead boundaries, thus provide additional sense of ownership for the users. Stabilized areas are an additional source of timber, fuel wood, fiber, food and forage, palatable grasses and legumes, fruits and other products (dyes, gum, medicinal, etc.). Achieving proper and productive stabilization will also encourage farmers to protect conserved areas and appreciate its effects.

Agroecology

Stabilization of the physical soil conservation structures with grasses, shrubs and trees exist in different parts of the country and the practice is applicable to all agro-ecological zones and virtually all structures can be stabilized. The potential for effective stabilization and production of biomass is higher in medium to high rainfall areas because of the better chances of establishing denser and vigorous vegetation provided control grazing is ensured. Thus the effectiveness of the vegetation for structural stabilization is determined by the amount of biomass and vigor of the vegetation, which in turn depends on the climatic (esp. moisture and temperature) and soil conditions of the area.

Design and Methods of Application

The design and method of application may vary with the type of plant species such as tree, shrub and grass species. As the main purpose of stabilization of the structures is to make them most stable and productive the design and method of application should take into consideration these basic principles. Suitable grass species are the best for structural stabilization as they provide dense ground cover and probably more fibrous root system binding the soil particles. The design and method of application for different species is illustrated in the following sections.

Stabilization with tree and shrub species

Tree/shrub species should be planted at close spacing: 30 to 60cm apart on single or staggered double rows (one on the berm and the other at the lower side of the embankment). For fodder production, preferably select nitrogen-fixing tree/shrub species such as *Leucaena leucocephala*, Pigeon peas and *Sesbania sesban*.

Stabilization with herbaceous grass and legume species

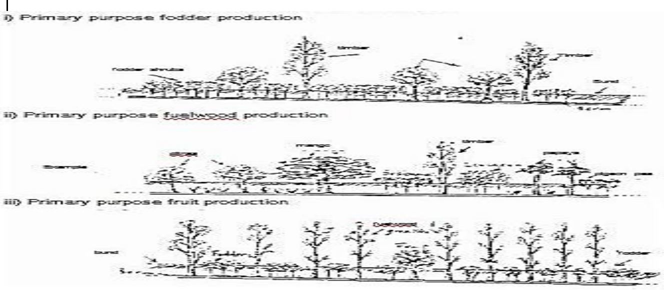
All physical structures can be stabilized with grass and legume pasture species including soil and stone-faced soil bunds, trenches and herring bones. Fodder grass and legume species can be integrated with compatible tree/shrub species in different patterns to provide denser ground cover and biomass to optimize the overall benefits of conservation and economic returns. In Ethiopia, there are several local grass species suitable for conservation and production purposes, which can be preferably used for different purposes in different localities in consultation with local communities. For instance, Desho grass from Chencha woreda of the SNNPR is one of the best examples of these types of species. The Choice of the type of forage species is determined based on soil type, water requirements, palatability and biomass production. The planting techniques, time of planting, etc and combination of legumes and grasses are the same with the techniques given in contour grass strips.

Fig 1. Tree/Shrub species for fuel wood and timber (left) and stabilization of structures with grass species (right)

This method of application is less effective for structural stabilization, but appropriate for the production of various wood products. Usually, single row is preferred to allow the trees to grow bigger and produce more branches and wood products. Planting with seedlings is preferable for better survival and establishment. Nitrogen fixing tree species such as Acacia species, AlbiziaLebbeck but also Leucaena, Sesbania, and Pigeon peas are preferable to accrue multiple benefits like soil fertility improvement and livestock feed. The species are planted in wider stands (1-2m).Shade tolerant grass species can be planted under the trees to optimize the overall amount of biomass production and hence economic benefits. Fruit trees and specific multipurpose tree species (AzadiractaIndica (Neem), Cordia, Ziziphus, etc) can be also combined.

Fruit trees

Fruit trees can be planted along bunds, bench terraces and in ditches, etc. Plantation of fruit trees with prudent management techniques such as optimal moisture conservation, soil fertility management and control of free livestock movement is very appropriate and grants incredible additional economic benefits. Preferable fruit tree species include mango, avocado, guava, citrus, papaya, banana and other species. Some other drought resistant perishable and non-perishable fruit trees species should be tried from other countries. High land fruits such as apples, plums, and peaches can grow at higher altitudes and make bench terraces an attractive and productive option. It is always recommended to plant fruit trees in combination with other multipurpose and compatible species to optimize the overall benefits.



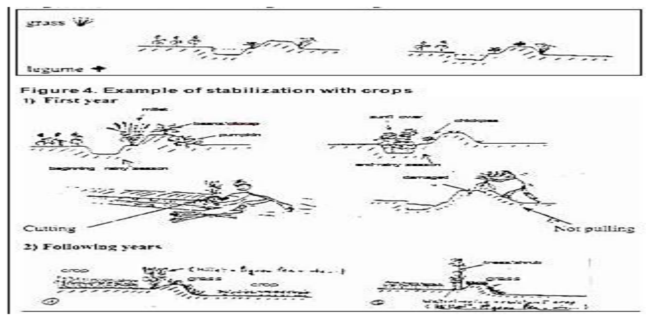


Fig 2. Plantation of fruit trees on bunds

Complementarities and Integration Opportunities

Structural stabilization canbeintegrated with various income generation activities. The structures should be stabilized with perennial and persistence crops that do not require frequent disturbance of the structures. Particularly, perennial grass species with high biomass production and nutrition value is most appropriate to effectively stabilize the structures on sustainable basis while still rewarding great economic benefits. The stabilization of the structures with such species enables the integration of small-scale animal fattening and/or dairy farm.

Management Requirements

After1-2 years from establishment and before the crops growing season, tree/shrub branches and foliage should be reduced by side pruning to avoid shade and competition for nutrients and water (depending on the type of species). Root pruning may be necessary after 2 years to avoid competition with crops. Apply “farmland closure” as a form of controlled grazing.

Acceptability and Sustainability	Constraints and Limitations
Stabilization of physical structures rewards a lot of economic and ecological benefits that justify its acceptability and sustainability. However, acceptability of the technology by the individual households or by the beneficiary communities depends on the level of awareness about the benefits of the technology. The type of plant species, the design and methods of application also make difference in realizing the benefits by the beneficiaries.	Free grazing remains the major obstacle to successful establishment of vegetative measures and stabilization of the physical structures. Wrong selection of species and their arrangement may increase weed infestation, shading, and competition for nutrients and moisture.

Name of Technology	COMPOST MAKING (CM)

General Description

Compost is organic matter that has been decomposed in a process called composting. This process recycles various organic materials and produces the compost. Compost is rich in nutrients and used for example in gardens,horticulture, urban agriculture and organic farming. Many soils lack sufficient ability to hold water, are compacted and lack soil microbes that are literally the life of soil. So, it is crucial to build soil organic matter content through the application of various organic materials such as compost.

Purpose and Benefits

Compost is used to improve fertility and productivity of soils to increase crop yields. Compost improves soil fertility, enriches soil helping retain moisture and suppress plant diseases and pests, reduces the need for chemical fertilizers and encourages the production of beneficial bacteria and fungi that break down organic matter to create hummus, a rich, nutrient-filled material. It is one of the best "hidden" water harvesting methods available (compost absorbs water 4 times its own weight.

Agroecology

Vast experiences exist in preparing and using compost in different agro ecological zones, traditionally and through new methods. Pit method is common in moisture stressed areas while heap method in moist WeynaDega and Dega areas. The process of preparing and using compost can be scaled up in most areas including in dry areas if the value and benefits of compost is practically demonstrated. In some places compost making can be built upon traditional practice of keeping animals under shed at night and collect waste and roughage around the homesteads and fields (Kraal or Ohura traditional system).

Design and Method of Application

In compost making (CM) the priority thing is securing sufficient amount of materials: - roughage, ashes and animal dung around the pit. Shaded places and areas having plenty of waste materials for compost making are selected. The size of the pit depends on the amount of material available for compost making. Training (demonstration) of group of farmers in CM is necessary. Link CM with area closure and homestead biomass intensification to secure enough materials as appropriate. Collect organic waste, animal manure and ash from kitchens. To carry the materials use a stretcher or a basket. Compost making (CM) can be performed by family labor or user groups. It is advisable to keep the materials under shade until compost preparation. While selecting site for compost preparation, keep away from areas that collect water. In cooler climates, avoid constant shade. Shred or otherwise cut materials into small pieces before placing them on the compost heap whenever possible; smaller pieces will decompose more quickly. Adding thicker, woody material will keep air flowing throughout the pile. Vermicomposting is also encouraged to speed up the composting process and to produce better quality compost. Procedures for pit and heap methods of compost making are given bellow.

(1) Pit Method

Demarcatearea for digging the pit using wooden pegs; then excavate and prepare the pit. In any case the pit should not be more than 2mwide, 4m long and 1.5m deep. Start with digging 2 pits, one nexttotheotheras shown in Figure 1below. Make a drain at the bottom of the pit to protect the pit from excess water. Steps for making compost layers:

a) Make layer a of material waste (roughage) of about 20 cm thick, compact lightly the materials and apply water (moist all layer),
b) Sprinkling of ash over the layer of plant waste: 0.5 kg/ m2 /layer will be enough,
c) Apply farmyard manure: 3-5 full spades/m^2/layer and
d) Some soil should be also spread (1-2 cm thick) on top of each layer. Repeat the same procedure till you reach the top of the pit,
e) To improve aeration in the pit bamboo or other sticks should be placed standing in the middle of the pit every 2m
f) Cover the pit with dry grasses or other dry residues
g) The pit is now left for one month, during this period check the moisture and add some water to keep the pit moist, never dry or wet; usually undertake this task once per week

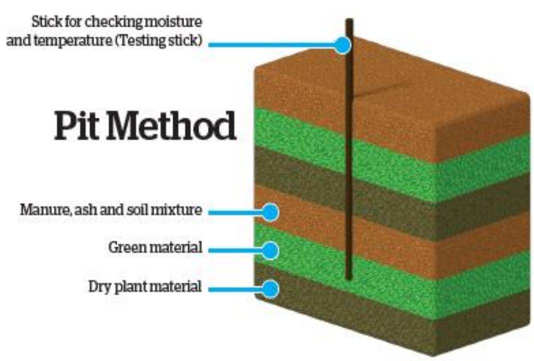
(2) Heap method

Demarcate the area for heap preparation using wooden pegs. Then dig a shallow pit (30cm deep) at the bottom of demarcated site for the collection of leached nutrients and moisture. The size of the heap depends on the amount of organic waste, but it should not be wider than 2m and 1.5m high, and as long as necessary. Then follow all the same steps used in pit method for making the layers. The sides of the heap can be also covered or plastered with soil to some height to keep the heap warm and to avoid drying by wind. Nutrients can be leached if heap not protected.

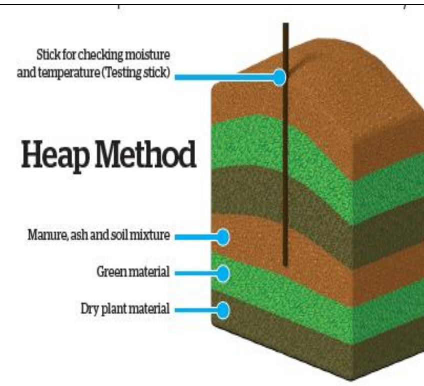
WORK NORM: 1 PD/linear meter (2mW x1.5m Height)

Heap Method Composting

h) After a month turns into the second pit and mix the compost. Compost is ready after 3-5 months - keep under shade and covered. Fig below shows Pit Method Composting



WORK NORM: Pit: 10 PD/pit (4mL x 2mW x 1.5mD)



Management Requirements

Sprinkle water into the pile when it appears dry. It is important to keep the compost pile moist, but not wet or dry because the beneficial organisms that cause the compost to decompose properly cannot survive in a wet or dry environment. Turn the compost regularly to ensure proper air circulation which speeds the decomposition process by encouraging beneficial bacteria and fungi growth. More frequent turning will help if you need to speed up the process.

Application rate:-compost application rate depends basically on several factors including the soil fertility status and the type of crops. The good news about compost or any most of organic fertilizers like farmyard manure is that the amount of nutrients like NPK are not all released in one season, but gradually over the years. So, there is less worry about toxicity with over dosages. The problem is often we do not have enough compost to apply the required amount of dosage. The scanty information available on the dosage indicates that about 5 tons of good compost can give us medium benefits from the crop and applying about 10 tons can give us optimal crop yields. But with horticulture crops like vegetables and improved forage crops we need much higher rates for optimal benefits. Anyway, it can be flexibly used based on the practical experiences of farmers.

Complementarity & Integration Opportunities	Constraints and Limitations
Integrated soil fertility management (ISFM) is a set of agricultural practices adapted to local conditions to maximize the efficiency of nutrient and water use and improve agricultural productivity. ISFM strategies center on the combined use of mineral fertilizers and locally available soil amendments (such as lime and phosphate rock) and organic matter (crop residues, compost and green manure) to replenish lost soil nutrients. This improves both soil quality and the efficiency of fertilizers and other agro-inputs.	The limited availability of adequate organic waste materials for compost making is one limiting factor. It also requires additional labor and time which farmers sometimes hesitate to commit. The bad smell during turning also discourages some farmers to readily adopt the technology. But all these limitations can be easily overcome once the farmers knew the actual economic and ecological benefits of such organic fertilizers as the benefits greatly overweigh the disadvantages. The inadequate advocacy on compost and other soil organic management techniques, as a result of poor agricultural extension system has limited the level of adoption, expansion and faster replication of the practice

Name of Technology	FERTILIZATION AND MANURING	
General Description	**Purpose and Benefits**	**Agroecology**
While fertilization refers to the application of chemical fertilizers. Manuring is the application of organic fertilizers such as compost, farmyard manure, green manure, etc. to improve fertility and productivity of soils. The technology is very crucial to improve fertility and productivity of soils to increase crop yields. The practice of improving soil fertility with organic manure enriches the soil with nutrients and soil organic matter content that helps soil retain moisture and suppress plant diseases and pests, reduces the need for chemical fertilizers and encourages the production of beneficial bacteria and fungi that break down organic matter to create hummus, a rich, nutrient-filled material.	The application of organic fertilizers replenishes lost soil nutrients and improves both soil quality and the efficiency of fertilizers and other agro-inputs. Improved soil organic matter helps soils to maintain a diverse community of soil organisms that in turn makes soils healthy. It also helps the soil to control plant diseases, insect and weed pests, form beneficial symbiotic associations with plant roots, recycles essential plant nutrients, improves soil structure with positive effects for soil water and nutrient holding capacity, and ultimately improves crop yields.	The technology is applicable to all agro ecological zones with some modifications based on the local conditions. Frequent application of ash is observed in the highlands probably because of its lime property that improves acidic soils. Ash is composed of many major and minor elements that can replenish soil nutrients.

Design and Method of Application

Chemical fertilizers are applied at planting time in different forms:- may be broadcast in the field, applied in the furrows or near the planting holes in case of hoe planting system and then covered immediately with soil. In case of organic fertilizers, they may be applied some time, say one week before planting. The organic material is spread in the field ready for planting and then plowed under. Also they can be applied to individual plants like fruits and other high value crops. The rate of application for chemical fertilizers would be the national recommendation rate. The organic fertilizers rate would be the same with the suggestion in compost application. The application of chemical and organic fertilizers is mostly performed manually by farmers and it is labor intensive and taking considerable time. The transportation mechanism includes human labor, carts, etc. Shovels and rakes may be used for spreading (application) of organic fertilizers. Probably it is advisable to develop simple mechanical devices that increase efficiency of application of the materials at least until improved technologies made readily available for resource poor farmers.

Complementarities and Integration Opportunities

Soil fertility management technologies are compatible with a number practices such as small scale irrigation, high value crops and other complementary income generation packages that can transform the economy of resource poor farmers. The integration of energy saving technologies such as improved stoves, etc can make the use of animal manure and crop residues for soil fertility management easier. The availability of improved livestock breed and intensive production of improved forage and multipurpose tree/shrub species can encourage farmers to focus on few quality animals managed at confined management system. This leads to achieving the long inspired improved livelihoods of rural communities and sustainable management of the natural resources.

Acceptability and Sustainability	Constraints and Limitations
The need of soil fertility improvement to ensure sustainable production is well understood among the large majority of farmers. Particularly the acceptability and adoptability of chemical fertilizers has greatly increased nowadays. Almost all farmers are keen to get and use the chemical fertilizers. But the level of awareness and the number of farmers using organic fertilizers is very much limited compared to chemical fertilizers. This clearly shows that much remains to be done on the part of the government to raise framers awareness on the value of organic fertilizers in sustainable soil fertility and productivity improvement. More importantly, the agricultural extension technical staffs should be equipped with the required skills, experiences, capacity and commitment to change the attitude of farmers on the use organic fertilizers. Farmers should be aware that the benefits of organic fertilizers by far overweigh the cumbersome nature of its preparation and application.	The major constraint in proper use of chemical fertilizers is affordability to buy and use the recommended rate of chemical fertilizers by most of the farmers. But when it comes to using organic fertilizers, the major constraint lies in limited awareness on the diverse benefits of the technology. Moreover, the limited skill, knowledge and commitment on the part of famers and extension staff for proper use of the technology appear serious concern. Most of the farmers are reluctant to prepare and use compost due to the laborious nature of the task and lack of the huge organic materials required for its preparation. Burning of the valuable animal manure and inadequate soil organic management system is a serious major constraint to use the material for soil fertility improvement. The limited advocacy on the use of organic fertilizers by farmers is another serious constraint.

Name of Technology	MULCHING AND CROP RESIDUES MANAGEMENT	
General Description	**Purposes and Benefits**	**Agroecology**
Mulching is the covering of the soil with crop residues such as straws, maize/sorghum stalks or standing stubble. Mulching, in addition to its positive effects on soil structure also helps in reducing evaporation and maintenance of soil moisture. The improved soil structure also increases water holding and moisture retention capacity of soils and consequently higher water budgets for the growing crops. In Ethiopia mulch is applied in several areas around high value cash crops such as fruit trees, coffee, etc. In order to conserve moisture and also to improve soil conditions.	The cover protects the soil from raindrops, drastically reduces splash erosion and velocity of runoff. It increases the infiltration rate and permeability of soils. The mulches or crop residues covering the soil surface are gradually incorporated into the soil and improves the soil organic matter content, which in turn improves soil structure, quality and productivity with great positive impact on crop yield. Mulching is strongly recommended for tree seedlings planted in dry areas with moisture conservation structures such as trenches and similar structures to reduce loss of moisture and also to improve soil conditions for better survival and establishment of the seedlings.	The suitability of mulching for soil fertility and productivity improvement greatly varies under different ecological conditions. In cool wet areas the rate of decomposition is low and it may cause water lodging and reduce soil temperature. In the low dry environment again the rate of decomposition could be retarded by low moisture conditions. Thus, it appears most appropriate in warm and moist environment for both erosion control and optimal soil fertility and productivity improvement.

Design and Methods of Application

There are different methods of mulch application including surface and vertical mulching. Surface mulching is a practice of spreading residues on the soil surface. Different crop (plant) residues can be applied (based upon availability), especially they are very beneficial on fallow lands to prevent soil erosion. It is recommended to spread the residues over the whole surface in a 2-5cm thick layer. At least 40% cover is recommended to reduce erosion by 60-70% based on slopes and type of soils. Vertical mulching-is applied to increase water infiltration at regular intervals between crops.It consists of opening shallow furrows every 2-6m, 20cm deep and along the contours. Then straws or mulch is buried with 20cm of height standing over the soil surface. In addition to reducing runoff it substantially increases water intake around the mulch area and nearby crops. This operation should be done 40-50days before sowing crops. Mulching of planted tree seedlings:-by the end of September it is advisable to cut and mulch the grass around growing seedlings in a thick layer; first around the planted pit and then if materials are sufficient inside the water collection ditches. These operations may be repeated after 2 years.

Work Norms: it includes cut and carry and transport of mulch to site (distance 300m from site max.) and layering of mulch over the entire area. For surface and vertical mulching the norm is estimated as 250PD/ha mulched.

Complementarities and Integration Opportunities

Mulching and crop residue management is compatible with many land and crop management practices. The technology is fundamental to the improvement of soil organic matter and fertility of the soil and hence its integration with other soil fertility improvement practices such as the use of compost, farm yard manure and chemical fertilizers can optimize productivity and fertility of the soil on sustainable basis. The traditional and improved methods of crop rotation, intercropping and other land management and agronomic practices can be easily combined with the technology for optimization of its benefits. In moisture stress areas the technology plays remarkable role in moisture conservation through reduction of evaporation and improvement of moisture retention capacity of the soil. Thus, it integrates well with moisture conservation techniques

Management Requirements

To ensure the socio-economic and ecological benefits of the technology, it is very crucial to control livestock interference from the areas being treated. If the mulching material is expected from outside of the area, it is necessary to have areas providing sufficient supply of the plant materials for mulching. To reduce the interference of the residues on cultivation operation, it might be necessary to undertake some actions to reduce the size of mulching material to facilitate easy incorporation and minimum interference on cultivation.

Acceptability and Sustainability

Acceptability and sustainability of the practice is a major challenge particularly under the current free grazing system. It requires lot of efforts to convince the target communities.

Constraints and Limitations

The major constraint for implementation of the technology is the traditional free grazing system. The lack or inadequate awareness of the role of the technology on erosion control, soil fertility and productivity improvement on the part of farmers and the limited skill, knowhow and commitment on the part of technical staff appear another major limitation for the promotion of the technology in our country.

Name of Technology: COVER/GREEN MANURE CROPS

General Description

Cover crops- are crops grown as ground protection under row plantation crops such as rubber and sisal or as conservation measure on fallow lands during off-season. Cover crops provide proper ground cover to protect the soil from erosive agents. While the main objective of cover crops is to protect the soil from the direct impact of erosive agents, they also play additional role of replenishing soil organic matter and nutrients. Cover crops are grown under tree crops mainly to protect the soil from the impact of water drops falling from the tree canopy. They are particularly important with tall trees, where their height causes the drops to approach erosive velocity.

Green manure crops: - are crops grown mainly to maintain or increase the soil organic matter and nutrients. In addition, the crops protect the soil against erosion during off-season. The major difference between green manure and cover crops is the main objective for which they are grown. Green manure crops are mainly grown to enrich the soil with organic matter and essential nutrients while the aim of growing cover crops is to protect the soil against erosive agents. Although the objectives of growing the two crops are different, the ultimate benefits gained are often the same.

Purpose and Benefits

The Cove/Green manure crops are leguminous plants that can fix huge amount of nitrogen that greatly improves soil fertility and productivity when incorporated into the soil. The incorporation of the materials also facilitates the bringing of nutrients to the top layer from deeper layers. The use of green manure corps has immense impact on reducing the requirement of chemical fertilizers It also improves the soil structure, increases water-holding capacity and decreases soil loss by erosion. Growing of cover/green manure crops in the off-season reduces weed proliferation and weed growth. Moreover, the growing of cover/green manure crops suppresses the growth of weeds and prevents weed infestation. Farmers cultivate their land a number of times basically to control weed infestation. Thus the introduction of cover/green manure crops minimizes the number of cultivation and helps the realization of minimum tillage, which reduces the requirement of traction power; labor and time for cultivation (weed control).

Agroecology

Under Ethiopian condition the technology is more applicable in areas with bimodal rains where the crops are grown during the small rains and the material incorporated into the soil at the beginning of big rains. This technology is less applicable to the dry conditions where the duration of the Meher rains and amount of Belg rains do not allow enough growth of cover/green manure crops that would be ploughed in before planting of the main crops. However, the technology is applicable to dry areas getting supplementary irrigation.

Design and Method of Application

In Ethiopia the cover/green manure crops can be planted in April/May, about 60 days before sowing of the main crops and ploughed under in June/July about 10-15 days before planting of the main crops. In areas receiving supplementary irrigation, planting of the cover/green manure crops could be done in any month of the year when the temperature allows germination and growth of the plants. But, the cover/green manure crops should be allowed about 60 days in the field to grow and produce enough biomass and nutrients before ploughed in to improve fertility of the soil. In areas where tree crops like Sisal and Rubber can be introduced, cover crops can be grown all the year round to protect the ground from erosive forces. The cover crops can occasionally be incorporated during the period of the year when the soil erosion risks are low to improve fertility of the soil. But another cover crop should be established, before the onset of rain that causes erosion (if possible). In the lowlands Lablab, Medicago, Colopogonuim, etc. are suitable species to be used while Viciciadasycarpa, Medicago, etc. are among the suitable species to be usedin the higher altitudes.Cover/green manure crops ready for incorporation are illustrated (Figure 1.).

Fig 1. Cover/Green manure crops (Velvet bean left and Lupine right) for protecting soil erosion and improvement of soil fertility

Complementarities and Integration Opportunities	Management Requirements
Cover/green manure crops can be integrated with various land management practices intended to improve soil fertility and control soil erosion. Particularly various soil erosion control measures and soil fertility management techniques such as compost or farm yard manure and inorganic fertilizers can be used to complement and/or optimize the expected benefits.	In order to optimize the benefits from the cover/green manure crops, it might be necessary to minimize the competition from weeds to facilitate vigorous growth and high biomass production which in turn optimizes the benefits of soil fertility management and soil erosion control. Certainly strict control of livestock interference is compulsory.

Acceptability and Sustainability	Constraints and Limitations
This technology is less or not commonly practiced in our country and its acceptability and sustainability could be very low at the beginning. MERET project demonstrated in a number of sites the benefits of green manure crops with lupine and Sesbania. The beneficiary farmers were very much impressed with lupine green manure and showed interest to adopt the technology.	The major constraint and limitation is the lack of exposure of our farmers to the technology and limited skill, knowledge and experience on the part of extension staff to facilitate the initiation and expansion of the technology in different parts of the country. Also the limited availability of suitable planting materials could be a limiting factor..

Name of Technology	ACID SOIL MANAGEMENT

General Description

Low soil pH and associated soil infertility problems are considered to be amongst the major challenges to higher crop production in Ethiopian highlands. According to the Ethiopian Soil Information System (Ethio SIS), about 40% of the total land area and about 28% of agricultural land is estimated to be acidic. Acid soil can be caused by many things and can occur naturally in areas with high rainfall amounts and by geological factors. Some soils have developed from parent materials which are acidic, such as granite and that may contribute to some extent to soil acidity. Studies show that significant yield reductions, and in more severe cases, even complete loss of production have been reported in several parts of the country because of soil acidity. Generally acid soils are common in many areas where rainfall or precipitation is high enough to leach appreciable amounts of exchangeable bases from the surface soils and relatively insoluble compounds of Al and Fe remains in soil. In general the fertility status of acid soils is very poor and under strongly to moderately acidic soils the plant growth and development is affected to a great extent. The crops grown on such problematic soils do not give remunerative return rather it lowers down the yield to a great extent. Acid soil conditions impact negatively on soil biological activity. Once a soil is found to be acidic, it requires correcting its acidity either though chemical amendment such as liming or some cultural management practices in order to improve its fertility status through the modification of soil reaction to a required level. Research results show that productivity improvements ranging from 50% to 100% achieved through liming in wheat, barley, Teff, soybean and maize under moderate to severe acid soil conditions.

Purpose and Benefits

Restoring pH levels in Ethiopia's soil via lime applications to agricultural land could enhance major crop productivity. Proper liming provides a number of benefits including helping plant roots to develop healthier roots because they are less exposed to potentially toxic aluminum. Better root growth may enhance drought tolerance. Lime will neutralize the acidity by dissolving, whereupon it releases a base into the soil solution that reacts with the acidic components, hydrogen and aluminum. Nutrient solubility is improved by a higher pH, so plants have a better nutrient supply. The optimum pH for most crops is 5.8-7.5. Increased soil Cation Exchange Capacity (CEC) occurs, as well as reduced leaching of basic cations, particularly potassium. Nodulation of legumes is enhanced, which improves nitrogen fixation.

Agroecology

Acid soil management practices including liming are applicable in any agro ecological zones where soil acidity is limiting crop production and productivity. In fact, soil acidity is a major problem to crop production in Ethiopian highlands receiving relatively high rainfall causing excessive loss of nutrients, particularly the basic cations. But soil acidity problem is not limited only to Ethiopian highlands, but the low and medium altitude areas in the south west and western parts receiving high rainfall are also exposed to the threats of soil acidity problems and requires attention and proper action.

Design and Method of Application

Lime requirement of an acid soil may be defined as the amount of liming material that must be added to raise the pH to mixed with the soil so that liming reaction can occur in a faster rate. Lime is usually applied to soils in the form of grinded limestone. The more pure the liming material, the higher will be its effectiveness for the amelioration of soil acidity. The rate of reaction of liming materials with an acid soil depends upon its fineness because finer materials increase the surface contact with the soil. If the liming materials are coarse, the reaction will be slight. The amount of finer fraction of liming materials required will some prescribed value. This value is usually in the range of pH 5.8 to 7.5 and easily attainable value within the optimum range of most crop plants. Generally lime should be applied well ahead of planting (sowing) and broadcasted limes are to be well be much less as compared to coarser fractions of the material to achieve a certain pH. The fineness is measured in terms of the ability of a material to pass through a sieve having 60 holes of equal size in one linear inch. Such a sieve is called a 60 mesh sieve and a material passing through such a sieve is allotted 100% efficiency rating (Fig 1).

The method of lime application includes spot, band and broadcasting. The application rates may vary with the level of soil acidity, soil fertility status and method of application. For instance, if the method of application is broadcasting, the rate of application may be higher than spot or band application. Result from Kenya shows that broadcasting of lime at 6 ton/ha gave the best maize crop yield than band or spot application. In this study the different methods did not give significant differences in the yield, but the rate of 6 ton/ha was superior to the other rates of 2 and 4 ton/ha.

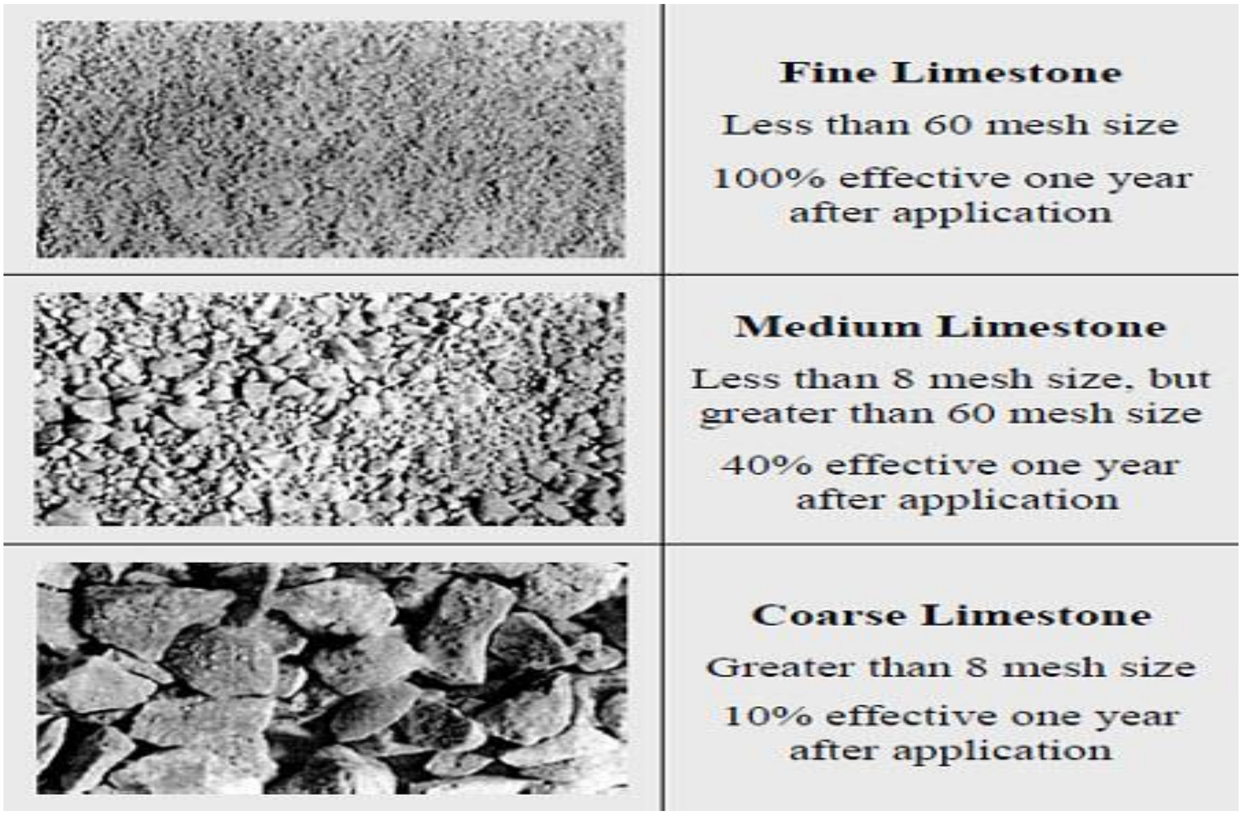


Fig 1. The various size of limestone on the level of its effectiveness

Complementarity and Integration Opportunities	**Management Requirements**	**Acceptability and Sustainability**
The importance of management of organic matter and manures in acid soil management is emphasized in many studies. Given that organic litter is so important in the recycling of nutrients in the forest, perhaps the inclusion of trees and shrubs in the farming system can help in acid soil management program. Soil organic matter (SOM) has long been recognized as an important indicator of soil productivity. Improvementof soil organic matter can be achieved by adopting appropriate soil and crop management practices. These practices include conservation tillage, crop rotation, and use of organic manures.	Given that organic litter is so important in the recycling of nutrients inclusion oftrees in these systems may stabilize the soil, recycle nutrients from the subsoil and provide leaf litter to protect the soil surface contributing to buffering of the negative impacts of soil acidity. Choice of acid-tolerant crop varieties and use of compost and farm manure may further reduce the amounts of lime required and make farming more attractive.	Acceptability and sustainability of the technology is becoming obvious in areas affected by soil acidity and where farmers perceived well the importance of liming. In areas where the use of lime showed significant improvement in crop yields, the acceptability of lime is quite high and sustainability of the use of the technology will be guaranteed particularly if the availability and economic capacity of farmers is reliable.

Constraints and Limitations

The major constraint to the adoption and expansion of the technology could be the cumbersome nature of the material for handling and application. The material is so bulky and difficult for transportation and application in the field. Moreover, the quality and effectiveness of the material greatly varies (Fig 1) and getting the most effective material could be a limiting factor. Thus, the current method of lime application and the availability of quality material could be among the major factors limiting the effective use of the technology.

Name of the technology	RECLAMATION OF SALT AFFECTED SOILS

General description

Salinity problems are caused from the accumulation of soluble salts in the root zone. These excess salts reduce plant growth and vigour by altering water uptake and causing ion-specific toxicities or imbalances, resulting in reduced crop productivity.

Salts accumulate in the soil of arid and semi-arid climates as irrigation water or groundwater seepage evaporates, leaving minerals behind. The source of salinity could be salt concentration of irrigation water or soils. Irrigation water often contains salts picked up as water moves across the landscape or are found naturally in groundwater.

Salt affected soils can be classified as Saline and Sodic soils. Saline soils have excessive concentration of natural soluble salts, mainly chlorides, sulphates and carbonates of calcium, magnesium and sodium. Their soil Electrical Conductivity (EC) of saturated soil extract is more than 4 ds/m, Exchangeable Sodium Percentage (ESP) is less than 15 and pH is also less than 8.2. While Sodic soils previously referred as Alkali soils are with Exchangeable Sodium Percentage (ESP) is greater than 15, pH is more than 8.2 and Electric Conductivity (EC) is below 4 ds/m.

Figure 1 salt affected soil

Recommended measures to solve the problem are leaching, surface and subsurface drainage, chemical amendments (Sodic soils), and crop selection. Among the above the practical solution for small holder farmers is leaching.

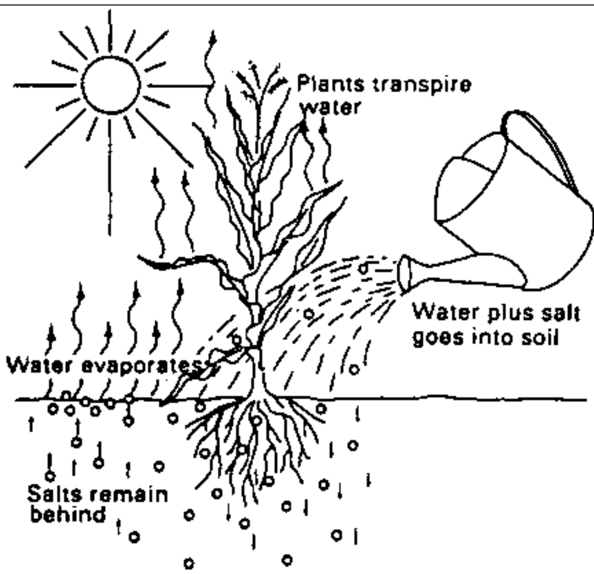


Fig:

Geographical extent of use

Reclamation of salt affected soil can be implemented in areas the case is affecting productivity. The problem is becoming serious most areas of irrigated fields of arid and semi-arid areas of Ethiopia. Currently, most areas of the Rift valley, the soils of the Melka Sedi-Amibara Plain of the Middle Awash Valley including Dubti and Tendaho of lower Awash are highly saline. Similarly, spot places in Tigray, Amhara are reporting that the problem is expanding following expansion of irrigation.

Technical specification

Measuring Salinity

Salinity is measured by passing an electrical current through a soil solution extracted from a saturated soil sample. The ability of the solution to carry a current is called electrical conductivity (EC). EC is measured in Deci-Siemens per meter (dS/m), which is the numerical equivalent to the old measure of millimhos per centimeter.

Salt concentration of soil extract (EC)		Salinity
in g/l	in millimhos/cm	
0-3	0-4.5	Non-saline
3-6	4.5-9	Slightly saline
6-12	9-18	Medium saline
More than 12	More than 18	Highly saline

Technical design requirements

The practical solution for managing problem of salinity for small holder farmers is to consider Leaching water requirement for removing salts below the root zone. Leaching is the application of more or additional water so that salts can be moved below the root zone. The depth of irrigation water applied for this purpose is called **Leaching Requirement.**

As can be seen from the equation an excess amount of water is considered during the irrigation, where necessary, for the purposes of leaching.

For surface and sprinkler irrigation method:

<table>
<tr><td>Estimating irrigation water requirement includes consideration of leaching requirement, however, most of the time it is neglected. Hence, in this info-tech we want to give some detail of how to calculate leaching requirement.
The Net Irrigation Requirement (IRn) is calculated as
IRn = ETc - (Pe + Ge + Wb) + LRmm
Where: IRn = Net irrigation requirement (mm)
ETc = Crop evapotranspiration (mm)
Pe = Effective dependable rainfall (mm)
Ge = Groundwater contribution from water table (mm)
Wb = Water stored in the soil at the beginning of each period (mm)
LRmm = Leaching requirement (mm)</td><td>$$LR_{(\text{fraction})} = \frac{EC_w}{5EC_e - EC_w}$$
Where:
$LR_{(\text{fraction})}$ = The fraction of the water to be applied that passes through the entire root zone depth and percolates below
EC_w = Electrical conductivity of irrigation water (dS/m)
EC_e = Electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable degree of yield reduction (dS/m)
Considering there is no effective rainfall (Pe), ground table contribution (Ge) mm and no water stored in the soil initially Net Irrigation requirement (IRn) $IRn = \frac{ETc}{1-LR_{fraction}}$ then find the gross irrigation requirement $GIR = \frac{IRn}{Ea}$</td></tr>
<tr><td colspan="2">Period of implementation across season</td></tr>
<tr><td colspan="2">During the irrigation time</td></tr>
<tr><td colspan="2">Planning and mobilization requirements</td></tr>
<tr><td>Before planning collect relevant data on soil, water and whether condition (metrological data) of the area</td><td>Tables and constants which are commonly used on for estimating crop water requirement</td></tr>
<tr><td colspan="2">Cost elements and work norm</td></tr>
<tr><td colspan="2">Mostly additional cost for irrigating the leaching requirement is needed.</td></tr>
<tr><td colspan="2">Management and maintenance:</td></tr>
<tr><td colspan="2">Apart from leaching techniques like selecting salt tolerant crops, drainage of the excess water for shallow water tables, soil amendment for sodic soils with gypsum, deep ploughing, addition of organic matter etc can be integrated.</td></tr>
<tr><td colspan="2">Benefits and acceptability</td></tr>
<tr><td colspan="2">Decrease problem of salinity and increase production</td></tr>
<tr><td colspan="2">Limitation</td></tr>
<tr><td colspan="2">If water is scarce addition of excess water for leaching may not be feasible solution.</td></tr>
</table>

Name of Technology	CONSERVATION TILLAGE

General Description

Conservation tillage is a tillage practice aimed at creating favorable soil environment for germination, establishment and plant growth. Tillage operations can loosen, granulate or crush or compact soil structure, changing soil properties such as bulk density and pore size and its distribution. Conservation tillage is, therefore, designed to avoid the tillage operations that destroy soil structure entailing problems of surface sealing and soil compaction with ultimate effect of ecological and economic shortfalls. The objectivesof conservation tillage include improvement of soil structure, soil permeability, soil aeration, root penetration, destruction of pests, soil inversion etc. Good seedbed is necessary for early seed germination and initial good stand of the crop. The seedbed should be fine for small seeded crops and moderate for bold seeded crops. Intimate contacts between the soil particles are necessary to facilitate movement of water for quicker germination. Conservation agriculture covers a spectrum of non-soil-inversion practices, from zero tillage to reduced tillage, aiming at maximizing infiltration and soil productivity and minimizing water losses while simultaneously conserving energy and labor. Minimum tillage and Zero tillage systems safeguard the soil fauna and the pore structure created by them. Because these systems tend to maintain more stable soil temperature and moisture regimes, they also protect the microbial population during the period of high temperature and prolonged drought.

Fig 1. Conservation tillage reduces the cost of production by 10-20%

Purpose and Benefits

Conservation tillage is proposed as one of the most promising means of reducing soil erosion and stabilizing crop yields in the rain fed farming systems of sub-Saharan Africa. Undisturbed soil that is permanently protected by vegetative cover improves the native ecosystems, including maintenance of porous and soft soil layers through litter accumulation, intense biological activity, movement of soil fauna, and root growth. These functions improve efficient water, heat, and gas transfers within the entire soil profile. The presence of crop residues on the soil surface minimizes soil evaporation, and in the regions of low rainfall it can conserve water and increase crop water use efficiency thus improving crop yields. Conservation tillage entails a reduction in soil manipulation, thereby minimizing the energy required for tillage and the retention of some crop residues on the soil surface even during seeding operations. The ultimate goal is to reduce soil nutrient and moisture losses. It has also been found that the straw enhances the formation of soil organic matter, which can store water better but also improves the nutrient availability for crops to be grown on that land.

Agroecology

It can be adapted and used in different agro-ecological zones with certain modifications based on soil and crop types and socio economic and cultural conditions. Tillage operations and the management of crop residues are important in water conservation, particularly in dry areas. In semi-arid regions, a change from conventional to conservation agriculture is known to increase crop productivity by 20-120% and water productivity by 10-40%. However, potential disadvantages include higher costs of pest control.

Design and Method of Application

Crop residues can and in many cases should be left over the surface as stubble mulch to protect against evaporation and erosion losses. Recently, considerable change has taken place in tillage practices and several new concepts have been introduced, namely, minimum tillage, zero tillage, stubble mulch farming etc. They often involve crop residue management; according to some information, conservation tillage is defined as tillage system in which at least 30% of soil surface is covered with crop residue. Some of the conservation tillage practices are described below.

Zero tillage: - is a tillage practice in which land remains untilled before planting, but planting furrow or hole is opened at planting. Zero tillage is an extreme form of minimum tillage. Zero tilled soils are homogenous in structure with more number of earthworms. The organic matter content increases due to less mineralization. Surface runoff is reduced due to the presence of mulch. The favorable effects of zero tillage on soil physical properties are apparent after two years of its practice.

Minimum /Reduce tillage: -is a tillage practice in which the least possible tillage operation is performed to break up hard pans/compacted layers and hence to increase infiltration/water storage capacity of the soil and to minimize resistance to root development. Minimum tillage is aimed at reducing tillage to the minimum necessary for ensuring a good seedbed, rapid germination, a satisfactory stand and favorable growing conditions. Minimum tillage has certain advantages improved soil conditions due to decomposition of plant residues in situ, higher infiltration caused by the vegetation present on the soil and channels formed by the decomposition of dead roots; less resistance to root growth due to improved structure; less soil compaction by the reduced movement of heavy tillage vehicles and less soil erosion compared to conventional tillage.

Mulch tillage: - is a tillage operation consistent with the principles of least soil disturbance and maximum crop residue application/maintenance. The crop Residue is often shredded and incorporated. The practice also includes in-situ mulch management system where residue of dead or chemically killed cover is left in place.

Strip/Zonal tillage: - is a tillage practice in which the seedbed is divided into two, that is seedling zone and soil management zone.

Complementarities and Integration Opportunities	Management Requirements
Conservation tillage needs to be integrated with various cultural and improved methods of weed control. Mulching and crop residue management could be one the most compatible methods for optimizing the suppression of weed growth and improving fertility and productivity of the soil. Mulching and crop residue management also gradually improve the soil organic matter content that greatly contributes to the reduction of infestation of the land by pests and diseases. In dry areas, moisture conservation techniques are compatible to improve the moisture conditions. The integration of cover crops and/or green manure crops can further optimize the suppression of weed and improvement of fertility and productivity of the soil.	The major management activities needed should be targeted at controlling weeds and improving the porosity and permeability of the soil to improve soil conditions for easier root system development, aeration and water circulation to improve the growth and vigor of the plants. Weed control may be the major management challenge that should be seriously considered and taken care of in conservation tillage practices. Free grazing system should be strictly controlled and animals should not be allowed to graze in the field. Higher dose of nitrogen has to be applied, as mineralization of organic matter is slow in zero and minimum tillage. As the chances of buildup of perennial weeds and pests are high in this system, it is important to closely monitor and control them.
Acceptability and Sustainability	**Constraints and Limitations**
As the practice is not commonly used and there is lack of success stories with conservation tillage, certainly the level of acceptability and suitability of the practice could be very low. In order, to increase its acceptability and sustainability, it is critically important to demonstrate the comparative advantages of the practice in terms of economic and ecological benefits. The design and method of application should be done by professionals, well skilled and experienced technical people to clearly demonstrate the comparative advantages of the practice in a way it gradually changes the mindset of the farming communities about the conventional tillage practices.	In minimum or zero tillage higher dose of nitrogen has to be applied as the mineralization of organic matter is slow. The chances of buildup of perennial weeds and pests are expected to be high in zero and minimum tillage. Seed germination is lower with minimum tillage suggesting the need of using higher seed rates. The residues left on the surface in mulch tillage may interfere with seedbed preparation and sowing operations. The major constraint and limitation to promoting conservation agriculture is the long history of mind set of the entire farming communities about conventional tillage practices. Farmers consider that thorough cultivation is the best way of seed bed preparation for optimal production.

Name of the Technology: BERKEN PLOW

General Description

Berken plow is a modification of the traditional "*Maresha*" by replacing the wooden "*Digir*" with a specially designed steel wings. The tip of the plow cuts deep at the center while the wings cut shallower on left and right sides covering a total width of 35cm in one go. The name '*Berken*' means 'in layers' to reflect the layered operation of the plow. The innovative tillage system creates invisible barriers in each furrow while leaving no unplowed land thereby avoiding cross plowing. The invisible barriers (hidden bunds) retard surface runoff and contribute to reduction of soil and water losses. As a result, they enhance infiltration, recharge groundwater, increase soil moisture, and ultimately increase crop yields.

Fig 1. *Berken* plow assembled by replacing the wooden *deger*

Geographical Extent of Use

It can be used in arid, semi-arid, and humid climates; flat, gentle and sloppy areas where cultivation operation is required.

Technical Explanation

- *Berken* plow is similar to traditional plow except that it uses metal wings
- Because of its design it cuts deeper and wider while requiring lower draft power. The traditional wooden *deger* is blunt and rough thus requiring more draft power and has a tendency of bulldozing the soil.
- *Berken* has metal connecting pin but farmers can use their own wooden pin, called *tikirt*.
- On assembly, by holding tip of the wooden pole '*mofer*' exactly at the height of the yolk, the wings should be 7-8cm above the ground so that the wings cut, on the left and right sides, at a shallower depth than the plow share at the center.
- If the wings are made closer to the ground then the whole layer will be disturbed leaving the soil with no hidden bunds that would protect it from erosion. Besides, the draft power requirement will be very high.
- Unlike the traditional plow, the wings of B*erken* plow minimize soil inversion thereby reducing soil evaporation especially in hotter areas with low rainfall. When soil inversion is required farmers can use the tie ridger during subsequent tillage operations.
- Farmers can decide on the number of plowing depending on the type of soil, type of crop and level of weed infestation.

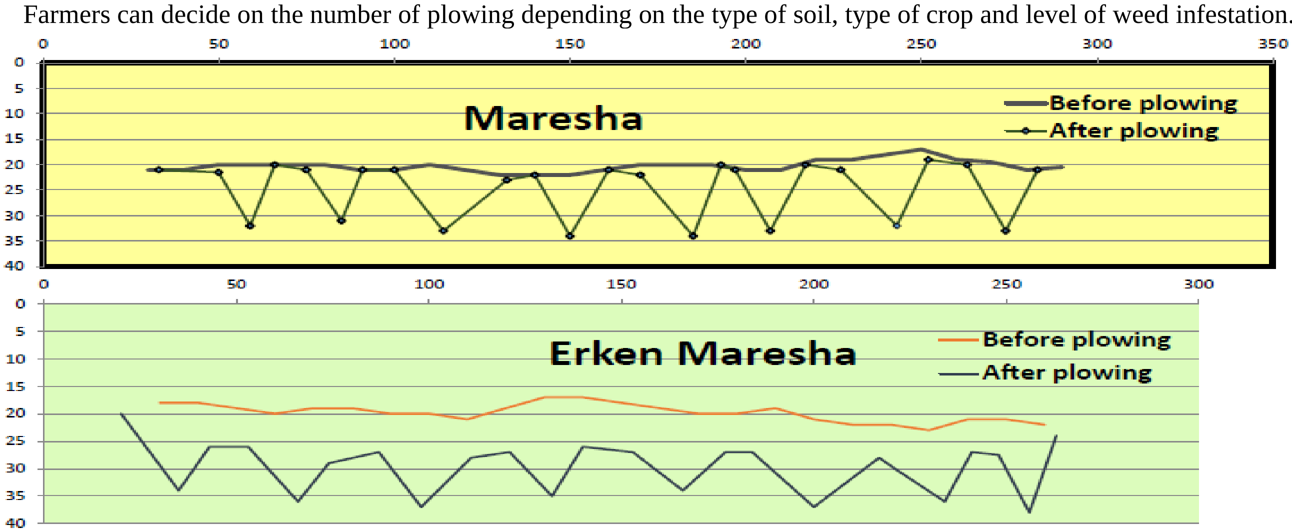


Fig 2. Profiles of land plowed with the traditional *Maresha* (top) and *Berken* Maresha (bottom)

The above two graphs display the profiles of land plowed with the traditional (top) and *berken* (bottom). In the traditional case (top), the tilled depth is shallower and also there are strips of unplowed land visible on the surface. In the *berken* case (bottom), the depth of plow especially at the center is higher with no unplowed strip left on the surface. The stepped tillage in the case of Berken has created a rough furrow bottom forming invisible barriers. These invisible barriers prevent the formation of rills by retarding the movement of water along the slope thereby reducing surface runoff and soil erosion. In contrast, the unplowed strips created by the traditional plow require cross plowing, which would be oriented along the slope thereby encouraging surface runoff and hence loss of soil and water.

Layout and Construction Procedures

- Tillage on sloppy fields is applied only along the contour
- To know the direction of the contour use techniques used in laying out soil conservation measures using simple surveying tools
- See Fig. 3 for Berken Operation

Fig 3. Picture showing *Berken* in operation

Period of Implementation Across Seasons

Can be used during times when the soil is friable. During all times when traditional cultivation operation can be carried out.

Planning and Mobilization Requirements

No special requirment is needed

Cost Elements and Work Norm

Current price of the Berken Plow is 400 Birr

Integration and Management Requirement

It can be integrated with I-bar tie ridger when water retention within the ties is required. The procedure is first we plow using *Berken* plow. Then using I-bar tie ridger assembly it is plowed on the same till line that the berken plow went on. However, on return plowing, due to the fact that I-bar tie ridger cuts wider than the *berken*, it is necssary to jump to the next furrow made by Berken (i.e. I-bar tie ridger works in alternate furrows). The two pictures, a and b display this. There are more integration benefits such as soil erosion reduction, groundwater recharging, and availing more water for dry season irrigation as stipulated under **Benefits and Acceptability** below. Ideal pictures to explain what is said in this technology /infotech, related to the difference b/n the *berken* plow and that of I-bar tie ridger are given below (i.e. Fig 4, 5, and 6).

Fig. 4. Land profile after tillage with *berken* Maresha (Invisible barriers are made visible after removing the loose soil)

Fig. 5 Tie ridger

Fig 6. Plough profile made using I-bar tie-ridger

Benefits and Acceptability

Advantages of *Berken Maresha* over the traditional *Maresha*

1. It requires low draft power
2. It reduces drudgery to farmers; It enables more women operate the plow.
3. It reduces the number of plowing
4. It avoids cross plowing
5. It reduces surface runoff thereby allowing more infiltration and increasing soil moisture
6. It reduces soil erosion
7. It increases groundwater recharge thereby improving dry season flow and making more water available for dry season irrigation
8. It reduces soil evaporation thereby improving soil moisture in dry areas
9. It penetrates deeper thereby breaking plow pan, allowing deeper root growth
10. It reduces weed population
11. It makes plowing in terraced fields convenient and increases the performance and life span of soil conservation structures
12. It increases grain yield
13. It reduces deforestation
14. It reduces clod formation

Limitations

Berken plow does not invert the soil. Hence, farmers have to use the ridger, after plowing with Berken plow, in areas where soil inversion is required.

Area Closure, Rehabilitation of Degraded Lands and Management Practices

Overview

Land users have developed over the years their own soil conservation and land management practices to control soil erosion and to maintain or improve fertility of their land. They are able to sustain their production through these technologies for centuries and still they play essential role in the agricultural productivity of subsistent farmers. The introduced Soil and Water Conservation and land rehabilitation measures started on large scale to the end of 1970s in Ethiopia. The introduction of improved soil and water conservation technologies enabled the rehabilitation of degraded lands, restoration of the disrupted hydrological balance, restoration and improvement of productivity of degraded lands in many parts of the country.

SWC practices has been expanded throughout the country since 1970s to contain the alarming land degradation problem and to reduce vulnerability to climate induced recurrent droughts and shortages of food. Area closures for land rehabilitation and management as a SWC practice has also been given due attention in the past decades. The practice of area closure and its management has become very common and important tool to the rehabilitation of degraded lands in most of the highlands. On top of land rehabilitation, the practice contributes to rural job creation by forming specific user group's to benefit from grasses, seeds generated or other products, or integrating the enclosure with income generating activities like Bee keeping, fattening, etc.

Thus, this thematic area of the guideline deals with various technologies pertaining to land rehabilitation and management practices. Each technology is described following established standard format depicted in an overview of biological soil conservation thematic area. The range of Area closure and associated

1. Area Closure
2. Re-vegetation/enrichment plantation
3. Rehabilitation and conservation of grazing lands

technologies for rehabilitation of degraded lands described under this thematic area are:

Name of Technology	**AREA CLOSURE AND MANAGEMENT**

General Description

Area closure and management in Ethiopian context can be defined as a degraded land (land not suitable for agricultural purposes such as cultivation and grazing, that has been excluded from human and livestock interference for rehabilitation with interventions for management and utilization purpose.

The inception of area closure and the experience of the management date back to the early eighties, which very much relates to the beginning of large-scale land rehabilitation and soil and water conservation program in Ethiopia. The process of area closure has been one of the strategies for rehabilitating degraded lands within the catchments delineated for rehabilitation and soil and water conservation program. However, the rate of recovery, productivity and the carrying capacity as well as the economic viability of the area closures very much depend on the appropriateness of the technological interventions and management practices. The experience of large-scale area closure management in Ethiopia proved that area enclosure is one of the most effective ways of rehabilitating the degraded lands and restoring their productivity. It increases communities' benefits from native and introduced multipurpose trees, grasses and some cash crops.

Fig 1. Typical area closure

Purpose and Benefits

The practice of area closure and its management has become very common and important tool to the rehabilitation of degraded lands in most of the highlands where land degradation has become pervasive due to the long history of agriculture, increased population pressure and poor land management practices. Area closure is not useful only for rehabilitating degraded lands, but also it is becoming a key tool for increasing biomass productivity and production per unit area that increases the carrying capacity of lands. The practice of area closure when integrated with appropriate physical and biological soil conservation measures restores the hydrological balance and productivity, stabilizes the degraded ecosystem and minimizes shortage of land, reduces pressure on adjacent potential lands, prevents siltation of water resources, flood damage to downstream farmlands, villages, infrastructures and lives; consequently it restores balance between carrying capacity and population pressure.

Agroecology

Area closure is suitable for the rehabilitation of degraded lands in most of agro-ecological zones with certain modifications in terms of its management and communities' participation. So far the most successful area closure management in Ethiopia is noted in the highland farming areas and to a lesser extent in agro pastoral areas.

Design and Method of Application

In order to protect the right of land users and to make the process and procedures of closing degraded lands fair and judicious, certain criteria have been developed and used in deciding the lands meeting the requirements. Lands considered for closure are those lands lost productivity for cultivation or grazing, often known as communal lands and characterized by loss of fertility, depletion of vegetation cover to less than ten percent, reduction of the soil depths to less than 25 cm and excessive exposure of rocks and advanced stages of gully development and eventually fail to produce any crop or vegetation at all leading to the abandonment of such lands. Hence, such lands are considered for exclusion (closure) for rehabilitation. The procedure for closure and rehabilitation should consider the community as major actors at all stages of development. Accordingly, the community should play active role in problem identification, selection of technology (development options), in reviewing and designing strategies for improvement, in developing management and administration strategies and utilization of the products. In order to minimize the problem of feed shortage for stall feeding after the closure of the land to free grazing, it is necessary to optimize forage production from other sources. This can be achieved by integrating improved forage production into farming system through the establishment of fodder banks on selected plots, intensification of forage production on conservation structures, farm boundaries, in gullies, adopting backyard forage development strategies, ley farming, increasing the productivity of grazing lands by introducing improved forage species and management practices.

Complementarities and Integration Opportunities

The vast area closures across the country should be converted into infinite sources of income, aesthetic values and treasury of human kind. These areas have proven to generate huge amount of biomass, many folds higher than before rehabilitation that can be used for livestock feed and other purposes. Moreover, these areas have become unprecedented haven of beekeeping and can be used as special place for apiculture industry. Area closure can be integrated with improved forage production and small scale animal fattening and dairy farming. The water sources from these conserved areas can be used for irrigating the downstream areas. The practice is also compatible with the protection of downstream proprieties. The downstream villages, farmlands and lives are rescued from flood damages and the tragic consequences. The communities have many socio-economic and ecological benefits, which improves their lives in their localities. These immense economic and ecological benefits can be relished and appreciated by the communities if supported by appropriate technologies and technical guidance.

Management Requirements

Absolute control of livestock interference is compulsory to get the maximum impacts of closed area management. The human and livestock interference is protected either by guards or the beneficiary households taking turn to safeguard the area against encroachment. The method of area closure management slightly varies from place to place, but in most cases the area closures are protected against encroachment by guards. In spite of the similarity of the method of protection, the level of protection and safety of the area greatly varies from place to place depending on the arrangement of assigned guards. In areas where the guards are hired on full time basis the area is relatively better protected because of the consistency in the protection. In contrast, in areas where guards are hired on part time basis, the level of encroachment is very high because of the inconsistency in the time guards are on duty. The experiences show that protection of the area closure is strict when the community is fully committed for the safety of the area and ready for backing the guards. Such commitment indeed requires support of formal regulations and actions as per the community bylaws. The community should be organized into formal groups for proper management and utilization of the closed areas and AC sustainable management should be supported by strict regulations based on the community bylaws for management and utilization. There should be close follow up, supervision and technical support from the responsible technical staffs at all levels, particularly from woreda and kebekle levels. **Work-norm for site guard is 4 person days/ha/year.**

Also it is necessary to control the competing vegetation with planted species in a 50cm radius. In general, continuous soil and plant manipulation is needed to optimize the benefits. It is also necessary to leave unplanted strips (grass strips) perpendicular to the direction of wind at certain intervals to control fire hazards. The strips left unplanted, at given intervals, to control fire hazards should always be cleared off any vegetation to make it effective in controlling the fire hazard. Moreover, the relevant teams of experts (multidisciplinary team) need to develop a management plan in consultation with the communities at the earliest possible for every area closure to optimize their economic and ecological benefits and ensure sustainability of the area closures as well as the economic benefits for the communities.

Although, there is no well-defined management plan for: deciding the proportion between grass and trees, thinning or pruning to minimize the suppression of dominant tree species and for removing weedy vegetation that suppresses the productivity of desirable species, etc. is critically important to maintain (build) the interest of the community and to optimize the level of benefits. For the first few years the vegetation (especially the grass) is often allowed to freely grow and disperse seeds and expand from the vegetative parts. When the area is fairly covered with vegetation and the risk of soil erosion is minimized, cut and carry management and utilization system is employed to ensure sustainability of the assets created. In order to maintain optimal production of the livestock feed it is essential to eliminate (replace) the unproductive species.

Acceptability and Sustainability

The value of rehabilitation of degraded lands and area closure management is well appreciated and accepted by the communities for the restoration of productivity of degraded lands and sustainable management of the natural resources in many localities in our country. However, there are external interferences and violation of the rights of user communities in some localities eroding communities' sense of ownership and sustainable management of the areas. Such interferences can seriously affect acceptability of the practice and sustainability of the assets created. But if such inferences are prevented and the communities are enjoying all the ecological and economic benefits of the practice acceptability and sustainability cannot be a challenge for the implementation and expansion of the practice.

Constraints and Limitations

Some of the social factors threatening sustainability of area closures are the traditional free grazing system followed in many places in the country and the illegal intervention of some community members, particularly in areas where there is lack of strict regulations backed by community bylaws. This is mainly attributed to the inadequate community participation and empowerment of the community for the development, management and utilization of the assets as well as lack of strict regulations backed by community bylaws. It is noted in some areas that the kebele administration overtook the decision making power and the income from sales of grass without the consensus and authorization by the communities. This is the most deleterious factor eroding communities' sense of ownership and commitment for sustainable management and should be avoided at any cost. Also the failure of adequately restoring the productivity of AC due to the inadequate use of appropriate type and mix of technologies can lead to lack of communities' commitment and interest for sustainable management of the AC. The commitment and competence of the technical staffs providing technical supports also affect the success of sustainable management of the AC.

Name of Technology	RE-VEGETATION/ENRICHMENT PLANTATION

General Description

Re-vegetation and/or enrichment plantation measures are measures applied to degraded lands that lost their vegetation cover, biomass and biodiversity with the intention to restore the lost productivity; biomass, biodiversity and vegetation cover following the treatment of the area with various moisture and soil conservation measures. Indeed, the first and foremost focus on the rehabilitation of degraded lands would be controlling the flood and accelerated run off through the construction of intensive water harvesting and soil and water conservation structures including hillside terraces, percolation ponds, contour trenches, and various micro basins on the hill sides and sediment storage dams (SS-dams) and check dams in gullies. The re-vegetation and/or enrichment plantation stabilizes the physical soil conservation structures, and stabilize degraded/fragile lands, restores and increases the biomass, biodiversity, vegetation cover and the productivity of degraded lands. These measures are made of various vegetation; predominantly trees, shrubs, grasses and herbaceous legumes applied in combination or pure in various forms for different ecological and socio-economic purposes.


Fig 1. Rehabilitated degraded lands through re-vegetation and conservation measures

Purpose and Benefits

The vegetative measures, in addition to increasing productivity, increase the biomass production and biodiversity of degraded lands. They are essential for restoring the hydrological balance, stabilizing the ecosystem and forming green environment suitable for the habitants and local agricultural system as a whole. The stabilization of degraded ecosystem and the increase of productivity and production minimize shortage of land, reduce pressure on adjacent productive lands, prevent siltation of water bodies (reservoirs) and flood damages to the downstream farm lands, villages, other properties, lives, etc. It also helps in restoring balance between carrying capacity and stocking rates as a result of increased productivity and hence carrying capacity of the degraded lands. The biomass provides substantial amount of livestock feed, fuel wood and construction materials or creates opportunity for generating income from the sales of the products. The increase in the biomass production also increases the population of wild animals and esthetic value of the environment.

Agroecology

The technology is more appropriate for areas receiving sufficient amount of rainfall for reliable establishment and survival of the vegetation. Sufficient moisture is also required for vigorous vegetation growth and vegetation cover to effectively control the runoff. Accordingly, it is applicable to many parts of the country receiving fairly good amount of rainfall for the survival and establishment of planted species. Especially Dega and Woyna Dega agro ecological zones where the amount of rainfall is sufficient and evapotranspiration is relatively low the intervention is very relevant and effective. The technology could also be applicable to dry areas where supplementary irrigation and systematic in-situ moisture conservation practiced.

Complementarities & Integration Opportunities

The re-vegetation and/or enrichment plantation measures are well compatible with the existing native vegetation and other income generation packages provided suitable and appropriate plant species are used. Depending on the interest of the beneficiary communities and soil and climate conditions right type of plant species and high value crops should be used to optimize the complementarity and integration benefits. Depending on the moisture conditions, technical supports and community's commitment for proper management, high value crops such as fruit crops, improved forage species, small scale animal fattening, beekeeping; etc. packages can be well integrated.

Design and Method of Application

In such degraded ecosystem it is much better to prepare the pit long before the planting time; the longer the period before planting, the more favorable conditions would be created for the seedlings. Thus, pits should be prepared at least six months or one year ahead of planting for optimizing the success of establishment and higher survival rate of planted seedlings. During pit preparation the top soil and the sub soil should be put separately and the top soil should be mixed with various organic materials such as crop residues and filled first in the soil and the subsoil on the top. This allows the organic matter to decompose and mix up with the soil creating conducive environment for the seedlings at the time of planting. The other factor seriously affecting the survival rate and establishment of the seedlings is the position of the planting pit and the level of the pit depth in relation to the level of harvested water in the basins (any structures constructed for water harvesting or moisture conservation). Quite often planting pits prepared at higher level (close to the surface of the land) whereas the harvested water (conserved moisture) in the structures is accumulated at much lower level from the surface and the roots of the seedlings cannot access and make use of the harvested water (conserved moisture). This is a big mistake and waste of resources; i.e. the purpose of water harvesting in planting sites is to supply adequate moisture to the growing plants and if the planted seedlings cannot easily access the conserved moisture then the efforts of water harvesting and moisture conservation are not relevant. Therefore, it is critically important to make sure that the root level of planted seedlings is in such away the harvested water (conserved moisture) gradually moves towards the root zone of the seedlings, i.e the seedling planting zone should either be lower than the harvested water (conserved moisture) level or at least in the same level. Therefore, the positioning of the planting pit and its depth in relation to the water harvesting structures should be correctly arranged from this perspective.

There are various forms of planting materials including seeds, seedlings, root splits and stem cuttings and different planting methods used for the re-vegetation or enrichment plantation of degraded lands. The forms (patterns) of planting could be dispersed or strip planting depending on the conditions of degraded lands and interest of the beneficiary communities. Dispersed planting is a planting system where the whole area is planted with the seedlings in dispersed manner throughout the closed area. Strip planting is a system where the planting of seedlings is made in alternate strips prepared in certain intervals. The size of each strip and the distance between the consecutive strips varies depending on various factors such as community needs for grass, etc. When the need for grass is high, then the size of strips would be smaller and the distance between the consecutive strips would be longer. Because of the vegetative forms like seedlings, root splits and stem cuttings are in growing process; they have more energy reserves and/or growing organs for better establishment and survival when planted out in the field. Therefore, when the vegetative forms are available and the transportation facilities and establishment costs are not discouraging, it is preferable to use the vegetative forms. However, it could be difficult to always use the vegetative forms of planting materials because of the difficulties in transportation and high transportation costs. This is especially a problem when the transportation distance is far and a large area of land is to be covered in a short period of time. Thus, under this condition it would be preferable to use seeds.

Planting techniques slightly vary with the different forms of planting materials. While the use of seed allows flexibility of broadcasting and /row planting, the use of vegetative forms of planting materials limits the technique to /row planting. The planting technique should always ensure good soil-seed/seedling contact for good survival and establishment. The details of planting techniques are available in other InfoTech's described for vegetative measures.

Species selection and composition: the type and quality of species is determined by their merits for stabilizing and rehabilitating the degraded ecosystem, meeting the multiple needs of the community and quality for increasing the carrying capacity of the land. Mono plantation is not preferred for sustainable production and protection of the environment. So, to guarantee effective ground cover, to allow under story/multi-story growth and exploitation of the physical resources (water, nutrients, etc of the soil) for maximum production, mixed plantation with various types of tree, shrub and herbaceous species is desirable. Therefore, we should go for diverse species and mixed plantation. The suitable species for meeting such requirements are given bellow for the various agro climatic zones.

Degaagro-climatic zone: Acacia melanoxilon (Omedla), A. decurrence, Eucalyptus globules, Grevillearobusta and Croton macrostachyus and Tree Lucerne, etc from tree/shrub species; Setaria and elephant grass in the lower and mid altitudes; Desho grass in mid and high altitudes.

Weinea-dega agro-climatic zone: Acacia saligna, Eucalyptus cameldulensis, Croton macrostachyus, Grevillea robusta and Leucaenaleucocephala, Sesbania species, Pigeaon peas, etc from the tree/shrub species and Rhodes grass, Guinea grass, elephant grass, Desho grass, Lablab, Siratro, etc from grasses and legumes.

Kollaagro- climatic zone: A. saligna, Azadiractaindica, Cassia Siamea, E.cameldulensis, Parkinsoniaaculata and Shinus mole, Leucaenaleucocephala, Pigeon peas, etc from tree/shrub species and Buffel grass, Rhodes grass, Siratro, Stylos, etc from grass and legume species.

Management Requirements

The first and foremost important management required to achieving the objective of re-vegetation and/or enrichment plantation is guaranteeing the protection of the site from external inference, particularly from livestock interference. Weeding, cultivation and mulching of the seedlings during the initial stage of growth (3-4 years) is an essential management requirement to optimize the survival rate and establishment of the planted species. A replanting activity to replace the failed seedlings takes place on yearly basis until the gaps are filled up. Improvement of the soil conditions is critically important to optimize productivity of the site and to optimize benefits from the introduced interventions and other complementary income generation packages. Particularly, intensive soil fertility management techniques such as soil organic matter monument and moisture conservation as well as supplementary irrigation could of paramount importance if high value cash crops are integrated to achieve the expected economic and ecological benefits.

Acceptability and Sustainability

The practice of re-vegetation and enrichment plantation in closed areas is associated with area closure management andthe acceptability and sustainability of the practice is similar to area closure management.

Constraints and Limitations

One of the major limitations in the re-vegetation and enrichment plantation of degraded lands is the slow process of the rehabilitation before obtaining good amount of biomass production to meet communities' needs. The capacity of such lands to produce biomass and vegetation cover greatly varies from place to place depending on the variability of environmental factors such as amount and distribution of annual rainfall, soil conditions, the level of degradation and the type and quality of the development intervention, etc. In areas where the land completely lost its productivity and turned to barren/rock outcrops, the rate of recovery is very low and the biomass production either from planted or naturally regenerating species is also very limited.

Name of Technology	REHABILITATION AND CONSERVATION OF GRAZING LANDS

General Description

Rehabilitation and conservation of grazing lands refers to the application of appropriate packages to the grazing lands lost productivity or having sub-optimal productivity to control the accelerated soil erosion and to increase their productivity. Grazing lands are lands delineated by individual households or by the community for livestock grazing. Most of the grazing lands in Ethiopia are excessively overgrazed; the stocking rates are too high compared to the carrying capacity of these lands. Productivity of these lands is very low because of the replacement of productive species by poor species and due to the reduction in the percentage of ground cover. Erosion damage is serious as the impact of raindrops and overland flow is very high. Grasslands generally need time to regenerate sufficiently, to provide 70 percent ground cover at times of erosion risk; but the application of this principle and practical action to mitigate the problem is missing in Ethiopia. The first and most essential approach in grazing land management is the establishment of balance between the stocking rates and carrying capacity of the grazing lands.

Purpose and Benefits

The main purpose of this particular intervention is to increase the amount of vegetation cover, quantity and quality of biomass production with aim of increasing livestock production, while ensuring sustainable productivity and management of the grazing lands. The increase in the amount of biomass production and vegetation cover also helps in effectively controlling soil erosion.

Agroecology

Grazing land management measures are applicable to all agro climatic zones with some modifications in the approach, technologies and species selected. In areas receiving high rainfall, the potential for increasing biomass production and vegetation cover is much higher than areas receiving low rainfall and moisture stress areas i.e. the success of gaining better economic and ecological benefits with the application of the measures is much higher than moisture stress areas. In moisture stress areas the level of its success very much depends on the effectiveness of moisture conservation measures and productivity of multipurpose species introduced.

Design and Method of Application

The first and most essential approach in grazing land management is the establishment of balance between the stocking rates and carrying capacity of the grazing lands. One of the development options to restore a balance between the stocking rates and carrying capacity is the improvement of productivity of grazing lands. However, there is a maximum limit beyond which productivity of grazing lands cannot be increased. After increasing the productivity of grazing lands to the optimum level, if their carrying capacity is still below the stocking rates, there is a need to consider destocking or other options for increasing forage supply from other sources. Probably diversifying the livelihood packages into non-farm activities may encourage farmers for destocking. In moisture stress areas contour furrowing can conserve moisture and reduce runoff contributing to increasing the quality and quantity of pasture production. The introduction of productive forage species and the application of manure or commercial fertilizers along with improved livestock breeds and moisture conservation measures can be beneficial in many areas. The two feasible techniques for introducing productive forage species are over sowing and strip planting.

Complementarities and Integration Opportunities

Conservation of grazing lands and the integration of productivity packages greatly increases the quality and quantity of livestock feed that makes the integration of small animal fattening and dairying very profitable and attractive venture. In addition, different grazing land management techniques also help to maintain sustainable productivity of grazing lands. These management practices include proper farm planning, early stock reduction in droughts and fodder conservation. Degradation of grazing lands is intensified by poor (inappropriate) farm planning in large grazing lands like pastoral areas. Proper farm planning such as siting of fences, water points, and gates to avoid stock concentration in erodible areas, can greatly reduce the risk of soil erosion.

Management Requirements

Freeing grazing lands from livestock interference at certain period of the year is critically important to maintain the productivity and sustainability of grazing lands. Resting is a very important management strategy to prevent grazing lands against degradation and to maintain their productivity. Plants have three growth stages: early period of slow growth; middle period of rapid growth; and final period of slow growth. The early period of slow growth is often a period when plants start to grow with the onset of rains after long dry season in which the plants are overgrazed and lost vigor. The plants start growing slowly until they form enough ground cover mainly because of the limited energy reserve in the plant parts and limited amount of ground cover intercepting the solar energy for photosynthesis.

Allowing animals to graze early in the growing season, or after fire, will deplete the pasture energy reserves. After seven or eight weeks of growth, grazing would have little effect. During dry season the plants remain dormant and maintain their energy (food reserves), which helps them for regeneration at the onset of rains. Thus, grazing during the dormant period does not affect the survival of plants as it does at the onset of rains. The onset of rain is a critical period for plants survival and it is a period when

most plants disappear as a result of over grazing. Therefore, it is critically important to protect livestock interference during this particular period. Improved grazing management systems shall be incorporated (Controlled grazing, rotational grazing cut and carry etc.)	
Acceptability and Sustainability	**Constraints and Limitations**
As it is true for any practice, lack or inadequate knowledge and awareness of the benefits of this practice can pose challenge to the acceptability and sustainability of the conservation of grazing lands. This requires prudent design and implementation of the practice in away the beneficiary communities witness clearly the benefits and advantages of realizing conservation of grazing lands.	Poor livestock management practices, particularly the free grazing system and overstocking and hence overgrazing have been identified as the major causes of grazing lands degradation. The inadequate and infrequent practices of resting grazing lands often led to the depletion and gradual disappearance of productive species leading to the replacement of productive species by weedy species. The limited availability of improved livestock breeds and improved forage species often does not encourage the farmers for holding smaller number of livestock and stall-feeding. This calls for addressing the root causes of the problems by introducing innovative technologies remunerating farmers with economic benefits. The practice of stall-feeding (zero grazing) can be realized if biomass production from forage trees and shrubs, herbaceous legumes and grasses from different land uses (closed areas, grazing lands, croplands, stabilized gullies and homesteads), intensified and readily available for the livestock feed. In line with the improved livestock management practices, improved breeds (if possible) need to be introduced to guarantee higher economic returns.

Agro-forestry Practices

Overview

Agro-forestry is an integrated approach of using the interactive benefits from combining trees and shrubs with crops; sometimes it includes livestock as its component. It requires both the agricultural and forestry technologies to create more diverse, productive, and sustainable land-use systems important to secure food and nutrition availability at local to national scale. Although there are various definition of the term agro-forestry, one that is commonly used by the World Agro-forestry Centre: *"Agro-forestry is a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos etc.) are deliberately used on the same land management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence"*. In agroforestry systems, there are both ecological and economic interactions between the different components.

All agro-forestry systems are characterized by three basic components namely, the woody perennials (trees/shrubs), the herbaceous plants (crops, pasture species), and the animals. More importantly, the woody perennial tree should have more than two benefits (i.e. fodder, food, timber, etc.). Owing to the variety ofmixtures,it is a more complex system in both ecologically andeconomically than a mono-cropping system. The aim and rationale of agro-forestry lieinoptimizing production on available land based on the positive interactions between the components introduced in the system and their physicalenvironment. In general, agro-forestry is advantageous over conventional agricultural and forest production methods through increased productivity, economic benefits, social outcomes and the ecological goods and services provided. Moreover, biodiversity in agro-forestry systems is typically higher than in conventional agricultural systems and has the potential to reduce land degradation through reducing soil erosion and climate change impacts through stocking atmospheric carbon dioxide for longer time-span.

The most common agro-forestry practices consider as info-tech are presented as follows;
The practices included here are just a few among the diverse Agroforestry practices that exist in most parts of Ethiopia. A brief description of the agro-forestry practices presented as info-techs are:

1. Tree Seed Collection
2. Quality Tree Seedling/Germ-plasm Production and Nursery Management
3. Home garden agro-forestry Practices
4. On-farm Tree Integration and Management Practices
5. Woodlot Establishment and Management
6. Tree Seedling Planting & Post Management Practices
7. Vegetative /Live Fencing
8. Bamboo Development

Name of the Technology: TREE SEED COLLECTION

General description

- Trees are propagated either vegetatively or from seeds. Seedlings can be produced either from natural regeneration or artificially from seeds in the nursery. Those types of trees that can be propagated from coppices, root suckers etc. also can be reproduced from seeds in the nursery and hence require seed collection, handling and proper management.
- Seed collection needs careful selection of mother trees because the nature of the trees affect the quantity and quality of products obtained from the tree. The best seeds come from strong and healthy parent trees. In general, good seed produces good tree. Quality seed implies a seed that is highly viable, vigorous and genetically well suited to the site and the purpose it is intended for.
- In most cases propagation by seed is the easiest and cheapest method for multiplying and expanding various tree species, while the vegetative propagation method can be a good method of propagation of tree species, but it may be costly to transport large quantity of vegetative materials to distant places.
- **Seed collection is divided into two:**
  (1) **Seeds of tree species**: mostly for indigenous trees to grow in nurseries for specific and multipurpose uses.
  (2) **Legume, shrubs and grass seeds**: can be used for stabilization, homestead plantations, grazing lands improvement, support to nurseries, fencing, gully control. This activity is especially valuable for grass seeds collected outside the nursery areas and seed multiplication centers, particularly native grasses of particular value for their palatability and adaptation to local conditions.
- Valuable seeds can be collected and networked between woredas and regions. The collection of local seeds is an effective way to protect valuable planting materials from extinction and to replenish depleted areas with materials collected from other areas.

Fig 1. Seed collection

Geographical Extent of Use

Seed collection is applicable to most of agro ecological zones preferably where diverse and large number of the required species exists. Under Ethiopian conditions moist and warm middle altitude appears the most suitable area for seed collection because of the accumulation and existence of naturally growing dense and diverse forest species. Diverse and large quantities of artificially grown tree species existed in urban and rural areas in different agro ecologies are also potential areas for seed collection.

Technical Design Requirements

The genetic quality of the parent tree species is an important consideration in seed collection because of characteristics such as fast growth, tree form, and resistance to diseases and insects can be passed on from the generation to the next. Therefore, seeds should be collected from mature good mother trees. Thus, collect seeds only from healthy and vigorous trees of reasonably good form, middle aged to mature trees.
Seeds should possibly be collected from dominant or co-dominant trees, which are better both in form and height than the existing trees.

Avoid seed collection from:

→ Young or over-mature trees, because of the seeds from those trees have low viability;
→ Trees that are crooked, deformed, abnormal growth, diseased and infested by insects;
→ Isolated trees, as they tend to self-pollinate; seedlings from those trees are either weak or malformed.

Seeds and fruits can be collected by:

→ Hand picking from a standing tree shrubs and trees that have low branches;
→ Cutting the branches that bear the seeds or fruits with the help of long pruning saw and collected from ground;
→ Climbing up the tree, or shaking trees to collect seeds by laying canvas on the ground.

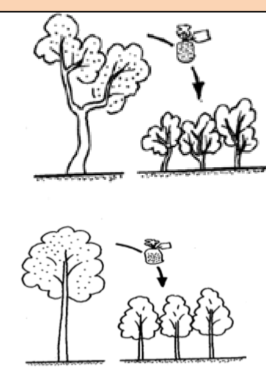


Fig 2. Avoid crooked trees

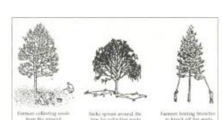


Fig 3. Seed collection methods

Period of Implementation Across Seasons

Seeds must be collected when they are ripe and ready for collection. Seed maturity can be detected easily for fruits and cones by their color. Most fruits turn yellow, red, brownish etc. (depending on their nature) when they are ripe enough. In the field, change in the color of the fruits and its readiness to fall are important methods for deciding the period of seed collection. Other methods like seed shape and size, moisture content, specific gravity, etc., can also be used. Fully ripened fruits can be picked directly from the trees or collected immediately as they fall. Seed bearing of trees/shrubs may not be regular every year. Since a good seed year is usually followed by a bad seed year in many cases, it is wise to make advantage of good seed year for collecting as much seeds as possible and use them during bad seed years.

Planning and Mobilization Requirements

Seed collection can be integrated with forest conservation and biodiversity management program. Probably integrating seed collection as a means of income generation program with the conservation and management of Ethiopian natural high forests could be a great opportunity for successful conservation and protection of these forests on sustainable basis. In this case, regions or woredas can facilitate the organization of farmers or user groups to undertake seed collection on contractual basis for the government or private company or other development agencies. Local government can play catalytic role in the arrangement of seed collection by private companies or development agencies in organizing and training farmers or user groups and linking the two parties deliberately to create an employment opportunity for the community as well as to create conducive environment for natural forest conservation and protection. Moreover, seed collection can be integrated with beekeeping practices. The government can play facilitation role in organizing farmers or user groups and provide the required trainings on technologies, inputs, credit and technical supports to launch beekeeping activities.

Cost Elements and Work Norm

The work norm involves: Selection of healthy and vigorous mother trees, collection of tree seeds at proper time; seed removal from pods or cover (threshing), drying, and seed extraction and removal of impurities (cleaning), bagging and storing.

- → **Tree seed collection:** Work norm is 20 PD/kg. Only exception is for *Grevillearobusta* for which the work norm is 60 PD/kg of clean seeds.
- → **Grass/legume/other seeds collection (closures, bunds, etc.):** Work norm: 10 PD/kg of grass seeds and small legume pasture seeds (does not include pigeon peas).
  - Seeds differ in size and weight and a standard work norm is of difficult application.
  - Woreda experts can take this norm as average for different seeds and adjust to reach the maximum indicated in the work norm.
- → **Materials and equipment required include:**
  - **Labels:** Give each collection a batch number, cross referencing these to records on: location/conditions of the tree and site, date, quantity, quality, etc.
  - **Containers:** Open weave sacks (polythene or hessian) are ideal for larger seeds/nuts. Polythene sacks (co-extruded) are useful for berries/wings. Paper bags can be used for smaller seeds (birch/alder).
  - **Gloves:** To hold thorny blackthorn, hawthorn branches, etc.
  - **Stepladder:** Preferred to pruners as hand picking minimises destructive seed collection. Pruners "Snip and grip" type are especially useful.
  - **Rakes/shovels:** For raking up larger quantities of seeds (beech mast, acorns, etc).
  - **First aid:** They help to ensure a safe and enjoyable days' work.
  - **Mesh sieves:** Different gauges to allow seeds to pass through/sieve out rubbish.
  - **Buckets:** To clean off seeds and float off residue/unviable seeds (remember not all floating seeds will be unviable! So separate them, but retain).
  - **Hose:** A high-pressure nozzle assists separation of pulp and seed.
  - **Aerated and dry store**

Management and Maintenance

The collected seeds need to be dried to the required moisture content prior to storage. Therefore, the collected seeds must be spread over canvas or mats for drying in the sun and air. During the drying process, turning over the seeds until they are fairly dry is necessary. To separate some seeds from their fruits, threshing and winnowing may be required. After the seeds are well sorted, they should be packed in sacks or bags and stored in a dry place. Seed processing may require also extraction from the fruits or pods and drying them before sowing. If seeds are enclosed in a fleshy fruit, remove the flesh with knife, wash off the rest under water and sow the seeds immediately. For seeds in a seed pod, such as *Luceanaleucocephala*, let the pods split open naturally by laying them in a semi-shade place. Similarly for other fruits with hard coat, drying them in semi-shade or gentle cracking could be applied.

A seed store needs to be free from moisture, a well-ventilated and raised bed and free from pests. In order to keep the seed cool, storage along a wall facing a southwesterly direction should be avoided since this wall tends to be warmer than the other walls during the afternoon. Also seed should not be stored too high in the building because hot air will concentrate under the roof. The sack, jars, or boxes with the seed must be placed in such way that air can circulate around each container. For this purpose shelves can be placed in the store.

Some seeds can be dried to low moisture content of about 5% and be stored successfully at low temperatures. Others cannot survive drying below 20 - 50% moisture content. Therefore, seed storage requires the knowledge of the nature of the species. Several species of leguminous and others have high longevity (surviving for long years), For example, seeds of *Acacia, Albizia, Cassia, Leucaena, Prosopis, Hibscus*etc, can be successfully stored for more than 20 years.

Benefits and Acceptability

Seed collection and use on large quantity is not commonly practiced by farmers in Ethiopia. Some farmers may collect limited amount of seeds that have high economic value, such as Eucalyptus species, for their own consumption.

Large amount of seed collection is mainly performed through government organizations for the establishment of artificial forests or for the rehabilitation of degraded lands, through FFW/cash payments or on voluntary basis. Some private companies sub contract the task of seed collection to supply seeds for government and some development agencies. Therefore, acceptability and sustainability of seed collection in large quantity cannot be expected from farmers for their own consumption at this moment.

Limitation

The limited knowledge and skills for collecting good quality seeds by farmers' are the major limitations. Less attention had been given for seed collection by the government, and seed collection has been carried out by local farmers based on traditional knowledge. Securing good quality seeds for seedling production was a serious limitation in most places. Moreover, only seeds that can be easily collected by farmers (e.g. *Eucalyptus*) were used for seedling production and re-forestation program. This limitation has been one of the major factors for the limited propagation and plantation of indigenous species and for the rehabilitation of biodiversity in many areas

Name of the Technology	QUALITY TREE SEEDLING/GERMPLASM PRODUCTION AND NURSERY MANAGEMENT

General description

Plant propagation is the process of creating new plants from a variety of sources: seeds, cuttings, bulbs and other plant parts. Plant propagation can also refer to the artificial or natural dispersal of plants.

Vegetative propagation is a form of asexual reproduction in plants. Asexual propagation or reproduction from vegetative parts of the original plant is possible because every cell of the plant contains the genetic information necessary to regenerate the entire plant. Reproduction can occur through the formation of adventitious roots and shoots or through the uniting of vegetative parts by grafting or budding. The simplest method of propagating a tree vegetative (non-sexually) is rooting or taking cuttings. The most common method of propagating fruit trees, suitable for nearly all species, is grafting or budding the desired variety onto suitable rootstocks.

A **Nursery** is a place where seedlings are propagated, managed and grown to plantable size. To ensure a good planting programme, good nursery stock is essential.

Geographical Extent of Use

It can be established in all agro-ecological zone, but the type of tree species and growing media type should meet the local specific condition.

Technical Design Requirements

Prepare the sowing beds and soil media preparation:

- The seeds should be sown in sowing beds.
- The sowing beds can be made from bamboo, wooden boxes or directly on the ground.
- The media consists of top soil, compost and sand
- The thickness of the media is 6 – 10 cm.
- The function of media is to assist the growth of seedlings. Media should support a healthy root system with enough oxygen, nutrient, and water.
- Type of mixed media is forest soil, topsoil from the garden, sand soil. Mostly use site-specific recommended soil mix ratio.

Pot filling

- This is the filling of polythene tubes with soil. This should be done under a shade near the heap of the soil at the site of the transplant bed. The soil should be moist enough to run freely into the tube and easily firmed to form the bottom of the tube (The way of pot filling)

Layout and Construction Procedures

Seed Sowing: There are three different sowing methods:-

- **Broadcasting:** this is spreading seed on top of the growing media either by hand or mechanical broadcast. Mostly used to small size seeds like *Eucalyptus glublous.*
- **Drill sowing:** it is sowing seeds by making drills in the soil, then seeds are linearly dropped in and lightly covered with soil. It is used when the seed is old or when the germination is unknown or low.
- **Direct sowing;** it is sowing seeds directly to the soil. When large size seeds are directly sown into the container or to the field.

Transplanting: is the process of transferring the seedling to polythene bags.

• The transfer will be done when the seedlings have two true leaves fully open
• If the transfer is delayed, the rooting structure will be affected
• Use a piece of wooden stick to remove the seedlings and place the seedlings on wet containers (could be banana leaves or plastic containers).

Layout and Planting Procedures for Vegetative propagation/Grafting

Grafting is a form of vegetative propagation, which involves the union of two separate structures, usually woody parts of two plants. The common parts which can be used for grafting are usually the stem. .

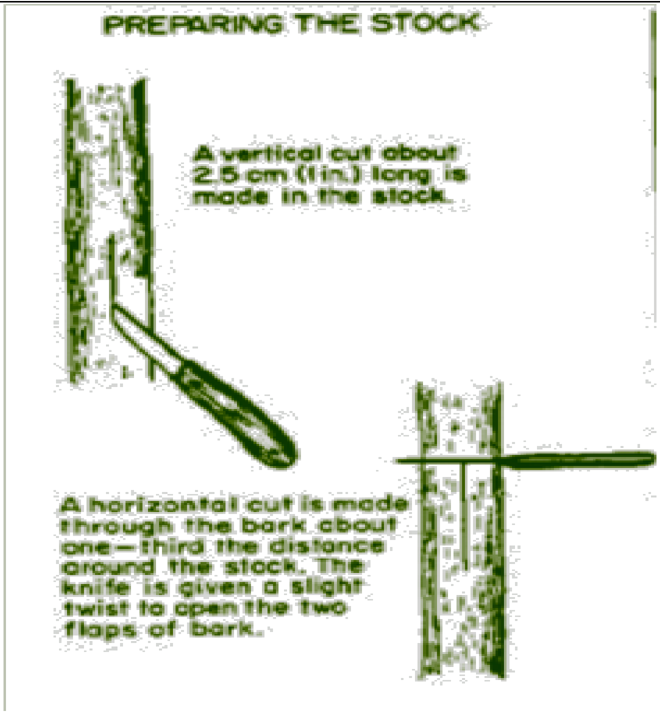
Selecting rootstocks and Scion: Rootstock can be raised from seed and must be a variety well adapted to the soil and environment where the grafted trees will be planted e.g. must withstand drought in dry areas or tolerate waterlogged soils in valley bottoms. Scion is obtained from the outermost branches of donor tree. The terminal parts should be well ripened. The branches selected should be vigorous with no pest infestation and there should be several well-developed buds. The buds should be swelling slightly but not actually busting. The diameter of the scion should be about the same or slightly smaller than that of the rootstock. To ensure the compatibility between rootstock and the scion, they must belong to the same plant species or to the same family

The requirement for scion selection: Quality of the fruits, productivity, early or late maturity, resistant to pests and diseases of the aerial parts, the shape of the tree canopy

I. Grafting methods:

1. Top/wedge grafting: This method consists of splitting the rootstock lengthwise and inserting the tapered scion into the cleft.

Steps to be followed:



1. Harvest scions from the desired mother tree and cut them about
   15cm long. Remove all the leaves carefully. The scions should be the same thickness as the rootstock stem. With a very sharp knife cut the bottom of the scions with two sloping cuts 3½cm long (A).
2. Cut off the top of the rootstock about 30cm above the soil. Make one straight cut about 3cm deep in the top of the rootstock (B) to form a wedge. Bind the two parts tightly together using a transparent plastic tape. Push the scions firmly into the rootstock cut. Leave ½cm of the cut scions outside the rootstock as shown.
3. Use clear plastic tape to wrap firmly around the graft. Do not remove the tape until the scion begins to grow – showing the graft has been successful.
4. Remove any buds which have grown below the graft.
5. The tape can be removed after the scion and the rootstock has been united.

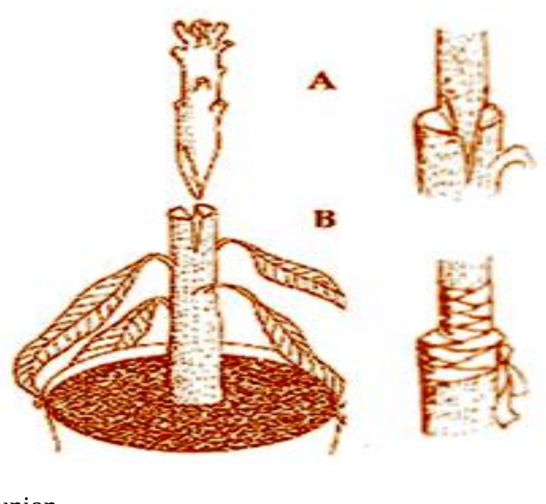
II. Splice grafting

In this method side joining of the scion and rootstock is done**.**

Steps to be followed:Select a rootstock of about the same size as the scion,cut the end of the rootstock in a slanting way as the lower end of the scion, place the scion against the slanting cut of the rootstock and cover the union with a wrapping tape that holds the scion firmly and binds the two plant parts together, cover the scion with a transparent plastic bug up to a point below the joint of scion and stock, put grafted plant under a shade (locally made), water regularly, remove polythene bag when new leaves appear on Scion

III. Budding

This is the technique of inserting a scion in the shape of a shield under the bark of the rootstock. In case of budding the scion part has only a single bud. The shield is a small slice of the shoot with a bud in the center. The shield is cut in such a way that it bears a bud, a piece of bark and cambium and a small tongue of sapwood.



Steps to be followed: Make a T shaped incision in the bark of the rootstock, cut the shield-shaped portion of the shoot with a bud (i.e. cut from the node). Cut off the leaf but leave a stub of the stalk, lift the edges of the incised bark of the rootstock, insert the bud shield between sapwood and bark. Never touch the cut part of either the rootstock or the scion shield, the bark of the rootstock is flattened back round the bud, tie the grafted part with a transparent polythene tape but leave the bud uncovered, put grafted plant under the shed, water regularly, when the bud starts to grow, cut off the upper part of the rootstock 1-2 cm above the point of union.

Managing Grafted Seedlings:

1. Grafted plants must be shaded and watered until the scions have taken off completely
2. Systematically remove all the shoots growing below the grant union

Period of Implementation Across Seasons

Time of tree Seedling production should be before the rainy season to ensurethat quality seedling can be accessed for planting in the rain season. Always graft in the rainy season when the trees are full of sap and the bark of the rootstock plants and the scions can be lifted easily. The rainy season is also the time when the cambium layer is most active.

Cost Elements and Work Norm

Depending on the conditions in your nursery, including the tree species (size of the seed), a number of plants to be produced, a method of production and labor availability will determine seedling production cost. For instance, direct sowing of seeds into containers saves time, labor and money, because the extra step of preparing a seedbed and transplanting is eliminated.

Management and Maintenance

There are several recommended operations and integrated activities while carrying out proper tree seedling production which includes:

Watering: The regular supply of clean water is essential to plant growth. Plants are made from more than 90% water. When grown in containers plants do not have an ability like matured trees to search for water from far below the soil surface.

The amount of water that seedlings require depends on seedling age, amount of sunlight, soil type and presence of wind turbulence. Remember; Overwatering weakens plants and causes many diseases. Avoid dirty water as it contains many plant diseases.

Weeding and Nursery hygiene: This is the operation of removing weeds in order to reduce competition for water and nutrients. Good hygiene of the nursery site will lead to healthy and quality seedlings produced in the nursery.

Root pruning: Is the cutting back of the actively growing roots of the transplants. Root pruning is carried out to avoid the roots of the seedlings intertwining, to enable the transplants to develop a well-established root system fit for the easy establishment in the field and for the transplants not to penetrate the soil and get established within the nursery site.

Hardening off: This is the process of creating hard conditions to the seedlings towards the planting season. This can be done by reducing the amount of water before seedlings are planted out.

Benefits and Acceptability

This practice is very promising and profitable business, especially for landless youth and women group.

Limitation

It requires higher establishment cost and qualified person for quality planting material propagation.

Name of the Technology	HOME GARDEN AGRO-FORESTRY PRACTICES

General Description

Home garden Agro-forestry practiceis a way of planting a mixture of crops, shrubs, and trees of different type and uses, including food crops, cash crops, fruit trees, woody perennials, and forage plants. It makes the land more productive and improves soil fertility, reduces temperature, provides shade, and increase family income, particularly during a period of drought.

Home gardens can be found in many parts of southern and South western regions of Ethiopia. Crops such as coffee, enset, pepper, and numerous kinds of vegetables are dominant components of the Ethiopian home gardens (Getahun 1988). Trees like Cordia Africana, Militia ferugenia, Albizzia gummifera, Ficus species, and Acacia species are among the species that form the upper storey of home gardens. The species diversity and structural complexity of Ethiopian home gardens agro-forestry practices varied from place to place. For instance, Gurage home garden agro-forestry practices mostly have two strata with Enset home-compound farms.

Home gardens supply much of the basic needs of the local population and help reduce the environmental deterioration. However, research and quantitative information on Ethiopian home gardens are in its infancy, with the exception of a few quantitative and descriptive studies.

Fig 1. Gedeo area home garden practices

Geographical Extent of Use

Homesteads are the primary suitable location to start new HGAgfP, for both day-to-day management activities and to protect fruits and other produce. Agro ecologically, sub-humid and semi-arid areas with rainfall above 600 mm are most preferable. However, HGAgfP is also possible in a drier location, especially if the area is located close to a water source and integrated with irrigation (drip, hand dug wells, etc). In Ethiopia, HGAgfPis common in Sidama, South Omo, and Gedeo areas

Technical Design Requirements

Select the area.

A well-drained site with soil depth not less than 50-100 cm and slope < 5-8% is preferable. Following site selection, it is important to decide the weather is appropriate for agroforestry practice in the area based on community need and their willingness or capable of adopting a Home garden practice.

Identify required tree and crop species to establish Home Grown Agro-forestry Practice site: The selection should strictly consider species agro-ecological ranges.

- Chose the major fruit trees that can grow and produce quickly and potential sources of income, for instance: mango, avocado, coffee, lemon, guava, castor oil, papaya
- Choose the multipurpose trees which can provide more than two benefits, such as for poles, post, timber, fuel wood, fodder, leaves for vegetables and medicines, for example, leucaena, cassia, neem, cordia, etc.

Characterize the minimum space requirements, water and fertilizer needs, and shade tolerance of the desired crops

Spacing guides for planting selected trees and crop species: The recommended spacing varied from species to species, such as for Mango, Avocado, and Guava is 6m*6m or 8m*8m and for papaya is 3*3 m. For Timber tree species, 5 x 5 m is recommended. However, if future thinning is considered the spacing for timber trees species can be reduced to 2.5 x 2.5 m. The suitable spacing for fodder shrubs planted in a row is 30 to 50 cm. Widely used spacing for common crops (cm), such as for maize 75 x 25, beans 30 x 15, potatoes 75 x 30, cabbages 60 x 60, tomatoes 60 x 60, carrots 30 x 30, rice 10 x 10 between raw and plant respectively. Moreover, caution is needed on the selection of species that may shade or compete with crops and reduce yields.

Layout and Construction Procedures

- Plan the proportion of the permanent fruit and lumber trees on the basis of relative importance to the farmer.
- Plan the spacing of long-term trees on the basis of final space requirements.
- Plan succession of annual and perennial understory crops, including crops for soil protection and enrichment.
- Adjust planting plan to place shade tolerant crops in most shady areas.
- Always keep the ground covered to reduce water loss and protect/reduce soil erosion.

Try the system on a small scale first.

Period of Implementation Across Seasons
Home Garden Agro-forestry Practices can be implemented all year round but the frequency depends on the availability of input, water, and labor.
Planning and Mobilization Requirements
Decide whether agro-forestry practice is appropriate based on on-site suitability, community needs and willingness/capable of adopting a Home garden practice. List the potential benefits, and their relative importance, of home garden agro-forestry practice in the area.Find the limiting constraints such as disease infestation, yield quality, and marketing. Technical preparedness needed
Management and Maintenance
• Compost making, half-moon, and eyebrows basins to support the growth of trees and any other activity enhancing fertility are recommended. • Integrate with irrigation when the annual rainfall is under 600mm rainfall • Perform a thinning and/or pruning when needed to reduce competition for nutrients, water,and light. The management methods differ from one species to another. Generally, tree canopy is cut at 20-50cm from the ground cover and will allow rejuvenating for the next six months
Benefits and Acceptability
Home garden AF practices provide several benefits including: ▪ Provision of food, fodder, construction materials, fuel, and shade; ▪ Improved year-round production of food and useful and saleable products; ▪ Improved year-round use of labor and resources; ▪ Reduce soil erosion and improvement of soil fertility (when legumes are included) ▪ Increased efficiency in the use of land; ▪ Short-term food production offsetting cost of establishment of trees; ▪ Furnishing of shade for vegetable or other crops that require or tolerate it; ▪ Medium and long-term production of fruits; ▪ Long-term production of fuel and timber ▪ Mitigate climate change through stocking willing or capable of adopting a Home garden practice.
Limitation
The most common limitation of HGAfP is the interaction effect among components, such as competition for light, water, or soil nutrients. However, Interactions between components of the home garden are often complementary. In a practice with trees and with livestock, the trees provide shade and/or forage while the animals provide manure. More importantly, the negative interaction effect can be reduced through careful selection of species and good management of the system.

Name of the Technology	ON-FARM TREE INTEGRATION AND MANAGEMENT PRACTICES

General Description

Trees on the farm are one of the forms of agro-forestry systems where trees are dispersed widely, either spaced systematically in a grid or scattered at random. On-farm trees integration is an old practice in many parts of Ethiopia and indispensable to sustain a green cover on the land throughout the year, increasing food and fodder production sustainably to improve the livelihoods of smallholder farmers and to sustain the natural resources upon which they depend

Geographical Extent of Use

This practice as one form/type of Agro-forestry is applicable to most of the Dega, Woina-Dega and Kola agro-ecologies. There are numerous multipurpose tree species that fit to the context of the various agro-ecological zones of Ethiopia.

Fig 1. On-farm trees integration

Technical Design Requirements

- Characterize the farming system and land management in consultation with farmers. Select contextually/agro-ecologically suit tree species having a minimum or zero competition with crops. These include, trees having a deep rooting system; light shade; ability to improve soil through nitrogen fixation; no tendency to harbor crop pests and provide multipurpose services and functions.
- Training or create capacity and knowledge of farming communities on the selected trees and their management and tending operations
- Encourage and manage naturally grown indigenous species as per their pattern and growth habit
- Moisture and soil fertility are the key challenges in dry land areas of Ethiopia. Thus, constructing moisture harvesting structures like large pits and/or circular basin across moisture-stressed arid and semiarid areas is necessary. If possible addition of compost/fertilizer helps a lot.
- For waterlogged areas, construction of drainage systems and/or use of raised planting bed/pit is important for better survival and growth of planted seedlings/seeds.

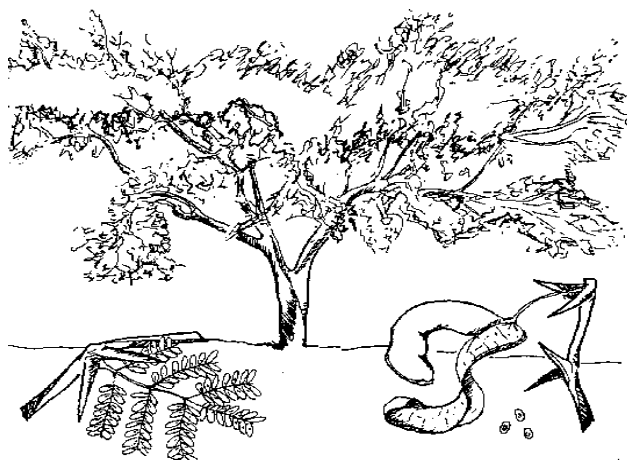


Fig 2. Trees of deep root, less light shade, nitrogen fixing, less harboring of crop pests, and multipurpose uses

Layout and Construction Procedures

- The layout and establishment of trees on the farm could vary on the type of techniques to be applied. The methods of establishment on the farm could be either through using direct seeding; seedlings grown in nurseries; natural regeneration or a combined way.
  - ✓ **Direct sowing:** In field direct sowing is especially good in relatively moist areas. Direct seeding of 1-2 seeds to the pits should be undertaken early in the rainy season, to allow as much time as possible for the plants to establish before the dry season.
  - ✓ **In the field through Assisted Natural Regeneration (ANR):** ANR is a very rapid, low cost, easily replicable and sustainable method of degraded landscape restoration. It

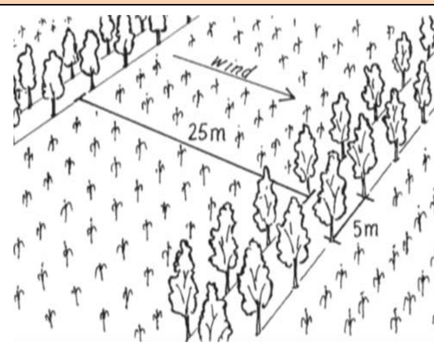
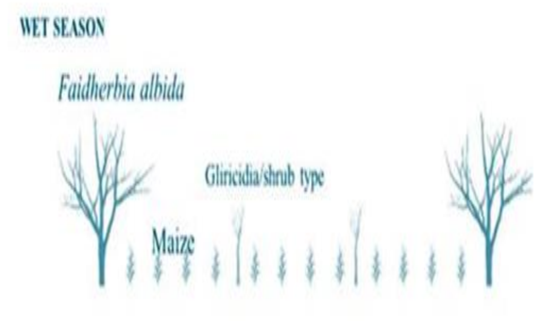


Fig 3. Establishing trees on farms.

involves selective thinning and pruning of re-growth from stumps, roots or seeds of any species coming out from the ground. ✓ **Seedlings growing in nurseries**: For this technique, prepare planting pits at least two weeks before planting, most preferably on row bases (e.g. 25m between rows and 3-7m between plants) in east-west direction to minimize shading effect to crops during the raining season or apply any relevant and proper silvicultural techniques (pollarding/lopping/pruning).	 Fig 4. Establishing Gliricidia /shrub type on farms

Period of Implementation Across Seasons

This varies as per the agro-ecological zones, resources availability, a method of application and farmers' willingness. Usually, direct seeding is undertaken early in the rainy season, to allow as much time as possible for the plants to establish before the dry season. Direct sown seedlings should be watered at about five-day interval for two or three times or till it gets well established.

One and more years seedlings will be the better establishment, but in the Ethiopian context, in most cases and for most tree species 6-9 months seedling age could be Okay for planting early/during the raining season. Assisted natural regeneration can be done throughout the year but activities, like thinning and pruning, should be conducted before the start of the raining season.

Planning and Mobilization Requirements

Farm enclosure/ex-closure is the key decision to promote trees on the farm as livestock and human encroachment. Thus, clustered based community movement is highly advised to create tree-based farm integration.

Cost Elements and Work Norm

Cost elements are similar to tree seedling planting PD that applies to this particular technology.

Management and Maintenance

Cultivation including weeding, watering and protecting from external factors like grazing is must in the early stages of trees. In addition to the selection of proper trees species, having proper design and pattern of trees on a farm like keeping the desirable spacing (scattered, in line, and in blocks) will also help to strengthen the advantages offered by the trees, while reducing the disadvantages. This can be done through various management techniques, mainly by applying the silvicultural techniques (pruning, lopping, controlled harvesting, pollarding).

- ✓ **Pruning:** it is the removal of branches from the lower part of the tree crown with the aim to reduce shade for crops near the tree; early harvest of branch wood for fuel or other use and to reduce competition and enhancing the growth of selected ones.
- ✓ **Lopping:** Lopping is cutting of branches randomly from the leafy crown. Also lopping is not always done starting from the lower part of the tree but can be more haphazard. If any selection of branches is made, the main criteria are often a good green leafy biomass since the lopping is usually done to obtain branches for fodder. This is mostly also common when trees are grown in rows in farmlands.
- ✓ **Pollarding:** It is the cutoff of all the branches and the top part of the trees with the main objectives of early harvest of wood and fodder production and reduction of shade for crops.

Moreover, the following management measures are important to consider in trees grown scattered in croplands:

- ✓ Weeding and cultivation at seedling stage
- ✓ Manuring if necessary at younger age
- ✓ When the stocking is more than necessary, thinning should be undertaken (removing inferior ones considering the spacing)
- ✓ Protection against termite attack
- ✓ Replacement planting

Benefits and Acceptability

In countries like Ethiopia, the integration of trees on agricultural Land scape could have various benefits. These include:

- ✓ Increase the yield and productivity of food crops;

- ✓ Regenerate soil fertility which is declining in many cases and make farming systems more resilient to stress and enhance Food and feed production on farms
- ✓ Increase energy supply and diversify farm enterprises
- ✓ Increase the farm asset base
- ✓ Carbon sequestration and changing microclimate

Fixing nitrogen from the air and bringing up water from a depth

Limitation

The technology mainly suffers from damage due to free grazing prior to gaining the required stand and no permanent protection made by individual farmers.

Name of the Technology	WOODLOT ESTABLISHMENT AND MANAGEMENT

General Description

Woodlot is an area entirely set aside for trees establishment. Woodlot can be establishedby planting selected tree seedlings or direct seeding, depending on tree species. *Acacia mearnsii* can be directly sown, and so can eucalypts, but the latter are difficult as the seeds are very small.

The overall objective of woodlot establishment is to create a healthy environment while providing fuelwood, timber, construction pole and wood pulp or carbon sequestration benefits. This is achieved by correct choice of species (matching species to the site), adequate ground preparation to support rooting and nutrient availability, control of competing for vegetation, proper pitting, spacing, and planting. In general species and site, machining remains very essential in woodlot establishment. Woodlot must be economically viable, socially acceptable and ecologically sustainable (Evans and Turnbull, 2004).In small-scale farming areas, woodlots are often very small, 0.1 hectares or less. Large-scale farms may have woodlots of many hectares.

Fig 1. E. globules woodlot in south wollo

Fig 2. Newly established E. globules woodlot

Geographical Extent of Use

This technology can be applied in different agroecology preferably in areas that have better rainfall distribution on both private and communal land with existed by law. In arid and semi-arid areas, woodlot plantation early growth should be complemented with supplementary irrigation particularly in the dry season.

Poor land that cannot be used for anything, but trees are primarily recommended for woodlots. In some areas, however, tree production may be as profitable as crop production, so it would be justifiable to establish a woodlot on good land where the trees will grow fast. In most part of the country, e.g. SNNPR, some farmers have opted to grow a tree on their small farms because the economic return is high compared to crop production. When discussing the location of a woodlot, transport requirements must be borne in mind. The site for wood production for domestic use should preferably be near the house to reduce the burden of carrying firewood, for example. Such considerations may also lead to a decision to use the better land for a woodlot rather than the poorest land which may be further away.

Layout and Construction Procedures

- Layout of planting position starts with establishing a baseline (50 to 100m) along the edge of the area to be planted.
- The Rope is marked at intervals with the desired spacing.
- A compass is used to make alignment (the 3,4,5 rule).
- Two cross lines at 90^0 (Marked with the correct spacing) at each end of the baseline are marked.
- The baseline is moved up between the two cross lines stopping at each mark and marking the pit on the ground based on the desired spacing (Fig). The procedure is repeated in the area next to marked one (SPGS, 2009).

NB: where holes are not dug immediately, a stick/ peg can be used as a pit mark.

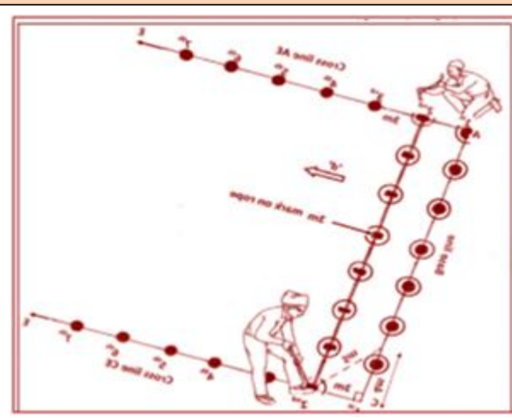


Fig 3. Diagrams/sketches to illustrate layout and construction procedures:

Planting pit preparation:

Planting Pits should be large; In wet regions 20- 30 cm deep * 20 – 30 cm diameter. In dry areas larger size pit is recommended 40 – 60 cm depth and diameter. Pitting is best when the ground is a bit moist from early rain (SPGS, 2009).

Planting: Planting is a critical part of woodlot establishment, thus planters must be properly oriented or trained to apply a good planting practice. Poor planting technique can result in poor survival and growth.

Planting procedure:

- Polythene containers must be removed carefully
- The roots are inserted into the pit up to the root collar

The soil gently returned to the pit and gently firmed around the root to eliminate air pocket and bring the earth into intimate contact with the root.

Period of Implementation Across Seasons

Time of planting is critical to maximizing initial seedling survival rate and growth. In many areas of the country, planting time is difficult to predict due to great variation in rainfall both in space and time. In general woodlot establishment should start during the rainy season when the soil is moist. Planting must be done on cooler or cloudy weather condition, with proper supervision and should be completed soon during the rainy season so that plants can establish a deep root system before the onset of dry weather.

Planning and Mobilization Requirements

Ensure planting site availability and allocation with local government administrative body. Proper planning in securing quality seedling source should be undertaken. Sensitization training for key stakeholders should be considered. Considering on preferred tree species by beneficiary farmers Legal status or agreement on woodlot establishment, management, and utilization

Cost Elements and Work Norm

- ✓ Inputs/materials and equipment required
- ✓ Labor requirement
- ✓ Budget needed per unit of the technology (for technologies to be quantified)

Management and Maintenance:

Replacement planting (Beating up): Seedling mortality is usually expected due to several factors e.g. poor quality planting stock, damage by domestic animals weed competition, moisture stress. Thus, woodlots should be inspected 3-4 weeks after planting to assess survival rate. If the mortality is high (20 % of 1250 seedling /ha, 10% for lower stocking. 5% of 625 seedling/ha) failure must be replaced and the area must be replanted when a very low survival is reported

Protection from livestock and fire is always important for young trees. Initial intercropping with crops or vegetables helps protection and weed control. Pruning and thinning must be continuous to produce good-quality poles and timber. Take into consideration free grazing control options through effective by law, fencing, and engaging in fodder development.

If the trees compete with adjacent crops, deep plowing or digging a trench 50-80 cm deep will reduce the penetration of tree roots into the rooting zone of the crop. A natural woodlot requires maintenance through selective bush clearing and protection in the early stages

Benefits and Acceptability

In woodlots, the most fast-growing trees, e.g. Eucalyptus, can be used since the land is used entirely for trees and there is little need to worry about competition with crops. A high level of wood production for domestic or cash-income purposes can be achieved. Trees in woodlots can also be a good way of making some savings. *Examples of species:* Fast-growing and coppicing species are best, e.g. *Eucalyptus* spp., *Acacia mearnsii*, *Markhamialutea* and *Cassia siamea*. Pinuspatula can also be used although it hardly coppices. *Cupressuslusitanica* has been used, but due to problems with the cypress aphid, it should not be encouraged at present. *Casuarina* spp. may be alternatives. *Grevillearobusta* can be used, but sometimes only the trees at the edge of the woodlot perform well, while trees in the interior are stunted due to competition and possibly allelopathy effects between the trees.

Limitation

- The negative aspect of woodlot is that land, which is normally scarce, is taken out of agricultural production.
- Due to less enforcement of existing land use, forest policy, and strategy, community motivation on woodlot establishment is limited.
- Law enforcement on effective locally available by law that determines woodlot establishment, production, and utilization.
- Proper management practices are not undertaken, mostly they managed it in the traditional way.
- Lacking Information on promising tree species for a given local specific condition.
- Tackle the issue of free grazing is also a practice detrimental issue.

Name of the Technology	TREE SEEDLING PLANTING AND POST MANAGEMENT PRACTICES

General Description

Tree planting and proper management practices are essential in establishing plantation for the intended purpose. Before planting seedlings in the field the site should be ready for planting. Site preparation includes removal of existing vegetation and preparation of the soil to enable the seedlings to utilize the existing soil moisture as effectively as possible. Planting site if possible should be ploughed or tilled to loosen compacted layer and improve water infiltration, root development and aeration.

Fig 1. Planted seedling under post management

Geographical Extent of Use

Tree planting and post management practices are essential interventions in all agroecological zones where trees can fairly grow and grant the intended economic and ecological benefits. However, the required techniques of site preparation for successful establishment may considerably vary from one agroecology to another. In high rainfall areas where the soil conditions are good for the establishment of seedlings it requires minimum investment for seed bed preparation and the time required for pit preparation is only few days before planting and the size of the pit is much smaller than what is required in moisture stress areas.

Layout and Construction Procedures

Planting seedlings starts with land preparation where the planting site is cleared from vegetation. Then planting pits are dug at preplanned size. **Sizes of the hole** would depend on site condition and seedling container size. A pit size of 30 cm x 30 cm is adequate for most of the tree species in wet areas. In arid areas and in hard soil surface, use of larger pit size up to 50 x 50 cm is recommended to improve water infiltration.

In moisture stress and harsher environment we need bigger size pits, as big as 60x60 cm or even more, and the pits should be prepared much ahead of time, six months to one year before the planting time, to allow conditioning of the pits and manure or residues can be added to the pits to improve the condition of the pits for better seedling survival and establishment.

Actual **spacing** varies with species. In dry localities it is necessary to plant widely apart and to remove all competing ground vegetation. Spacing for woodlots depends on purpose of plantation, the type of species and site conditions.

For other forms of planting (around homesteads, along paths and roads, etc) no fixed rule can be given.

To ensure the survival and establishment of the seedlings in dry areas, it is important to harvest run off by applying the necessary in-situ water harvesting SWC structures to harvest water (ref. info-tech).

Usually, seedlings should be delivered to sites one day ahead of planting. Where shade and watering facilities are available, seedlings can be taken to the planting site several days before planting takes place. As soon as the plants arrive at the planting site, they must be watered and stored in cool, moist and shaded place until they are planted. Maximum care must be taken for the seedlings when they are transported from nursery to planting sites to reduce wastage and effect on survival rate.

After planting the seedlings, gently compact the soil around the seedlings with hands or feet to increase contact between the roots and the soil. The soil around the plant should be made level as a depression around the stem easily creates waterlogged conditions that damage the plant. Care must be taken so that none of the roots of the seedlings turn upwards while planting.

Period of Implementation Across Seasons

Planting may be started during the onset of small rain, which allows the seedlings to receive additional rain from the small rains in addition to the main rainfall. Where small rain is not available, planting can be performed at the beginning of big rain when the soil is sufficiently moistened; usually when the soil is moist to a depth of approximately 20 - 30 cm. Generally, tree planting should start soon as the rainy season begins and the soil is sufficiently moist below the rooting depth of the plants.

Planning and Mobilization Requirements

Planting trees can be integrated with different income generation activities like small scale animal fattening, beekeeping, fruit trees, etc. to maximize its economic benefits as appropriate. During the early stage of tree establishment plenty of grasses grow in between the seedlings, which can be used for dairying or small scale animal fattening. Improved herbaceous grass and legume species can be incorporated to increase the amount of biomass and nutritive value of the feed. If beekeeping is considered for integration, selection of tree species suitable for bee forage should be taken into account to create favorable condition for the beekeeping.

Cost elements and Work Norm

The work norm for tree seedling planting is 1PD/50 plants that include transportation of seedlings from planting site and watering after plantation if required. Operation and management activities should be covered by self-help contribution.

Management and Maintenance

The establishment of tree seedlings in the field requires close follow up to replace individual plants fail to survive and grow as well as to ensure successful establishment and management of the plantation. Accordingly, the following tasks are important to be considered after planting: survival count, replacement, weed control, tending operations and protection against livestock interference.

Survival count is done to know how much of the planted seedlings have successfully survived and grown. One of the failures to have a well-stocked tree stands in many plantations or closures are the lack of beating up (replacement planting). Two to four weeks after planting, it is important to undertake survival count. In case of failure of seedlings, the dead should be replaced as soon as possible. Therefore, vigorous reserve seedlings have to be maintained in the nursery for **replacement planting**. **Weeding** is important operation needed to eliminate or suppress undesirable vegetation that would impair the growth of the seedlings (trees). Failure to keep young plants free from weed competition too often leads to mortality and delayed canopy closure. Depending on the objectives of planting trees, **tending operations** such as thinning and pruning may be needed. Protection includes preventing damage by fire, pests, domestic animals and wildlife grazing and human interference.

Benefits and Acceptability

Tree planting and establishment has a number of socio-economic and ecological benefits. Trees and forests contribute to saving lives since they remove particles polluting the environment often causing heart and respiratory diseases; provide natural filtration that helps getting clean water that also reduces the job and costs of cleaning water; reduces the release of carbon dioxide into the atmosphere, which otherwise changes our climate in dangerous ways. Studies indicate that a tree can absorb as much as 21.6 kg of carbon dioxide per year and can sequester one ton of carbon dioxide by the time it reaches 40 years old. The shade and wind-breaking of trees provide benefit everyone taking shelter from a hot summer day. Trees can hold vast amounts of water that would otherwise cause flood damage to properties and lives. Planting and protecting trees has many more economic and ecological benefits especially to the rural farming communities.

Planting trees is widely practiced by farming communities and it is well known to the people; as a result acceptability does not seem to be a problem. However, there are many conditions challenging sustainability of planted trees in the field. The most important challenge and constraint for sustainability of established trees is the long standing traditional free grazing system in Ethiopia. In case of communal planation, the second challenge for sustainability of planted trees may be lack of adequate and genuine community participation from the beginning up to the management and monitoring and evaluation stages. The plantation program should take into account the problem of the community and it should be developed in a way it is significantly contributing to solving their relevant problems in addition to their genuine participation.

Limitation

There are many constraints that limit the promotion and expansion of tree plantation in Ethiopia. These constraints include the lack of seeds of various species, limited availability of various tree seedlings in required quantity and quality, poor management practice at the field level that affects the survival and establishment of planted tree seedlings. One of the principal reasons for poor survival rate is that seedlings are mishandled during transport, loading and unloading operations.

Name of Technology	VEGETATIVE /LIVE FENCING

General Description	Purpose and Benefits	Agroecology
Vegetative (Live) fences are lines of trees or shrubs planted on farm, around homestead, field boundaries or any development site that provide protection against cattle, human and wild life interference, act as windbreaks, enrich the soil, provide bee forage, provide shade, and control dust. They are less expensive and more useful than fences made of wood, barbed wire, or stone masonry. Various species have been tested to discover their suitability for use as bio fencing plants.	Depending on the type of species, their density and methods of establishment, they may create a "conservation webs or nets" capable to trap sediments and moisture in various directions. They also act as wind breaks and reduce evapo-transpiration of cultivated plots. Assist in providing psychological security regarding tenure and encourage investment for better land care. Also it can be used for dividing grazing lands into controlled grazing paddocks and on farm boundaries. In Ethiopia plant species such as Euphorbia candelabra (tall Euphorbia or "Kulqual") and finger Euphorbia ("Kincheb"), Erithrina ("Korch"), Aloe, Sisal and other plants are established as vegetative fences to protect properties and/or development activities from livestock or human interference	It is commonly practiced in most agro ecological zones in Ethiopia along farm boundaries and around homesteads using different local species to protect the development activities from livestock and human interferences.

Design and method of application

Vegetative fences may be single or multiple rows of trees, shrubs or grasses established for protecting properties and/or assets in a given closures. In double rows vegetative fencing, the seedlings may be planted at 30-40 cm spacing between the seedlings in staggered pattern; and the same spacing can be maintained between rows. In single row vegetative fencing, closer planting is advised to establish a tight and resistant vegetative barrier. In fact the design and spacing of the vegetative fences considerably varies with type of species and their growing characters. Planting grass/legume species from inside while strengthening the resistance of vegetative fence, it is also optimizing biomass production for various purposes. That means it will further support and make the fence thicker and more productive. While direct sowing is possible with shrub species such as Sesbania, Pigeon peas, Acacia Saligna and Tree lucerne, it is advisable to use seedlings to get quick and reliable vegetative fence establishment. WORK NORM:40 person days/km.

Complementarities and integration opportunities	Management requirements
Vegetative fencing can be integrated with all possible watershed treatment measures on hillsides, gullies, grazing lands and farms. Studies in Asia demonstrated that an entire "web" of green boundaries projected over large areas had huge implications in terms of incentives for "intensive land care", water harvesting (recharge of water tables) and erosion control. Combined with land use certification, it can generate high level of investments. This activity can be combined with many other activities related to the treatment of hillsides closures, gully control, etc.	In order to make the vegetative fence very effective at all times for protection, it is necessary to closely monitor the gaps between the branches or plants in view of bridging the gaps through training of the growth of the branches, which is done through pruning and intertwining the branches. If there are gaps between the seedlings or too much widening between the plants from the beginning there is a need to replant the gaps. The other management aspects needed for optimizing the economic benefits depends very much on the various activities integrated for various purposes and the management can be performed accordingly. The area should be strictly protected from livestock interference particularly during early establishment of the vegetative fence.

Acceptability and sustainability	Constraints and limitations
If the technical staff engaged in promoting the practice are skillful and are committed to demonstrating the right design and establishment, suitable species and integration with complimentary activities where the beneficiaries can enjoy and appreciate the optimal benefits, the acceptability and suitability is highly guaranteed and vis-versa.	Lack of suitable species for establishing vegetative fences and limited awareness of farmers about the multiple benefits of the technology may be major factor limiting the initiation and expansion of the technology.

Name of the Technology	BAMBOO DEVELOPMENT

General description

Bamboo is a strange plant - Woody Grass (not a grass not a tree). It is in a grass family Poaceae belonging to the subfamily *Bambusoideae*.
What bamboo differs from a tree is:

- It has no secondary growth,
- Has special branching patterns without main trunk,
- Has very long vegetative cycle

What differs bamboo from grasses is:

- Ever green,
- Has special blade,
- Special mesophyll cells, arm cells, fusoid cells and has short petiole

Ethiopia has only two indigenous species grown in natural forests and homesteads private lands.

Bamboo development is activity/technique of developing bamboo forest (covering specified area with bamboo plants either by afforestation or reforestation techniques in a watershed). Objectives of bamboo development are improving bamboo resource base of the target watersheds which could help to mitigate land degradation in watersheds; reduction in deforestation and land degradation; increase contribution of bamboo for sustainable land management and for improvement of the livelihood of the target beneficiaries.

Fig 1. Scene of bamboo forest

Geographical extent of use

The two indigenous species of Ethiopia are restricted to limited agro-ecological regions; high land bamboo that grows in ecological zones of the country between 2200 – 3500 meters above sea level and lowland bamboo that grows in agro ecological zones between 1200-1800 meters above sea level. Many agro ecological sites are not suitable for the available indigenous species. There is very high risk of discontinuity of culms supply during flowering of indigenous species. To make species diversification within the indigenous bamboo growing areas and expanding the resource base in the broad agro-ecological zones of Ethiopia efforts have been made to introduce exotic bamboo species from different parts of Africa and Asia by different bamboo pilot projects assisted by INBAR in areas where indigenous species could not grow.

Technical design requirements

It has all year round phase especially for afforestation techniques (preparation of inputs) and reforestation (especially for implementing assisting natural regeneration).

1st Preparatory Phase: Awareness creation (workshops, Trainings, promotions, publications and visits)

2nd Principal Phase:

- Bamboo Nursery Establishment/Strengthening
- Seedling production
- Planting Bamboo in Target areas (Bamboo Development)
- Plantation Management/ Silivicultural Operations
- Harvesting and Handling Techniques

Bamboo seedlings can be produced in two ways:

1. By Sexual propagation- involves the production of new bamboo plants/ seedlings through seeds. If wildlings or naturally growing lowland bamboo seedlings in the forests are available, these can be collected and used as planting materials. Bamboo seeds are viable for a limited time, seldom for more than 10 months. Because of this poor viability, seeds need to be collected and sown in nursery beds without delay.

Seedlings from seeds can be raised;

a. bare – for further multiplication (better than preparing in the pot)
b. potted – for directly taking to planting site

Fig 2. Seedling in nursery

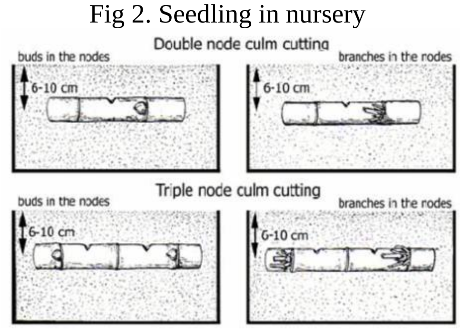


Fig 3. Culm Cutting

The potting containers should be large enough to allow root development of plants of different sizes.
Polythene tubes with 20 cm diameter x 40 cm height x 0.04 mm thickness are sufficient and 25 pots/m^2 can be found. Larger polybags with a 40 cm diameter x 50 cm height will be needed to transplant the seedlings once they have grown and have started developing new shoots.
Sexual propagation has a serious limitation/disadvantage due to unreliable seed availability due to peculiar flowering habits of bamboo. Many species only flower once in 30 to 70 years, other species don't flower at all and many that do die as a consequence. Only few bamboos flower and produce seed frequently.
Advantage: easy to transport, better and faster germination rate, may got a different Varity. For the majority of species, bamboo growers shall only rely on cloning methods for propagation.
Bamboo seeds should not store for a long period of time, best to sow them right after collection. It can be stored in a special seed storage bank where the temperature ranges from 0-5 degrees, may maintain over 1 year. For lowland bamboo, freshly collected seeds, and 60 -90% (field experience).
2. Asexual propagation: Two methods can be used in this regard.

a. **Culm cuttings:** burying one–node, or two-node culm
b. **Offsets:**is a conventional method of clonal propagation and much followed in communities for raising a few clumps in homesteads. A bamboo culm with rhizome attached -called 'offset'- is separated from a clump and transplanted.

Fig 4. Preparation of offset


Fig 5. Planting offset

Planning and mobilization requirements

- **Nursery operation:** should consider (refer nursery requirements Info-Tech)
- **Planting material preparation** should consider using pure bamboo seeds, Wildlings or Culm cuttings.

1. **Seedlings:** prepared from seeds or Culm cuttings.
2. **Offsets:** is a conventional method of colonial propagation and much followed in communities for raising a few clumps in homesteads. A bamboo culm with rhizome attached -called 'offset'- is separated from a clump and transplanted.

- **Planting:** site selection and planting strategy identification. Offsets or seedlings can be used as planting materials. Degraded communal land, Gully, roadside, backyard, agroforestry. Based on planting strategy, purpose of planting and the size and growth habit of the species different spacing can be used :

Recommended spacing is 7x7m or 204 plants per hectare. This distance provides sufficient space for intercropping & agro-forestry if the patch managed intensively and allows greater ease of movement for maintenance and harvesting activities. A 5x5m layout with 400 plants per hectare may however be used for riverbank and gully stabilization. Based on the purpose of plantation, on degraded communal lands the above two options can be used. For culm production 7x7m is used, 5x5m- 4 x 4 (625plants/ha) is used principally for soil& water conservation purpose in severally degraded communal lands. Field planting can be done either by direct planting of culm offsets or by using nursery-raised plants. As mentioned earlier, the use of culm offsets for a large plantation is not practical. The preferred types of planting materials are bamboos raised at a nursery.

Cost elements and work norm

The cost elements include nursery operations (refer nursery InfoTech).From Experience one potted bamboo seedling can be sold about 42 birr. Planting using offset and potted seedlings: 0.5 m^3/PD pit excavation considering average pit size of (1*1*0.6) m^3 the work norm required is 6 PD/3 pit

Management and maintenance

As a multiple purpose and fast-grown resource, with superior physical and mechanical properties, bamboo offers great potential as an alternative to wood. Bamboo can widely substitute not only wood, but also the plastics & other materials in structural and product applications through improvements in processing technologies. Bamboo based industry has vast potential for generating income and employment, especially in the rural areas. A number of pilot projects were working towards promoting the usage of bamboo into value-added products but resource development shall go in line with promoting technologies for value addition mechanisms that would bring business opportunities with a focus on sustainable development. Identifying the use and opportunities of natural and social conditions, the Ethiopian government now a day has given a focus to this untapped resource development and industrial utilization. Approaches to be followed to increase the potential use of this resource are:

- Integration of bamboo as strategic plant in watershed approach development projects so that resource base can be expanded in addition to managing the natural bamboo forest,
- Create value addition and income generating opportunities through creating SMEs and support private sectors already working in bamboo manufacturing,
- Linking bamboo producers with SMEs and manufacturing industries for better broaden market opportunities and effective utilization.
- Due to the nature of the plant, utilizing bamboo cannot detach with its cultivation. It has to be utilized to have sustainable management and development.

These leads to two main possible impacts:

- Efficient use of bamboo resource for watershed development/ soil and water conservation purpose in addition to using marginal degraded lands, private pocket lands and wastelands to the resource development and
- Create job opportunities and income generations to the community ultimately to livelihood improvement.

Benefits and acceptability

The various species of bamboo are excellent choices for restoring degraded landscapes, as they are well adapted to tropical and semitropical conditions. Planting bamboo in communal degraded lands, private lands and pocket waste lands in the way helping for SWC by using different planting strategies and making unproductive land to be productive.By using bamboo as a timber substitute, pressure on forests can be reduced.In recent years, Y. alpina has been used for manufacturing industrial products such as parquet flooring, window blinds, and curtains. It is also a plant with nutritional value that young bamboo shoots can be cooked and eaten as a vegetable, and the foliage can be used as animal fodder.Bamboo provides livelihoods to communities at risk from climate change, especially to their most marginalized and vulnerable members, whose development options multiply as research improves crop management and expands the range of products made from bamboo.

Bamboo is a fast growing woody grass, and as such, it is a renewable source of fuel which has a heating value comparable to that of timber from trees.

Communities that include bamboo in their strategies for adapting to climate change benefit from the resilience that derives from bamboo's fast growth and ability to recover quickly from extreme weather events, as well as its use in constructing climate-smart housing, and provision of climate-friendly alternative fuel.

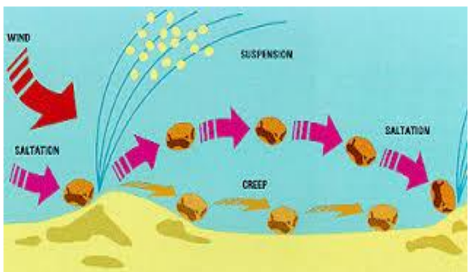
Limitation

Unreliable seed availability due to peculiar flowering habits of bamboo. Many species only flower once in 30 to 70 years, other species don't flower at all and many that do die as a consequence. Only few bamboos flower and produce seed frequently. Moreover, Very short viability of bamboo seeds, seeds of bamboo cannot be stored for a long time. Developing bamboo forests from seeds helps to know the exact age of bamboo for further multiplication and exact age of bamboo for future generation.

Wind Erosion Control Measures

Overview

The problem: Wind erosion (wind speed /velocity and its shearing action) is a serious threat to food security, by causing soil erosion and formation of sand dunes, and contributes to the degradation of a sustainable agriculture throughout the world in general and in the Eastern Nile Regions in particular. Wind erosion physically removes the lighter, less dense soil constituents such as organic matter, clays, and silts. Thus, it removes the most fertile part of the soil and lowers soil productivity. In addition, dust storms affect air quality and airborne dust has significant economic, health, ecological, and hydrological impacts. Apart from damaging agricultural /cropping fields sand dunes create a lot of obstruction to infrastructures as well.



Action of wind erosion has three forms: i) **Saltation** i.e. series of particles jumping and bouncing; ii) S**urface creep** of heavier soil particles on the surface; and iii) **Suspension** or blowing of fine clay particles in the air and its deposition somewhere else.
Generally soil erosion by wind is worse in arid and semiarid regions.
Wind Erosion Control Measures are, among others:
a) Physical or mechanical sand dune fixation/stabilization;
b) Biological sand dune fixation/stabilization;
c) Establishment and management of shelterbelts;
d) Establishment of wind breaks with ditcher; and
e) Establishment of shelterbelts using disc plough. Further below the detail of it is presented:
The following wind erosion control measures described in this Guideline are:

1. Shelterbelts or Windbreaks
2. Biological Sand Dune Stabilization / Biological Sand Dune Fixation
3. Checkerboard
4. Wind Erosion Control with Improved Tillage Practices

Name of the Technology	SHELTER BELTS - WINDBREAKS

General Description

Windbreaks or shelterbelts are plantings of single or multiple rows of trees or shrubs that are established for environmental purposes. The height of the tallest row and overall density of foliage and branches of an individual planting greatly influence the size of the nearby area that is protected or sheltered. Windbreaks or shelterbelts are generally established to protect or shelter nearby leeward areas from troublesome winds that cause soil erosion. Living conditions and agricultural production can often be improved by planting trees and shrubs in protective windbreaks and shelterbelts which reduce wind velocity and provide shade. Windbreaks and shelterbelts, which are considered synonymous, are barriers of trees or shrubs that are planted to reduce wind velocities and, as a result, reduce evapotranspiration and prevent wind erosion; they frequently provide direct benefits to agricultural crops, resulting in higher yields, and provide shelter

Fig 1. Source: USDA, Windbreak/Shelterbelt, Conservation Practice, 1997

to livestock, grazing lands, and farms. Quite often, protection can be combined with production by choosing trees and shrub species that, apart from furnishing the desired sheltering effect, yield needed wood and other products.

Geographical Extent of Use

In arid zones, where the harsh climate and the shortage of water are intensified by strong winds. Windbreaks are "environmental buffers" that are planted in a variety of settings, such as on cropland, pasture, and rangeland (sometimes referred to as "living barns"), along roads, farmsteads, homesteads, feedlots, and in urban areas.

Technical Design Requirements

To get effective protection from windbreaks and shelterbelts the following parameters need to be dealt carefully:

- When considering windbreaks or shelterbelts planting, three zones can be recognized: the windward zone (from which the wind blows); the leeward zone (on the side where the wind passes); and the protected zone (that in which the effect of the windbreak or shelterbelt is felt).
- The **effectiveness of the windbreak is influenced by its permeability.** If it is dense, like a solid wall, the airflow will pass over the top of it and cause turbulence on the leeward side due to the lower pressure on that side; this gives a comparatively limited zone of effective shelter on the leeward side compared to the zone that a moderately permanent shelter creates.
- Optimum permeability is 40 to 50 percent of open space, corresponding to a density of 50 to 60 percent in vegetation.
- Permeability of dense shelterbelt can be improved by pruning lower branches at 0.5 – 0.8 m from the soil level.
- It is generally accepted that a windbreak or shelterbelt protects an area over a distance up to its own height on the windward side and up to 20 times its height on the leeward side, depending on the strength of the wind. In reducing wind speeds, narrow barriers can be as effective as wide ones. Furthermore, a narrow shelterbelt has the advantage of occupying less land.

Selection of tree and shrub species: In the selection of tree or shrub species for windbreaks or shelterbelts, the following characteristics should be sought:

- Rapid growth, straight steams, wind firmness, good crown formation, deep root system which does not spread into nearby fields, resistance to drought and desired phonological characteristics (leaves all year long or absent only part of the year).
- Some possible trees and shrubs for windbreaks area Accacia species (Nilotica, Senegal, etc.), Azadiracta indica, Leucaena lecocephala and Zizyphus spinachristi.

Site preparation: Remove debris and control competing vegetation to allow enough spots or sites for planting and planting equipment. For plantings requiring supplemental moisture, prepare and ready applicable materials for installation.

Additional requirements:

A windbreak or shelterbelt usually consists of multiple rows, with shrubs in the outer rows and taller trees in the interior. Complementary practices work with these environmental buffers to further control wind erosion and snow deposition and modify site characteristics for habitat and screening purposes. For comprehensive protection of a field, windbreaks are placed in a series across the area (typically spaced at intervals of 5 to 20 times the height of each windbreak), with individual windbreaks running parallel to one another, but perpendicular to prevailing winds.

Layout and Construction Procedures

Establishment: The main method of establishing windbreaks is by seedlings. Planting a single line of trees is sufficient to mark a boundary and to serve as a windbreak. A windbreak should be established at a right angle to the prevailing wind direction. The spacing between trees is normally 2 m, but this may vary with species.

The efficacy of a windbreak can be improved by planting tall trees in the first line and shorter trees in a parallel line. In this condition, small shrubs, medium trees and bigger trees will be planted consecutively in parallel rows. The spacing between the rows can be from 3 – 4 m. If the boundary separates two fields, the first line of trees should be placed one or two meters inside the boundary. If both farmers are interested, each can plant a line of trees inside their boundary.

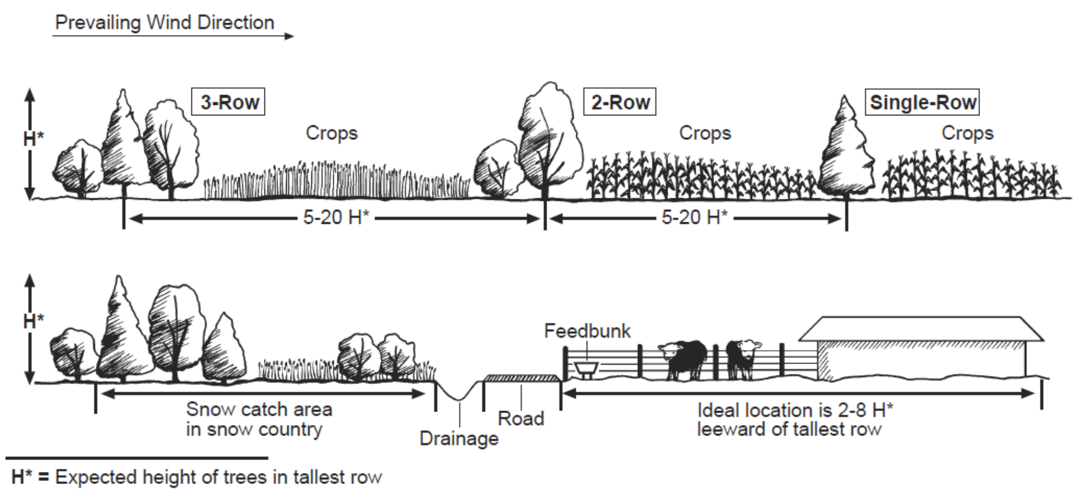


Fig 2. Windbreak layout

Period of Implementation Across Seasons

Raising seedling over the dry seasons and planting at the onset of rains.

Planning and Mobilization Requirements

Temporary Storage Instructions: Planting stock that is dormant may be stored temporarily in a cooler or protected area. For stock that is expected to begin growth before planting, dig a V-shaped trench (heeling-in bed) sufficiently deep and bury seedlings so that all roots are covered by soil. Pack the soil firmly and water thoroughly.

Cost Elements and Work Norm

Seedling preparation, transporting, planting and nursing until they get established. Adopt work norm used for tree planting.

Management and Maintenance

Protect young trees against livestock and fires. Termite control is necessary for trees such as eucalyptus which are susceptible to termite attack. Mature trees can be selectively pruned or pollarded to reduce the shading effect on the adjacent agricultural crops.

Windbreaks and shelterbelts are normally established concurrently with other practices as part of a conservation management system. For example, proper crop rotations and tillage techniques and management of residue in fields (conservation, crop rotation and residue management) work with windbreaks to control wind erosion. The planting must be inspected periodically and protected from damage so proper function is maintained. Replace dead or dying tree and shrub stock and continue control of competing vegetation to allow proper establishment. For plantings requiring supplemental moisture, install and begin operation of the irrigation system. Periodically prune trees and shrubs to repair environmental damage and maintain plant health and vigor.

Benefits and Acceptability

Such plantings are used to reduce wind erosion, protect growing plants (crops and forage), manage snow, and improve irrigation efficiency. Windbreaks also protect structures and livestock, provide wildlife habitat, improve aesthetics, and provide tree or shrub products. Also, when used as a living screen, windbreaks control views and lessen noise.

Limitation

No significant limitation as such. But trees such as Damas in semi-arid areas like Sudan need irrigation.

Name of the Technology	BIOLOGICAL SAND DUNE STABILIZATION - FIXATION

General Description

Biological measures of wind erosion control or sand dune stabilization / fixation techniques are those already known for water erosion control. These could be those dealing with agronomic, soil management and vegetative means.
However, for sand dune stabilization, i.e. sand dune already created or on the process of its formation needs special attention other than mechanical or physical stabilization. This focuses more on vegetative stabilization of sand dunes by live grasses, bushes, shrubs and trees. See the picture at the right.

Fig 1. Sand dune fixation

Technical Design Requirements

Biological sand dune stabilization can be applied in coastal as well as inland areas. A common strategy to restore degraded soils is to re-establish a vegetation cover, because plants are able to protect the soil from wind erosion in various ways, e.g. by sheltering the soil from the erosive force of the wind and by stabilizing the soil with their roots. Plants play a key role in wind erosion control measures, because they are able to protect the soil in various ways. Wind erosion has been shown to decrease significantly with increasing level of soil aggregation. Soil and air humidity are important determinants of the erodibility of the soil.

Most plants form symbiotic associations with mycorrhizal fungi which have the potential to improve both plant growth and soil aggregation. The above-ground parts of vegetation modulate wind erosion processes primarily through the following mechanisms:
i) Vegetation can shelter the soil from the force of the wind by covering a fraction of the surface and providing lee-side wakes in which the average wind velocity and friction velocity are substantially reduced;
ii) Vegetation can extract momentum from the wind, thus reducing the erosivity of the wind;
iii) Vegetation can trap windborne particles, thereby reducing total sediment flux and providing chance for sediment deposition;
iv) Plants protect the soil below-ground i.e. by stabilizing the soil structure and by affecting near-surface soil and air humidity; and
v) Plant roots stabilize soil structure by enmeshing individual soil particles and by releasing glue-like exudates, thereby contributing to the formation of stable soil aggregates. Wherever the plant (*Caparies decidiau)* is, there is deposition of sand around it, in Sudan. Salvadora persica (up right) and Panicum maximum (lower) under trial in Um Groad Village West of Atbara, Sudan - Community Watershed Management Project, May 2014.

Fig 2. Panicum maximum (lower), Salvadora persica (up right), and *Caparies decidiau*

Period of Implementation Across Seasons

As per the individual species requirement depending on dry or wet planting/seeding.

Management and Maintenance

Requires fencing of the seeded and planted saplings to avoid grazing by livestock and wild animals.

Benefits and Acceptability

The biological or vegetative barriers apart from filtering and fixing the sand increase soil organic matter and soil structure formation.

Limitation

Very appropriate plant species that suits the niche should be identified and these may not be many.

Name of the Technology	CHECKERBOARD

General Description

This is one of the physical or mechanical stabilization technique. Stabilization of dunes effected by the planting of marram grass (*Ammophila arenaria*), or rice grass, whose long roots bind the surface layers of sand and so hinder its removal by wind.

Technical Design Requirements

The straw checkerboard technique is used for fixing sand dunes. Straw of wheat, rice, reeds, and other plants is placed in the shape of a checkerboard. Half is buried and half is exposed.

Fig 1. Wind break from crop straw balled

Fig 2. Dry straw in a checkerboard arrangement

Fig 3. Shrub, grass and another woody biomass used as checker board

The straw decreases the wind velocity near the ground surface and can prevent wind erosion of the soil. In regions where the annual precipitation is over 200 mm, bushes and herbs can be planted to further improve the windbreak and sand dune fixation qualities. After establishment, the straw gradually rots to become soil organic matter.

Period of implementation across seasons

Anytime when there is availability of the dry matter.

Benefits and acceptability

The establishment of a straw checkerboard changes the structure of the airflow and changes the ground surface status from erosion to deposition. Owing to the deposition of fine particles, a soil crust is formed and soil formation begins.

Limitation

It is not possible to apply it in areas where the straw is needed for other purposes such as, fodder, fuel, roof thatching, etc.

Name of the Technology	WIND EROSION CONTROL WITH IMPROVED TILLAGE PRACTICES

General Description

In normal tillage operation, where wind erosion may not be a problem, then it would be wise to prepare smooth seed bed preparation. However, this is unlikely when it comes to wind erosion control and the surface, as much as possible, left with high surface roughness. Field with rough or ridged tillage and clods is less likely to be affected by wind erosion. See Picture.

Fig 1. Wind erosion resulted from fine seed bed, East Atbara, Sudan

Technical Design Requirements

The concept of working only a very narrow width in the bottom of the furrow for seed placement and leaving the ridge between rows untilled with chemical weed control probably would provide good protection from wind erosion. Some information on the most desirable degree of roughness for maximum efficiency in controlling erosion can be obtained from trials and experiments.

The most effective height is 5 to 12cm (2 to 5 inch). The deep furrow drills used to plant small grains generally produce roughness within that range and, consequently, provide an erosion-resistant surface. Generally, two methods of tillage operations are common:

i) Establishment of wind breaks with ditcher; and

ii) Establishment of shelterbelts using disc plough.

Fig 2. Surface left rough by tillage operation to control wind erosion

Period of Implementation Across Seasons

During tillage operations.

Limitation

Need of tractor for the ditcher and the disc to pulled i.e. mechanization.

Rainwater Harvesting - Structural Storage

Overview

Water shortage is already a problem in many parts of Ethiopia, particularly in arid and semi-arid areas of the country where the area is characterized by very high spatial and temporal variability in rainfall pattern. The human induced changes in land use and low level of water management have accelerated desertification processes. This situation is exacerbated by climate change as projected precipitations are small and erratic with temperature and evaporation are projected to rise. Land degradation and consecutive droughts have led to chronic water scarcity across many parts of the country, leading to acute water shortage. This means all areas, which are especially dependent on rain, are getting exposed to water shortage in the year where the seasonal rainfalls perform poorly and fail to recharge rivers, groundwater and soil moisture for optimum plant growth.

Besides, water resources are globally and particularly in Ethiopia are becoming limited and land holding due to the ever increasing of population is becoming fragmented, in which blue print traditional practices increasing area of cultivation cannot be considered as an option to address the current climate change. Rather harvesting the existing water potential and utilizing it effectively for different development interventions needs no reminder.

In Ethiopia, promotion and application of water harvesting technologies as alternative interventions to address water scarcity for irrigation, animal and domestic water supply and build the resilience of communities has been taken as a core intervention by the government and many of the development projects and programs. The country GTP recognizes the promotion of water centered sustainable rural development as key intervention in achieving food security at household level to build their resilience to climate change. Considering their importance, a quick reference for experts, development agents and other professionals who are involved in the implementation of water harvesting technologies as a short information kit is prepared to guide on the selection, design and implementation of water harvesting technologies is presented here under.

The Water harvesting Technologies described as info-techs are the following:

1. Rooftop Rainwater Harvesting
2. Rainwater Storage Cisterns
3. Geomembrane Lined Pond
4. Spring Development
5. Hand Dug Well
6. Manual Tube Well Drilling
7. Community Pond
8. Check-dam Pond
9. Diversion Weir
10. Water Spreading Weir
11. Road Water Harvesting
12. Sand Dams
13. Subsurface Dams in Dry Sandy Rivers
14. Small Earth Dam (Farm Dam)
15. Small Masonry Dam
16. Irrigation Canal Construction

Name of the Technology	ROOF TOP RAINWATER HARVESTING

General Description

- Rooftop rainwater Harvesting is a system of collecting rainwater that it falls on roof catchments built with metal/corrugated sheet, or any roofing material that is waterproof and does not contain any chemical dangerous to water supply for domestic, livestock and crop production
- The water collected from roof catchment can be conveyed using appropriate conveyance devices and stored in structures constructed either aboveground or belowground structures. The water storage structures can be constructed using different construction mistrials, such as, bricks, masonry, ferro-cement, geo membrane, reinforced concrete, etc.
- The water harvested from roof catchment system can be used for multiple uses including, water supply for domestic, water supply for livestock or household irrigation or in combination of these.
- Roof top rainwater harvesting system consists of three basic components:
- Catchment,
- conveyance (gutter and down pipe) and storage

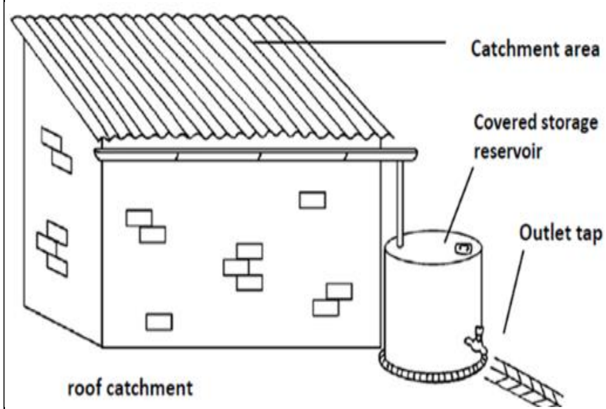


Fig 1. Roof top rainwater harvesting

Geographical Extent of Use

Roof top rainwater harvesting can be applied in all parts of Ethiopia. However, it will be more feasible in arid and semi-arid parts of Ethiopia where the access for surface water and groundwater is very limited and expensive.

Planning and Design Mobilization Requirements

Planning and design requires for roof top rainwater harvesting include: Estimation of runoff amount from a given catchment area can be referred in Annex 1 of Technologies.

Estimating household and livestock water demand can be estimated using the following Equation.

$$D = [(\boldsymbol{N} * \boldsymbol{Q}) + (\boldsymbol{n} * \boldsymbol{q})] * \boldsymbol{T} * \mathbf{1.2}$$

You can further refer Annex 8 of technologies.

Sizing the storage facility

While sizing your water storage tank, one can follow the following general steps

Step 1. Determine Your Annual Water Demand. The first thing that you need to do is to figure out how much potable water you and your family need each day

Step 2. Determine the Amount of Rainfall You Can Capture

Step 3. Determine How Big Your Storage Tank Needs to Be

For ease estimation,

- Volume of storage (M^3) = total annual demand (M^3) + Total demand*20%) + Total demand*10%)

20%= estimated amount due to over consumption because of ease access

10%= water loss due to leak or sedimentation

Technical preparedness needed

Technical Design Requirements

- The height of the storage structure (if above ground) should be less than the height of the building/shed/house
- If low cost options are considered, the total volume of rooftop rainwater harvesting is recommended not to be over $10M^3$ capacity
- The catchment area should be free from any chemical
- The storage structure should be free from leaking
- The storage structure should be away from deep rooted trees
- The storage structure should be provided with vent, and if possible, should be dark by protecting it from direct sun rays

Period of Implementation Across Seasons

Roof top rainwater harvesting can be implemented throughout the year but the construction be completed before the beginning of the rainy month/s.

Layout and Construction Procedures

Basic procedure for construction includes:

- Layout
- Excavation
- Construction
- Supervision and monitoring

For example: layout /construction for Ferro cement tank is given in the below Figures

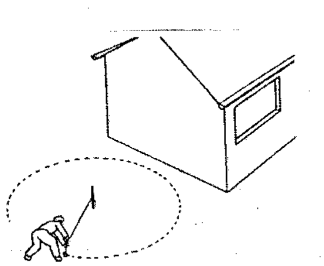


Fig 2. Layout making for tank placement

Fig 3. Different stages of tank under construction

Management and Maintenance

`Management of rooftop RWH includes:

- Inspection, regular cleaning and minor repair of the whole RWH system; the catchment, the conveyance, the tank and the various tank components
- Removal of branches of trees over hanging on roofs and bird droppings
- Inspection of water quality in the tank, testing from time to time and treating/disinfecting regularly
- Provide mesh for any opening in the RWH system
- Treatment of Stored Rainwater (Chlorination, use of filters, boiling, etc)

Regular supervision for any leak and does the required repair and maintenance

Cost Elements and Work Norm

Cost items can be categorized as follows:

1. Material: Hand tools (tools required for mason, carpenter, steel fixer, excavation); Construction materials (Cement, sand, gravel, wire mesh, steel, gate valves, gutter, downpipe, etc.)

➢ Labor: Excavation (un skilled labor), Manson, Steel fixer, Carpenter

2. Work norm.

The work norm for roof top rainwater harvesting system using above ground structure up to $10M^3$ capacity include excavation (foundation), masonry/cement work, gutter and downpipe (carpenter), steel fixing. Total labor required for $10M^3$ capacity is 30PD.

Benefits and Acceptability

- Can provide domestic water supply
- Reduces the cost for pumping as the storage tank is in most cases is above ground
- Provides high quality RAIN water, which is soft and low in minerals
- When recharged to groundwater it improves the quality of groundwater through dilution
- When applied to significant scales in urban areas reduces soil erosion and flooding
- Compared to groundwater abstraction and piping through long distances is less expensive
- Rainwater harvesting systems are simple and divisible which can be adopted by individuals
- Rooftop rainwater harvesting systems are easy to construct, operate and maintain
- Relatively cheap materials can be used for construction of containers and collecting surfaces
- Provides a supply of safe water close to homes, schools or clinics, encourages increased consumption, reduces the time women and children spent to collect water, reduces back strain or injuries from carrying heavy water containers

Limitation

- If workmanship is not properly supervised, leaking of structure
- The height and area of the roof limits the capacity of the structure
- Because of the limited capacity (up to $10M^3$), the cost per M^3 is relatively high
- Required appropriate ventilation system for proper aeration

Name of the Technology	RAINWATER STORAGE CISTERNS

General Description

- All rainwater-harvesting systems need somewhere to store the water. This may be a tank/cistern, an excavated or embankment ponds, dams, or the soil itself.
- Cisterns are ex-situ types and are defined as structures constructed artificially using different construction materials including the soil itself either above or below the ground surface for the purpose of rainwater storage.
- Cisterns, may store water collected from ground surfaces, from rooftops, green houses, or from any permanent or seasonal water sources. The stored water can be used for:
  - Irrigating crops (supplementary, complete irrigation or both)
  - Water supply for livestock and human, and
  - Any combination of these

Cisterns in which their storage capacity is ranging from 10 to 100m^3.

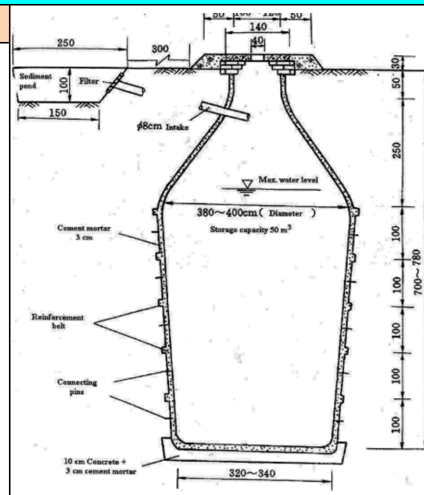


Fig 1. Underground bottle shape tank lined with cement mortar

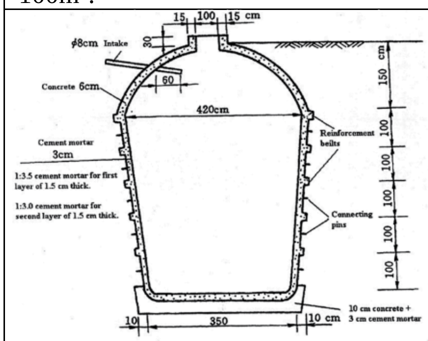


Fig 2. Dome cap tank made of cement concrete

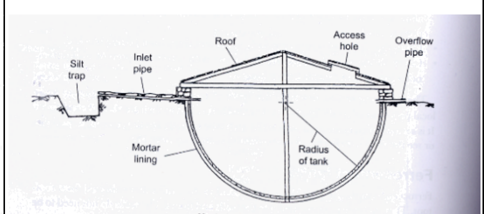


Fig 3. Hemispherical underground and cement lined tank

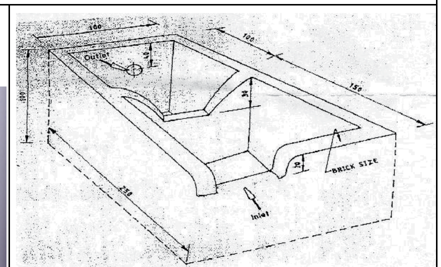


Fig 4. Silt trap to be attached to the above three tank shapes

Geographical Extent of Use

Rainwater harvesting cisterns can be used in all Ethiopian agroecology where water is a major problem. However, the type of structures in positioning and shape should be selected based on the soil and geology condition of the specific area planned to be implemented.

Technical Design Requirements

The choice of a suitable tank design to match an existing catchment and local conditions is important, and careful consideration should be given in selecting the right one. The following are key requirements common to all effective tank designs:

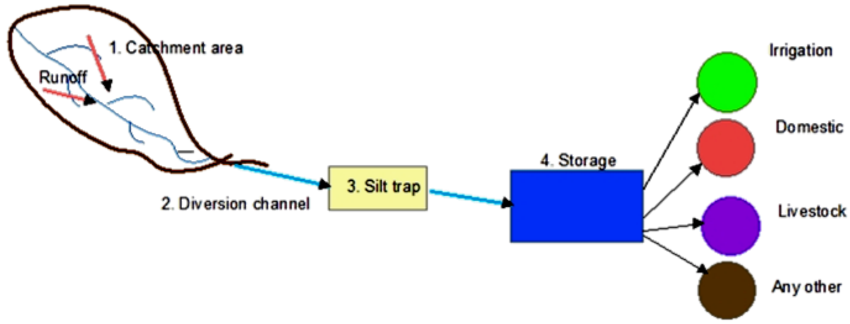
- Durable and cost-effective
- Functional and watertight
- Solid, secure cover to keep out insects, dirt and sunshine
- Screened inlet filter
- Screened overflow

As a general rule, water tanks should ideally be cylindrical, spherical or frustum. This is because these shapes optimize the use of materials and, increase the wall strength. To maximize the storage volume while minimizing the cost, the tank should be reasonably evenly proportioned i.e. the depth/height and diameter or width must be evenly proportional. For example, tall tanks with narrow widths and very low tanks with large diameters require more materials and cost more per unit volume.

During design, the following key parameters should be considered:

- Estimation of runoff amount from a given catchment area:
- Estimating water demand (irrigation, domestic, livestock, etc.)
- Sizing the storage structure, Cistern (See Annex 9 of Technologies)

- Manhole, access for cleaning, repair and maintenance
- Extraction system
- Device to indicate the amount of water in the tank
- Sediment trap



Layout and Construction Procedures

- ➢ Select suitable construction site
- ➢ Locate the position of silt trap
- ➢ Level the area and site clearing
- ➢ Excavation (for foundation purpose or storage if the cistern is to be below the ground surface)
- ➢ Construction of the cistern and silt rap with recommended construction material). As an example: Hemispherical and dome shaped structure are given in Annex 1.
- ➢ Provide roof to prevent from water loss due to evaporation
- ➢ Fence the structure with appropriate material

For more, as example refer, Annex 9

Period of Implementation Across Seasons

For immediate use, preferably make construction of cisterns before the rain starts.

Planning and Mobilization Requirements

For sustainable use of the water storage structures, cisterns are preferably implemented at household level, rural clinics, rural schools, etc. Since excavation of cisterns is a very drudgery work and labor has to come from family members, the quality of the structure should not be compromised, and to this end construction work required to be done by skilled artisans, masonry work, steel fixing or carpenters works.

Cost Elements and Work Norm

Cost elements required that are required for cistern construction include:

- ➢ Hand tools for layout, excavation and construction
- ➢ Labor (unskilled labor for excavation, un skilled labor/assistant for technicians, technicians for construction: - mason, steel fixer, carpenter)
- ➢ Construction materials (rubble stone, bricks, soil-cement blocks, steel, mesh wires, plastics, etc.)
- ➢ Work norms: Excavation: (1PD/0.5 m^3)
    - ➢ Masonry (stone collection and shaping) + carpenter, steel fixing) (1PD/4 m^3)

Management and Maintenance

- ➢ Construct non leaking structure with appropriate filter mechanism
- ➢ Integration with appropriate water lifting devices
- ➢ Use water efficient irrigation type, since the stored water is too small for large area
- ➢ Select appropriate commodity that fits to the capacity of the cistern (livestock, domestic or irrigation)
- ➢ Provide proper fence
- ➢ Removal of silt from reservoir/silt trap as required
- ➢ Check for any cracks and do require supervision and maintenance
- ➢ Provide appropriate cover

Benefits and Acceptability

Cisterns could pay an important role for supporting the following key activities:
Major advantages of implementing the technology
How communities respond to the technology
To what extent it can be scaled-up
Overall conclusion about the technology

- Homestead irrigated crop production
- Livestock management (dairy farm, fattening, poultry, etc.) through providing water supply and feed production
- Water supply for sanitation use at various levels, household, rural clinics, schools, etc.

For sustainable use of cisterns, need based development and promotion with quality of work should be considered.
Limitation and Challenges
Sedimentation and water losses through seepage and evaporation are the most outstanding problems in water tanks. In order to reduce these problems, the following measures should be taken: **Seepage losses**: apply appropriate and low-cost lining materials; **Evaporation losses**: in arid areas evaporating water is invisible and such losses are not often recognized. Therefore, storage tank should be covered with appropriate roofing materials, surface area of the storage tank should be minimum to reduce the cost of tank roofing; **Sedimentation of tank**: To reduce the problem of sedimentation in a water tank: select suitable water source (catchment) area with minimum sediment load, treat the water source (the catchments area), and provide appropriate silt trap with filter mesh.

Name of the Technology	GEO-MEMBERANE LINED POND

General Description

Geo-membrane lined ponds are small tank or reservoir like constructions, constructed in the ground for storing the surface runoff, generated from the catchment area. The geo-membrane will control the infiltration and the stored water will be used during the dry seasons for domestic, livestock or irrigating small gardens.

Geographical Extent of Use

Suitable in areas where there are no surface and underground water resources or uneconomical to develop or where scarcity of water is severe. Mostly suitable around homesteads for protection and management in all agroecology, however can also be applied in cultivated or grass lands with workable soils up to 3m depth having flat to gentle slopes.

Fig 1. Set of figures on geomembrane RWH and its use (right)

Technical Design Requirements (Shape, Design and Volume)

For lining geo-membrane suitable shape of pond is usually trapezoidal shape wide at the surface with sloping sides depending on the soil type and narrow towards the base for stability. With standard side slope
i.e. 1:0.5 vertical to horizontal for stable soils and 1:1 vertical to horizontal for unstable soils (vertisols)
The size of trapezoidal shape pond is calculated by $V = \frac{H}{3}\left(A_t + A_b + \sqrt{A_t * A_b}\right)$
Where V= storage capacity, m^3; H = water storage depth, m; A_t = top area of storage = L × W, m^2 ;
A_b = base area of storage = l × w, m^2
The standard design for household pond constructed under stable soils is 8m x 8m top width and length and 3m depth 5m by 5m bottom width which can store $129m^3$. Geo-membrane with black in colour with 0.5mm thick and 12.5-13m width with 13-13.5m Length is enough for lining.

Layout and Construction Procedures

Method 1
1) Mark the top area of the pond on the ground
2) Mark the bottom area of the pond on the surface
3) Start excavating the bottom area to the required depth
4) Reshape the sloping side, triangle
5) Place the excavated soil 1.5 meters away from the pond

Method 2
1) Mark the top area of the pond on the ground with pegs
2) Mark an area inside the top area maintaining the side slope and start excavating to 1m depth
3) Repeat the same procedure until the required depth is reached, the excavation is like stairs
4) Shape the stairs by excavation to the design slope
5) After completing the excavation inspect the geo-membrane for any leakage, if you find any, maintain it with corrugated iron sheet plaster or maintain with CM 43 glue similar like maintaining flat tyre &line it.

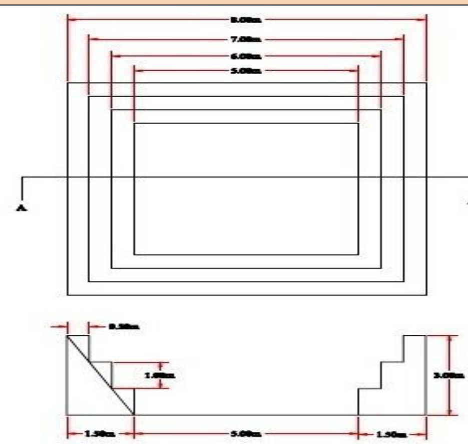


Fig 2. Top and crossection of the pond

Fig 3. Construction stages /steps

Fig 4. Elimination of the steps and final shaping of the pond

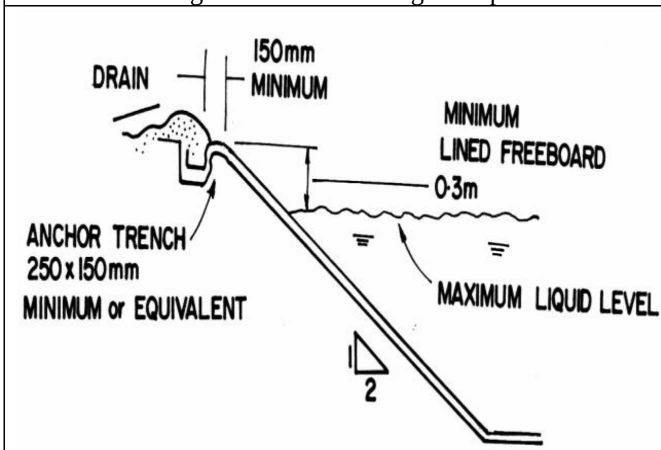


Fig 5. Crowning of the edge of the plastic in the ditch

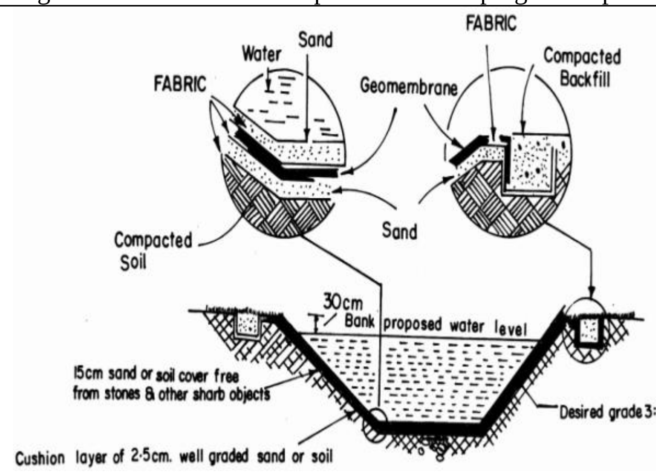


Fig 6. 15v samd or soil cover free from stones and other sharp objects to avoid the piercing of the plastiic

Period of Implementation Across Seasons

Construction of ponds should be during the dry season and to protect the exposure of the geo-membrane to sunlight lining of the geo-membrane should be done on the onset of rainfall.

Cost Elements and Work Norm

Tools like measuring tape, string, pegs, crowbar, pick axe, shovel are needed for surveying and construction. The major cost is the geo-membrane.

Work norm

(1) Excavation (1PD/0.5 m³) (2) Stone collection and shaping PD/0.5 m³) (3) Others as required (such as small cutoff drains and waterways see other info-techs).

Management and Maintenance:

Fence the pond, with live or dry material for safety purpose, i.e. protects animals and children from drowning into the pond. And also adopt suitable water lifting technologies to abstract water. Integrate with water lifting technology i.e. Pedal pump, Rope and washer pump etc. For installation of rope and washer see Annex 10 on Technologies.

Benefits and Acceptability

The technology is benefiting many farmers in the country for supply of water for livestock, domestic use and supplemental irrigation for high value crop. The technology is highly adopted in the country and in some areas it is the most acceptable technology for harvesting water and use it in the dry season.

Limitation

The quality of the geo-membrane is a concern affecting the adoption of the technology.

Name of the Technology	SPRING DEVELOPMENT

General Description

A spring or seep is water that reaches the surface from some underground supply, appearing as small water holes or wet spots on hillsides or along river banks. The flow of water from springs and seeps may come from small openings in porous ground or from joints or fissures in solid rock.

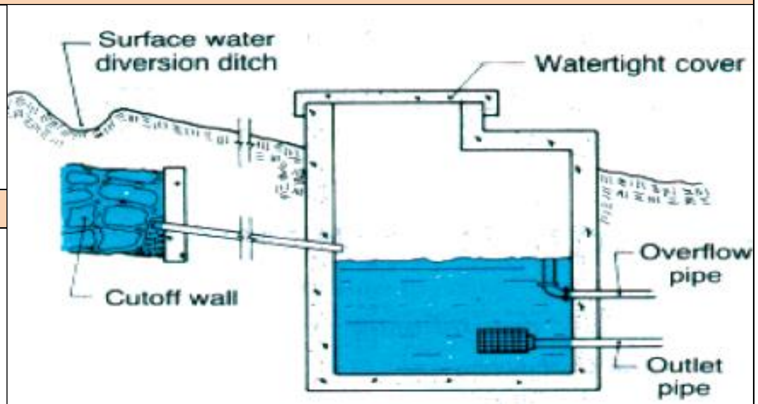


Fig. 1 Typical cross-sectional view of spring development

Geographical Extent and Use

There are two categories of springs: a) **Gravity springs** (which include: depression springs; contact springs; and fracture or tubular springs); b) **Artesian springs** (which include: artesian fissure springs; and artesian flow springs). i) **Depression springs**: are formed when the land surface dips (forms a depression) and makes contact with the water table in permeable material. Water yield will be good if the water table is high, but the amount of available water may fluctuate seasonally.

A gravity depression spring may not be suitable for a drinking water source since it may dry up; ii) **Contact springs**: are formed when downward movement of underground water is restricted by an impervious underground layer and the water is pushed to the surface. This type of spring usually has a very good flow throughout the year and is a good water source; iii) **Fracture and tubular springs:** are formed when water comes from the ground through fractures or joints in rocks. Often the discharge is at a single point and protection is relatively easy. Fracture and tubular springs also offer a good source of water for a community supply; iv) **Artesian springs**: occur when water is trapped between impervious layers and is under pressure. There are two types of artesian springs: fissure and artesian flow: i) **Artesian fissure springs**: result from water under pressure reaching the ground through a fissure or joint. Yield from Artesian spring development will be very good and this source is excellent for a community supply; ii) **Artesian flow springs**: occur when confined water flows underground and emerges at a lower elevation. This type of spring occurs on hillsides and will also offer an excellent supply.

Technical Design Requirements

Before reaching the surface, spring water is generally free from harmful contaminants. To avoid contamination, the spring should be protected at the point where the water leaves the ground. That is why structures such as spring water collection box is required. There are three methods of spring development for use as drinking water sources: 1. Spring boxes; 2. Horizontal wells; and 3. Seep development.

Spring Boxes: There are two basic types of intakes for spring development and collecting water from springs and seeps. The first, and easiest to install, is the spring box. A small area is dug out around the spring and lined with gravel. A concrete box with a removable cover is placed over the spring to collect and store the water.

The cover prevents contamination and should be heavy enough to keep people from removing it to dip buckets and cups into the collection box. A tap and an overflow to prevent a back-up in the aquifer should be installed. For springs that flow from one spot on level ground, an open-bottomed spring box should be placed over the opening to capture all available flow. The trenches are deep enough so that the saturated ground above them acts as a storage reservoir during times of dry weather. Generally, the trenches should be 1 meter below the water level. Collection pipes are placed in the trenches which are lined with gravel and fine sand so that sediment is filtered out of the water as it flows into the pipes.

Clean, clear water flows from the collection pipes to the storage or collection box. For spring flows that cover a wide area, a concrete wall should be installed to collect all flow.

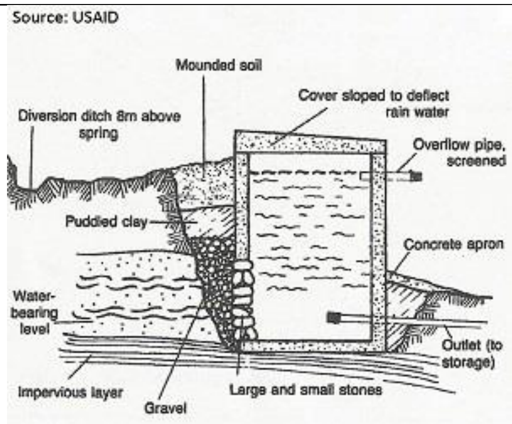


Fig 2. Spring box with pervious side

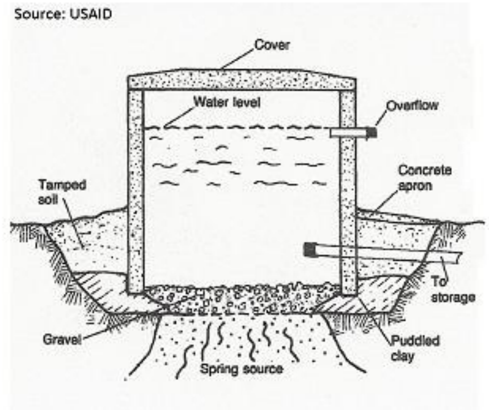


Fig 3. Spring box with pervious side

Horizontal Wells: For spring development on a hillside, a box with an open back should be placed against the hillside and the water should be channeled into the collection box. See Figures 1 and 2 for examples of these types of spring collection. Where a spring has a steeply sloping water table (steep hydraulic gradient), horizontal wells may be used for spring development. Horizontal well intakes must be located in an area with a sloping water table in order to have adequate discharge.

Pipes with open ends or with perforated drive points or well screens can be driven, jetted, or augured into an aquifer horizontally or at a shallow slope to tap it at a point higher than the natural discharge. The pipe must also enter the aquifer deeply enough to ensure the required minimum flow throughout the year. The water supply reaches the surface by flowing from the tapped aquifer through the installed pipe. See Figure 4 for an example of intake placement for horizontal wells.

Horizontal wells are installed in a manner similar to driven and jetted wells except that care must be taken to prevent water from flowing through the annular space outside the pipe. Any flow can be stopped by grouting or by constructing a concrete cut-off wall packed with clay backfill.

The advantages and disadvantages of spring development of this type are similar to those of the spring box mentioned above. Horizontal wells are fairly inexpensive, spring water is relatively clean, and gravity flow may be acceptable. Springs with flat water tables are not suitable for the use of horizontal wells, and the quantity of water may fluctuate with the season.

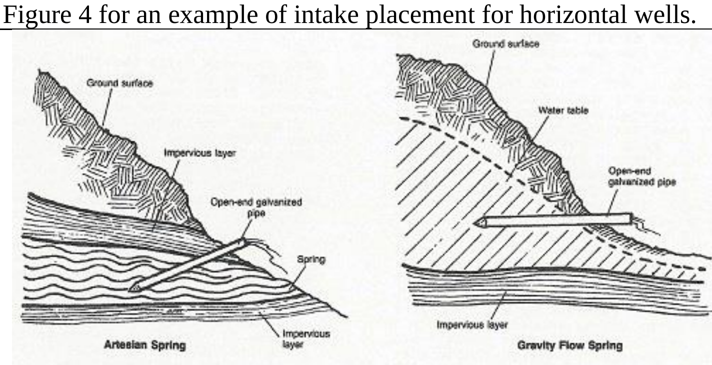


Fig 4. Horizontal wells, Source USAID

Seep Development: If water seeps from the ground and covers an area of several square meters, a third method may be used. Pipes can be laid to collect the underground water and transport it to a collection box as shown in the figure right. A poured concrete wall just down slope of the pipes can trap the water for more efficient collection. Intakes for seeps and some springs can be perforated plastic or concrete pipe placed in trenches or collection ditches.

With this seep water collection method, maintenance costs are higher as pipes often clog with soil or rocks. Also, the expense and difficulty of construction may prohibit its use. Unless the seep supplies abundant quantities of water, this method should not be considered. Figures for an example of a spring box with collection pipes.

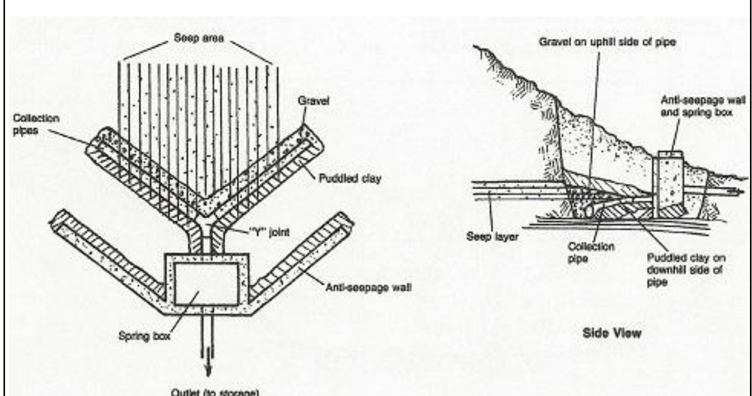


Fig 5. Seep and spring intake with collection pipes: Soruce USAID

Layout and Construction Procedures
a) Dig test holes uphill from the seep to find a point where the impervious layer below the water-bearing layer is about 1m underground. Water flows on top of this layer in sand or gravel toward the surface seep; b) Dig a 60cm-wide trench across the slope to a depth of 15cm below the water-bearing layer and extending 1.5 to 2m beyond the seep area on each side. Install a 10cm collector tile and completely surround the tile with gravel; c) Locate the collection walls (spring box) Connect the collector tile to a 10cm line leading to the spring box. The box inlet must be below the elevation of the collector tile; insert a collector pipe low in the cutoff wall to guide water into the spring box; d) The spring box should be watertight. It should be at least 1.2m high and should extend at least 30cm above ground level when buried. It should be at least 1m square.
Period of Implementation Across Seasons
Only during the dry season and period not interfering with wet seasons
Planning and Mobilization Requirements
Community/groups and individual owners' discussions/ agreement on layout, spacing and management requirements, usually in groups of 5-20 households. Training of the beneficiaries, acquiring of masons.
Cost Elements and Work Norm
The cost of spring development is minimal and the system is relatively maintenance free. The worknorm applies for excavation, stone collection, foundations/key excavation and proper placement of checkdams and drop/apron structures - $0.5M^3$ / PD. Masonry WORK NORM: 0.5 m3 / PD. Skilled artisan required. Also cement, gravel, sand, reinforcement bar (as required), pipe and its fittings need to be estimated accordingly.
Management and Maintenance
Springs are susceptible to contamination by surface water, especially during rainstorms. Therefore: 1. Divert all surface water away from the spring as far as possible; 2. Do not allow flooding near the spring; 3. Fence an area at least 30m in all directions around the spring box to prevent contamination by animals and people; and 4. Avoid heavy vehicle traffic over the uphill water bearing layer to prevent compaction that may reduce water flow. Disinfection of fresh spring water may not be required, but is always recommended. Since springs are generally located on hills, a simple gravity flow delivery system can be installed.
Benefits and Acceptability
Protected spring water sources are useful for domestic water supply, livestock and use of nurseries.
Limitation
Springs are susceptible to contamination from surface runoff. A disadvantage of spring development is that the quantity of available water may change seasonally. Local community members should be consulted as to the reliability of the source.

Name of the Technology	HAND-DUG WELLS

General Description

Hand-dug well, as the name implies, are excavated wells, and the digging (excavation) is done by hand and their Ø is larger than 1m. Hand-dug -wells for communities or schools are lined or use concrete tubes (Caisson sinking). In this guideline, hand-dug wells where the surface area is covered and the upper part of the well shaft above the water level is water tight sealed and protected from any runoff or dirt entering the well. If technically feasible, hand-dug wells can be constructed within the premise of the schools, and it can provide a cheaper water supply services. The existence of shallow water bearing geological formations - aquifers within less than 30 meters depth suit to the Hand-dug well technology. Perched water tables are less reliable water sources and it should be avoided. The construction of hand-dug wells is done manually using skilled local artisans. Their depth ranges b/n 8 and 15 meters as typical and between 6 to 25 meters as effective limits.

To make the construction of a hand-dug well viable, water must be available in sufficient quantities at shallow depths (6 to 25m) that will allow safe excavation and economically feasible exploitation of the water resources in the well. This will depend, of course, on local conditions, for instance it must have stable soil and a depth to the water table that does not allow pollution.

Geographical Extent of Use

Site selection: The site selection should be done by a tem which needs to include the community and school administration and a suitable qualified water engineer or hydrologist. The first option for selection should be within the premises of the school compound. Some of the factors to consider are: A preferred well site: i) Nearby springs; ii) In low lying area or valley bottom, depression or dry river bed; iii) The presence of ever green bushes and shrubs; and iv) Weathered rock zones. On the other hand a bad well site is: i) On a hill; ii) Near latrine or sewer line; iii) Flood prone areas; and iv) Swampy ground. However, it may be important that the engineer or hydrologist check the proposed site is appropriate. The well site should have to be on a relatively high spot to prevent surface water from entering in to the well.

Technical Design Requirements

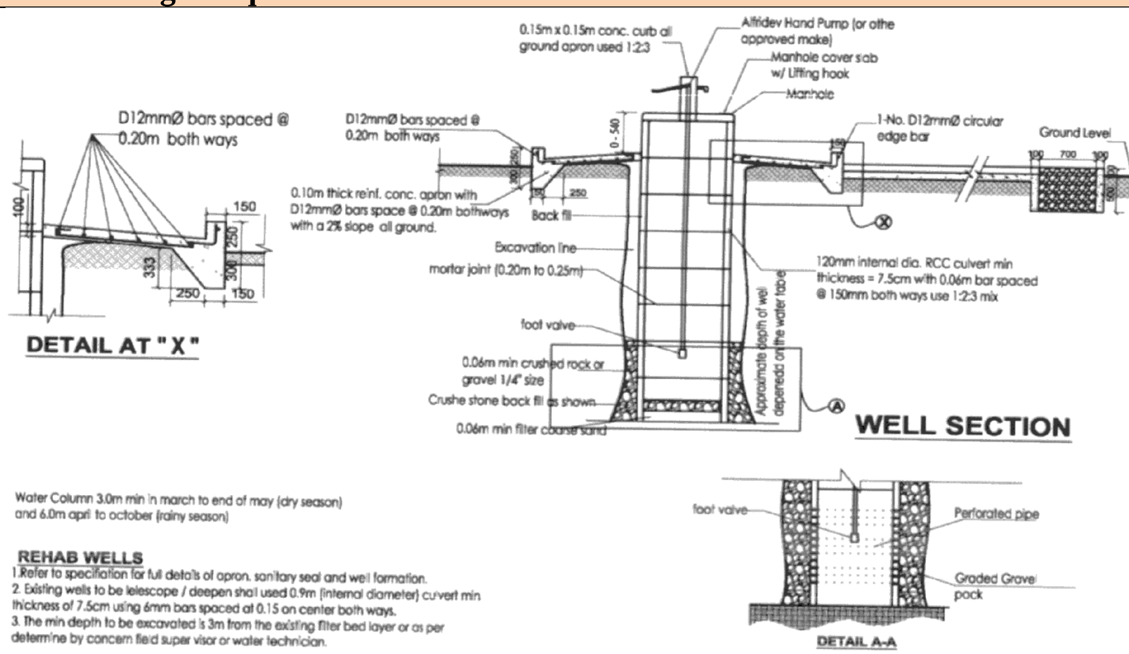


Fig 2. Graphical parts of a hand dug well

Source: Ministry of Health, Education and Water and Energy in collaboration with UNICEF

Detail well specification: Inside Ø of a Hand-dug well / well shaft: the standard Ø ranges between 1300 to 1500mm. The inside Ø for water intake area could be lesser or equal to the Ø of the well shaft above it.

Depth of the water column: The depth of water column in the water intake area must be in the range b/n tree and six meter depth or more to take the well more productive. The well yield should meet dry period water demand and must secure a minimum of three meters of water column during the dry period b/n March and May.
Well cover (apron): The well cover will have a Ø of 3m apron and a thickness of 150mm and should have reinforcement bar of 12mm Ø edge bar. A 40x40cm plate with a circular opening (150mm Ø) at the center of the plate that has a bolt at each corner is constructed and put in place for installing the hand pump. A 60x60cm access hole is also constructed with a RC cover slab located at one convenient side of the apron as shown in the above Figure.
Soak away: The excess water is channeled to a soak away facility and detail on the design and specification of the well cover is shown on the figure. The soak-away should be located at a recommended distance of at least 20m and a minimum of 10m away from the well. For those schools and communities with additional fund, the soak-away could be replaced with an underground cistern (made from masonry or concrete) to store and use the excess water for gardening and for greening the compound.

Layout and Construction Procedures

i) Construction: The construction of a standard hand-dug well has three main elements: i) The well shaft; ii) The well bottom; and iii) The head work

The well shaft

- A Hand-dug well for schools or communities is required to be lined so that it can provide long years of service. Lining could be done with bricks or stone or use of prefabricated reinforced concrete tubes. This manual recommends the use of Caisson sinking for proper digging of the well and safety during construction. It is an effective method of digging and deepening Hand-dug wells in both stable and unstable formations, provides long duration of service. The procedure is similar to what is seen in the Picture below.
- A minimum thickness of 75mm for precast concrete is suggested;
- The Ø could range b/n 1.3 to 1.5m but this could depend on the mould available for local manufacturing for RCBs;
- At least the top 3 meters depth is sealed to prevent surface water from entering the well;
- The void b/n the well lining and the surrounding ground should be packed with graded aggregates for those with precast concrete rings. Ensure the well is deep enough (more than three meters) to provide water through the dry season.
- The well below the water table or often called intake section of the well should be deepened enough (if technically possible up to six meters) below the water table to ensure a continuous and dependable water supply in all seasons;
- Caissons all the way along the well shaft: Caisson sinking provides a safe working environment, a superior and very cost effective method of lining Hand-dug wells, and simpler and requires less costly equipment purchase;
- The concrete casings above the phreatic line or water table are blind, and the concrete casings below the level of the water table are perforated;
- Use perforated concrete rings below the water table to allow water to enter to the intake area of the well. The digging/excavation works below the water table requires additional equipment - a dewatering pump. The water in the well is regularly dewatered to allow further excavation (deepening) to reach a minimum depth of three meters and a maximum of six or more meters.
- After the perforated concrete rings are put in place, a well graded gravel envelop surrounding the perforated concrete rings is packed to prevent clogging the perforations by the soils and also to improve the hydraulic conductivity from the aquifer to the wall.

Well Bottom: The well bottom is the water bearing formation of the well. Water enters both along (horizontally from the wall of the well and also vertically upwards from the lower side of the bottom), and it should be designed and constructed considering such hydraulic features. Well bottom should have the following:

- It should penetrate the aquifer adequately by at least three to six meters;
- Five to six meters for minimum yield of 10 liters per minute;
- Four meters for 15 liters per minute;
- Three meters and a minimum yield of 20 liters per minute;
- Place layer of gravel in the bottom of the well to facilitate flow from below and to avoid silting up.

Head works: Head works include the protective apron, channel for drainage water and the soak-away pit. It stands out above the surrounding ground, and it requires proper design and construction for stability of the soil and rock at the site, to support the hand pump and avoid potential seepage into the well from excess water from the pump (drainage water) and surface runoff from the surrounding areas. Proper care should be taken in mixing the concrete and reinforcements and allow them to cast properly.
In general the head work for Hand-dug wells should have the following:

- A minimum of at least 3m Ø protective apron which has a 25cm of height; a height from the surrounding ground surface. A foundation masonry structure of 45 to 60cm is constructed after the land and debris are cleared and a superstructure of the hand-dug well rests on it;

- Should have a cover slab which seals and protects the well shaft, but with an access hole and removable hatch and a 150mm Ø hole for installing a hand pump rising main (See Figure above);
- Having selected the most appropriate hand-dug well design, the construction work will have to be organized. Whichever option is chosen, the involvement of the school and/or community in any decision making including school children is important;
- The excess or drainage water is directed to a soak-away pit or underground cistern.

The headwork is designed on an elevated platform of about 1.5 to 2m masonry structure above the ground surface so that the pump outlet is connected to a ROTO storage facility so that a drinking fountain can be designed at lower elevation to allow gravity supply.

Construction safety: Artisans should have the necessary protective equipment. During the construction period, a protection wall of at least 70cm high wall must be built to prevent school children /people falling in until the well is fully completed with cover slab and a hand pump installed. Skilled and knowledgeable contractors have to be contracted to ensure the successful completion of the well and safety of workers during the construction process. Hand-dug well digging and inserting the concrete ring (See Picture and Figures).

Period of Implementation Across Seasons

Be dug during the dry season when the water table is likely to be at or near its lowest point.

Planning and Mobilization Requirements

Land use, soil and topography assessed; Discuss/agree with farmers on design and layout + and provide on-the-job training; Precise layout and follow-up/adaptations.

Cost Elements and Work Norm

Equipment and materials. The major equipment and tools required for the excavation and digging of hand-dug wells include Tripod with on tone Chain Block for Caisson sinking, excavation hand tools, dewatering pump etc. Work norm for digging is $1m^3$ / PD for the first 1m depth; $0.5m^3$ /PD thereafter. Stone Excavation $0.3m^3$/PD. The work norm involves digging, disposing of spoil, excavation of diversion canal. Work norm for gravel and stone collection is $0.5m^3$/ PD.

Management and Maintenance

Open wells should be inspected every day to ensure that no debris enters the well, while closed wells should be inspected periodically for the same reason. Cut off drains should be well maintained to prevent runoff, spilled water and animal waste from seeping or entering directly into the wells. To prevent contamination of the water, the rope and bucket used to collect the water should be suspended from the wellhead so that it cannot touch the ground. Groundwater recharging activities such as terracing, gully plugging, and sediment storage dams increase their sustainability and acceptability. To avoid contamination closed well with pulley or roller attached to a rope and bucket can be used. See info-tech on low-cost water lifting (CBPWDP, Guideline Part I).

Benefits and Acceptability

Dug wells provide a viable alternative to many of the unhygienic and unprotected water sources that are being used by a large part of the communities. It is less expensive and also avoids high capital and maintenance costs compared to machine drilled wells. Open or head caped Hand-dug wells are used to irrigate small plots or to supply drinking water for human and livestock. Hand-dug wells are very common in areas where watersheds have been treated. Additional source of water for human and livestock use and irrigation. Hand-dug wells or shallow wells are more reliable water sources than surface ponds and various cisterns. Unlike surface runoff harvesting using ponds and cisterns the water for Hand-dug well is continuously recharged through the ground. Therefore, it is more sustainable compared to other water harvesting structures. With Hand-dug wells there is high potential for using it over the dry season. Depending on the geology of the area recharging the groundwater artificially could be required.

Limitation

Open Hand-dug wells are constructed in areas where there is an urgent need for a water source and the community cannot afford for the lining material and cover. The water is recommended for irrigation of small plots and not to be directly used for human consumption. The other demerit of open wells is that they require wider space especially in unstable soils. The sides of an unlined well may collapse when wet if adequate slope is not provided.

Name of the Technology	MANUAL TUBE WELL DRILLING

General Description

- Manual tube well drilling technology is a technology, operated by human power to drill shallow groundwater for productive uses, such as for small-scale irrigation, for domestic and livestock water supply.
- Manual tube well drilling technique uses different tools. Simple sludge in combination with percussion tool is the most common techniques used in Ethiopia (Fig 1-3).
- Manual tube well drilling technique using simple sludge and percussion is suitable for drilling in unconsolidated and consolidated formations: sand, silt, stiff clays, gravel, sandstone, laterite, weathered rock and fractured granite. It is also appropriate to shallow groundwater depths in which its static water depth not more than 30 meter deep

Fig 1. Manual tube well under construction

- The problem of well collapse in hand dug wells, especially in sandy and clays soil conditions can be improved by using tube well drilling techniques. Using manual tube well drilling techniques can solve the problem well collapse in hand dug wells specially in sandy and clayey soil condition.

Geographical Extent of Use

Manual tube well drilling techniques can be applied in all agroecology where groundwater resources are shallow, the soil formation is not hard and where water is a problem and developing groundwater resources is relatively simple and cheaper than when compared to developing other water resources. Moreover, manual well drilling be more sustainable in the area where hand dug well development is common and where collapse of hand dug wells is a major problem.

Technical Design Requirements

The following are design steps while developing shallow groundwater resources:
Design steps:

- Know the static (at rest) water table depth
- Decide the type of pump to be used (suction or lifting)
- If the static water depth is over 4-meter-deep and suction pump is considered, excavate pump house (3m*3m and depth as required). AS a rule, the depth of the pump house excavation will be equal to the vertical height (depth) difference between the center of the pump position and the static water level. This depth difference should not be over 4 meters. Then drilling will start at bottom floor of the pump house (see Figures below)

In the case of using lift water lifting devices such as rope and washer pumps, submersible pumps (ether solar, electric or generator driven) are to be used, drilling can start from ground surface. In this case, excavate 1.5m wide *1.5m long *0.5m deep trench for ponding drilling fluid (water) (Fig 1)

Drilling Procedures

`The following are drilling procedure using manual well drilling techniques:

- Start drilling with simple sludge tool using 1½ inch galvanized iron pipe
- Whenever, the formation is becoming hard use percussion tool as required
- Collect soil samples every one-meter drilling depth to determine where to stop drilling and for determining well casing arrangement (blind and screen). Reaming using, 3, 4, 5 and 6-inch diameter reaming bit (Fig) assembled all in one or turn by tern.
- Insert casing, blind and screen according to the soil sample (cutting) report made by the geologist. Fill river gravel pack (see Figure to the right). Well development using appropriate water pump
- Install water lifting device/pump

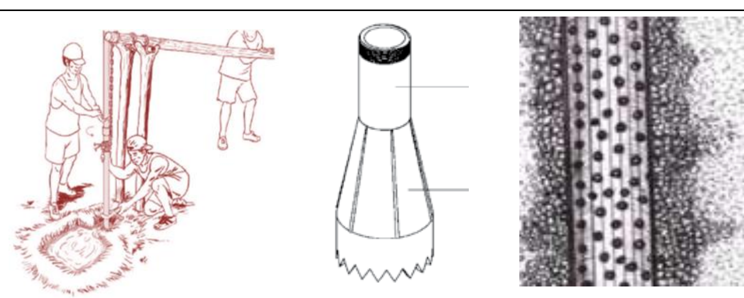


Fig 2. Manual drilling, reamer, and filter for the establishment of the tube well

Period of Implementation Across Seasons

- Water well drilling is done during the dry season where the static water lower to the maximum.

Planning and Mobilization Requirements

- Need assessment with full community/users' participation
- Check its requirement (fulfilling) the required technical specification? Soil formation, water table depth, available water lifting device, available command area size, drilling tools availability in the locality, knowledge and skill in the locality, etc.
- Determine its future use (identify best commodities), irrigation, livestock water supply, domestic water supply, or multiple use

Cost Elements and Work Norm

Cost items can be categorized as follows: **Material** ➢ Hand tools ➢ Drilling tools ➢ River gravel pack, ➢ PVC Casing ➢ Water lifting (treadle pump, suction diesel/petrol engine or lift devices (such rope and washer, hand pump-Afridev, etc.)	**Labor** ➢ Driller (#1) Assistant driller (#4) **Work norm** The work norm for drilling of shallow groundwater include trench for drilling fluid, drilling, reaming, installing casings, gravel packing, installing water lifting devices, grunting, well development and pump testing. The average work norm for such task (average 30-40 meter depth with 5 people) can be considered 0.6m depth per person (0.6m pd).

Management and Maintenance

- Groundwater resource, if not properly managed or used, it can be depleted. Therefore, for sustainable use of groundwater, development of shallow groundwater must be according to professionally recognized well spacing and as the same time it should be integrated with appropriate groundwater recharge techniques.
- For groundwater use, must obtain approval from an authorized institution in the woreda

Benefits and Acceptability

- All the materials are available locally
- Simple technology, very cost-effective
- No drilling mud is required.

Limitation

Promotion of manual tube well techniques will be difficult in the area where the soil formation is hard (granite, basalt, etc.) and the groundwater depth is as deep as over 30meters.

Name of the Technology	COMMUNITY POND

General Description

Definition: are small pond or reservoir like constructions greater size of house hold level pond but the construction is able by the community and constructed for the purpose of storing the surface runoff, generated from the catchment area.

The community pond is used for livestock watering and other purpose depending on the water insecurity problem of the area.

Fig 1. Scene of community ponds (trapezoidal – left) and circular (right) in dry areas primarily for LS purpose

Geographical Extent of Use

Suitable in areas where there are no surface and underground water resources or uneconomical to develop or where scarcity of water is severe. Mostly suitable in the Rift valley, semiarid and arid area. Moreover, the site selection is preferable at lower catchment area on which less than 5% slope for protection or reducing erosion however can also be applied in grass and communal land with workable soils up to 3m - 6m depth having flat to gentle slopes.

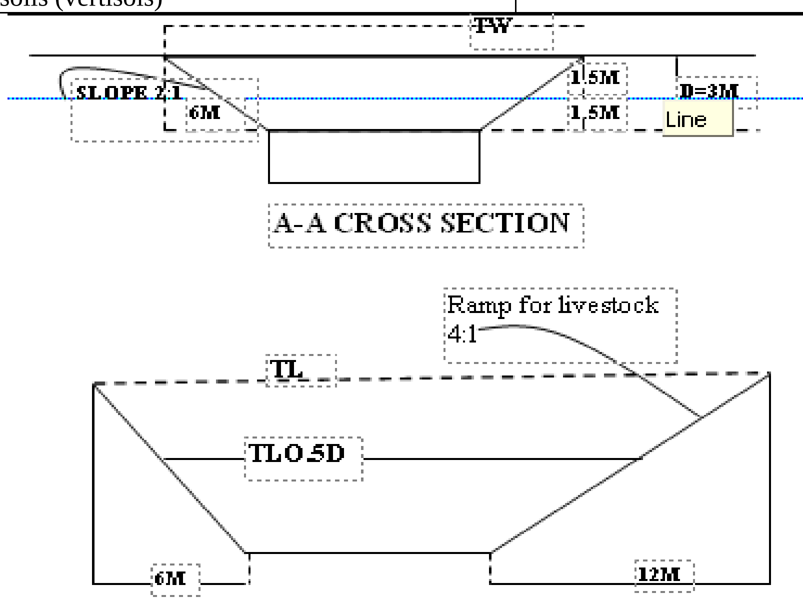
Technical Design Requirements

Design steps to be followed, For suitable shape of pond is usually trapezoidal and frustum of Cone shape wide at the surface with sloping sides depending on the soil type and narrow towards the base for stability, i.e.1:2 vertical to horizontal for stable soils, 1:3 or 1:4 vertical to horizontal for unstable soils (vertisols)

Where $V =$ storage capacity, m^3
D = water storage depth, m
A= top area of storage = L× W, m^2
B=Middle area (average of the top and bottom)
C= base area of storage = l× w, m^2

1. The size of trapezoidal shape pond is calculated by Where $V =$ storage capacity, m^3
H = water storage depth, m
A_t = top area of storage = L× W, m^2
A_b = base area of storage = a× b, m^2

$$V = Dx \frac{[A + 4B + C]}{6}$$



B-B Longitudinal Section

2. The pond site generally should be evaluated with respect to frustum of cone shape
V=1/3IIr^3 = Cone volume
Frustum of cone V = 1/3IIR^3-1/3IIr3
V=1/3II(R-r) (R^2 +r^2+Rr)
Where R Top Diameter in meter
r Bottom Diameter in m
R-r = the depth of pond H in m
V = Volume of the pond in m^3

Fig 2. Cross section of a circular pond showing cross-section and LS access ramp

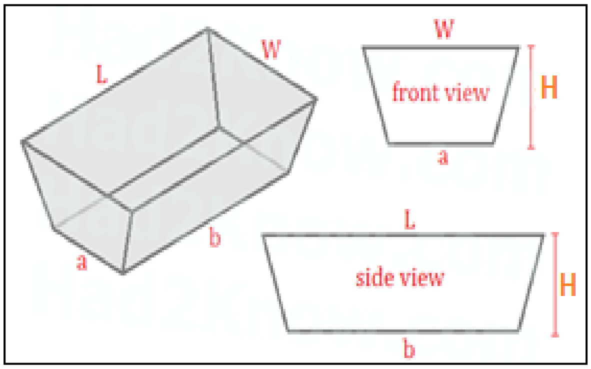


Fig 3. Projections of front view and side view of a trapezoidal pond

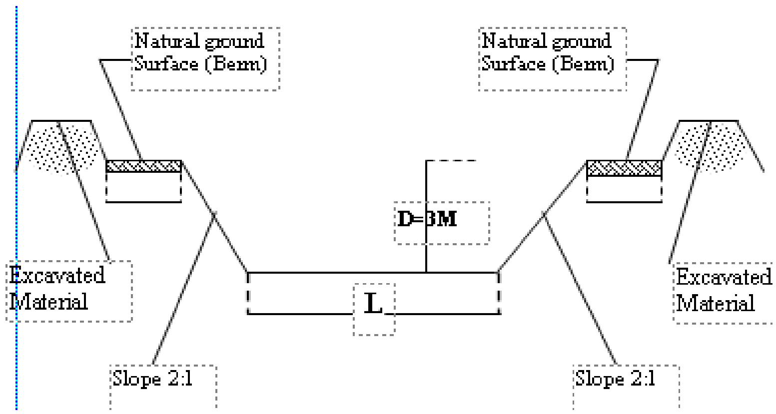


Fig 4. Labled parts of a trapezoidal pond

$$V = (A + 4B + C)/6 \text{ x} D$$

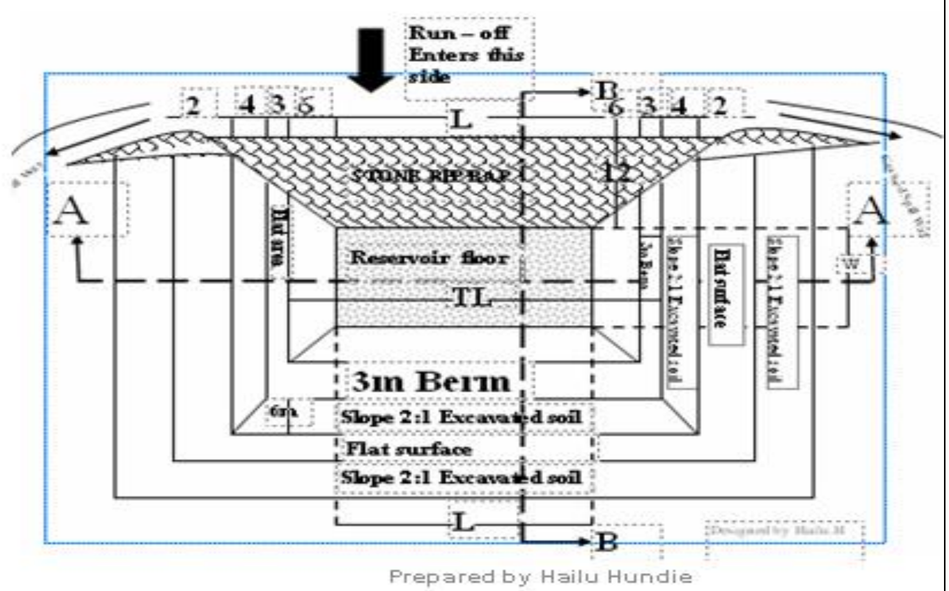


Fig 5. Excavated rectangular pond (left)

Note: Five Border lines shown in the top view of the pond is just to provide brief description on section parts don't consider as step or ladder. So that starting from the box like boarder line is reservoir Floor, then next to it is the pond full level, the third box like border line is left for Berm (3m) , fourth embankment slope at upper stream 2:1, then top part of embankment compacted Flat surface and downstream side of the embankment slope is 2:1

Frustum of Cone Shape

Based on the above empirical formula the pond type classified into three Topography, Catchment, Foundation, Soil type and Spill way Type 1 40m Top diameter,28m bottom diameter and 6m depth of the pond=5504m^3

Type 2 30m Top diameter,20 m bottom diameter,5m depth of the pond=2487m^3

Type 3 25m Top diameter, 17m bottom diameter and 4m depth =1401m^3.

D	L	W	TL	TW	TL0.5 D	Tw0.5 D	Storage capacity (m^3) $V = Dx\frac{[A + 4B + C]}{6}$
3	40	40	58	52	49	46	6816
3	30	20	48	32	39	26	3096
3	35	35	53	47	44	41	5466

Trapezoidal/Rectangular section shape

Calculated volume Type 1 40m Top diameter,28m bottom diameter and 6m depth of the pond $V= 1/3\ IIh(R^2+Rr+r^2)=$ $1/3II6m(20^2 +14^2+20*14)$, $876*6*II/3=5504m^3$

Type 2 30m TD,20mBD, $V=1/3\ II\ 5m(15^2+10^2+15*10)=2487m3$, Type3 25mTD and17mBD, $V=1/3$ $II4m(12.5^2+8.5^2+125*8.5)$, $V= 334.75*4*II/3$, 1401m3

Layout and Construction Procedures

Method 1
1) Mark the top area of the pond on the ground (CD)
2) Mark the bottom area of the pond on the surface (AB)
3) Start excavating the bottom area to the required depth (AB) hatched part
4) Reshape the sloping side, triangle
5) Place the excavated soil 3m away from the border of the pond

Method 2
1) Mark the top area of the pond on the ground with pegs
2) Mark an area inside the top area maintaining the side slope and start excavating to 1m depth
3) Repeat the same procedure until the required depth is reached, the excavation is like stairs
4) Shape the stairs by excavation to the design slope

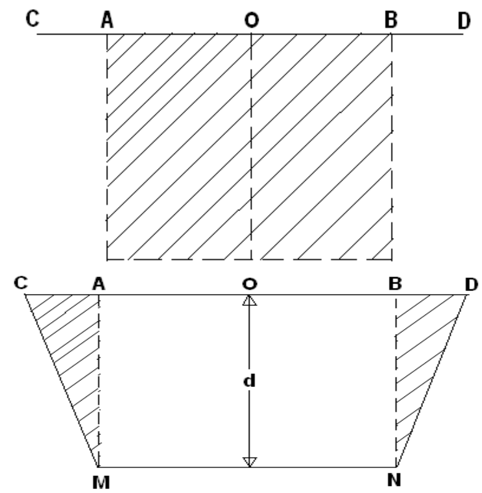


Fig 6. Layout and construction procedures of an excavated pond

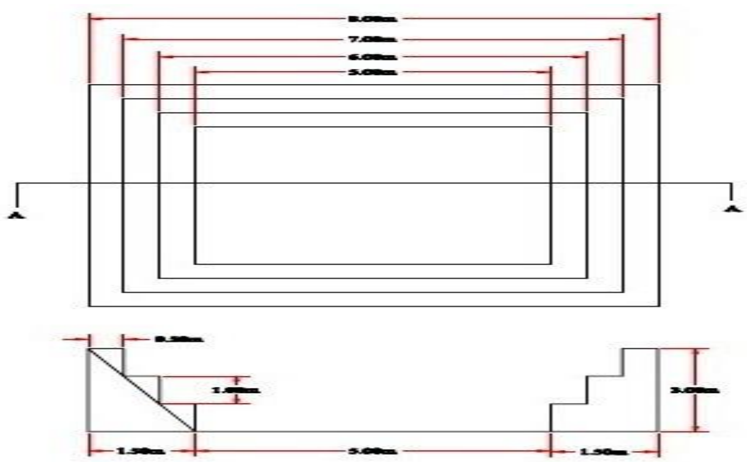


Fig 7. Various pond dimensions labled

Period of Implementation Across Seasons

Construction of ponds should be constructed during the dry season

Planning and Mobilization Requirements

Check the availability of labour and land, mobilizing materials measuring tape, string, pegs, crowbar, pick axe, shovel and lifting mechanisms like treadle pump

Cost Elements and Work Norm

Excavation and hauling less than or equal to 1m depth 0.5m3/PD while for greater than 1m depth 0.5m3/PD for excavation and separately 0.5m3/pd for hauling.

Management and Maintenance

Fence the pond with live or dry material for safety purpose, i.e protects animals and children from easily drowned to the pond. And also adopt suitable water lifting technologies to abstract water. Integrate with water lifting mechanisms like the technology i.e. Treadle or Pedal pump, Rope and washer pump etc

Benefits and Acceptability

To store water for use during the dry seasons for domestic, livestock watering or irrigating small gardens

Limitation

Excavated soil or Bulk management, needs intensive labour

Name of Technology	CHECK DAM POND

General Description

Check dam pond is a structure of masonry with Gabion or alone where the water flows over the top when the storage is full to collect water and can be applied for nearby Farm fields. A check dam constructed on watercourses (i.e. rivers, streams, gullies) to harvest surface runoff. **Major objective** of check dam pond is to store water for use during the wet seasons or additional water to cultivated plots; Check dam pond is to provide direct irrigation when rains fail (diversions). Check dam pond is to facilitate the recharging of surrounding wells through percolation of water from check dams (reservoirs).

Fig 1. Checkdam pond

Geographical Extent of Use /Suitability

Suitable in areas where scarcity of water is severely a problem and there are no surface and/or underground water resources that are economical to develop. Therefore, the storing technology are mostly useful the arid and semiarid areas of Ethiopia. Harvesting technology suitable in locations where there is enough catchment area that supply water to be stored in the soil or storing structure. Although needs to be constructed in lower catchment areas (farm, grass and communal lands) with a slope of less than 5% for protection or reducing erosion.

Design and Construction Procedures

Site selection:

- Topography of the site: narrow gorge, opened upstream, small length of barrier/wall, slope of watercourse not exceed 5%
- Sufficient catchment area to generate the required flood.
- Command area and the canal network located at the downstream
- Spillway site: Presence of efficient and economical spillway route
- Geological condition: the stream have good rock for foundation and prevent percolation
- Sediment load; should be as less as possible
- Availability of sufficient construction material in the area
- Water tightness of reservoir; the bed and the side flanks of the reservoir upstream of the dam must be watertight i.e. strong abutments to key the structure.
- Cost: minimum construction, operation and maintenance cost.
- Accessibility; sites should not be very far from roads.
- Social and Environmental aspects; less social and environmental impact as possible.
- Upstream watercourse should be with least meandering & braiding.
- Water Demand

Design Steps:

- Before starting the design of the water harvesting check dam, the water demand of the local community has to be known.
- The amount of water used by people for domestic purposes as drinking, cooking and cleaning, as well as for irrigation is assumed to remain the same all year around.
- The number of hhs benefiting from water from the check dam reservoir needs to be determined.

The water requirements of the individual hs have to be carefully assessed on both domestic needs and the water requirements for irrigation or cattle

- Demarcate the Catchment area that is contributing runoff water to the check-dam pond site.
- Calculate river discharge either by cooks, rational or empirical formula method.
- Survey the cross-section and L-section of the river.
- Calculate top width and bottom width of the check-dam.
- Height of check dam will be limited by height of banks and level of farmer's field.
- Use bigger size openings (gates) which can flush amount silt load carried by rivers.
- Determine spillway dimension for safe disposal of water

Check dam pond is a gravity dam type depend solely on weight for their stability (Refer weir design about stability against sliding, stability against overturning, safety against tension, safety against bearing capacity of foundation, safety against seismicity). There are two types of check dam pond. 1. Concrete mix only 2. Masonry 1:3 mix ratio with gabion mesh

1. A symmetrical section can be used, or gives the same height with less material and is more usual. For check dam pond not built in steps, the back slops is at 2 horizontal and 3 vertical, so the width W at any height h is:

$W = c + 2/3(H-h)$ where c is the crest width and H is the height of the check dam pond. The crest width depends on the wall height, H is 1 up to 2m, this can be for concrete formed by pouring concrete into wooden shuttering. Alternatively, masonry can be used to form the outside layer and also to act as shuttering.

2. Dimension of Water harvesting Check dam pond with masonry work with gabion mesh and can be built in steps

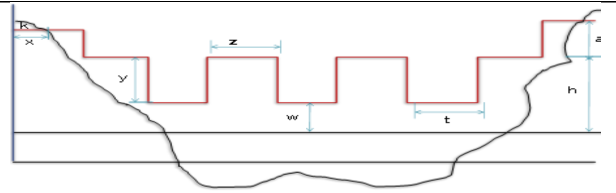


Fig 2. Front view of a checkdam pond

Where:

- h= Effective height= 2-2.5 m
- t= 1m
- x= 2.5-3m
- z= 1.5-2m
- K= key
- y= Live storage = 1-1.5 m

w = Dead storage = 0.5-1 m

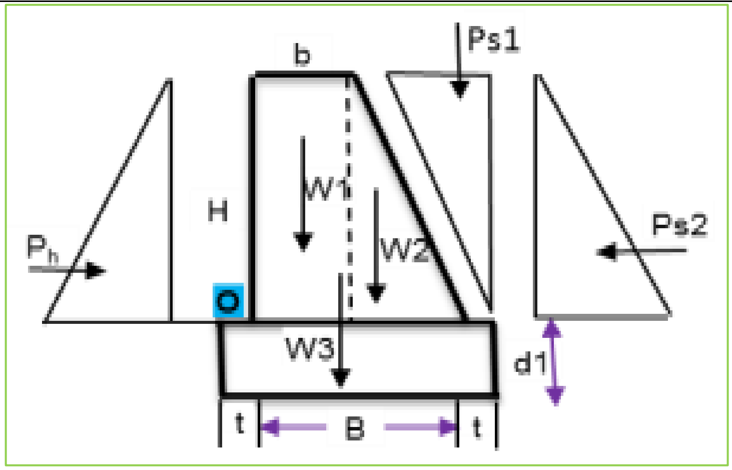


Fig 3. Forces acting on the checkdam structure

Laying out Requirements

- ✓ Measure the appropriate distance starting from one of the river banks to the other depending on bank characteristics and fix pegs perpendicular to the river course at certain intervals.
- ✓ Use a plumb bob to locate the appropriate position and fix pegs.

Construction Procedure

- Foundation has to be excavated up to the hard soil. (Minimum 1.5 – 2.5m, but it depends on the site condition). In sandy soil it may go deeper.
- Remove the excavated soil and fill stable soil and compact it strongly, then level it with cement (lean concrete), before putting gabion boxes.
- Make sure the availability of proper filling materials (basalt, granite and hard sandstone are best) with appropriate size
- After the proper foundation is prepared, put the gabion box on top and fill with properly shaped stones.
- Tie the gabion box and plaster it with mortar ratio of 1:3, put slots (gates) at certain intervals along the gabion box as per the required design of spillway.

Implementation Period Across Seasons

During the dry season. It should be constructed and ready for water harvesting mechanism system during the wet season. Then the runoff from stream harvested in wet season and used for crop production as supplementary irrigation for nearby farm land.

Benefits and Acceptability

Contribute for climate towards multi-functional and climate resilient community; adapt landscape continuum-based land and water management.

Work Norm

Estimate about requirements based on the following work norms: The work norm for the check dam pond (inclusive of all elements) is estimated as 0.75 m³ of volume work (earth and stone fill) per person/day. S**urvey tools and equipment**: long rope and wooden pole, measuring tape or marked string Tools: crow bars, shovels, pick axes, local stretchers (barilla) to carry soil, sledge hammers. Volume of stone work per ha varies from 70 - 280m3 based on slope. Gabion mesh, masonry 1:3

Maintenance and Management

The check dam pond require maintenance per after rainy season. It will tolerate some overtopping in heavy floods. But there may be some stones washed off, which will require replacing, or tunnelling of water beneath the gabion mesh and need packing with small stones and mortar. No structure in any water harvesting system is entirely maintenance free and all damage, even small, should be repaired as soon as possible to prevent rapid deterioration. Agree with the land-owners/users on both sides of the dam, where to place the structure (s). If the dams are constructed in series start from the top of the stream or gully.

Limitations, Challenges and Constraints

The main limitation of check dam pond is that they are particularly and require considerable quantities of loose stone or large quantities of stone needed as well as the provision of site specific, transport. Labour intensive and needs thorough follow-up. Difficult in areas with limited expertise or engineers at site level. Not suitable in sandy and sodic soils.

Intuitional Responsibility

Fully on groups/individuals +/- community (commitment to management). DAs and woreda experts - technical support and follow-up/management with the assistance of Agricultural or Irrigation Engineer.

Name of the Technology	WEIR DSIGN AND CONSTRUCTION

General Description

A weir is a structure constructed across a river that raises the water level on its upstream and so that waster can be diverted to a main canal. To divert stream flow to the canals and to supply water to the field for use during dry seasons. The diversion weir serves to raise the water level in river to irrigate the target command area, regulate the intake of water in to the irrigation canal, control the silt entry in to the canal by the provision of under sluice structure and reduce fluctuations in the level of supply in the river

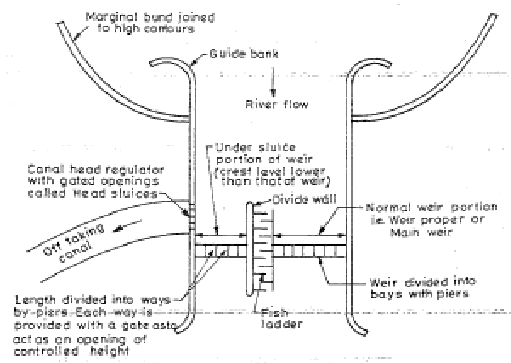


Fig 1. Typical plan view of a diversion weir

Geographical Extent of Use

The technology can be applied in all agroecology where there is a need to divert water from rivers.

Technical Design Requirements

1 Site selection

The actual site for weir construction is selected with the following considerations

- A reasonably wide and well-defined channel with reliable River bank (abutment) & river bed stability & water tightness
- The associated canal alignment should enable adequate command without excessive excavation or embankment;
- The elevation of water surface with respect to the adjoining land surface should not be so low which might require an excessively high weir;
- Easy arrangement of flow diversion during construction; and
- Should be located with firm, well defined banks so that the river couldn't overtop its embankment and change its course.
- It should not submerge costly land and property on its upstream
- Proximity of the irrigable area (not too far)
- Availability of construction material at the nearest place.
- Good foundation should be available at the site.
- The site should be easily accessible

2. Components of a weir

In small scale projects the components of diversion weir structure are

- Weir body
- Under sluice including its gate and operation slabs
- Intake including its gate and operation slab
- Aprons for energy dissipation works
- Upstream and downstream cutoffs
- Flood protection walls or wing walls as shown in the figure above

But in some projects one or two of the components may not be required. For example, if the river bed is sound rock aprons for energy dissipation work is not required

3. Data required for the design of weirs

The following data are essential for the design of the weir and its appurtenant structures

Topographic data: A topomap of the area around the proposed site at least 1:500 with contour intervals of not more than 0.5m, up to an elevation of at least 2.0m above the highest flood level is required. It shall extend 1.0km on the upstream and 0.5km downstream of the proposed site and up to an adequate distance on both flanks. Cross-section of the river at the proposed site and longitudinal section of the river at intervals of 50m both on upstream and downstream up to at least 300m and the topo-map of the target command area with scale of at least 1:1000 is required.

Geology and Geotechnical data: The over burden information and their suitability; bank stability and workability; river bed stability and workability and availability, quality, quantity and proximity of construction material

Hydrological Data: Design flood, design lean flow or base flow at the proposed weir site after considering upstream and downstream allowances and catchment characteristics from erosion risk point of view is required.

4. Weir design

Design of rectangular broad crested weir with vertical U/S and hard rock foundation

Calculate design flood (Q) using rational method for small catchment area < 5km^2, and USSCS for larger catchments as attached in the Annex 1.

a) Weir Height

length b/n command and head regulator); water depth required in the canal; head loss across head regulator given as 0.1-0.2m.

Height of the weir H=(maximum command elevation+ canal drop+ water depth in the canal

Input data are river bed level (deepest point of the river); maximum command elevation; main canal drop (calculated from canal slope and + head loss across head regulator + working head (1m) – river bed level)

b) Weir crest length (P): calculated using Lacey's formula $P = 4.75\sqrt{Q}$ where Q is design flood

Lacey's flow regime width may be used if the width of the river is higher than the Lacey's crest length value but if river cross section is lower value adopt the river section as crest length.

C) Top and Bottom Width:

Top width T in m, $T = \frac{H_e}{\sqrt{\rho - 1}}$

Bottom width B in m, $B = \frac{H + H_e}{\sqrt{\rho - 1}}$

Where H, is Height of weir (m), He is specific energy head (over flow depth + approaching velocity head (m)), ρ is specific weight of weir body (2.3 for cyclopean concrete or masonry and 2.4 for reinforced concrete)

Q = 1.7 L He 3/2 hence $H_e = \left[\left(\frac{Q}{1.7*L}\right)^{2/3}\right]$

where L= weir crest length in m including scouring sluice width (1m)

Note: Top and bottom width should be adjusted to satisfy the stability criteria (as discussed in the masonry dam design).

If the design of the weir is on alluvial soil foundation sufficient apron length and thickness should be provided with u/s and d/s cutoff with sufficient analysis of hydraulic jump and seepage analysis. Whichever the case one needs to adopt the longest length.

D) Design of divide wall: The divide wall serves to separate the under sluice and the weir flow section besides helps to support operation slab.

A divide wall is a wall constructed at right angles to the axis of the weir in order to separate the scouring- sluice section from the rest of the weir. This wall is usually made1-2 m thick and extends up to 3 m beyond the canal head regulator.

U/s wall height = U/s HFL - foundation level + free board. Adapt 0.477m free board.

D/s wall height = D/s HFL - foundation level + free board

e) Design of Under sluice gate

The bottom of the orifice opening (crest) should be kept as close as possible to the level of the riverbed. Thus, the crest of the scouring should be much lower (0.5 -1.2 m) than the crest of the canal head regulator. This is to ensure that the water passing through the scouring sluice can scour the silt deposited in front of the canal head regulator.

- The opening should not be less than 1 m wide and 0.5 m deep. The width of the opening is usually kept equal to twice the depth of the opening. It is recommended to have two or three small opening rather than one large one.

Design of flood protection wing walls the height is similar to the divide wall for the u/s and d/s side the thickness can be 1m top width with 1:1 side slope to the embankment side based on the height the bottom width will be decided (you should also check for stability analysis which needs the support of an engineer).

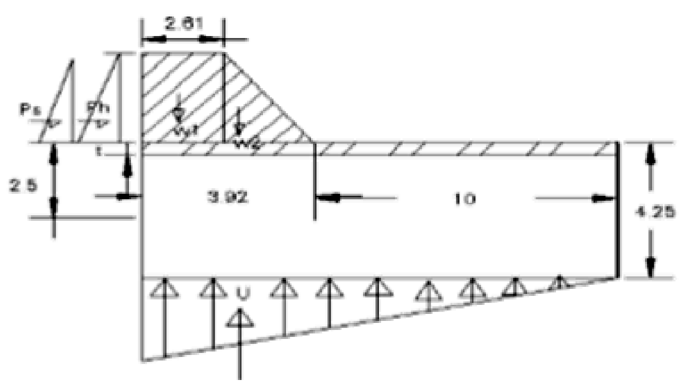


Fig 2. Free body diagram of the forces acting on the diversion weir for stability analysis

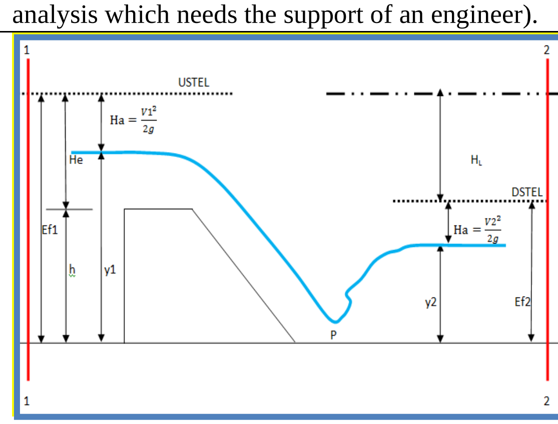


Fig 3. Graphics for the design of rectangular broad crested weir

Management and Maintenance

For operation and management of the technology farmers should be organized through WUA or IC. One technician to be trained as gate operator. The gate operator is responsible to operate the canal head regulator and the under sluice gate. During the dry season when water is needed by the community the gate operator will close the under sluice gate and open the canal head regulator to let irrigation water to the main canal and during the rainy season when irrigation water is not needed no more the canal head regulator is closed and under sluice gate will be opened to protect sedimentation upstream of the weir. Besides all moving parts should be greased to for ease of operation periodically.

Fig 4. Scene of a diversion weir

Fig 5. Diversion weir functioning, see the control gate (left)

Fig 6. Closer look of a properly functioning diversion weir

Fig 7. Upstream and downstream scene of the weir structure

Period of Implementation Across Seasons

Construction period for diversion weirs should be during dry seasons, usually January to May.

Cost Elements and Work Norm

Minimum tools required include (1) Surveying equipment (theodolite, line level, and GPS), (2) Wooden pegs, measuring tape or marked string. (3) Sledge hammers, crow bars, shovels, pick axes, wheel barrows & barilla (to carry out soil), buckets; (4) soil augers & test kits. Proper engineering cost estimate for sand, stones, cement and reinforcement etc. is needed. Average work norm is 3000 pd/weir. The work norm includes surface clearing, leveling, removing of foundation materials, stone masonry works, stone collection, backfill and off taking structure and other excavation works. Skilled masons are needed for masonry works.

Benefits and Acceptability

The technology is highly acceptable by farmers because it ensures the availability of water for irrigation through gravity force and farmer's livelihood will be improved by increasing their produce through irrigation. Hence farmer's income and livelihood will be improved and enhance their resilience to climate change.

Limitation

Cost and skilled manpower to properly design and construct the technology are the major limitations of the technology.

Pictures of diversion weir

Name of the Technology	ROAD WATER HARVESTING - RWH

General Description

Road water harvesting is a common method to collect water and can be applied in many different ways. A common definition of water harvesting is: "The collection and management of floodwater and rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance." All water harvesting systems have some characteristics in common: A surface that does not adsorb all the rainfall and therefore generates runoff water. This is commonly called catchment surface. A place where the water can be stored – this can be in many forms. Common storage types are cisterns, ponds, the soil and shallow aquifers. A combination (conveyance system) of channels, drains, pipes or gutters to bring the water from the catchment to the storage. Sometimes the catchment surface is directly connected to the storage. The **objective** of Road water harvesting is to store water for use during the dry seasons or additional water to cultivated plots; Divert additional water to SS dams and cropped areas inside gullies; Divert additional water into reservoirs for irrigation and/ or domestic use.

Geographical Suitability

Suitable in areas where scarcity of water is severe and there are no surface and/or underground water resources that are economical to develop. Therefore, the storing technology are mostly useful in the arid and semiarid areas of Ethiopia. Harvesting technology suitable in locations where there is enough catchment area that supply water to be stored in the soil or storing structure. Although needs to be constructed in lower catchment areas (farm, grass and communal lands) with a slope of less than 5% for protection or reducing erosion. In Semi-arid areas with big variations in water availability, water from roads can be a main contributor to water security. In other agro-ecological landscapes additional options may also apply for water harvesting from roads. Implementation of Road water harvesting requires careful selection of surface slope, soils types, and drainage gradient. Slopes range from flat up to 5%, with even topography. The recommended C:CA ratio is 2:1 for 2m spacing between ridges: and 3;1 for 3m between ridges suited to area with rainfall of 350-750mm/year.

Road Water Harvesting Design

Consideration and standard
Road water harvesting can be divided in three categories:

1. Runoff harvesting from roadside drains using mitre drains
2. Runoff harvesting from culverts
3. Runoff harvesting from road surface using rolling dips and water bars

The most common road surface drainage methods are A. Rolling Dips, B. Water bars C. Side drains or lead-off ditches and D. Mitre drains E. Culverts

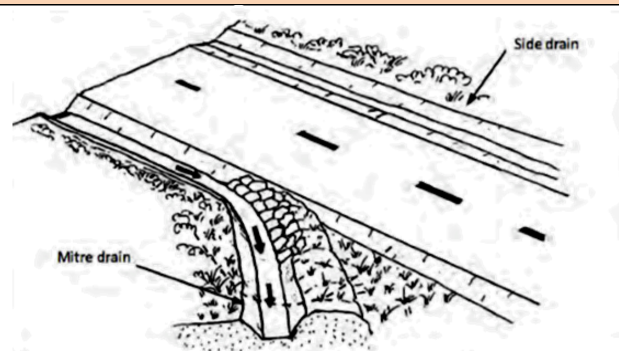


Fig 1. Runoff harvesting from the road drain via the mitre drain

A **rolling dip**: collect road surface runoff and divert it away from the road. They are broadly angled dip drains with a cross slope of 4-8%, steep enough to flush away accumulating sediments. They are excavated cross-drains at gentle gradients, between 2 – 5%.
Earth **water bars**: are narrow, earthen bunds built across roads. They divert water off and away from roads or trails into vegetated areas before it causes erosion. To build an earth-berm water bar, excavate a trench at a 30- to 45-degree angle across the traffic surface.
Side drains: water from down-slope drains can be used for water harvesting directly along roads. The water from the road drain may be routed directly to the land to recharge structures, small reservoirs improved structures. Low volumes of flow and low velocities should be achieved at each discharge point to minimize erosion.
Mitre drain: divert water from main road side drain. This diverts water to a stable area. The water can also be diverted into storage or recharge structures.

Culverts: design of side ditches and spacing of culverts varies with terrain and whether paved or unpaved road just as erosion control and water harvesting options vary with terrain. No culverts are required on flat terrain. As a general rule 1-2 culverts/km are required on rolling terrain to carry water from upslope drain to the down slope of road rising to 5-6 culverts/km in hilly and mountainous terrain.

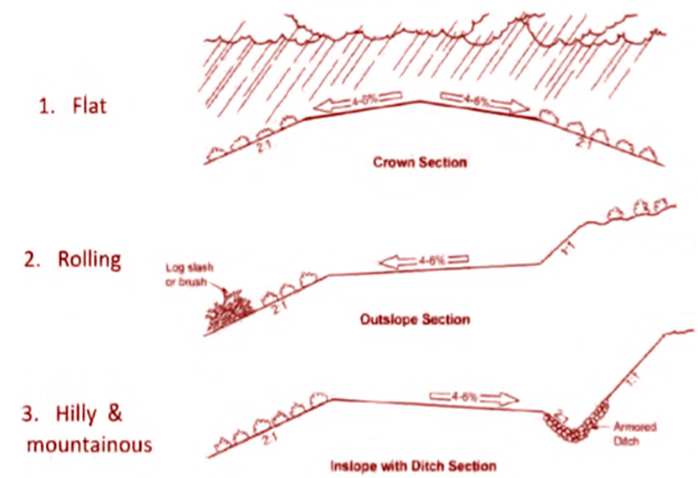


Fig 2. Different road types give different opportunity for RWH

Max. distance of mitre drains (Adapted from ERA guideline B)

Road gradient in %	Maximum mitre drain interval (m)
12	40
10	80
8	120
6	50
4	200
2	80
< 2	50
A Maximum of 100 m is preferred	At low gradient silting becomes the major issue

Generally, though, it is also good to note that there are nine Road water management option. 1. Road water harvesting from road surface 2. Road alignment 3. Cross drainage and culvert 4. Road side drain 5. Borrow pits 6. Newly opened springs 7. Fords (Irish Bridges) flood water spreading weirs 8. Road side vegetation 9. Manging and harvesting sediments.

Period of Implementation

During the dry season period different types of water harvesting structure should be constructed and ready for Road water harvesting mechanism system during the wet season. Then the runoff from road diverting to the constructed harvesting structure should follow.

Cost Elements and Work Norms

Work norm is 250 Pd /km. For layout line level, range poles, 10 m string, digging tools, compacting tools to stabilize the bund.
The diverted runoff from Road the conveyance mechanism is by constructing ditch similar with the Graded soil or graded stone-faced soil bunds. Here care is needed in the design and construction of the bunds and spillways to prevent breakage and the assistance of an agricultural engineer should be sought.

Maintenance and Management Requirements

The fields need to be levelled and homogenous. If there is a slope it is important to construct flat terraces. II. Each field should be bonded. Construct a soil bund on the edge of the field to retain water. Small contour ridge 15-20cm high and spaced 1.5 to 3m apart have proved technically successful for water harvesting on flat alluvial soils. Slopes range from flat up to 5%, with even topography. The ridges are constructed on the contour by digging a furrow and throwing the soil to the lower side. The land shall be prepared before the rains or as soon as the soil becomes workable. Farmers need to monitor their land closely and run to the field when runoff. Farmers should be ready to divert and stop diversion to their fields. The water should not overtop the field bunds or will cause erosion - it is therefore key to break the bunds when a field is full. When all

fields are full the upper diversion structure (at the culvert or end of mitre drain) must be broken to stop irrigation. Requires attention and maintenance for proper management of the channel surface. Need proper distribution of top soil uniformly over the embankment
Challenges and Constraints (Limitations)
Erosion risk at the outlet due to improper attention for provision of drop Structures. Excavation is labour intensive, and it requires regular maintenance and management.

Name of the Technology	SAND DAMS

General Description

- A sand dam is a partially subsurface dam build in a dry and sandy riverbed on river bedrock or an impermeable layer.
- It is constructed across a river to block the subsurface flow of water, hence creating a reservoir upstream of the dam within the riverbed material.
- The main function of sand dams is to store water in the sand of the riverbed and therefore increase the volume of sand and water in riverbeds.
- The reservoir will be filled due to percolation of water during flood events.
- The water within the riverbed (reservoir) can be used for domestic use and livestock. Other functions of sand dams can be: sand harvesting, rehabilitation of gullies and groundwater recharge.
- Sand dam can also be classified according to the material they are constructed of as stone masonry dams, reinforced concrete dams and earth dams.
- Masonry dam is built of concrete blocks or stones. It is durable and suitable for any dam height. It is relatively cheap when the construction materials are available within the dam area.
- Reinforced concrete dam is a thin wall made of reinforced concrete. It is a durable structure, relatively expensive but suitable for any dam height.
- Earth dam is made of impermeable soil material (mostly clay or clayey soils, or black soils).

Fig 1. Sand dam in dry river

Fig 2. Sand dam with water hand pump close to it for water abstraction

Geographical Extent of Use

Sand dams are more appropriate in the area where water supply for livestock and domestic is a critical problem and the land use of the catchment for the dry river is not cultivated but protected with different soil and water conservation measures and the soil character of the area sandy and gravel.

Technical Design Requirements and Construction Procedure

a. Estimate water demand and water yield

Water demand (m^3)=Water yield (m^3) + Volume of increased reservoir or additional reservoir(s) (m^3)

➢ The amount of water which can be extracted from a sand dam reservoir (the water yield) can be calculated in two ways as given in box 4 and 5.

b. Estimating water yield of the sand dam:		
The sand volume, Sv in m^3 can be calculated by:		
$$S_v = 0.5\left(D*L\right)*W --------(15)$$		
Where	Sv =	Sand volume (m3)
	D =	Depth of sand at sand dam location (m)
	L =	Length of reservoir (m)
	W =	Average Width of the storage bed (m)
And length of the reservoir (Lr) can be calculated as:		
$$L = \left(D*100\right)/S_{rb} --------------- (16)$$		
Where	Srb=slope of river bed (%)	
The water volume (yield), Y (= water yield) can then be calculated by:		

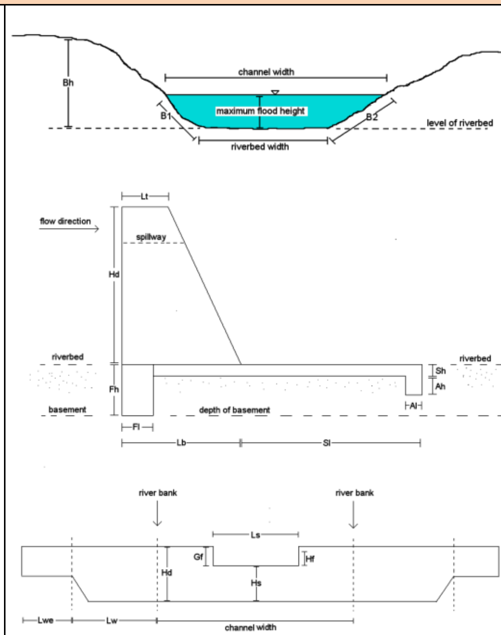


Fig 3. Original river, side view and front view

$$Y = S_v * (Syr/100) -------------- (17)$$

Where Syr = specific yield riverbed (%)

c. After determining the water demand and the water the **sand dam dimension** can be made. There are 4 different parts within a sand dam:

- The dam;
- The spillway;
- The wing walls;
- The stilling basin.

Summary of designing criteria (Nissen-Petersen, E. 2006):

- The width of the base should be 0.75 (3/4) of the height of the dam and the thickness of the key of the wing walls should be 0.55 of the height of the dam: to counter balance the force of the water and sand in dam reservoirs against the dam.
- The width of the crest and its height on the downstream side should be (1/5) of the height of its dam wall.

Gf = gross freeboard (m)
Lw = length of wing wall (m)
Hf = height freeboard (m)
Lwe = length wing wall extension (m)
Hd = total height of dam (m)
Hs = total height of spillway (m)
Ls = length spillway (m)
Hd = height of dam (m)
Sl = length of stilling basin (m)
Fh = height of foundation (m)
Sh = height of stilling basin (m)
Fl = length of foundation (m)
Lt = length of top of dam (m)
Ah = height of anchor (m): 0.4 m
Lb = length of base of dam (m
Al = length of anchor (m)

- The front of the dam should be leaning downstream with a gradient of (1/8) of the height of the dam.

d. Construction of access for use (abstraction well/s)

Abstraction well should be located on the upstream side and very close to the dam embankment (within 3-10 meter)

Period of Implementation Across Season

The construction of sand dam must be constructed when the river is dry.

Planning and Mobilization Requirements

During planning for sand dam construction, the following parameters should be considered:

- The riverbanks should consist of bedrock or a strong soil type to ensure a strong anchoring of the dam into the riverbanks.
- A riverbed width preferably doesn't exceed 25 meters. The reinforcement required for such kind of long dam walls is too expensive; hence the sand dam will not be cost-effective.
- The riverbed slope must be higher than 5% to ensure that deposition of silt not to occur
- To ensure storage of water within the sandy riverbed, the dam has to be built onto solid bedrock or an impermeable layer. Otherwise the water will infiltrate into the subsurface layers.
- Dam walls should never be built on fractured rocks or large boulders because they can have cracks, which will drain water from the reservoir into the ground below
- If salty rocks (white and pink mineral rocks) are situated in the riverbanks upstream of a dam, then the water may be saline and therefore only useful for livestock

Cost Elements and Work Norm

- Surveying tools/equipment and masonry tools are the most important equipment required for construction of sand dams
- Brick, stone, cement and steel (optional) are common construction materials
- Construction of SS dam involves excavation of foundation and keys, disposing of excavated soil, stone collection and building of the dam structure (masonry work, concrete work or earth embankment) and drop/apron structures and construction of abstraction well (see Fig 3.)
- Masonry and concrete works require special skill. The average work-norm used as national norm for constructing stone-faced earth SS dam (inclusive of all elements, excavation to embankment construction) is 0.75 m3/PD.

Management and Maintenance

- Repairing cracks and weak points in the dam
- Sand dams require careful maintenance, and immediate repair, as flooding causes hundreds of tons of water to fall over the dam wall and onto the spill-over apron. Flood water may also spillover and erode the wing walls and, perhaps, even over the riverbanks during heavy rains.
- Cleaning of the outlet
- It is very important that the outlet isn't blocked with silt of other fine textured material. Therefore, during construction it is always important to have a good access to the outlet construction. Also cleaning of the riverbed after a flood, can prevent silt from blocking the outlet.

- Removing silt from the top of riverbed of the reservoir
- The riverbed of the reservoir has to be cleaned: rocks, branches, leaves, dead animals, animal dropping and fine textured material can reduce the capacity of the dam, lead to blocking of the reservoir and outlet or cause, damage to the dam structure and lead to contamination of the water within the reservoir. Moreover, it is wise to have a strict schedule for inspection of the dam and its surroundings.

Benefits and Acceptability

Sand dams reduce the flow of water which could negatively impact upon downstream communities. There is potential for inter-community conflict related to the positioning of neighboring sand dams. When several sand dams are built in a row, in the same riverbed, and at overlapping distances, stored water volumes decrease. Sand dams have specific construction requirements. They are only suitable in areas with favorable geology and hydrology.

Limitations

An earth dam can easily be damaged and even destroyed by underground flow.

Name of the technology	SUBSURFACE DAM IN DRY SANDY RIVERS

General Description

Subsurface dam is about storing water in the pore space of the sand aquifer within the dry riverbed system. An underground water tight barrier built across an ephemeral river bed over impermeable formation that arrests the flow of water within the sandy aquifer. It is about blocking the underground flow of water at shallow depth by construction barrier across the narrow channel to the impervious formation below the groundwater channel.

The **purpose** is, primarily, for village water supply; human and animal consumption. It can also be used for water storage for irrigation of horticultural crops and crop production; aquifer recharging of downstream dug wells and shallow boreholes. It can also serve for soil and water conservation and retaining of sediment transportation.

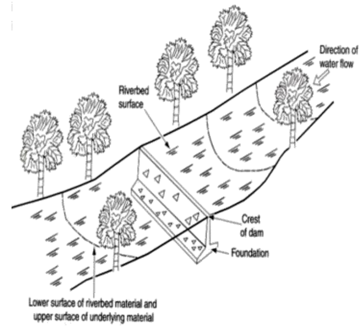


Fig 1. Subsurface Dam since 1993 - BishanBahe, Dire Dawa, Ethiopia; Fig 2 Schematic view of subsurface dam

The technology helps also too block the subsurface flow and enhance percolation to groundwater and allow it to be stored for immediate or future use and to raise the water table level and thus make the water easily accessible for diverting by gravity and hence reduce pumping cost.

Geographical Extent of Use

Arid, semiarid and dry areas. Recommended for low topographic gradient; relatively deep impervious layer; and availability of local construction materials. Blocking at the narrow channel section is preferred to be economical. Seasonal recharging happens to the natural aquifer and the maximum storage volume remains the same overtime. Subsurface dam is a water storage system without land submergence. Evaporation is very low since there is no open water surface and the water quality is normally very clean and safe. With due consideration of such advantages, subsurface dam can be constructed in stream/gully where the following conditions are fulfilled:

The riverbed should be gently sloping

The soil of the dam area consists of sand and gravel with rock at a depth of few meters

Locations with wide valley and narrow out let.

River beds containing coarse sand as it stores more water than fine –grained sand

Presence of the surrounding basement rock with low permeability

Presence of a porous layer for water storage

In areas where groundwater levels are declining on regular basis

Types of Subsurface Dams

Subsurface dams can be classified into four types depending on the materials used for construction:

- Reinforced concrete subsurface dams
- Masonry subsurface dams
- Earth subsurface dams
- Geo-membrane subsurface dams

The types of subsurface dam to be constructed in an area depends on the availability of materials in the surrounding.

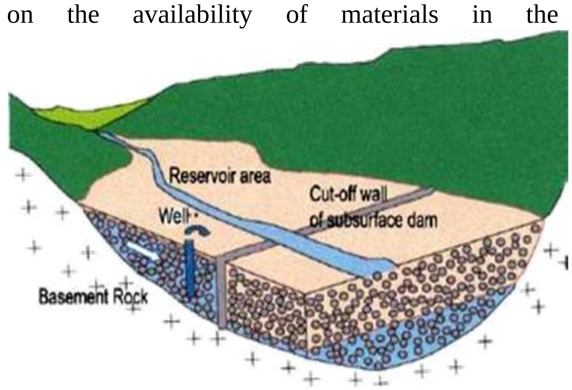


Fig 3. Another prospective view of subsurface dam

Technical Design Requirements

The porosity of the sand in the dry river, say 35-40% multiplied by the average length, width and depth of sand within series of consecutive sand dams will give us the total available water for dry season after the end of rains. Sit visit, consultation of communities, selecting proper site, conduct proper site investigation, deciding the type of material to be used for construction the cutoff wall (clay soil, masonry/concrete, plastic sheet/geo-membrane). Prepare the design of the subsurface dam and the BoQ to estimate the budget requirement including necessary drawings.

Layout and Construction Procedures

The following procedures will be followed for layout and construction:

- Site is already selected, and design prepared, if not select appropriate site along a stream/river/gully bed
- Site clearing: The site must be cleared of all sand, rubbish materials and vegetation before the start of the work.
- Do the surveying work and put pegs as per the design

- After selection of a suitable site, and site clearing a trench of 1-2 m wide is dug across a valley or stream until it reaches to the impermeable layer
- An impervious wall is constructed in the trench up to the ground level
- The cutoff wall can be constructed with clay soil, masonry/concrete or plastic sheet
- For clay soil, when the impervious basement on the dyke has been reached. the selected clayey soil is spread across the trench in layers and then properly compacted layer by layer.
- When the clay soil compaction has nearly reached the riverbed surface level, concrete cover is lined on top and at the sides of the clay wall to a depth of 0.50 m.

For other materials follow their standard of design for construction

Fig 4. Subsurface dam under construction - Dire Dawa area

Period of Implementation Across Season

Construction shall start and be completed in the dry season

Planning and Mobilization Requirements

The excavation, filling and compaction of the cutoff-wall and the overall dam requires mobilizing of community labour. Consequently, the surrounding community, mainly the beneficiaries must be consulted from the very beginning. As far as agreement is established among the communities and hence required labour is mobilized, the overall construction process can be executed with the technical support and coaching from concerned experts. All necessary construction materials and working tools should be mobilized to the site including timely demobilizing it when the work finished. Contractor should not be trapped in wet seasons in the area. On completion all the necessary site cleanup should be carried out.

Fig 5. Subsurface dam under construction

Cost Elements and Work Norm

Based on engineering drawing and BoQ. For sand excavation and digging for the foundation and key $1M^3$ per person day including debris carting away. The structure can be built from local materials like concrete, masonry, solid blocks, clay, etc. **Working tools and materials**: shovels and pick axes with handles, wheelbarrow, iron bars, shelter or from work, cement, solid cement blocks, etc.

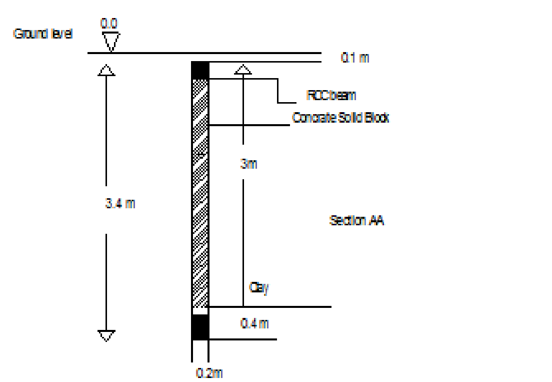


Fig 3. Vert. section of the water impounding structure

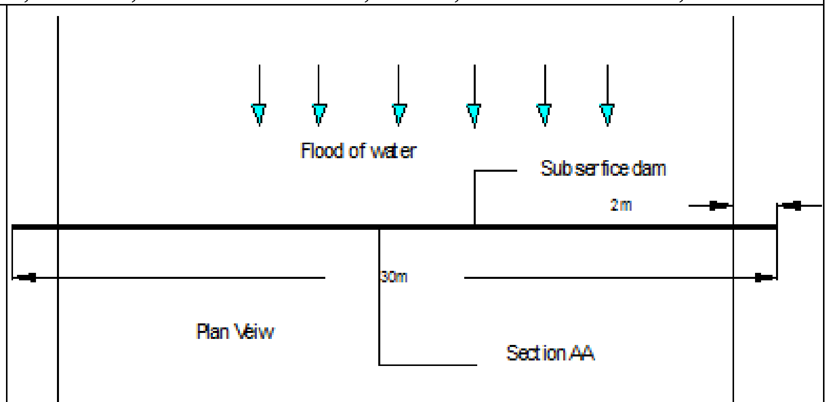


Fig 4. Plan view of the sub-surface dam

Management and Maintenance

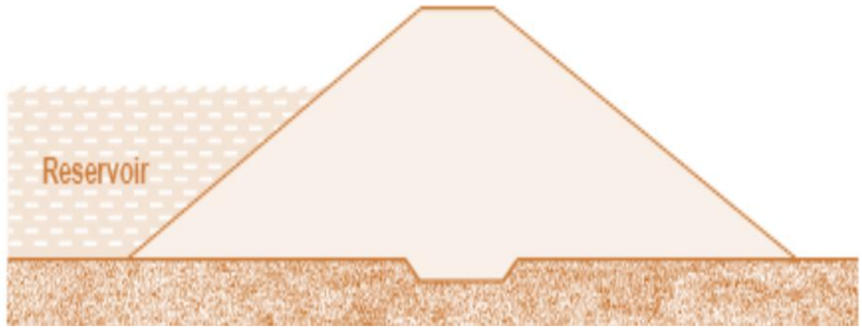
Extraction of water is by shallow wells constructed either within the sand river itself or wells constructed at the side of the bank. It is primarily used for communal water ownership; however, individuals can also practice river side horticultural irrigation. Water collection by sand mining (instead of dug-wells) and sand mining by trucks be avoided.

Benefits and Acceptability

Ideal water supply sources for drinking and irrigation if properly developed in its right niche. Water is not lost to evaporation, no significant waterborne diseases such as malaria, less chance to contamination and pollution. The technology is simple to design and can be constructed using local materials such as clay soil. The technology is being promoted in many dry sandy river areas such as Borana and Dire Dawa of Ethiopia and there is huge potential for its expansion in the Eastern Nile Region.

Limitation

Only applied where the niche exists in dry sandy rivers and sand mining should not be practiced.

Name of the Technology	SMALL EARTH DAM (FARM DAM)
General Description	
Definition: Earth Dam is a structure built across a river to create a reservoir on its upstream side for impounding water. Made from earth materials by compacting to the required height. **Objective**: to store water behind the embankment for use during the dry seasons for water supply (domestic and livestock) and/or irrigation (full or supplemental irrigation).	 Fig 1. Homogeneous Earth Dam

Geographical Suitability and Site Selection

Earth dams can be constructed in all areas where water is needed for dry areas, however the following criteria for site selection should be considered:

- Dam site should be at narrowest part of the valley
- The dam site should be as nearer to the area to be served as possible
- Foundation area should be reasonably impervious and strong thus it should be able to support the weight of the dam;
- Strong, stable and water tight abutments
- The dam should be located at a relatively narrow part of the valley and it should back up into a sufficiently large storage pond
- The ratio of the catchment area to the irrigable area should be reasonable. A too large catchment area above the dam site may require unduly expensive spill way and, on the other hand, a too smaller catchment area may not yield sufficient runoff to meet the storage requirement.
- The dam site and the reservoir rim should offer a reasonable configuration for provision of a spillway; and the site shall have suitable location for the provision of spillway
- Construction materials should be available in sufficient quantity and good quality within a reasonable distance
- The site shall be accessible
- There shall be sufficiently large submergence
- The site should be environmentally friendly, socially and culturally acceptable, economically feasible

Period of Implementation Across Seasons

Earth dam is constructed during the dry season.

Design and Construction Requirements

The basic requirements for earth fill farm dam are reasonable degree of imperviousness and stability under all working conditions. Purely sandy soils make the first requirement impossible while clayey soils do not satisfy the second criterion. The most commonly used types of earth fill farm dams are homogeneous type and zoned section.

The homogeneous type utilizes sandy clay soils and is presently restricted only for small dams. The entire section is made of the same type of soil unlike zoned section. To avoid seepage through the foundation and the body of the dam, proper compacting of the soil at fixed layer is very important **Spillway**:- is part of the structure which disposes the excess runoff to a safe outlet. To avoid overtopping removing the excess water to a safe outlet, a properly designed spillway is very essential.	The basic requirements for earth fill farm dam are reasonable degree of imperviousness and stability under all working conditions. Purely sandy soils make the first requirement impossible while clayey soils do not satisfy the second criterion. The most commonly used types of earth fill farm dams are homogeneous type and zoned section.

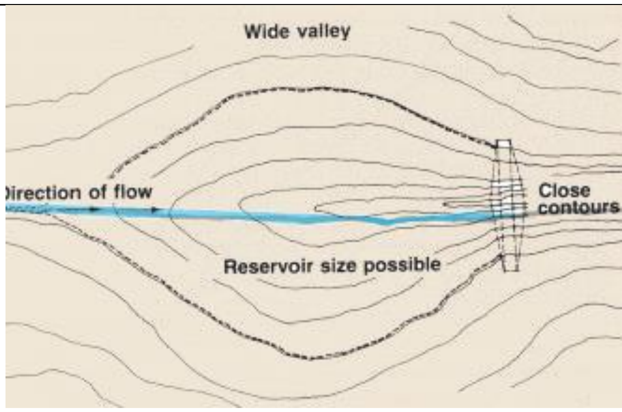


Fig 2. Top view of reservoir area and location of dam axis

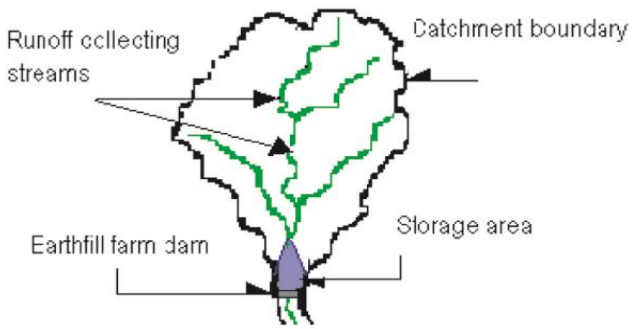


Fig 3. Catchment area from which runoff is collected

The dam crest length at the dam top level can then be found from contour map, or dam axis survey data using AutoCAD or direct survey of this elevation.

Top width of a small dam can generally be governed by services of the top dam for free mobility of the construction equipment or using the following equation. The minimum of which cannot be less than 4m.

$$T = \frac{h}{5} + 1.5m$$

Example: For h=14m,

$$T = \frac{14}{5} + 1.5m = 4.3m; for\ h = 5m;\ T = \frac{5}{5} + 1.5m = 2.5m\ say\ 3m$$

The downstream and upstream side slopes depend upon various factors such as the type and nature of the dam, foundation materials, height of dam, etc.Upstream and downstream slope ratio where H and V are horizontal and vertical distances, respectively.

construction material type	U/S slope (H:V)	D/S slope (H:V)
Homogeneous well graded	2.5:1	2:1
Homogeneous Course silt	3:1	2.5:1
Homogeneous Silt clay:		
1. H< 15m	2.5:1	2:1
2. H>15m	3:1	2.5:1

Height of dam:
The Height of a farm dam should be designed so that it is not overtopped any time. Thus, after studying the wave height, wind setup, likely maximum water elevation, etc. the free board varying between 3 to 5m is provided depending up on the nature of the spillway and height of the farm dam, as also the degree of seismic activity at a proposed site.Preliminary dimensions of an earth dam are given in the table below:

Design of spillway

- Excess water above the capacity of the reservoir should be removed from the dam safely
- Spillway is a structure constructed to safely remove the excess water from the reservoir
- Design of spillway is complicated but a width of 10m can be adopted for small earth dams

Cutoff trench

- Provide cutoff trench to the required depth based on the geology report in order to minimize seepage through the foundation
- The width of the cutoff trench depends on the type of machinery for construction

Height of dam, m	Max. free board m	Top width, m	U/S slope (H:V)	D/s slope (H:V)
up to 4.50	1.20 - 1.50	1.85	2 : 1	1.5 :1
4.50- 7.50	1.50 - 1.80	1.85	2.5 : 1	1.75 : 1
7.50 - 15	1.85	2.5	3 : 1	2 : 1
15 - 22.50	2:1	3	3 : 1	2:1

Fig 4. Cutoff wall construction and compaction

Fig 5. Scene of completed earthern dam, see the stone rip-rap on the upper side of the embankment

Planning and Mobilization Requirements

Adequate and well organized prepardness is needed

Cost Elements and Work Norm

1) Surveying equipment (such as water level, theodolite), range poles, measuring tape or marked string.
2) Handmade sledges, crow bars, shovels, digging hoe, pick axes, wheel barrows, soil compacting tool, soil dumper
3) Workers /laborers.

If machinery you need 1 excavator, 1 loader, 1 dozer, more than one dam trucks, 1 watering truck, 1 roller compactor. The average work norm for small farm dam is 0.40 m^3/pd. The work norm is calculated in terms of volume of fill materials. It refers to soil and stone movement, placement of stones for a spillway rip rap, sodding of grasses on downstream face, stone riprap on upstream face, and placement of sand and toe filters.

Management and Maintenance Requirements

Proper upper catchment protection works need to be applied.

Benefits and Acceptability

Properly applied earthen dam is a good source of water during the dry season. Apart from that it reduces downstream erosion and flooding, it improves the microclimate.

Limitations

If breached it has a consequence of catastrophic failure. If the upper catchment is not treated adequately and in a quality manner there is a potential risk of silting up. It needs heavy investment and consumes a lot of labor and machinery.

Name of Technology	SMALL MASONRY DAM

Brief description

A Dam is a structure built across a river to create a reservoir on its upstream side for impounding water. Made from masonry or concrete relatively safer and durable than the other types of dams, but expensive.

Period/ phases for Implementation

Masonry dams can be constructed during any season of the year and they can remain uncompleted for years because they are normally not damaged by over-flowing water.

Site Selection

The following factors shall be considered very carefully when selecting the site of a dam:-

- **Topography,** the dam site should be located where the river has a narrow gorge which opens out upstream to create a large reservoir. In that case, the crest length of the dam would be small and the capacity of the reservoir on its upstream would be large, that would also minimize the height of the dam.
- **Geology and foundation conditions:-** narrow stream flowing between high and rocky abutments (i.e., deep gorges) with sound rock foundation.
- **Construction material**:- type, suitability and availability of construction materials. (water, sand, stone etc)
- **Water tightness of reservoir**, the bed and sides of the reservoir should be quite watertight to reduce leakage losses of the stored water.
- **Submergence:-**The area submerged by the reservoir on the upstream of the dam should be small. Moreover, the reservoir should not submerge costly land and property. It should also not submerge rare structure of archaeological or historical importance.
- **Accessibility**, the site should be easily accessible. It should be preferably well-connected by a road line. This would facilitate transportation of labor and materials.
- **Catchment condition:-** with low sediment, the dam site should be such that the reservoir would not silt up quickly. Small catchment (less than $5KM^2$) with proper catchment treatment.
- **Reservoir Area:-** Flat reservoir areas of low-value land that can store a relatively large volume of water with a low embankment height.
- **Purpose of stored water:-** Sever water shortage or nearby irrigable area in relation to the dam
- **Catchment size and condition:-** Size, vegetation cover and other physical characteristics of the catchment area.
- **Excess water removal:-**Suitable location for constructing spillway

Main Objective /Purpose

To store water behind the embankment for use during the dry seasons for water supply (domestic and livestock) and/or irrigation (full or supplemental).

Relevant Data Collection

Collect the following relevant data and conduct analysis for design

- Delineate the watershed area, and develop land use, slope and soil texture map of the watershed
- Estimate the run off generated from the catchment with simple empirical formula
- $Q = \frac{KPA}{1000}$ where k is the runoff coefficient, p is the average annual rainfall and A is the area
- Develop contour map of the reservoir area
- Drainage slope and cross section of the dam site.

Demand Analysis

To know the demand, decide the purpose of the dam either for domestic and livestock water supply or irrigation. Then calculate the demand. Look Annex 8 how to decide demand.

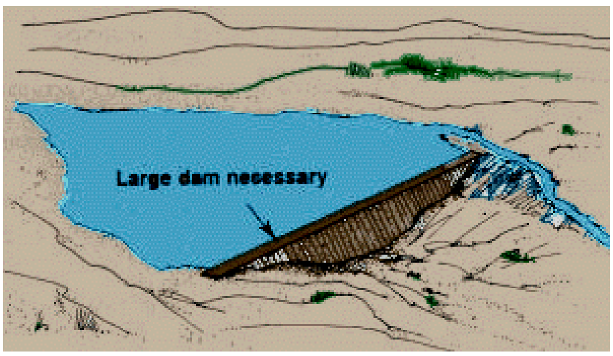


Fig 1. Panoramic view of a masonry dam

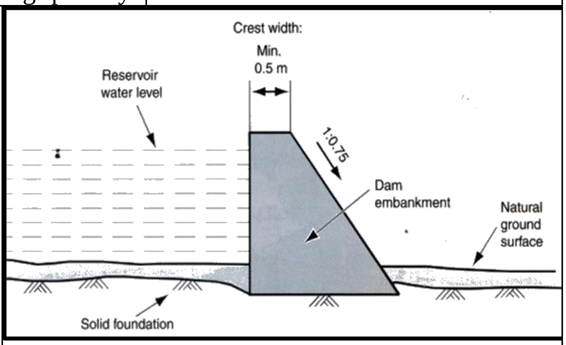


Fig 2. A typical Masonry or Concrete Dam

Water Supply Analysis

To design a water harvesting dam, it is mandatory to estimate the volume of runoff that can be collected from a catchment. This is known as catchment yield determination. Since the

Storage capacity

Storage capacity can be estimated roughly by assuming the reservoir is having triangular section:

Q= L x T x H/6

catchment area is too small, the rational formula is used for estimation.

$Q = \frac{CIA}{3.6}$

Where, Q: design peak discharge (m3/sec).

C= runoff coefficient that can be taken from table.

I = rainfall intensity in mm/h for the design return period and for a duration equal to the ''time of concentration" of the watershed.

A= the watershed area (km2).

Where

Q is storage capacity in m^3

L is the top (Crest) length of the embankment in meters

T is the distance from the dam embankment to the tail end of the reservoir in meters

H is the maximum height of the embankment in meters.

Design of Dam Body

First understand forces acting on the dam

The most common external forces that act on the Dam are:-

Hydrostatic Water pressure (Pw)

Silt pressure (Ps)

Uplift pressure (Pu)

Frictional force between the dam bottom and the foundation material f

The stabilizing forces is the weight of the dam itself ($W=W_1+W_2$)

As shown in the figure

Top width of storage masonry dam can be taken between 0.75m to 2m depending up on the height of the dam.

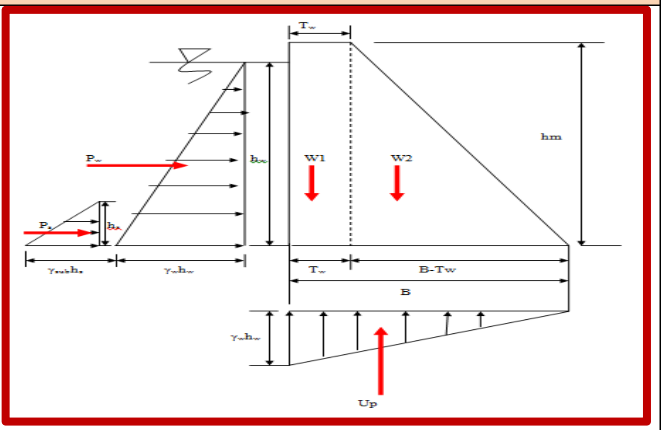


Fig 3. Free body diagram for the calculation of acting forces

<u>Note</u>:-

The recommended top width for masonry dam having height less than 5 m is 1 meter and for dam's having height between 5-16 meter is 1.5 meter.

The height of the dam is decided by the volume of water that must be stored and site topographic situation. Then what is left is to decide the bottom width B. The minimum width of the Dam is the width at which the overturning moments are fully counterbalanced by the resisting moment. But actual width of the dam should exceed from that minimum allowable width that meets all the criteria's put under the stability analysis below. To conduct the stability analysis you better request the support of someone who has the knowledge of engineering background. To reduce seepage through the body of the dam, provide with 30 cm thick concrete sandwich in the body of the dam.

Stability Analysis Criteria

- The sum of stabilizing moment must exceed the sum of overturning moment of the structure for safety against overturning.

$$FS_{overturning} = \frac{\sum M^+}{\sum M^-} > 1.5$$

- The structure subject to differential lateral pressure must capably resist the tendency to slide for safety against sliding.

$$FS_{sliding} = \frac{\mu \sum V}{\sum H} > 1$$

- The resultant of all forces acting on the structure should fall within the middle third of the structure base so that tension will not develop at the base.

$$e_x = \left|\frac{B}{2} - \frac{\sum M^{net}}{\sum V}\right| < \frac{B}{6}$$

- The contact pressure (stress) at the toe or heel of the weir body should be less than the allowable bearing pressure of the foundation material.

Design of Spillway

- A spillway is an important component of a dam.
- It allows the design discharge (mostly 20% of it) to leave the dam and so protects it from over-topping.
- Is located at one side of the dam embankment.
- A spillway location having no direct contact with the dam is mostly preferred.
- In masonry or concrete dams, excess water can be allowed to pass over the dam embankment

Silt Excluder /Under sluice/

- Small Masonry Dams are usually provided with silt excluder. The importance of this gate is to safely dispose the coming flood directly at the beginning of the rainy season and to remove accumulated silt in the reservoir easily.
- Provide 1m by 1m silt excluder at the base of the dam; if the silt load is expected to be higher it is possible to provide more than one silt excluder.
- Provide gate which is located at the downstream side of the embankment.

Work Norm

$$P_{max} = \frac{\sum V}{B}\left(1 + \frac{6e}{B}\right) < P_{all}$$ For the dam to be safe it should satisfy the above criteria's	• A single work norm may not be applicable for the technology but site specific bill of quantity (BoQ) for the following activities should be prepared to estimate cost of the project • Site clearing, excavation on soft soil, excavation on hard soil, concrete work, masonry, plastering, curing, pointing, outlet pipe and gate installation etc.
Integration Requirement	**Operation and Maintenance**
Provide gated outlet for extracting water, if the water is for domestic and livestock use, integrate it with watering trough and water distribution point. To minimize silt load integrate it with catchment treatment. Integrate the irrigation with water saving technologies.	The gate must be closed after the first rainy days and opened when the dam is empty. If silt is accumulated in the reservoir the gate should be opened to remove silt for some time.
 Fig 4. Masonry dam	 Fig 5. Double silt excluder

Name of the Technology	IRRIGATION CANAL

General description

Irrigation canal is a ditch constructed to convey water from the source to crop or fodder field plots. It could be lined or unlined canal. We can classify canals based on their size as **Primary canal (main canal)**: - a canal which conveys water from the source to the command area. **Secondary canal** is the canal which conveys water from the primary canal (main canal) to the tertiary units. **Tertiary canal is** a canal which feeds a tertiary unit and conveys water from the secondary canal to the quaternaries. **Quaternary canal** is channels which conveys water to field channel or directly to the farmers. **Field channels** are channels which convey water to farmers' fields from the quaternary canal.

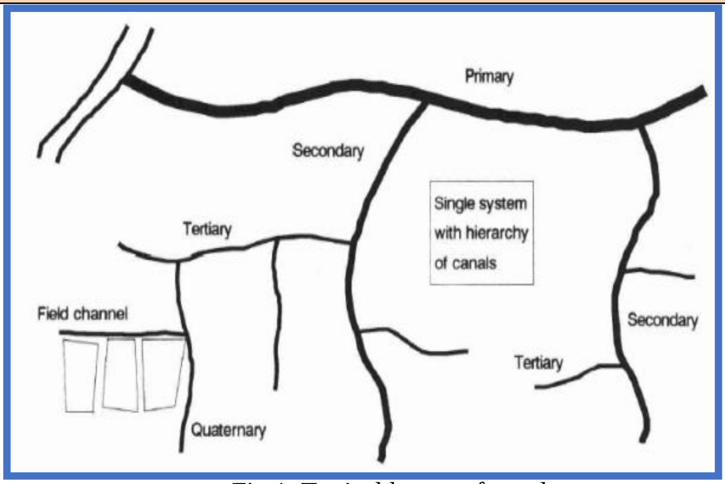


Fig 1. Typical layout of canals

Fig 2. Lined canal laid out along the hillside

Fig 3. Unlined earth canal drawing water to irrigated fields

Geographical Extent of Use

Irrigation Canal can be constructed in all agroecology, but suitable soil should be selected for construction otherwise consider cut and fill options with suitable soil type. Getting the agreement of farmers should be given a priority

Technical Design Requirements

The design for constructing irrigation canal should include all dimensions, top and bottom widths, depth, shape, discharge of water to be transported velocity, slope of the canal and length of the canal; field area to be irrigated, and source of water. The design should be supported with diagrams/sketches of the canal and the field showing the development map of the area. Estimate the budget required to construct the irrigation canal. Proper BoQ should be prepared based on local condition to estimate the cost requirement to construct. Besides, prepare also the work schedule to construct the canal.

i. Estimate the discharge (Q) expected to flow through the canal.
ii. Estimate the cross-sectional area of the canal using the basic flow equation for open channel:
$Q = AV$, or $A = Q/V$,
Where Q = Discharge in the canal (m^3/sec); A = Cross-sectional area of the canal (m2); V = Maximum permissible velocity in the canal (m/sec)
iii. Select appropriate velocity for the canal from standard tables. Typical values are 1 -2m/sec
iv. Decide on the shape and gradient of the canal. Typical shape for the hand dug canals is trapezoidal while the suitable canal gradients for unlined canals range 0.1-1%
v. Determine the dimensions of the canal (depth, bottom width, top widt h and slope of the sides) using the known values and by trial and error.

Layout and Construction Procedures

Remove/clear obstacles such as tall grasses and shrubs from the path/general direction of the survey. Do the surveying work by available surveying instrument. For additional refer the graded line surveying procedure in Annex 3.

i. Mark the top and bottom widths of the canal on the ground keeping the survey marks (pegs) at the center.
ii. Dig ditch between the marks and throw the soils down slope to form an embankment and compact it to ensure stability. Leave a space (berm) about 15 - 30 cm wide between the ditch and the embankment to prevent the embankment soils from sliding into the ditch.
iii. In digging the ditch, proceed by first cutting rectangular sections to the desired depth and then shape the sides later to give it the desired shape, either trapezoidal or parabolic shape.

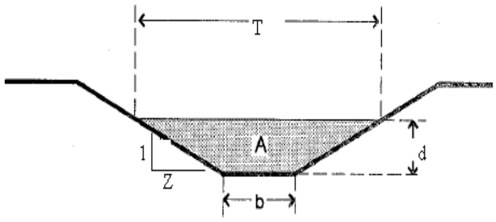


Fig 4. Typical dimensions of trapezoidal canal

Period of Implementation Across Season

Flexible; preferably during the dry season and period not interfering with activities of agriculture and/or normal/customary mobility for pastoralists.

Planning and Mobilization Requirements

Proper consultation of farmers (who own the land where the canal is going to be constructed) on their willingness to make land available for constructing and the contribution of the community in the construction process should be clearly discussed. Consider also organising water users in to groups for management system, probably WUA.

Cost Elements and Work Norm

The main tools required to construct canals include: -Measuring tape, string, pegs, crowbars, pick axes, shovels, sledge hammers etc. Materials needed to construct lined canal include: - Cement, stone and sand. Work norm for excavation is $0.7m^3$/PD for mixed-farming, $3.5m^3$ /7PD for the pastoral. Masonry work needs skilled man power.

Management and Maintenance

For management purpose the water users should be organized in to groups or formal institution like water users association; Design a system for conducting maintenance activities like routine maintenance, major maintenance and emergency maintenance.

Benefits and Acceptability

The technology is highly accepted by farmers, water is transported and delivered to field points

Limitation

If the canal is unlined seepage and waterlogging are some of the problems associated with the technology

Water Lifting Technologies

Overview

A **pump** is a device that moves fluids, specifically for this manual water by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: *direct lift*, *displacement*, and *gravity* pumps.

Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work for moving the water. Pumps operate via many energy sources, including manual operation, electricity, engines, solar or wind power. They are built in many sizes, from small to large pumps. For this manual we are referring for pumps used at household level widely adopted in Ethiopia for lifting water for irrigation, domestic and livestock watering.

Mechanical pumps serve in a wide range of applications such as pumping water from wells, rivers, ponds, lakes etc in the agriculture sector. Mechanical pumps may be **submerged** in the fluid they are pumping or be placed **external** to the fluid.

Pumps can be basically classified in to two types by their method of displacement as positive displacement and centrifugal. Although axial-flow pumps are frequently classified as a separate type, they have essentially the same operating principles as centrifugal pumps.

For this manual we have prepared inftech (short information on technologies) having description, geographical extent of use, technical design, installation, operation and management etc, as reference to guide experts, development agents and other development partners working at grass root when they are in need (especially when they are on duty). For further information and knowledge about the technologies they are advised different manual and books as required.

The major water lifting technologies that included in this guideline include:-

1. Treadle - Manual water lifting pumps
2. Rope and Washer
3. Solar Pump
4. Peripheral Pump
5. Small Engine Pump (5-7hp)

Name of the Technology	TREADLE PUMPS

General Description

- Treadle - Manual pump is mechanical equipment that serves for lifting water from a lower level to a higher level using human labour specially women friendly technology and low cost
- The main points considered in selection of the pump type are total head, cost, availability of spare parts, and ease of operation and maintenance, preferably by the farmers.

Fig 1. Treadle pump under operation

Geographical Extent of Use

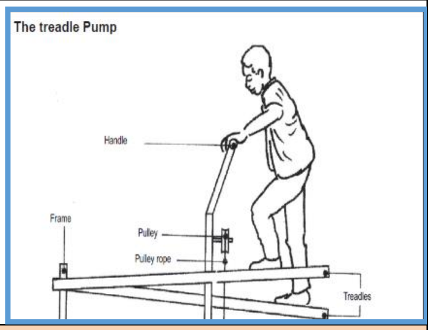
Treadle-Manual pump is applied in the area where shallow groundwater or surface water is available; and in such cases when gravity irrigation is impossible and there is a need to lift water.

Technical Design Requirements

Treadle pump

- The principle of treadle pump is based on suction lift system with suction lift up to 6 meter, and delivery lift up to 6 meter and about 10 meter of total lift.
- Treadle pumps have cylinder and piston to draw water from a source below ground level, for example a river or shallow groundwater.
- Two pistons are used, each connected to a treadle. They can be about 1-meter-long, hinged at one end and supported at the other by a rope or chain running over a pulley.

Fig 2. Parts of a treadle pump



Installation

Before installation, level the ground for placing the pump on the selected site. A completely installed treadle pump has essentially the following parts:

a) Cylinder and valve assembly: used for conveying water from the well and store until deliver to the irrigated land or other place. Valve box assembly helps filling the water in the cylinder and delivers it.
b) Piston and chain assembly: This section transfers person power to the pump for suction.
c) Treadles: The operator stands on the treadles and pushes them up and down to work the pump.
d) T-hand: The operator uses this component to use as handle during operation time.
e) Suction and delivery hoses: - These hoses are for conveying the water from the water source to the command area.
f) Foot valve with strainer: - For the water to pass only in one direction and serves as silt trap

Period of Implementation Across Season

It can be used throughout the year whenever the demand for water lifting do exist

Planning and Mobilization Requirements

- Willingness of the beneficiaries to install and use
- The source of water (well, river, pond, etc.)
- The required pumping flow rate (q)
- Suction and delivery head (m)
- Size of command area (m^2) and its distance from source

Cost Elements and Work Norm

The cost elements for manual water lifting pumps include:

- The pump it self
- Suction hose (10 m)- treadle
- Delivery hose (as required)-

Management and Maintenance

- Proper management is required for all types of pumps
- Regular maintenance is necessary to keep the pump in good shape and guarantee a long running time.
- Clean the parts with a steel brush and roughen it with sand paper. Then apply anticorrosive primer paint, and when it's completely dry, finish it with paint. Allow the paint to dry in the shade

Benefits and Acceptability

- Low cost options
- Low weight and possible to move from place to place and secured against any theft
- Simple to use specially by women and the technology is women friendly

Name of the Technology	ROPE AND WASHER PUMPS

General Description

- Rope and washer - Manual pump is mechanical equipment that serves for lifting water from a lower level to a higher level using human labour specially women friendly technology and low cost
- The main points considered in selection of the pump type are total head, cost, availability of spare parts, and ease of operation and maintenance, preferably by the farmers.

Fig 1. Rope and Washer Pump, Amhara R. Sekela Wereda, Lay Guder CW

Geographical Extent of Use

Rope and Washer -Manual pump is applied in the area where shallow groundwater to lift water from the well to the surface of the earth.

Technical Design Requirements

Rope and Washer pump

- Rope and Washer pumps have cylinder and piston to draw water from a source below ground level, for example a river or shallow groundwater.

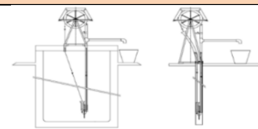


Fig 2. Rope and washer pump

Installation

Rope and washer pump

a) The principle of rope and washer pump is based on lift pump system with suction lift up to 30 meter, and with no delivery lift.
b) The Rope pump consists of a wheel and an endless rope with small pistons, made of polyethylene (or car tire in homemade models) which are attached to the rope at intervals of 1 m. The pistons fit, with a clearance of around 1 mm, in the PVC pipe called 'rising main'. The rope and pistons move freely (no pipe) down into the well. At the bottom, the rope is led by a guide box into the rising main.
c) The rope and pistons are lifted by the wheel. The weight of the water column forces the rope further into the V-shaped wheel, creating more resistance between the wheel and the rope. This prevents the rope from slipping. (It's therefore that U-shaped concrete wheels don't work). The water is brought up by the pistons and discharged at the surface.
d) Different size of PVC pipes can be used based on depth of lift (1" PVC up to 10 meter water depth, ¾" PVC up 20 meter depth and ½" up to 30 meter water depth. For more see Annex 8.

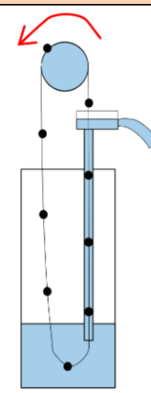


Fig 3. Scene of the rope and washers in the water

Period of Implementation Across Season

It can be used throughout the year whenever the demand for water lifting do exist

Planning and Mobilization Requirements

- Willingness of the beneficiaries to install and use
- The source of water (well, river, pond, etc.)
- The required pumping flow rate (q)
- Suction and delivery head (m)
- Size of command area (m^2)and its distance from the water source

Cost Elements and Work Norm

The cost elements for manual water lifting pumps include:

- The pump it self
- Suction hose (10 m)- treadle
- Delivery hose (as required)

Management and Maintenance:

Rope and washer pump; potential maintenance and repair are:

- Checking the tension of the rope and adjusting when needed.
- Lubricating the bushings every 2 weeks or when the bushings are running dry.
- When the rope shows a lot of damage, the rope should be changed preferably before it breaks.
- The pistons should be changed, when the user has noted a reduction in output.
- *To* avoid corrosion, it is essential to paint parts

Benefits and Acceptability

- Low cost options
- Low weight and possible to move from place to place and secured against any theft
- Simple to use specially by women and the technology is women friendly

Limitation

Continues use may not be possible since they use human labor. Their application is limited since the discharge is minimal, max 0.5-0.7 lit/sec.

Name of the Technology	SOLAR PUMPS

General Description

Solar water pump is a pumping device powered by solar energy, consists of solar panels, solar pumping inverter and pump, can be used for irrigation in agriculture, domestic water supply and water for livestock. The solar water pump is well suited to cover the needs of those smallholder farmers as it is an affordable irrigation technology for individual use that combines environment- friendliness and low maintenance costs with income, productivity and labour saving benefits in the rural areas of Ethiopia.

Fig 1. Solar pumps in operation

Geographical Extent of Use

Solar water pump can be used for irrigation in agriculture, domestic water supply and water for livestock.

Technical Design Requirements

Solar water pump

A solar-powered water pump is a pump running on electricity generated by photovoltaic panels or the radiated thermal energy available from collected sunlight as opposed to grid electricity or diesel run water pumps. Solar water pump is cost-effective and easy to operate and sustainable energy solution to farmers for water lifting.

Solar pumps utilize the photovoltaic effect to produce free electricity used for water pumping. A photovoltaic solar panel can power a pump, which can move some liters per hour based on the solar panel power and pump capacity. For example, A 50-watt photovoltaic solar panel can power a 12-volt pump, which can move 1,300–2,600 liters per hour.

The water pumping amount requirements (m^3/d), electricity supply and sun irradiance conditions determine the overall size of the PV system. The capacity of the pump depends not only on the size of the solar panels, but also it depends on the depth of the water source and the delivery head (Table 1). Some solar pumps can extract water from 7meters deep (suction), but it is advisable to minimize the suction depth to 3-4m. Small solar pumps can discharge above 15m head based on the solar power, for example 80-120W Solar water pump can deliver water at 15m vertical lift and horizontally can convey up to 500m.

Table 1. Example of capacity of solar pump

Power	1-meter lift	6-meter lift
80W	2200 lit/hr	2000 lit/hr
120W	3600 lit/hr	2500 lit/hr

Detail online Solar water pump calculator can also be used for best fit pump purchase (such as the following characteristics listed in Table-2 below).

Table 2 Example of Solar water pump characteristics

Storage (lit/s)	SWL (m)	Delivery head (m)	Total loss (m)	TDH (m)	Area, (Ha)
10,000	3	6	1	10	0.25

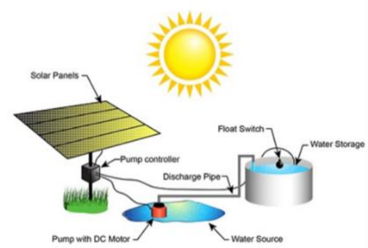


Fig 2. Solar pump layout

In order to select the best possible pump, using tables, with the supporting PV energy power supply the following checklists /questions need to be answered /reviewed:

Water requirement – demand calculation

Water source – surface /well, depth of water source /static water level (SWL)

System layout - determining the layout of the proposed system, identification of all necessary distances and elevations for the intake point, pump, PV panels, water tank, and water troughs

Water storage i.e. determine the volume of storage and head

The site-specific solar energy (Solar insolation[1]) and PV Panel location - average daily sun-hours

Design flow rate for the pump - the pump's design flow rate is based on the operation's estimated water needs (Step 1) divided by the number of peak sun hours

Total dynamic head (TDH) for the pump

Pump selection and associated power requirement

Layout and Construction Procedures

PV panel selection and array layout
PV array mounting and foundation requirement
Water flow rated and delivery point pressure – estimated pump flow in lit /sec, recovery rate for well/ drawdown, to ensure there is adequate pressure to operate
Summary description of the system i.e. system layout

A solar water pump system is fairly simple structure and typically consists of a water pump (submersible or surface pump), control electronics, solar panels and tubes. Most solar water pump systems do not use batteries.

Period of Implementation Across Season

It can be used throughout the year whenever the sun ray available for water lifting do exist

Planning and Mobilization Requirements

The "Mounting Structure" should have the following features:

Preparation of Scheme: on the basis of water quality and yield, the plan and estimates of the scheme to be made by an engineer

- ✓ He /she should decide the location of solar unit
- ✓ It should not be located under a tree or in shadow area

It should have space for fencing for protection

- ✓ It should have proper foundation as the steel structure of solar panel has to withstand wind of up to 200 km/hr velocities
- ✓ Hence it should not be located on exposed rocks

Management and Maintenance

When installing a solar pump, keep a few things in mind. Solar panels operate more efficiently when pointed in direction sun's rays. Set the solar panel at allowable distance, considering the suction length and depth. The delivery or the collector should fit with the delivery head of the pump, for this one needs to refer the pump characteristics curve (Fig 3). Distance between the pump and the PV panels should be kept to a minimum to reduce voltage drop in the cables. Consider mounting solar collectors on polls to avoid damage from children or animals, and to keep the cells from being covered by dust or other debris.

Panel Cleaning: Clean the panels regularly to avoid particles, feces, leaves, and other residues from blocking the sun. Panels can be cleaned with a plain piece of cloth with the use of some water when available.

Panel Inspection: Inspect the PV panels to make sure there are no cracks or damages

Shadow Prevention: Check the panels for any shadow and perform necessary trimming of trees if necessary.

Wiring inspection: Check wires regularly for fraying (decaying), splitting, or damage

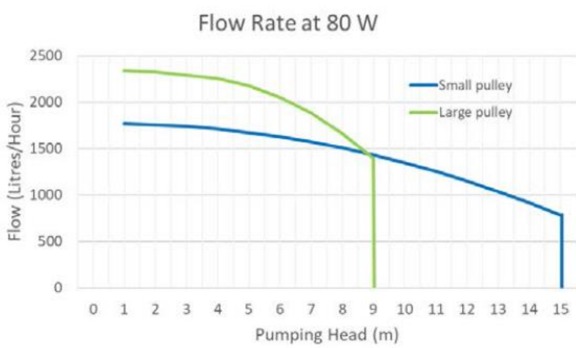


Fig 3. Pump characteristic curve

Cost Elements and Work Norm

The cost elements for manual solar water lifting pumps include:

- The Solar panel
- The Solar pump inverter it self
- Suction hose (6 to 10 m)- solar Pump inverted

Delivery hose (as required)- Technical preparedness needed

Benefits and Acceptability

- Low cost options
- Low weight and possible to move from place to place and secured against any theft
- Simple to use specially by women and the technology is women friendly
- Environment friendly

Fig 4. Installation of a solar pump

Limitation

- Limited power (at current stage of development)
- Technology may not be well understood by beneficiaries (compared with diesel) – risk of damage to sensitive electronic components
- Solar arrays may be attractive to thieves and vandals
- Technical expertise/support limited outside in rural areas
- Variable yield: The water yield of the solar pump changes according to the sunlight.

Example of Solar water pump recommendation

Solar power (Wp)	Voltage (V)	Lift height (m)	Max Flow rate (m^3/h)	Max Flow rate (lit/min)
100- 300	24-48	0-50	0.8	13.3
100-300	24-48	0-30	1.2	20.0
100-300	24-48	0-20	2.7	45.0
300-500	48-72	0-140	0.5	8.3
400-900	48-72	140-180	0.5	8.3
300-500	48-72	0-80	0.8	13.3
400-900	48-72	80-140	0.8	13.3
400-900	48-72	40-90	1.2	20.0
400-900	48-72	30-60	1.9	31.7
300-900	48-72	0-50	2.7	45.0
400-900	48-72	0-30	3.6	60.0
350-500	72-96	0-140	0.5	8.3
400-900	72-96	140-240	0.5	8.3
350-400	72-96	0-80	0.8	13.3
400-1200	72-96	80-160	0.8	13.3
400-1200	72-96	40-120	1.2	20.0
400-1200	72-96	30-80	1.9	31.7
350-1200	72-96	0-60	2.7	45.0
500-1200	72-96	0-40	3.6	60.0
100-450	12--24	2--22	5	83.3
300-900	48-72	0-25	7.5	125.0
300-900	48-72	0-18	11	183.3
350-1200	72-96	0-40	7.5	125.0
350-1200	72-96	0-24	11	183.3
350-1200	72-96	0-15	21	350.0
350-1200	72-96	30-60	6	100.0
300-1800	72-96	12--40	11	183.3
300-1800	72-96	25--12	16	266.7
300-1800	72-96	2--12	22	366.7

Name of the Technology	PERIPHERAL PUMP

General Description

Peripheral pump are pumps used to lift water at lower discharges, usually used in water supply system to boost the energy head of town water supply and lift the water to elevated buildings and store it in a tanker. In agriculture these pumps are used to lift water from hand dug well to the surface of the earth and store it in geomembrane lined pond, which then be used to irrigate the farm using surface pump.

Fig 1. Peripheral pump

Geographical Extent of Use

Peripheral pump can be used in an all areas where we need to lift water at small discharge rate and where there is electric power available in the area.

Technical Design Requirements and Construction Procedure

Components of peripheral pumps include pump and motor.
Pump: the pump is specially designed for all small scale domestic and commercial uses. It is of high specification peripheral featuring copper windings, a high capacity motor and stainless-steel housing inserts to ensure free impeller movement. The pump body is manufactured from cast iron and impeller from brass.
Motor: Pumps are closed coupled to reliable TEFC electric motors designed for continuous operation and provide with a thermal cutout to protect against electrical load. They can be connected directly to the main power supply through a 10 A fuse or MCB.
Operating condition
Pumped liquid: Thin, liquid, without solid particles and fibers
Max Fluid Temperature: + 60^{0}C
Max. Ambient Temperature: +40^{0}C
Max Suction lift: 7m at sea level

PUMP DATA

Model	Motor		DN1 (")	DN2 (")	Dimensions (mm)			Weight (kg)
	(kW)	Current (A)			L	W	H	
DDP 60	0.37	2.5	1	1	265	118	151	5.3
DDP 65	0.75	5.2	1.5	1.5	305	136	181	10

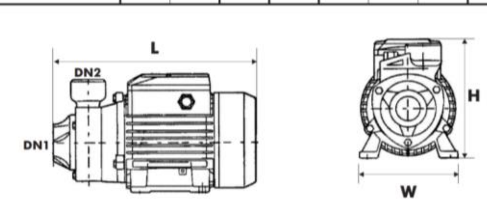
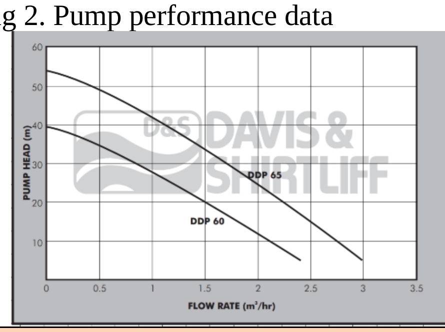


Fig 2. Pump performance data

Fig 3. Pump curve



Installation

- Connect the dynamo pump with electric supply, and attach the dynamo motor with strong cable/rope for taking in and out the pump from the hand dug well
- The pump must be placed at least 1.5m above the static water level in the hand dug well
- For placing the water pump prepare a flat timber firmly attached or inserted on the side of the hand dug well on level position to avoid the dynamo motor pump slipping into the water. Besides
- Provide training on how to start, stop the water pump quickly & how to operate the controls as per the user manual provided. Do not use the pump against the prescribed operating rules

Connecting the water inlet
Connect the water inlet with a commercially available hose, connector and fastener clip. The inlet hose must be a continuous non-foldable structure with a length not more than required length. The pump should be placed near to the source of water.
Connecting the water outlet
Connect the water outlet with available hose of suitable diameter, hose connector and fastener clip. The delivery hose could be simple like watering vegetable garden from the town water supply system.

Period of Implementation Period

The installation of Peripheral pump is done during the dry season in a place where there is groundwater and when there is a need to lift water from the well and store it in a pond.

Cost Elements and Work Norm

The farmer should be willing to cover the following costs

- For constructing the hand dug well
- For pond construction
- For dynamo motor/peripheral pump
- Pump for irrigating the field

Planning and Mobilization Requirements

The following parameters should be considered while planning for peripheral pump:

- The farmer should have hand dug well,
- A pond to store the water
- There must be reliable electric power supply from the grid or using generator.

➢ Water abstraction from the pond to the field • The technology needs investment cost, hence there should close discussion with farmers to get their willingness to cover the costs	
Management and Maintenance	
• Training of farmers on operation and maintenance is very crucial • The pump should be installed during the dry season and put in the store during the rainy season • The farmer should closely inspect the static water level • The pump should be operational until the groundwater is depleted, farmers should supervise the water amount and turn off the pump when the water is depleted, and turn it on when the hand dug well is back recharged • If the pump needs maintenance the farmer should contact technicians around	
Benefits and Acceptability	**Limitation**
Peripheral pump is used to lift water for irrigation and farmers benefit from the available water through irrigation farming.	In areas where there is no electric supply difficult to implement

Name of the Technology	SMALL ENGINE PUMP (5-7HP)

General description

- Small Surface water Engine pump is a technology used for water pumping in situations where site conditions do not favor the use of gravity supply
- Small engine pumps can be used to lift water from surface water or shallow groundwater in which the depth of suction head is not deeper than 6 meters from surface of pump center.

Fig 1. Small engine pump on operation at the access ramp of a HDW (left)

Fig 2. Small engine pump on surface (right)

Geographical extent of use

Small Engine water pump can be used in all agroecology where there is available water for pumping for various

Technical design requirements

For selecting/designing of engine water pumps, the following parameters are considered: (more more detailed ref: guideline for manual well drulling and installation, MoA, (PP 96-116)

1. Know total volume of water to be pumped
2. Determined the pump power requirement (WHP) to pump the known volume of water, in horsepower (WHP=Q*TDH/273), Q, m3/hr, TDH (Total dynamic head, m), WHP, water horsepower)
   TDH= HS+Hd+hf
3. Calculate the actual power required to run the pump (BHP) – WHP/Pump EFF
4. Calculate the motor horsepower, in horsepower (BHP/engine Eff (-drive)

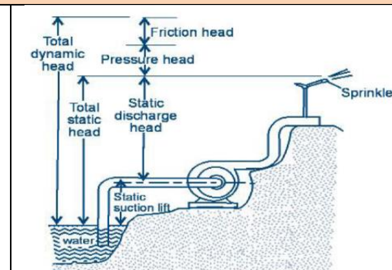


Fig 3. Head layout of pumps

Pump Installation

- Place the water pump on a solid, level position surface to avoid tilting or turnover that may give rise to spilling of fuel.
- To prevent fire hazards, keep the pump well ventilated during operation and maintain a distance of at least 1 meter between the machine and the wall or other machines.
- Keep away from inflammable substances. Do not allow children and pets to enter the working area as this may increase the chance of their getting burned by hot surfaces of the operating parts.
- Know how to stop the water pump quickly how to operate the controls. Do not use the pump against the prescribed operating rules

Connecting the water inlet

Connect the water inlet with a commercially available hose, connector and fastener clip. The inlet hose must be a continuous non-foldable structure with a length not more than required length. It should be placed near to the source of water so as to achieve the pump should be fitted to the end of the hose with the hose connector.

CAUTION: Before pumping water, attach the filter to the end of the hose to filter out foreign matters in the water, the presence of which may cause clogging and damage to the wane wheel.

NOTE: The hose connector and fastener clip should be securely fastened to prevent air leaks and reduction in suction power. A loose hose will reduce the pump performance and self-suction capacity.

Connecting the water outlet

Connect the water outlet with a commercially available hose, hose connector and fastener clip. Large diameter hoses are the most effective while small ones will increase the flow resistance and reduce the output power of the pump.

Period of Implementation /Use Across Seasons

It can be used throughout the year whenever the need to irrigate land available for water lifting do exist

Planning Considerations

- ✓ For using engine pump farmers should be aware of all costs
- ✓ The command area and the pump capacity should compatible
- ✓ Farmers should be organized in groups so that when some ones pump needs maintenance he should borrow from others for that time

Cost elements and Work Norm

The cost elements for Small engine pump water lifting pumps include:

- Initial cost for the purchase of pump and, Operation and maintenance costs

Operation and Maintenance

PRE-OPERATIONAL CHECKS AND SAFETY PRECAUTIONS

Before starting the engine, perform inspections according to the procedures described on pre-operation inspections to avoid accidents & damage to machine.

CHECK THE ENGINE OIL AND THE FUEL

Use 4-stroke engine oil, API Service classification SE class or equivalent. Or use as per the user manual recommendation.

Oil level Check method are:

1. Remove the dipstick and clean it.
2. Reinsert the dipstick into the oil filling hole w/o screwing it, & check oil level.
3. If the oil level is too low, add the recommended engine oil up to the oil filling neck.
4. Reinstall the dipstick.
5. Lubrication oil capacity K180 -3 0.6 L
6. Running with insufficient oil may damage the engine severely.
7. Remove the fuel tank cap and check the fuel level
8. If the level is too low, refuel the tank. Remember adding fuel not over the fuel filter shoulder

STARTING AND STOPPING PROCEDURES

STARTING ENGINE

1. Turn on the fuel tap (by setting it to the ON position)
2. Close the choke, NOTE: The choke is not required when starting the engine warm or the ambient temperature is rather high, (i.e. keep the choke open when starting the engine).
3. Set the engine switch to the ON position
4. Turn the throttle control lever slowly to the left
5. Gently pull up the starter lever till a resistance is felt & then quickly pull it up
6. CAUTION: Do not allow the starter lever to retract quickly into the engine. Let it go back gently to avoid damaging the starter.

i The gasoline fuel is highly inflammable and may explode under certain conditions

ii Do the fueling with the engine shut down & in a ventilated environment. No smoking & no open fire or sparks allowed to exist in areas where fueling is carried out or the fuel is stored.

iii Do not allow the fuel to overflow the fuel tank. Be sure to recap the tank and tighten it after refueling.

iv When fueling, take care not to spill the gasoline about as the gasoline vapor may easily get ignited to cause a fire hazard. Be sure to remove the spilled gasoline as by wiping before starting the engine.

v Do not run the engine indoors or in a poorly ventilated space as the exhaust gas produced by the running engine contains toxic carbon monoxide that may cause the loss of personal consciousness or even death. Below chapter is on **Diagnosing pump and Seal Problems in Field**.

TROUBLESHOOTING, ENGINE UNABLE TO GET STARTED:

i Is there enough fuel? Is the fuel tap turned on?

ii Has the fuel reached the carburetor? Make the check by unscrewing the oil drain screw from under the carburetor with the fuel tap turned on.

WARNING:

iii Should there be a spill of fuel, be sure to clean it before checking the spark plug and start the engine or otherwise the spilled fuel or fuel vapor may get ignited

iv Is the engine switch set to the ON position?

v Is there enough oil in the crankcase?

vi Is the spark plug generating sparks?

vii Uncap the spark plug, clear off the dirt from around the plug and remove the spark plug

viii Fit the spark plug into the plug cap

ix Turn on the engine with the side electrode and pull up the starter lever to see if there are sparks generated

x Ground the engine with the side electrode and pull up the starter lever to see if there are sparks generated

xi Replace the spark plug if no spark is found

xii Start the engine as directed in the operation manual if sparks are generated

xiii If the engine still refuses to get started, send the pump to authorized dealers

THE PUMP UNABLE TO SUCK

1. Is it filled with enough amount of water?
2. Is the filter clogged?
3. Is the hose fastener clip tightened?
4. Is the hose damaged?
5. Is the suction head too high?
6. If the pump still fails to work, send it to any of the authorized dealers

THE PUMP UNABLE TO SUCK UP WATER

Is it filled with enough amount of water?

Is the filter clogged?

Is the hose fastener clip tightened?

Is the hose damaged?

Is the suction head too high?

If the pump still fails to work, send it to any of the authorized dealers

Benefits	**Limitations**
Small engine water pumps are simple and movable so that farmers are secure from theft, etc.	Costs are limiting for the technology application.

Irrigation Water Application and Management

Overview

Irrigation is the controlled application of water for agricultural purposes, particularly crops, pasture, trees and other plants, to supply water requirements not satisfied by rainfall. It is an intervention that seeks to artificially increase water made available to the crop root zone. There are many types of irrigation systems. In some systems, water is supplied to the entire field uniformly, while the more efficient methods supply water only to the plant root zone. Irrigation water comes from rivers, groundwater or wells, ponds, springs, water harvested from rainfall etc. Many of the technologies are discussed in the water harvesting info tech part.

The main objective of developing an irrigation system is to apply water to the soil/crop, so that moisture will be readily available at all times for crop growth, regardless of the rainfall availability. Irrigation is necessary for crop production in situations where rainfall is lacking e.g. in deserts, or too little e.g. in dry areas, or where rainfall is unreliable in amounts and distribution. The latter is the case in most agricultural areas where rain-fed agriculture is practiced. Thus, crop irrigation is vital in order to provide the world's ever-growing populations with sufficient food. Irrigation is also used to boost productivity of land, by increasing cropping intensity. Irrigation makes it possible to plan crop sequencing better, enabling market targeting and improving the quality of produce. Irrigation enables farmers to have control of water availability and use (unlike rain-fed agriculture, where rainfall/water availability controls what the farmer may do).

Whatever irrigation method is being chosen, the purpose of irrigation is to attain a better crop and a higher yield. Therefore proper design, construction and irrigation practice are of utmost importance. Irrigation is useful in areas with inadequate and/or unreliable rainfall and for bridging crop production during the dry seasons, which is called supplementary irrigation, Irrigation has many advantages, some of the main ones include: increased agricultural productivity, increased yields, improved incomes, improved quality of produce, crop diversification, labor productivity, stability, environmental conservation, climate change mitigation.

The suitability of the various irrigation methods, i.e. whether surface irrigation, sprinkler or drip irrigation, requires an analysis of the technological and socio-economic considerations, as well as assessing the advantages and disadvantages of the various methods. It is important to know which method suits the local conditions best. The crop type is usually matched to irrigation method. For instance, surface irrigation can be used for nearly all crops types albeit it uses more water. Surface irrigation methods are commonly used for staple food crops e.g. rice, maize and legumes. Drip irrigation is suited to irrigation of individual plants or trees or row crops such as vegetables, sugarcane or fruit trees. In selecting an appropriate system, it is important to note that surface irrigation systems apply water to the land by an overland water flow regime. Within this group are the furrow and basin irrigation systems widely that are adopted in the country. Micro-irrigation systems such as drip supply water directly to the root zones of crops and have the highest efficiencies. Spate irrigation is a special type of irrigation using flood waters. Hence the following technologies are presented in this section.

1. Furrow Irrigation System
2. Basin Irrigation System
3. Spate Irrigation System
4. Family Drip Irrigation System

Name of the Technology	FURROW IRRIGATION

Brief Description

Furrow irrigation refers to irrigating land by constructing furrows between two rows of crops or alternately after every two rows of crops, particularly for narrow spaced row crops such as onions, cabbage and pepper. It involves only wetting part of the surface of the soil and water in the furrow moves laterally by capillaries to the un-watered areas below the ridge and also downward to wet the root zone soil.

Fig 1. Scene of furrow irrigation under practice

Main objective(s)/purposes

Furrow irrigation reduces evaporation losses, improves aeration of the root zone, less puddling of the soil surface and permits earlier cultivation after irrigation. Besides, furrow prevents an accumulation of salts near the plant bases, in areas where salts are a problem. Furrow irrigation is, perhaps, the most widely used method for row crops.

Suitability and Geographical Extent of Use

The furrow method is well suited both to small and large farms. It is also suitable for many crops, and especially row crops, tree crops. Furrow irrigation adapts better than any other method to crops that are grown in rows with more than 30 cm spacing, such as vegetables, maize, groundnut, sugarcane, cotton, and potatoes. Fruit crops are also irrigated by furrow method. Crop types, farm equipment to be used and planting distances between plants are the factors that determine furrow size and shape.

Design and Layout

Furrow Layout: - In deciding the most practical and efficient length of furrow to be used a number of factors need to be considered, such as Slope, Soil type, stream size, Irrigation depth, cultivation practice and field length.

Furrow Length

The type of soil- coarse texture or clay soil, the size of the irrigation stream, the slope of the land, and the irrigation depth or duration of the water application. In general, **furrow lengths range from 60 m to 300 m** or more depending on the determining factors mentioned above but the field size and shape of fragmented fields of the subsistence farmers put practical limits on furrow length as well. The recommended maximum furrow lengths for different soil types and slopes are given in Table 1.

Table 1. Recommended furrow lengths for different slopes, soil types and net depth of water application, mm

Furrow Slope, %	Maximum flow of water per second (l/sec)	Furrow length (m)							
		Soil types and available soil moisture in mm/m depth of soil							
		Clays			Loams		Sands		
		50	75	150	100	150	50	75	100
0.05	3.0	120	300	400	270	400	60	90	150
0.10	3.0	180	340	440	340	440	90	120	190
0.20	2.5	220	370	470	370	470	120	190	250
0.30	2.0	280	400	500	400	500	150	220	280
0.50	1.2	280	400	500	370	470	120	190	250
1.00	0.6	250	280	400	300	370	90	150	190
1.50	0.5	220	250	340	280	340	80	120	190
2.00	0.3	180	220	270	250	300	60	90	150

Source: Irrigation Agronomy Manual, Revised version, former MoA /ADD, March 1990, Addis Ababa

In order to control or at least minimize erosion, particularly in areas where there is heavy rainfall a particular hazard of irrigation schemes located in highland areas, furrow must have a limited slope and the following guidelines are recommended (see Table 2 below).

With furrow irrigation, the water is applied to small channels, known as furrows that are between the rows of plants. Water is admitted to the head of each furrow, and the rate of flow is adjusted so that the furrow flows full without overtopping. As the water reaches the end of the furrow, the required amount of water has infiltrated into the soil to satisfy the irrigation requirements. The rate of flow into the furrow depends primarily on the intake rate of the soil and the length of the furrow. Infiltration rates for various soil textures and suitable furrow flow rates per 100 m

Table 2. Slope of furrow related to soil type

Soil type	Max. recommended slope, %
Sand	0.25
Sandy loam	0.40
Fine sandy loam	0.50
Loam	2.50
Clay	6.25

length of furrow is given in Table 3 below. In order to determine the correct flow rate per furrow requires testing in the field. A simple advance and recession test can be done

Table 3. Soil Infiltration rates and suitable furrow inflows per 100 m of furrow length/furrow spacing 1 m/

Soil Type	Infiltration rate, mm/h	Furrow inflow l/sec/100 m length
Clay	1- 5	0.03- 0.15
Clay loam	5- 10	0.15- 0.30
Silt loam	10- 20	0.30- 0.50
Sandy loam	20- 30	0.50- 0.80
Sand	30- 100	0.80- 2.70

Source: Stern, P.H. 1985. Small- scale Irrigation

Furrow Spacing

Furrows are usually v-shaped in cross section, 25- 30 cm wide at the top, and 15- 20 cm deep, shallower in lighter soils and deeper in heavier soils. Wider, U-shaped furrows with a greater wetted area are sometimes used on soils with slower water intake rates. Usually, the spacing between furrows is narrower in sandy soils and wider in heavy soils. This is to ensure that water spreads laterally into the soil below ridges and downwards in the effective rooting depth uniformly. Furrow spacing in sandy soils is in a range of 60 to 80 cm, whereas in clay soils 75 to 150 cm and in loam soils 60 to 90 cm. Shallow rooted and transplanted crops using seedlings require small width and shallow depth, while deep rooted crops have wide and deep furrow depth. There are 3 different types of furrow methods: straight level furrow, straight graded furrow and contour furrow, see Fig 1 below.

Period of Implementation

It is usually practiced on gently sloping land up to 3% in arid climates but restricted to 0.3% in humid areas because of the risk of erosion during intensive rainfall. From a farming point of view furrows should be as long as possible as this reduces the cost of irrigation and drainage and easy for mechanization.

Contribution to climate change	Challenges and constraints (limitations)
• Water saving, • Production increase (biomass and yield) • Reduce soil erosion • Mitigate soil salinity	Poor wetting pattern can be caused by • Unfavorable natural condition; - compacted soil layers, uneven slope can result in uneven wetting along the furrow. This problem can be overcome by changing the land to a uniform slope. • Poor layout: - furrow spacing too wide then the root zone will not be adequately wetted. • Poor management; - a stream size that is too small will result in inadequate wetting of the ridges. It is also poor water distribution along the length of the furrow. Overtopping of the ridge may occur, stop the inflow too soon is also common management fault.

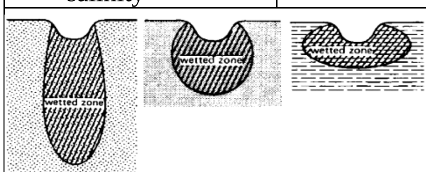


Fig. 2. Wetting pattern of furrows for sandy, loam and clay soil types, respectively

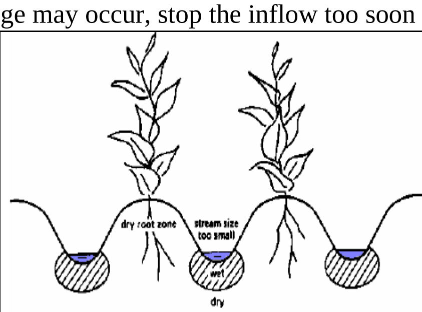


Fig 3. Root zone remains dry due to too small stream size

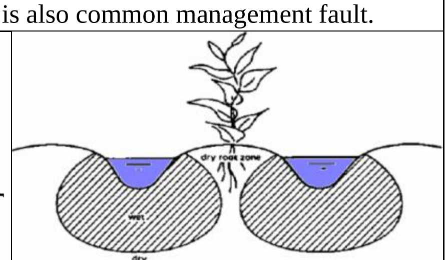


Fig 4. Root zone is remaining dry b/c of too wide furrow spacing

Name of the Technology	BASIN IRRIGATION - BI

Brief Description

Basin irrigation method consists of dividing the field into several relatively level plots called checks surrounded by low soil bunds. Water is conveyed to checks by a system of supply channel, laterals and field channels. Basin irrigation is the simplest and most widely used of all surface irrigation methods because of its simplicity. Efficient utilization of irrigation water and boost production.

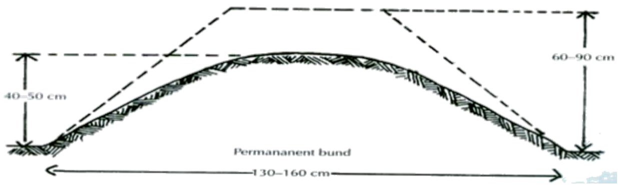


Fig 1. Shape and dimension of permanent bunds

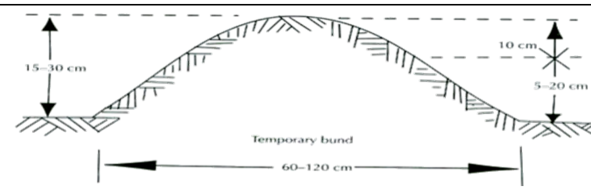


Fig 2. Shape and dimension of temporary bunds

Fig 3. Panoramic vie

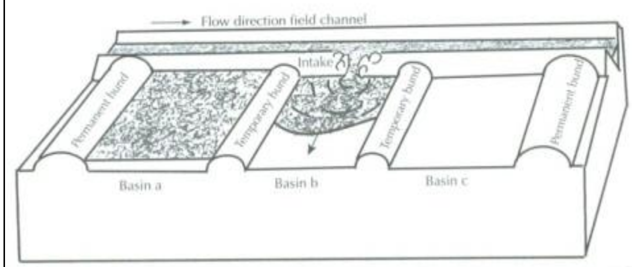


Fig 4. Schematic view of BI (Left and right bunds are permanent while the two in the middle are temporary

Suitability or Geographical Extent of Use

Most suited to flat lands with soil types having moderate to slow infiltration rates, but can be used on sloping land, provided that the soil is deep enough to allow leveling without exposing the subsurface soil. Is most suitable irrigation method for smallholder farmers and suitable for many field crops especially for Paddy rice. Grows best when its roots are submerged in water and other uses like alfalfa, clover, citrus, banana, cereals (maize, wheat, barley) etc. Basin Irrigation is generally not suited to crops, which cannot stand in wet or waterlogged conditions for periods longer than 24 hours. These are usually root and tuber crops such as potatoes, cassava, beet and carrots, which require loose, well-drained soils.

Site selection

Three factors, which may affect basin width, are the depth of fertile soil, methods of basin construction, and agricultural practices. The size of basins depends not only on the slope but also on the soil type and the available water flow to the basins. The relationship between soil type, stream size and size of the basin is given in table

Table 1. Suggested maximum basin areas (m^2) for various soil types and available stream size(lit/sec)

Stream size l/sec	sand	sandy loam	clay loam	clay
5	35	100	200	350
10	65	200	400	650
15	100	300	600	1000
30	200	600	1200	2000
60	400	1200	2400	4000
90	600	1800	3600	6000

Layout

Basin layout not only refers to the shape and size of the basin but also to the shape and size of the bunds. The shape of the basin: squares, rectangular or irregular? What is the shape of the basin: 10, 100, or 1000 or 1000, or 10000 m^2. How high should the bund be: 10,50, or100cm?

Shape and size of basins

Approximate values for the maximum basin or terrace width(m)

Slope%	Maximum width(m)	
	Average	Range
0.2	45	35-55
0.3	37	30-45
0.4	32	25-40
0.5	28	20-35
0.6	25	20-30

	0.8	22	15-30
	1	20	15-25
	1.2	17	10-20
	1.5	13	10-20
	2	10	5-15
	3	7	5-10
	4	4	3-8

Benefits and Acceptability

Potential to Increase/sustain Productivity and Environmental Protection (impacts). Advantages of the method are: variable sizes of streams can effectively be used; it can be adopted for a wide range of soils; water application efficiency is high as compared with wild flooding; no loss of water by run- off; rain and irrigation water can be used for wetting the active root zone soil; water logging conditions can easily be created, which is favorable for rice cultivation and leaching down of salts can easily be done. It contributes to adaptation to climate change through: water saving, production increase (biomass and yield), reduces soil erosion, and mitigates soil salinity.

Design Considerations

Basin should be small if the:	Basin can be large if the:
1. Slope of land is steep	1. Slope of the land is gentle or flat
2. Soils sandy	2. Soil is clay
3. Streams to the basin are in small	3. Stream size to the basin is large
4. Required depth of the irrigation application is small	4. Required depth of the irrigation application is large
5. Field preparation done by hand and animal traction	5. Field preparation is mechanized

Design basins

Shape and dimensions of bunds

Bunds are small earth embankment which contains irrigation water within basins. They are sometimes called dykes or levees

The width of the bunds,

Temporary bund 60-120cm at the base, height of 15-30cm above the

Original ground surface, including a freeboard of 10cm

Permanent bund 130-160cm at the base, height of 60-90cm above the

Original ground surface, the settling height 40-50cm

Basin Construction

There are three steps:

1. **Setting out is** relatively simple and involves only straight lines. Terrace is set out by first locating a suitable contour lines contour line across the land slope. This is the line along which the first bund is constructed. A second line is then set out along a contour further up the slope to mark the location of the next bund.
2. **Forming of the bunds**: - both temporary and permanent bunds can be formed by hand or by animal or tractor-powered equipment. The constructed bund should be properly compacted so the leakage cannot occur.
3. **Smoothing the land**;- On flat land this involves smoothing out the minor high and low spots so that the difference in level is less than 3cm .This could be difficult to see by eye a 3cm difference but it can be easily apply water it will become obvious where high and low spots still exist.

Limitation

The principal limitations of the method are: Interference of the ridges with other farm activities, considerable land is wasted, which occupied by ridges and lateral field channels, impedes surface drainage, since the land is flat and ridged, precise land grading and leveling are necessary, labor requirements for land preparation and application of irrigation water are much higher, high initial capital investment as compared with other surface methods and the method is not suitable for irrigated crops sensitive to wet soil conditions.

Name of the Technology	SPATE IRRIGATION - SI

General Description

Spate irrigation is a system of irrigation where cultivated land is irrigated by flooding. It is a unique method of irrigation which utilizes flood water, harvested from ephemeral watercourses during and immediately after a rainfall event. It is concerned with diversion of large quantities of flood flow from highlands into leveled basins in the lowland "wadi or lugga"). More specifically, FAO in 1987 defined spate irrigation as “an ancient irrigation practice that involves the diversion of flashy spate floods running off from mountainous catchments where flood flows, usually flowing for only a few hours with appreciable discharges and with recession flows lasting for only one to a few days, are channeled through short steep canals to bunded basins, which are flooded to depths of 0.5 m or more. Subsistence crops, often sorghum, are planted only after irrigation has occurred. Crops are grown from one or more irrigations using residual moisture stored in the deep alluvial soils formed from the sediments deposited from previous irrigations.

Conditions that favor spate irrigation

SI schemes contain unique features and considerations must be made to ensure the following features are attainable.

- Ingenious diversion systems, built to capture short floods but also designed to keep out the larger and most destructive water flows;
- Sediment management, as the flood water has high sediment loads that would otherwise fill reservoirs and clog intake structures and distribution canals; these sediments are used to build up soil and level the land but can also result in excessive rising of land and loss of command;
- Soil moisture conservation, is a core component of spate irrigation, especially as floods often come ahead of the sowing season;
- Social organization is necessary to manage the sometimes complex system, ensure timely maintenance of the structures and channels and oversee the fair distribution of the flood.

Geographical Suitability

Suitable crops

Spate irrigation is best practiced with drought resistant crops, such as sorghum, millets and pulses and trees e.g. mango. Sometimes, the crops are grown using one or a few flood events, by utilizing the residual moisture stored in the deep alluvial soils formed from the sediments deposited in previous irrigations. Although spate irrigation has been primarily developed for cropping, it rarely serves only agriculture. In many instances, it also sustains rangelands and local forestry, and helps recharge groundwater, thus providing drinking water for humans and livestock.

Suitable Soils

The cropped area under spate irrigation should have deep alluvial soils which can hold moisture for long periods of time. The soils should also have relatively moderate infiltration rates that vary with soil texture, density and soil management practices. Generally, spate soils are largely built up from the heavy sedimentation loads of spate water and thus their textures vary within the spate systems as a result of the sediment transport and depositing pattern.

Design of Spate Irrigation Systems

The design of a spate irrigation system involves:

- Determination of volumes of expected runoff
- Site investigation and characterization
- Design of water delivery and diversion structures, division boxes, canal networks, field intakes, drainage outlets, spillways, and field embankments or bunds.

Diversion structures

Diversion Structures can be:

Estimating flood flows: The flood flows should be properly evaluated in order to determine how much area to irrigate and therefore, enable the design of the different structures required. The proportion of the mean annual runoff that can be diverted to the fields is an important parameter in determining the potential command area and also the peak flood to design diversion structure. Hence either Rational method or USCS method can be applied based on the catchment size and data availability.

- Temporary diversion structures – usually made of compacted earthen bunds with bushes
- Permanent diversion structures – made of masonry, concrete or gabions.

Their design is already discussed can be referred in diversion weir construction. The only difference in the design is the designer should understand that large volume of flood with high sediment load is diverted in short period of time and the canal and intake structures should be designed considering the sediment load and the volume of water.

<u>Intake structures</u>

Intakes in spate irrigation systems are used to divert large and varying volumes of flood flows, delivering water to canals at a sufficiently high level to ensure command over the irrigated fields. The canals should be capable of conveying large volumes of water to fields quickly in the short periods when flood flows occur. The timing, duration and maximum discharge of spate flows are unpredictable and thus canal capacities have to cope with a wide range of design conditions. The types of water distribution systems developed for perennial irrigation are thus not appropriate for spate systems as canal capacities are determined for a relatively narrow and predictable range of design conditions. Canals used for spate irrigation are much larger, wider and with control structures to absorb the scour expected for the largely turbulent flows.

Fig 2. Gabion diversion structure

Fig 1. Spate irrigation on bunded field

Water Management and Control

Field water management in spate irrigation systems is as important as effective water diversion. Owing to the great temporal and special variation of its floods, the nature of spate irrigation does not allow farmers to follow a predetermined irrigation schedule where water quantities are applied to a crop when it is needed.

It is recommended to divide flows into proportions which farmers can manage. Earthen structures are relatively cost effective to build but require considerable maintenance and repairs during the irrigation season to remain functional.

The design of the command area also plays an important role in field water management.

Field bunds play an important role in field water application. They should be higher in areas where water supply is less reliable, while they remain relatively low where water supply is frequent and abundant.

Maintaining field bunds is an individual responsibility with a collective impact because, if bunds in one field are neglected, the water will move across the command area in an uncontrolled fashion, not serving large parts of it and causing field erosion at the same time.

Implementation Period

Spate irrigation needs headwork to divert the flood water, canals to transport the flood to the field and field with impounding bunds. All these structures must be constructed before the flooding season (i.e. to mean during dry season).

Limitations of Spate Irrigation

Spate irrigation is implemented bearing high levels of risk and uncertainty. This is due to the unpredictable nature of rainfall events, their timing, quantities and consequent flood volumes. Sometimes, there are occasional very large floods occur which wash away diversion structures. The main flood flow may change course leaving the channel from which the water was intended to be diverted. Sedimentation is a major problem in spate irrigation. However, sedimentation processes can be manipulated for the benefit of farming by building up on nutrients transported with sediments from upstream catchments to maintain soil fertility. Spate irrigation is as much about sediment management as it is about water management.

Maintenance of spate irrigation embankments is quite labor intensive; and is usually done through community initiatives.

Name of the Technology	FAMILY DRIP IRRIGATION SYSTEM

General description

Drip irrigation is an irrigation system in which water is applied at or near the root of the plant, drop by drop. It is the slow application of water to the soil through mechanical devices called emitters, located at selected points uniformly spaced along the delivery line (Figure on the left side). The system consists of a network of pipes along with water filtration provisions and suitable emitting devices, which could maintain high frequency application of water in and around the root zone of plants. The system is based on the fundamental concept of irrigating only the root zone of the crop, which would maintain excellent soil-water-plant relationship. Drip irrigation has high efficiency rates as much as 95%. Drip irrigation, is a very good option for increasing water-use efficiency, reducing labor requirements and improving harvests in both quality and quantity. Family drip irrigation could be bucket or drum type.

Fig1. Scene of family drip systems under practice

Geographical extent of use

The technology is applied in arid and semiarid areas where there is scarcity of water, needed to increase the water use efficiency. The technology is best suited for horticultural crops, especially high-value vegetables and fruits.

Technical Design Requirements

Drip irrigation delivers water directly to the plant through a system of plastic tubes with minimal water loss. The family drip system operates under 1 to 2 m water pressure head. One family drip system can irrigate from 25m^2 to 1000 m^2 and over. The system is suitable only for row planted crops. The drip can bucket (small area) type or drum type (relatively larger area.

Layout and construction procedures

Prepare the field properly, construct 1m vertical head for mounting the drum or the bucket, Prepare the layout of the mains and the laterals.
Assemble the drip system by fitting the down pip, the filter and mains in to the drum. The laterals will be fitted in to the mains

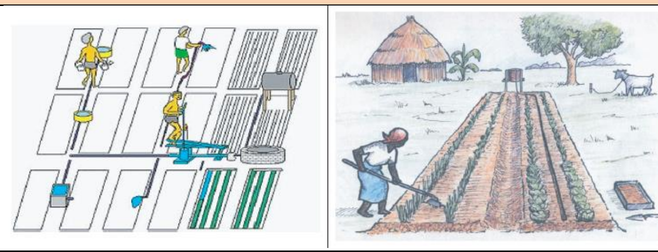


Fig 2. Layout of drip systems

Period of implementation across season

Can be installed any time of the year.

Planning and mobilization requirements

Planning follows group/community or individual owners. Discussion and agreement with owners is crucial especially on layout spacing type of crop to grow.

Land use, soil and topography should be assessed. Discuss and agree with the farmers on the design layout and if possible provide on the job training.

Management and maintenance:

Training in the area of irrigation agronomy, water management and drip irrigation, operation and maintenance is essential.
Ensure the water is properly filtered and the pipes are flushed once in a month. UREA can be supplied to the crops through the drip system. But, it is not recommended to apply DAP using the system as it clogs the emitters.

Benefits and acceptability

The technology is good in saving water, reduce competition from weeds results in improved plant growth and yield increases of 30 to 50 percent.
Limitation
Cost and clogging of emitters are the main limitations of the technology

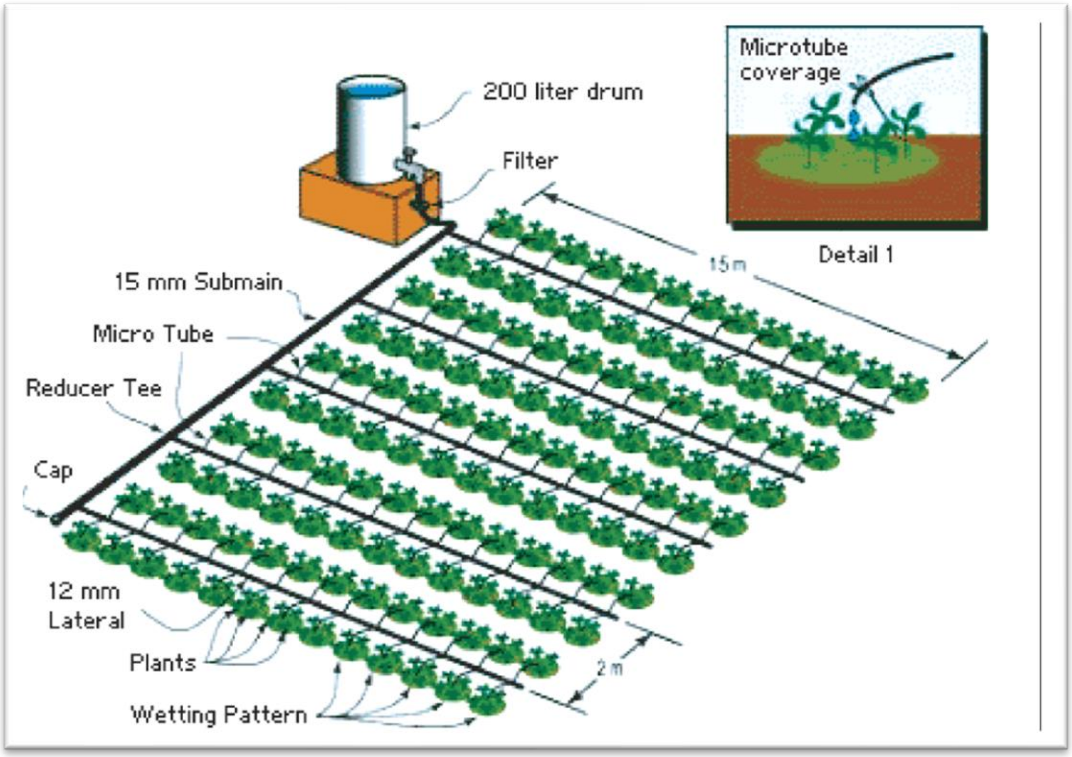


Fig 3. Typical family drip system configuration with 15mm submain (with 5 Tees), 12mm lateral line (with 130 microtubes)

Homestead Development and Livelihood

Overview

A growing population pressure and limited size of land holding means, there is a need to adopt a farming system accommodating more agricultural intensification and diversification of livelihoods. Agricultural intensification and diversification of livelihoods are crucial to reducing the negative impacts of climate change and to improve the living standards of small holder farmers. The experience of homestead development with agricultural intensification and diverse income generation at the homesteads demonstrated the possibility of improving food security and overcoming poverty in a short period of time. Thus, this thematic area of the guideline deals with various technologies and approaches known to increasing productivity and improving the livelihoods of small holder farmers. Each technology is described following the established standard format depicted in an overview of biological soil conservation thematic area.

The Homestead and Livelihood Technologies and /or approach described under this thematic area are:

1. Homestead development
2. Bee keeping
3. Small scale animal fattening
4. Pond Fish Culture
5. Energy saving stoves
6. Biogas development
7. Milk Collection Center (Milkshed)

Name of the Technology	HOMESTEAD DEVELOPMENT

General description

Homestead development is a key strategy for intensification and diversification of livelihoods with great potential of poverty alleviation among the small holder farmers in Ethiopia. It is mainly implemented around a residence which may include farmlands and other land use types close to a residential place. Homestead development has many comparative advantages than other lands located at distant from residential houses. It is an area close to a house that can be easily fenced from livestock interference. Family labor can be better exploited and made more productive all the year round and the use of local resources like compost and animal manure can be optimized. The following are some of the major homestead development interventions. Multi-storey home gardening/homestead development/ perma-culture agro-forestry system that includes Spices, Medicinal plants, Soil fertility and conservation, Backyard forage, Root crops, Live fence, Grape, Silk /sericulture. Some of the major homestead development interventions are illustrated in Fig 1.

Figure 1. Some pictorial examples of homestead development (rolled cabbage, fattening, fruit, and vegetable gardens)

Purpose and Benefits

The HSD approach:

- Fully empowers individual households in all aspects and engages the whole family in development process at all stages. Particularly women are fully empowered for active participation and decision making.
- Intensify productivity and optimization of multiple products in homestead areas
- Improved production and farm gate market throughout the year.

Geographical /Agroecology of its Use

Homestead development is applicable to most of the agroecological zones. As the intention of HSD is intensification and diversification, the feasibility of the approach and technologies is more feasible in areas where the moisture conditions are optimal and soil organic matter management can be deliberately and sustainably optimized. Thus, it is highly applicable in high rainfall areas, and in moisture stress areas with supplementary irrigation.

<table>
<tr><th colspan="2">Design and Methods of Application</th></tr>
<tr><td colspan="2">In order to guarantee the protection of the development interventions at the homestead live (vegetative) fences of suitable species found effective while providing other ecological and economic benefits such as Dovialis abyssinica, Erythrina, Euphorbia, etc. species are planted close to the dry fence with the objective to gradually replace the dry fences. Dry fences also require additional labor, time and material for maintenance. However, "SOCIAL FENCING" is the best way of ensuring sustainable protection. That is, the community should be convinced about and committed to protecting the area from livestock interference. Next to the live fence, from inside:-in addition to the income generation high value crops, various multipurpose plant species are planted for the intensification of biomass production (fig.2). This includes species such as Leucaena leucocephala, Acacia saligna, Elephant grass, Sesbania susban and other multipurpose species producing high biomass and having the value of livestock feed, soil fertility improvement and fuel wood. The intensification of biomass production also includes other strategies such as planting of the high biomass producing tree, shrub and grass species in degraded and closed areas for rehabilitation in and around rehabilitated gullies, on farm boundaries, on conservation structures, across the slope of farmlands in the form of shrub/tree hedges, grass hedge, grass strips, etc. Moreover, extension approach (participatory technology development and learning) should be designed for effective homestead development</td></tr>
<tr><th>Complementarities /Opportunities</th><th>Management and Integration Requirements</th></tr>
<tr><td>Homestead development approach and technologies need to be
• Integrated with market-oriented production system.
• Integrated with capacity (skill, resource, institution knowledge) development.
• Value addition of the multiple products</td><td>The success of homestead development very much depends on prudent and intensive management interventions throughout the year. The various high value crops require proper and timely cultivation, elimination of weeds, timely irrigation and application of organic/inorganic fertilizers and pest control. In order to optimize the synergy among the various components such as improved forage production, small scale fattening, high value crops and soil fertility management should be carefully handled to optimize their synergy effects.</td></tr>
<tr><th>Acceptability and Sustainability</th><th>Constraints and Limitations</th></tr>
<tr><td>• The homestead development approach and technologies will acceptable and sustainable if the following conditions are taken into consideration:
• Technically and economically feasible environmentally sound and socially acceptable
• Should be gender sensitive</td><td>• Lack of awareness
• Weak extension service for promoting HSD
• Absence of home agents
• Lack of credit service</td></tr>
</table>

Name of the Technology	BEE KEEPING

General Description	Purpose and Benefits
Beekeeping (or **apiculture**) is the maintenance of bee colonies, commonly in man-made hives, by humans. A beekeeper (or apiarist) keeps bees in order to collect their honey and other products that the hive produce (including beeswax, flower pollen, bee pollen, and royal jelly), to pollinate crops, or to produce bees for sale to other beekeepers. Studies indicate that there are about 10 million bee colonies in our country, out of which 7.5 million (75%) colony in traditional hives, 1 million (10%) are in transitional and modern frame hives, while 1.5 million (25% are found in forests and caves. Also, studies indicate that Ethiopia is the first country for having more colonies in Africa.	Bee keeping has many important socio-economic and ecological roles including meeting the beverage requirements of the population, income generation among the rural community, balancing the nutritional diets of the users, pollination of various crops, producing various products such honey, beeswax, pollen, bee venom, royal jelly and bee brood, which are used for different purposes. It is not also labor intensive and does not take productive land for its production (fig.1), the technologies and techniques required are not too complex and can be easily undertaken by households' members, relatively requires less capital for investment. Bee keeping is very friendly with natural resources conservation, biomass production and biodiversity. Can be undertaken as full or part-time engagement and the products are not perishable, can stay for longer time.  Figure 1: Modern beekeeping practice

Geographical /Agroecology Extent of its Use

Beekeeping is applicable to most of the agro ecological zones (Dega, WeineDega and Kolla) in Ethiopia. However, studies indicate that higher honey production was possible in the middle altitude than either higher or lower altitudes. In addition to the favorable climate condition, the availability of more vegetation and water resource in the middle altitude may be favored higher honey production than other altitudes. However, with proper management and supply of the necessary requirements there is room for improving the level of honey production in a wider range of altitudes.

Design and Method of Application

It is very important that bee keepers have sufficient skills and knowledge in order to harvest appropriate quantity and quality of bee products. Training could be one way of equipping the bee keepers to master the characteristics of bees, system/mode of productions, precautions to be taken on the management and harvesting of bee products etc. The apiary site must be suitable for bee keeping in regards of availability of bee flower/plants, ample water, protected from winds, and be free from parasites/termites. In tropical countries there are apiaries with 10, 20 or 30 bee colonies but in developed countries however the commercial beekeepers can have up to 1000 colonies per apiary with appropriate management. Under tropical condition, the most appropriate and manageable size of beekeeping is 30 to 50 bee colonies per apiary. However, an apiary can be established by 2 or 3 colonies and can be increased from year to year up to the above tropical recommendation size. The most important parameters to be considered in Apiary site selection are: presence of natural vegetation and fresh water, presence of native honey bees and chemical poisoning and pollution. To produce and harvest honey various inputs/equipment are needed including honey colonies, hives and their shelters, various handling materials, clothing, tools and may other things required under tradition, transitional and modern beekeeping that should be made ready before or while on the way of running the system. Components of the improved (modern) hive (with 10 frames) illustrated (fig.2).

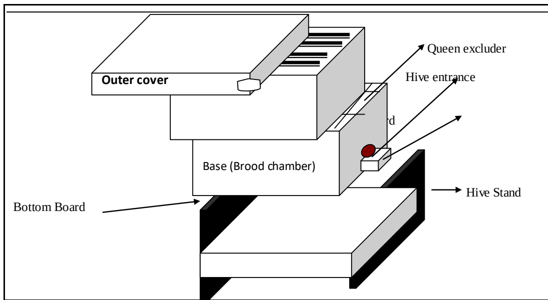


Fig 2. Components of improved (modern) hive (with 10 frames

Complementarities and Integration Opportunities

Bee keeping is compatible with many activities and can be easily integrated with different agricultural, income generation and natural resources management activities by individual or group of farmers interested to promote apiculture.

- At household level, it can be integrated with horticulture development and income generation activities.
- The interesting area of integration is area closure management. There are many countless closed areas excluded from external interferences in our country that are well rehabilitated and covered with dense forests and multiple floras. These areas can be excellent haven of apiculture. They can be excellent sites for promoting apiculture industry with some modification of the sites
- Making the availability of water and other requirements in the vicinity.

Management Requirements

There are two ways (methods) of inspecting established hive colonies: these are designated as internal and external. In external inspection, the beekeeper should observe normal flying in/out of the colony, speed of flight (high or slow). In internal inspection, bee keepers' should be prepared for internal hive inspection that will minimize sting by bees.

These include arranging the working hours, wearing of protective clothes which are light colored and clean, using a good quality smoke, taking care not to crush the bees while removing the frames. In addition to their natural feeding, supplementary or emergency feeding is required. In order to maximize the production the following are required, building up colonies, fulfilling the missed, broken or old frames and combs, adding or reducing hive boxes, inserting queen excluder, harvesting the honey crop, feeding colonies of bees,etc,. The best time or season to transfer colonies of bees from one hive to the other is a period of honey flow. An ideal time is during honey bees' plant bloom at the first week of active season (at the end of heavy rainy season or the end of dry season).

Acceptability and Sustainability

Acceptability and sustainability of beekeeping greatly varies from place to place and from farmer to farmer. In areas where traditional beekeeping is common, the level of acceptability of the technology is high and so the sustainability of the practice. Similarly, farmers who used to promote traditional beekeeping are much more open for adopting the improved methods of beekeeping and the chances of success and sustainability of the practice appears to be higher with these farmers. In general, acceptability depends on the knowledge and awareness of the practice by farmers. Therefore, it is necessary to organize and conduct practical trainings and demonstration for the target beneficiary in a way it fully equips them with full knowledge and technical knowhow on the practice and its socio-economic benefits. When it comes to sustainability, it depends on the level of benefits gained by the target beneficiaries.

Constraints and Limitations

The major constraint for the adoption, promotion and sustainability of the practice is the limited exposure to undertaking the practice and limited awareness about the economic benefits of the practice. Therefore, the blame lies in the weakness of the agricultural extension system, which could not create the required awareness, knowledge and skills among the farming communities for promoting the technology and obtaining the maximum possible benefits out of the practice. Moreover, the market outlet is not very conducive for accommodating a large amount of honey supply to reward the beneficiaries with the expected economic benefits. The lack of appropriate mechanisms for market value addition is the major constraint and limitation.

Name of the Technology	SMALL SCALE ANIMAL FATTENING

General description

Building food security and improving livelihoods of the rural farming communities is the main objective of agricultural extension system. The small household farm is a small complex agricultural production system comprising soil, crop and livestock management practices. When these components are managed efficiently they are expected simultaneously to achieve soil and water conservation and improved farm production and farm income for the small holder farmers. The main reasons for poor livestock production are poor breeds of animals, insufficient year round supply of good quality feed and indeed very poor management systems. However, there is considerable scope for improving livestock production on the small farms by following simple but improved livestock management practices. The livestock is an integral and important component of the agricultural sector. In terms of commodity, livestock is the second most important commodity next to crop production, which is unfortunately the most neglected. A small scale animal fattening is one of the income generating packages which can be easily undertaken by the farm family with available forage and livestock resources.


Fig 1. Small scale animal fattening

Purpose and Benefits

There is an opportunity to improve animal production by following a small scale animal fattening system as a component of income generating activities on the homesteads. This system allows efficient utilization of animal and forage resources available at the homesteads resulting in improved income from the sale of fattened animals. This is a very simple practice which can be undertaken by the household family on the homesteads and can give profitable returns over a short period of time with little or no external inputs, especially when combined with improved forage production. It also gives an opportunity to utilize animal and feed resources more efficiently and effectively without causing overgrazing and soil erosion. The practice encourages the farmers to keep smaller number of animals under controlled management, because of its relative advantage over the traditional practice of holding bigger number of animals those results in less economic returns but more environmental costs.

Geographical /Agroecology Extent

Small scale animal fattening is applicable nearly to all agroecological zones where the weather condition and availability of feed supply allow the achievement of good body weight gains by the intended animals. The determining factors for successful animal fattening include the availability of nutritionally balanced feed supply on sustainable basis, conducive weather condition for animal fattening and good market out let for competitive prices in addition to access to good animal health. However, suitability of the agro ecological zones may vary also with type of animal for fattening and availability off market outlets. In general, warmer climates are preferable to cooler climates due to the lower energy loss and better body weight gain in the warmer climates.

Design and Method of Application

In order to undertake small scale animal fattening by small holder farmers efficiently and effectively it is necessary to consider various components and requirements. The components necessary for undertaking a profitable fattening programme at the homesteads include willingness of the farmer and his family, availability of suitable animals, shelter for the animals, water, feed and technical services. The target farmers and their families are the most important requirements for the success of small scale animal fattening at the homesteads should be convinced about the program. Animals for fattening should be selected carefully either from those available on the farm or if necessary be purchased from the market. In case of cattle, initially young oxen can be purchased for draft power and later on can be used for fattening as it is done in Hararge fattening system. The following elements should be considered in selecting animals for small scale fattening. The animal should belong to good breed in the area with area with the capacity to respond fast to improved management systems. The animal should be well domesticated so that any member of family especially the women and children can look after it. The animal preferably should be young between 1-3 years (in case of cattle and one year in case of sheep) because young animals grow and gain weight faster. Definitely old and worn out draft animals must be avoided.

The animal should be healthy and free from any diseases and physical defects. It is advisable that necessary drenching and vaccination of animals is carried out in advance of organized feeding and veterinary services are ensured as and when required. The number of animals to be fattened and the period of fattening will depend on the availability of feed and the marketing conditions. This means that the animals should be fattened when forage is easily available and market prices are high. On a homestead, generally one or two young oxen or equivalent number of sheep can be easily fed for fattening. Availability of good quality feed in is required in quantity for a required period is important to complete the fattening programme satisfactorily. On the small farm roughage in the form of forage, crop residue and/or conserved fodder are the main sources of animal feeds. As far as possible, the feed requirement is met from various sources that are available on the farm, however, easily available outside sources especially for concentrates etc should also be considered. The objective here is to prepare the best combination of feeds from all available sources to meet the nutritional requirements of the animal. Selling the fattened animals at the right stage is very important as the sole objective of this programme is to make maximum profit. In order to prepare the animals ready for such periods, the programme of fattening must be planned accordingly for the period when sufficient feed is available on the homestead.

Complementarities and Integration opportunities	**Management Requirements**
Small scale animal fattening is compatible with a number of land rehabilitation, productivity improvement and livelihood packages. It is well compatible with degraded lands rehabilitation, particularly through area closure management. The practice of area closure should deliberately design strategies for increasing the quantity and quality of forage production by introducing improved forage species into the closed areas and by preventing competition from native vegetation through pruning and thinning them as required. Moreover, in order to optimize the quantity and quality of forage production intensive water harvesting and moisture conservation is required. The application of compost and farm yard manure with light cultivation of the forage species greatly contributes to increasing the quality and quantity of forage production wherever possible. Small scale animal fattening is also compatible with horticulture development as the products which do not qualify for marketing can be used for fattening the animals. The shrub and herbaceous legume fodder plants introduced to the homesteads can play both the role of soil fertility improvement while supplying feed to fatten the animals. The animals also furnish animal manure for improving soil fertility at the homestead for the horticulture crops.	The animals require close follow up and timely supply of feed and water; to this effect, some body assigned to consistently and properly undertake these activities is required. The health condition of the animals should also be reported to the responsible nearby veterinary services. Moreover, it is necessary that livestock specialists and veterinarians from extension services regularly visit the activities of small animal fattening and provide necessary technical supports as required.

Acceptability and Sustainability	**Constraints and limitations**
Small scale animal fattening is not a new practice in Ethiopia. In many parts of the country farmers fatten and sell animals at higher prices. In many areas farmers use oxen for cultivation during planting season and fatten lean oxen and sell them during off season at good prices. Then they buy other lean oxen for cultivation. In this way they make a lot profit out of the practice. The intensity, frequency, knowledge and skills of traditional small scale animal fattening greatly varies from place to place and so the acceptability of the practice. For instance, Haraghe farmers are highly specialized in fattening and selling animals, particularly they are proficient in fattening oxen. Therefore, the acceptance of the practice may vary from place to place accordingly. In parts of the country, where the acceptance may be low, it is simply because of the limited exposure and knowledge about the profitability of the practice. In order to advance the level of acceptance of the practice throughout the country, it is critically important to further develop the knowledge and skill of farmers on simple but highly profitable techniques of small scale animal fattening. Sustainability of this and many other practices mainly depend on the efficiency and effectiveness of the existing extension system. Provided the extension system is strong enough and effective, certainly sustainability of the practice would be guaranteed as its profitability is proven beyond doubt when supported by the right skills and knowledge.	The main constraint and limitation for the adoption and expansion of the practice appears to be the limited exposure hence the knowledge and skills for undertaking the practice in a way it is rewarding the expected economic benefits. Probably, the availability of feed, suitable animal and market out let may be a pretext for not regularly undertaking the practice. But the major limitation is the lack of reliable knowledge and skills for simple and remunerative small scale animal fattening. This limitation can be mainly attributed to the weak extension system that could not create enabling environment for the adoption and promotion of the practice. If there were strong extension system, all the problems of feed and other facilities could have been in place and the practice could have been easily promoted.

Name of the Technology	POND FISH CULTURE

General Description

It is the most common method of fish culture. Water is maintained in an enclosed area by artificially constructed ponds where the aquatic animals such the finfish and shellfish are reared. The ponds may be filled with canal water, rain water, and bore well water or from other water sources. The pond must be constructed after proper site selection. The climate, topography, water availability and soil quality of the region influence the character of the fish pond. The practice of pond aquaculture in Ethiopia has generally been small-scale with part-time farming for home consumption. This practice is somehow found increasing in the country especially where the potential for the practice existed. However, lack of training and extension support hampers the acceleration of required level of expansion of this valuable practice in our country. In general, there are little efforts made to promote the required knowledge and skills through trainings, research works and practical demonstrations to motivate and engage many more farmers or group of users in this field.

Fig 1. Some pictorial examples of pond fish culture

Purpose and Benefits

A pond fish culture, as such incurs little additional costs for promoting the practice. Water is often collected and managed for other purposes such as irrigation and domestic consumption. The inclusion of pond fish culture in these water bodies is just like an incentive to farmers to get additional income and food with little additional costs. Aquaculture is recognized as an alternative means to food security and poverty alleviation and there is believed significant potential in Ethiopia, but so far there is no national strategy on its development. Fish is a highly nutritious food supplement and also a very good source of income when sold in the market. Fish culture is simple, easy to manage and cost effective which can be integrated with other agricultural activities on a small farm. Small pond fish culture has been very successful and profitable in many Asian and African countries providing nutritious food and substantial income. In addition to the income generated from the sales of grown fish to the consumers, farmers also get large number fingerlings, which can be sold to new fish farmers generating additional income to farmers.

Geography /Agroecology Extent of Use

Pond fish culture can be promoted in most of the agroecological zones and the variability may exist for the type of fish to be practiced in different agroecological zones. However, it is best to position the fishpond in a place sheltered from wind. The advantage is to slow down temperature drop when there is strong wind during winter. Water temperature of a sheltered pond may remain one to two degrees higher than that of an exposed fishpond. The climate, topography, water availability and soil quality may influence the character of the fish pond. The topography determines the size and shape of the ponds. Sites, where huge individual ponds could be built, can be divided into smaller ponds built in series. The availability and quality of water determine where and what type of pond should be made. Growing and harvesting are more challenging in watershed ponds than levee ponds due to erratic water supplies, uneven bottom and side, and size and excessive depth of the dugout.

Design and Method of Application

The major factors to be considered are soil type, characteristics, topography and water supplies. The soil type influences how well the ponds will hold water; mud and mud-silt type soils are preferred for pond construction because it prevents leakage. The good quality soil containing a lower limit of 20 percent clay is necessary for making ponds. The pond topography decides the size of the pond; generally, rectangular pond size is chosen due to its greater simplicity and ease of harvesting and feeding. Variety of earthen ponds including community, nursery and individual households' ponds can be constructed. Alternatively, ponds of a desired size can also be constructed at selected sites, which are safe, near the source of water and where soils are deep and heavy to hold water. The pond should be rectangular in shape and having a depth of about one meter. It may be necessary to provide an inlet from one side to fill water and out-let from the other side to drain the water. The walls and bottom of the pond may be plastered to prevent leakage. In areas where

the soil is permeable it is advisable to line up the bottom and walls of the pond by durable plastic sheet like geo-membrane.	
In order to encourage growth of phytoplankton (micro plants) and to provide feed for the fish, a jute sack with micro holes containing about 10 kg of compost is advised to be kept floating always in the pond. In about two weeks after applying the compost, the water in the pond turns light green, as a result of growth of the planktons, indicating that the pond is ready to receive fish. About 140 fish fingerlings (baby fish) each weighing about 8-10 grams and about 6-9cm long can be introduced in a micro pond with a size of 9x5x1 meter. With 10-15% mortality about two fish per m^2 were expected to remain until the time of fish harvest. The fish starts breeding in the pond in about 3-4 culture.	
Integration Opportunities	**Management Requirements**
Pond fish culture can be easily integrated with many other packages generating income for small holder farmers or user groups provided water is available. Especially integrating fish culture in small scale or even large irrigation scheme is a great opportunity for individuals or user groups, which incurs little costs but granting huge additional economic benefits. That means the pond fish culture generates additional income for the promoters and hence optimizes their economic returns with little additional costs. Fish culture can also be integrated with many other income generating activities such as poultry, beekeeping, small scale animal fattening, etc to optimize the overall economic returns of the promoters.	Daily feeding of fish is the most important activity should the fish culture reward the required socio-economic benefits. Under controlled commercial conditions formulated feed (concentrated and nutritionally balanced) is daily fed to fish at the rate of about 3% of the body weight. About 100g of wheat bran, 50g noog cake and about 50g of finely chopped and crushed green material can be fed daily to fish growing in the above indicated pond size for the first month and this level can be increased by 20% every month to meet the feed requirement of growing fish. It is necessary to supply feed at least once in a day in addition to the feed they get from the planktons and compost in the pond. About 3mg/litter or 3ppm concentration of oxygen is considered ideal. Hence, in order to maintain the level of oxygen the water in the pond should be regularly changed. In case where fresh water is not frequently available, oxygen from the atmosphere can be mixed by disturbing surface of the pond with the branches of a tree. The level of the water in the pond should be maintained at 10 to 15 cm below the top surface of the pond. The pond must be inspected regularly and kept clean and safe from any outside interference, chemicals, etc.
Acceptability and Sustainability	**Constraints and Limitations**
Pond finish culture is not commonly practiced by farmers in Ethiopia and farmers are not well aware of the socio-economic benefits of the practice. Therefore, acceptability of the practice certainly expected to be low during the initial stage of the initiative. This requires rigorous extension support and demonstration of the practice until the farmers master the practice and well understand the socio-economic benefits. Sustainability largely depends on the economic benefits and continuity of the extension services that can guarantee sustainability of the knowledge and skills to efficiently and effectively run the scheme. The other important factor determining the sustainability of the practice is access to market out let. Farmers should get encouraging economic return from the practice, which in turn requires easy access to market out let. To this end, more farmers should be engaged in promoting the practice in organized manner to produce enough supply that attracts buyers (traders).	There are a number of constraints limiting the promotion of the practice in Ethiopia. Firstly, farmers are not traditionally familiar with the practice. Secondly, the agricultural extension service is not strengthened to provide the necessary technical and advisory supports in this area. In general, the information, knowledge and skill in this area are very much limited and also acquiring the fingerlings (baby fish) is not easy. Market outlet is another limiting factor for the promotion of the practice. While the potential for promoting the practice is high, the above major factors are limiting the scope of adopting and scaling up the practice. This requires special attention on the part of the government to strengthen the extension and research activities and market out let to ensure the adoption and gradual expansion and sustainability of the practice.

Name of the Technology	ENERGY SAVING IMPROVED COOKING STOVES

General Description

Rural energy in Ethiopia entirely depends on biomass energy (99%) from wood, cow dung and crop residue using traditional open stoves, which are low in energy efficiency utilization and are apparently the major cause of deforestation.

Low-income households, social facilities and small and medium enterprises gain sustainable access to improved energy technologies and services, since ICS reduce deforestation and indoor air pollution, and offer more time for education and improved living conditions especially for women. Depending upon the type of stove, the reduction in wood use can range from 25-60%. The technologies vary – from the basic mud stove to factory manufactured metal stoves

ICSs can be demonstrated and promoted to the community by organizing self-help groups (SHG), specially women and youths, to serve as an income generating option. Some of the various types of ICS products promoted in Ethiopia are: *Tikikil, Lackech, Mirt, Gozie*, etc.


Fig 1. Traditional 3-stone open stoves and *Lakech*

Suitability and Applicable Area

ICSs can be applicable to the rural and urban community in all agroecology, at HH level, in places where internally displaced persons (IDPs) or refugees are settled temporarily, institutional compounds, etc. as far as perception or behavioral change of the community convene, affordability of the products and cultural usage of ICS by the community are positive, local resources are available and the necessary arrangements are done by the local government/project.

Planning and Implementation Procedures and Approaches

Step 1: Understand the problem of target beneficiaries: Conduct assessment and collect background information of the area: - target group population and local resources; social and cultural issues; the local fuel supply and access to fuel limitations; types and efficiency of existing cook stoves traditional and improved; risks and challenges; etc.

Step 2: Propose appropriate ICS technology: Select the appropriate ICS type for the area by analyzing the collected information. ICSs can be categorized in a variety of ways, based upon design principles, construction materials, fuel type, and other factors. Justify for your selection and any measures you propose.

Selecting the most appropriate design will depend upon a number of factors, assess the following:

- **Wood-fuel use** – some stoves are designed for charcoal and some for fuel wood. Encourage the use of efficient wood burning stoves
- **Local resources:** check the availability and access of resources (both materials and skilled workers) for the construction of the selected ICS.
- **Cultural issues** - cooking habits and user acceptability, types of food, cooking methods, time, etc.
- **Other factors:** institutions and capacity, financial sources, local climate, market access and risks, etc.

Step 3: Prepare for Implementation: As a first step to implement your plan, you must address barriers and convince users by developing strategies, creating awareness and conducting behavioral change activities. The following approaches are recommended as a foundation for your plan implementation:

Brainstorming and developing possible strategies: Barriers of market and accessibility; establishment of production or supplier and distribution centers; affordability, etc. should be considered specific to the local context. In creating access, user's value added ICS products should be considered beyond availability. The following are some of the possible mechanisms to develop sustainable market, enhance HHs to purchase and own ICS:

- Subsidizing the cost of stoves through providing support to the producer and distribution groups with start-up materials and tools, by local government/project as possible.
- Promotion of the private sector to facilitate local production of ICS.
- Arrange installment based payments through traditional Saving and Credit informal groups, rural saving and credit associations (RuSaCCos) or other rural saving and credit institutions as convenient.
- Other options can be applied depending on the local context.

Awareness raising and behavioral change approaches: The approach intended to make a transition from the traditional stove to improved stove use.

- Brainstorm the concept of ICS, communicate uniquely to each target area with a due consideration of their social & cultural context.
- Provide trainings for producers to improve their technical, business and marketing skills.
- Communicate information with a collaborative efforts of offices (energy, agriculture, health (HEW) and women affairs),
- Most applicable awareness raising communication media includes:
  - → **Applying contests & stove demonstrations**: Can be applied in a larger community gathering in the kebele.
  - → **Pilot Kitchens:** Use healthy kitchen promoters in the community willing to pilot the product and demonstrate, and provide training on the usage of the product.
  - → **Posters and printed promotion materials:** can be often used at local environments to provide detailed information about the product features and benefits through messages and pictures. Others..

Step 4: Implementing your plan - the pilot phase: A pilot phase before the full roll-out is important to help identify potential problems and to ensure that users will be satisfied with ICSs and will be able to use them correctly.

Step 5: Implementing your plan - Stove dissemination and end-user training:

SHG Establishment and Implementation Procedures:

- Organize SHGs from both male-headed and female-headed HHs to produce ICSs in the kebele/watershed. Jobless girls might be considered.
- Provide practical training on ICS production to the SHG members together with the watershed committee.
- The WSC should help the SHGs in promoting the technology for the watershed community and in facilitating the marketing of the stoves and other supports.
- The woreda/projcet might support the SHGs by providing molds to precast different parts of the stove, and cement and sand for initial production.

Step 6: Monitoring, testing, and reporting:

- **Monitoring and evaluation: C**onducted for tracking the effectiveness of the social marketing, the progress and the impacts. The monitoring is conducted to assess whether a marketing approach has resulted in increased demand, the use of ICS have resulted in improved health, reduced fuel consumption, and reduced time spent collecting fuel.
- **Modify the approach based on results:** Assess the proposed approach effectiveness and make small modifications to improve the process. There should be continuous consultations with partners on the approach being implemented, and it is always possible to generate ideas on what could be improved for generating more effective impact in the uptake of ICSs by the local community.

Design and technical specification: Technical Specifications of Common ICS Technologies:

Mirt Stove: used for both baking injera (traditional bread) and for cooking at the same time. It is made of a sand-cement mixture and can save up to 50% fuel compared to the three-stone open fire with a thermal efficiency of around 22%.

Fig 2. Mirt stove for baking Enjera

Overall stove dimensions

Cylindrical enclosure	**Rear parts:**
Diameter: 64-70cm	32cm wide
Height: 22-24cm	26cm deep
Fuel/air inlet: 4cmX11cm	35cm high
Smoke outlet: 19cmX7cm	

Tikikil Stove: a portable HH cook stove made of galvanized sheet metal with a ceramic liner. It saves up to 50% of fuel compared to the three-stone open fire; its heat efficiency is around 28%.

Fig 3. View of Tikikil stoves (right)

Institutional Rocket Stove (IRS): a portable stove used for larger-scale cooking in institutions. The stove can potentially save up to 70% of fuel compared to the three-stone open fire with a thermal efficiency of 40-50%.

An example IRS without chimney stove size for a 50 litre pot:

Pot	**Stove**
Pot diameter: 50cm	Skirt diameter: 524cm
Pot height: 27cm	Skirt height: 255cm
Pot volume: 53 litre	Combustion chamber size: 15cmX15cm
	Combustion chamber box size: 45.3cmX31cmX31cm

Fig 4. View of Tikikil

Cost Elements and Work Norm

Costs of elements includes investment cost of casting molds, and production costs composed of labour cost to transport sand and produce stoves, and cement cost. The casting mold can be supplied by a project or local gov't on credit or subsidy. The construction material and labour costs depends on the type of stove. For example, to produce four Mirt stove, 140 kg of sand, 50 kg of cement, and 0.75 women-day are required. The cost will be estimated based on the local material and wage rate.

Management Requirement

Some of simple techniques to ensure the optimum performance of ICSs are:

- Keep any gap between the cooking pot and the stove (the annulus) as small as possible and preferably not more than 2cms;
- Ensure that pot lids are kept on during cooking;
- Encourage the use of dry wood wherever possible;
- Pre-soak appropriate foods such as pulses and beans;
- Encourage use of a pot with as large a base as the stove will reasonably accommodate to maximise the heat transfer area;
- Do not overload the stove with wood and avoid wood protruding from the fuel inlet by using smaller pieces.

Benefits and Acceptability

Direct Benefits:

- ICS can burn a variety of biomass fuels such as crop residues and dung.
- ICSs are produced with locally available material - that sustain their production and inexpensive to purchase
- ICSs increase fuel wood efficiency than traditional three-stone open fire stoves: Use of more efficient and cleaner biomass stoves can reduce fuel wood 50-60% and perform cooking more quickly, heat efficiency of at least 20%.
- ICS reduce indoor air pollution - protect women and children from heat and smoke during cooking;
- Access to ICS technologies and services are much important to low-income HHs, social facilities and small and medium enterprises for sustainable use of biomass.

Indirect Benefits:

- Pressure upon local biomass stocks is lowered: an average HH saves around up to 500 kg of wood per year using an ICS. This means conserving natural resources, reduce deforestation and lowering CO_2 emissions, as well as time, labour and money.
- The adverse health effects of indoor air pollution and time for fuelwood collection are reduced, especially for children and women who are intensively exposed, thereby freeing women and children to spend more time in education or involvement in alternative livelihood activities.
- Small-scale stove producing SHGs can benefit from self-sustaining income generating opportunities: SHGs can sell produced ICS to farmers living within and outside the watershed.

Limitation

Limitation of the promotional approaches for the required behavioral change owing to lack of collaboration and partly because of the limited coverage of the promotion - particularly in lacking a clear strategy to reach to different segments of the community such as the low income rural HHs. Financial resources - Credit availability. Market problems.

Name of the Technology	BIOGAS DEVELOPMENT

General Description

Biogas is a gas produced through the digestion of organic materials in anaerobic conditions by specific bacteria, called methanogens. Typical biogas compositions are methane, carbon dioxide and water. Biogas being mainly composed of methane (CH_4), and it is a flammable gas, thus it can be used as a fuel for heating, cooking and lighting. Biogas can also be used to feed engines to produce electricity. The digestion process is performed in a physical structure called **digester or bio-digester**. There are different types of biodigesters characterized by their shapes, sizes and construction materials, installation, lifespan, cost, biogas production, operation, etc. The common types for domestic purposes at a HH scale are plastic tube digester, plastic tank digester, fixed dome model, and floating drum digester.

Fig 1. Model of homestead level biogas use

Though relatively expensive, dome shaped concrete digesters have long life span (>20 years), easy to operate, less damageable and needs minimum O&M, common in Ethiopia. During digestion, about 25 - 30% and 70 - 75% of the total solids feed will be converted into a combustible gas and a residue, respectively. The residue comes out as sludge is known as digested slurry or bio-slurry, which can be used as income source by selling, or as organic fertilizer for home garden production.

Geographical Suitability

Suitable in diverse agroecology. The practicability in a target kebele and the appropriateness of the technology at a certain location (HH or Communal areas) have to be assessed based on the technical, economic, social and institutional factors (Refer below).

Technical Design and Implementation Procedures

1. Determine the size of the digester: Critically consider the amount of dung available, amount of gas required by the family and the amount of gas produced per amount of dung (see Table 1 below).

Table 1: Determining the size of a Biogas digester

Capacity of plant (M^3)	Daily gas production (M^3)	Fresh dung required every day (Kg)	Water required every day (litre)	Number of Cattle requirements
4	0.8 - 1.6	20-40	20 - 40	2 - 4
6	1.6 - 2.4	40-60	40 - 60	4 - 6
8	2.4 - 3.2	60-80	60 - 80	6 - 8
10	3.2 - 4.0	80-100	80 - 100	8 - 10

The main parameters for the design size of a bio-digester are:

- **Organic waste:** quantity of organic waste that feeds the digester (typically animal dung/human faeces) per day.
- **Water quantity:** used to dilute organic waste. Typical "waste to water" ratios are between 1:1 for fixed dome technologies to 1:4 or more for plastic tube technologies.
- **Retention time (RT):** It is the time required by the bacteria to digest the organic waste and produce biogas, usually between 20-45 days depending on the digester temperature, ideally in between 15°C–30°C, and pH of 7.
- Calculating the size of plant: Cow dung/cow/day multiplied by number of cows multiplied by two multiplied by the retention time, then divide all by 1,000. For example, if a farmer has four cows with each producing 15kg dung per day, the size of his digester will be: 15 x 4 x 2x45)/1,000 = 5.4m^3. Use allowance in case of extra waste, this farmer can construct a 6m^3 digester.
- About 0.5m^3 of gas can be generated from the 15kg of dung/day a cow produces. Thus, the amount of gas in m^3/day can be estimated by multiplying the number of adult cows by 0.5. An efficient biogas burner utilizes about 0.5m^3 of gas per hour. Farmer with 4 cows can have four hours of continuous cooking from a single efficient burner.

2. Decide Location: The selection location of the digester shall be approved together with the user. (Table 2).

3. Site clearing and leveling: After decision on location, level the site, start lay outing from the center of the location.ne.

4. Excavation work to install digester: Should be done precisely by free labor with the support of skilled persons.

5. Construction of Digester: the construction should be done by skilled persons with free labour contribution of the user. The work includes: Foundation, digester wall, gas holder, piping works and ditches, steel and metal works, electrical and mechanical works, etc.

Table: The space required for installing SINIDU biogas plants

Digester size	Width (Meter)	Length (Meter)
4 m^3	2.8	9.5
6 m^3	3.5	10.5
8 m^3	3.5	10.5
10 m^3	3.5	11.5

6. Starting of Biogas Digester: Biogas digester needs a large quantity of cow dung at the time of starting. The following are general requirements for starting biogas digester:

1) Collect and store cow dung during the construction period or even before. It should be kept covered to avoid drying. Collecting and preserving the cow dung in a pit or under shade with a cover is recommended.
2) During starting, if possible, obtain slurry from other existing digester to accelerate biogas production, and store it in a sealed container and strictly kept from exposure to air during transportation.
3) Strictly avoid pesticide sprays, antibiotics, and other sterilizing agents getting into and mixed with cow dung. Make sure slurry outside is free from components indicated.
4) Make sure that cowshed is modified so that transportation of cow dung and urine is possible by gravity using a graded ditch to channel and transport feedstock by gravity. Similarly, make sure biogas slurry can be supplied to the garden at the lower elevation of the digester by gravity.

Suitability and Selection Criteria of Location

Technical factors:

- **Feedstock (cattle holdings) and water:** to secure a continuous supply, adequate amount of feedstock and (fresh) water must be available year-round. (Within 20 minutes walking distance) in the biogas site. A minimum of daily availability of 20kg dung is required. The time to transport water to HHs should not be more than 20 minutes. Note that starting up a digester requires a multitude of feedstock and water to be made available in a short period of time.
- **Local construction materials:** availability local materials sand, stone and gravel nearby sources.
- **Temperature and terrain condition:** Temperature affects action **of** methane-producing bacteria. The ideal temperature for maximum gas from a biogas digester is within a range of 20 - 37 ^{O}C. The terrain height differences and rockiness should be taken in consideration. The terrain should fit for excavation.. Moreover, the digester should be placed near the end-user(s) (for communal use near interested/selected farmers within max. 10 minutes walking distance) with a sufficient space around the digester (inlet & outlet) for adding feedstock and removing slurry. A nearby place to apply or process (compost), IG activities using the bio-slurry-such as vegetables and fruits planting.

Economic factors

- **Fuel wood & value of biogas:** There should be a need for alternative energy technologies due to the scarce fuel wood, the value of biogas, workload & time spent in collecting fuel wood, health problems, etc. can be the driving forces for HHs to adopt biogas.
- The potential IGAs from the use of bio-slurry, and availability of affordable and accessible credit facilities.

Social factors

- Cooking customs compatible with use of biogas.
- Traditional practice of using dung as organic fertilizer/compost.
- Custom of hard working and need for improved livelihood, and other social aspects.

Institutional factors

- Existence of better extension service: in application of compost and promotion in the kebele.
- Capability and willingness of local stakeholders to support the biogas implementation (manpower for proper work for feedstock input and utilization of output).
- A biogas plant works if there is strong ownership of the plant and the roles of everyone participating are well-defined and discussed with members in communal plants.

Implementation Procedures and Approaches

1: CREATING AWARENESS: Public awareness should go hand in hand with the actual construction of plants in the field, to lay basis to disseminate biogas technology at grassroots level and enhance the understanding of rural HHs and motivate them.

→ Create awareness on benefits and pitfalls,
→ Arrange farmers' field day/experience sharing visit.

3. TRAINING APPROACHES:

Pre-construction training: Use well-trained biogas construction masons if available. If there is no trained masons, provide on-site training during constructing demonstration biogas digesters to selected 2-5 persons from the kebele, on all the steps starting from site selection up to O&M. This will be a multiple opportunity to create off-farm IG for the HHs, beyond creating skilled persons and installing a demonstration biogas plant in the area.

Selection of local masons for training will be based on:

2: DEMONSTRATION: is an approach of making the biogas digester benefit more than one household. The options for demonstrating are:

- Selection of host/lead farmers from existing or from a new host identified by DAs.
- If biogas is new in the area, construct and install demonstration biogas digesters at model/lead farms (2-3) for demonstration.
- At communal lands or FTC, School, Clinic, etc. as demonstration sites that can be accessed by the community.
- Decisions on the options with the target community to enable to choose from the available options or suggest new feasible practices that met the physical, social and cultural contexts.
- Host farmer and enterprise members':

→ Should be in close proximity to facilitate the daily activities during construction, sharing of lessons learned, and efficient use of the resources, and

→ Willing to share the benefit (bio-slurry) with his/her neighboring HHs and facilitate experience learning among them.

Take full ownership of the plant: Group members will have learning sessions to understand the benefits and will be later motivated to own construct a biogas plant for themselves.

- Have some level of experience and skill in construction;
- Willing to promote and build biogas digesters in different parts of the kebele and outside.

Post construction trainings and capacity building supports: These trainings are required for biogas beneficiaries, and supports include:

- Training for proper use & sustained functioning of biogas plant; on the use of bio-slurry application and compost making;
- Coaching members on business planning, and facilitate groups to design business plan for their IG activities and link with sources of credit based on their business plan.

4. FINANCING APPROACHES:

Local and industrial materials, and skilled and non-skilled labor are the initial investments associated with a biogas digester.

Interested HHs are required to supply locally available materials (such as stone, sand, gravel) and contribute their own labor freely for the preparation of the site and during construction process.

Investment subsidy approach for some of the industrial materials might be arranged by local government to enhance the affordability of the technology by local people at the initial stage. Part of the investment cost should be covered by HHs by providing them access to credit either from micro finance institutions (MFIs) or rural saving and credit (RuSACCOs) service providers.

Develop an appropriate credit delivery model (either in-kind or cash delivery mechanism) easily accessible by poor HHs depending on the specific context. One of the options includes the establishment of Village Saving and Lending **(VSLA)** groups. For establishing VSLA, contact woreda experts.

Cost elements and work Norm

In general, two skilled persons, mason and plumber, for 16 - 20 person days and 1 - 2 person days, respectively are required in average for installation of a domestic biogas digester size ranging from 4 - 10 m^3. Local daily unit cost rates should be used in estimating the cost.

Management, Operation and Maintenance

Biogas systems are NOT maintenance free. The system requires manpower and proper work for feedstock input and utilization of output. Users need to participate in O&M training during construction by the supplier. The following are the operation and maintenance items for biogas digester cooking stove:

Daily Routine Works of Biogas Digester:

* Daily feeding of the biogas plant with the amount collected in the cowshed, mixing the cow dung with urine/water in the ratio 1:1 (for 100 kg of cow dung mixed with 100 kg of urine/water) and sort out straw and wasted fodder before feeding the biogas plant. It could take up to 40 days or longer to fill the plant completely (depending on amount of cow dung available)
* Open the digester manhole, check if scum is formed/seen and remove the scum to make the gas outlet easy.
* If the digester has a lid, the sealing of the lid must stay moist. The space above the lid must therefore always be fully and completely covered by water. This water jacket should be made and maintained.
* Pour some heavy oil or waste vegetable oil on top of the water on the lid to reduce water evaporation and to avoid breeding mosquitoes.
* Regularly maintain and clean all gas consumption accessories, manometer, pipe, and cooking stove.
* Cooker and lamps should be cleaned every day. Clogging of pipes will reduce power. Replace mantles when torn or worn out. Close valves when appliances are not in use.

Check biogas available for use in cooking stove, by using gas pressure (manometer). If there is no manometer, a simple manometer can be installed by connecting a U-shaped piece of transparent hose filled with water to measure pressure of the gas line.

Periodic Works: periodically check filter, slurry pH, gas pipe line and removal of moisture, etc.

Safety issues in the use of biogas technology: Biogas is highly explosive when mixed with air. Hence, safety issues during the installation and use of the biogas should be kept. Contact woreda experts for the safety issues needed and provide the information to users for their attention.

Benefits and Acceptability

- The production of clean energy: Micro-economic benefits through energy substitution and increasing yields of agriculture; bright light to help in quality education and household works.
- The transformation of organic waste into high quality fertilizer;
- The improvement of hygienic conditions through reduction of organic waste;
- Environmental advantages through conservation of soil, woody vegetation and reduction in GHGs, especially methane;
- Workload reduction (less time spent on firewood collection and cooking), especially for women and children; Saving time for women to be used in other income generation activities;
- Contribution to Livelihood - Income Generating Options:
  - → Through applying bio slurry at homesteads / on communal land (School, FTC) owners can plant high value fruits and vegetables and get income from selling;
  - → Compost-making and selling to the local small holder farmers, large farms and institutions;
  - → Running a petty trade such as mini café services-coffee, tea, fast foods by using the biogas cooking stove

Challenges/Limitations

- Challenging issues regarding operation can be related to inappropriate amount of water input; low acceptance of dung to feed the digester resulting in inadequate dung input; and reluctance to use bio-slurry as fertilizer for food crops.
- The initial investment costs is one of the barriers to the technology adoption by rural HHs, especially the poor.
- Accessibility of MFIs and the willingness of the poor HHs to take credit owing to repay loans.
- **Social constraints:** Mainly concerns with the use of biogas produced from human and animal faeces for cooking, in case of toilet connection to a digester. They may also constitute a possible constraint for a large diffusion of domestic biogas units in some communities.

Name of the Technology	MILK COLLECTION CENTER (MILKSHED)

General description

Milk Collection Centers (MCC) has been introduced in various parts of the country to support the marketing of milk from small holders to consumers, the processors and retailers in the larger towns thereby create income to producers. MCC can be important links between the producers and the processing plants or the consumers. Milk collection is often one of the first activities of milk producer user groups, to collect milk from several group members in a central location, the milk can be processed or transported to processing centers or markets. The objective is to collect and retail adequate quantities of quality milk, and establish a viable and sustainable source of income that also helps to create a reliable market in and outside the pastoral community.

Fig 1. Typical MCC Borena area

Agroecology and Site Selection

MCC is applicable in all milk producing areas. MCC can be a constructed building or a shade. An open shade is often sufficient for collecting the milk, simple testing and transporting to the processing center.

A decision should be made on the number and sites of MCCs that are needed in the area covered by the user group. Many factors influence this decision:

- Estimated milk volume of each producer and total volume of milk,
- Time to transport the milk and distance from members settlement;
- Distance from the MCC to the processing center or market;
- Whether milk collection is once or twice per day.

Discuss with the user group members to decide on the best areas for the MCC. Consider the following points for selecting the ideal site for a MCC: Close to the road, and accessible for all milk transport vehicles; and easy to construct a building or a shade and the area should not be dusty and with poor drainage.

If the group plans to process the milk in the future, the group might select a site that can also be used as a site for a processing center. In this case it is essential that electricity is available.

Design and Method of Application

- Establish Milk producer user group in milk producing area identified. Consider settlement, interest and social interactions. Consult local cooperative experts during forming groups.
- Depending of the funds available, MCC can be a constructed building or a shade or rented house.
- An open shade is often sufficient for collecting the milk, simple testing and transporting to the processing center.
- If it is a constructed building, it will be best if the floor is a hard washable surface.
- If the user group plans to expand its activities in the future and wants to include milk processing, it is better to construct a building that can also be used for this purpose.
- The MCC should be well equipped with furniture, testing tools, measuring and preservation materials, etc.

Planning and Mobilization Requirements

- The commitment of key stakeholders (pastoral office, local administration, cooperative agency, credit providers, etc.) are crucial to ensure a sustainable and profitable MCC.
- For proper MCC, formation of a well-organized user group, training, livestock extension services, credit access, technical and management support are required by the local stakeholders.
- Direct advice and support is needed for the milk user group on feasibility study or livelihood business planning and on market information.
- Milk should be collected within four hours after milking.

Design and Method of Application

- Establish Milk producer user group in milh producing area identified. Consider settlement, interest and social interactions. Consult local cooperative experts during forming groups.
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- An open shade is often sufficient for collecting the milk, simple testing and transporting to the processing center.
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- If the user group plans to expand its activities in the future and wants to include milk processing, it is better to construct a building that can also be used for this purpose.
- The MCC should be well equipped with furniture, testing tools, measuring and preservation materials, etc.

Management and Maintenance Requirements

The first step in management of MCC is establishing a milk user group in milk producing community. Establish Milk producer user group based on their settlement, trust, and social and economic background. Use open and democratic methods based on cooperative principles and consider men and women.

Milk hygiene and milk quality: Good hygiene must be observed during milking and when handling the milk, at all stages of milk production, handling and sale. The hygienic practice must begin at the household level. Good hygiene will ensure low levels of spoilage bacteria. To ensure good quality, advising milk suppliers about milking of cows and prevention methods for milk spoilage are necessary.

Basic milk quality test: You can check whether the milk you collect from individual households is of good quality by carrying out one or more of the following four simple tests:

- **Sight-and-smell (organoleptic) test:** Basic assessment of smell, appearance and color.
- **Clot-on-boiling test: an assessment to check m**ilk freshness, kept uncooled longer, developed high acidity, or change in color. Such milk does will clot at heat treatment.
- **Alcohol test:** Used to check milk coagulation, with Equal amounts of milk and a 79 % alcohol solution.
- **Lactometer test:** The lactometer test is used to determine if the milk has been adulterated or diluted with added water or solids.

Keeping records of milk collected: Includes amount collected, milk composition and results of milk quality testing. Important for identifying quality and grading, setting a price, users reward mechanisms, etc.

Milk Transport and storage: Decide to keep the transport costs as low as possible, use the most appropriate way of transport.

- Group transport can be arranged for individual supplies of milk.
- Transporting milk in small containers is advantageous separate poor and good quality milk- not mixed.
- Milk transport to the collection center should always be as quick as possible to prevent spoilage of the milk.

To ensure hygienic milk storage, preservation and handling at processing and retailing stage, appropriate milk handling and storage equipment's at milk outlet and appropriate milk preservation methods are required. The following points must be followed:

- Suppliers should transport the milk quickly after milking (<4 hours), avoid any delays in milk collection,
- All containers and equipment's used should be clean and made of food-grade material like stainless steel or aluminum and are wide-opening vessels that are easy to clean, sterilize and disinfect.
- Storing area should be kept clean, pest-free, well ventilated with adequate lighting, and protected from dust, rain and direct sunlight, and avoid storing milk in the same room with other products (e.g. onions) or chemicals like paint.
- Store milk cooled in a metal containers to avoid milk spoiling (don't left at high temperatures for long periods and don't store in plastic jerry-cans).
- Milk may also be pasteurized to destroy spoilage bacteria but it must be quickly cooled thereafter in a cold water bath so that it remains fresh.
- All employees in the retail outlet must always maintain personal hygiene and wear clean protective clothing while handling milk and dairy products; milk handlers should undergo periodic medical check-ups and certified to be allowed to handle milk.
- For more information contact subject specialist in your area.

Benefits and Acceptability

- MCC generates income for the milk user group, creates job for unemployed youths and women, and ensures reliable market to the local community, and by far will develop growing dependence on market dynamics in pastoral societies, potentially triggering processes of sedentarization, and sustain local livelihoods.
- Milk payment systems follows screening to the visual method and can be priced according to: quantity, composition, hygiene, and a combination of these criteria's.
- For price decision, the user group should know all the cost expenses, i.e. milk transport, milk collection, milk testing, milk preservation, milk processing, etc.
- **Milk processing** (if applicable) the processors/user group can produce a wide range of dairy products, i.e. Pasteurized milk, Cream, Butter, Ghee, Fermented milk and Cheese, and generate more income from milk production if it is easier to access markets. Reasons for processing are:
- Processed products attract a higher price;
    - Increased keeping time of the product;
    - More distant markets can be accessed;

- Processed products are generally easier to transport (lighter/less bulky);
- Increased quality and hygienic safety;
- More flexibility in satisfying consumer demands, (make more or less liquid milk, more cheese, etc.);
- It creates employment.

- The user group can decide to market milk and milk products by themselves, but knowledge of the markets, collection of information and feasibility study are essential.
- Carry out a detailed market/feasibility study to decide type of dairy products the group is going to make for better income to the group.
- Don't decide to market a product that does not make any profit.
- Choose a product that seems to offer the most potential for meeting consumer demands. Consider the following steps for decision:
    - **STEP 1. Study the potential customers who buy the product:** Know the customers, and their interest, what (new) products do they need, their location, capacity to pay, time the product needed, their expectation, the expected changes in the market, etc.
    - **STEP 2. Study the competition:** Know who is competing with the group for the same customers, products do they sell and packaging hey use, product supply capacity and selling area, their customers and satisfaction with the products, selling price, expected change of products, conditions of payment and time they sell, etc.
    - **STEP 3. Determine what is required to make the product**: Consider all the costs involved, the labor and financial resources needed, materials and equipment, skills (training needed), time, buildings or land, transport, licenses, other support needed, etc. Make a list of all the requirements and make estimate all the costs involved.
    - **STEP 4. Analyze all the information:** Before making a decision, analyze the information collected in the above steps.
    - **STEP 5. Make a decision:** Discuss the risks involved with all members, and make sure you can make a profit on each product before decision.

Cost Elements and Work Norm	Constraints and Limitations
• Milk transport, collection, measurement and testing equipment; storage and preservation materials; • Buildings (constructed or rented) with furniture; water and electricity (optional); • Record keeping stationaries, etc. are the required cost elements. • In addition, management costs such as temporary and permanent skilled personnel payments, and other service costs are few of the cost elements.	• A possible group domination by only a few members and problems of participatory decision-making. • Animal health problems, poor hygiene and poor vet services; poor quality of feed and nutrition; the genetic verities that depend on local species and traditional management are some of the major constraint of dairy development that causes poor milk production. • Milk collection, processing, handling and marketing needs external technical support and supervision by subject matter professionals and may not be adequately performed by the user groups or by the support of Kebele level experts alone. • Frequent drought, water shortages, harsh climates (high temperatures for long periods), local skilled personnel requirements and unreliable market access are some of the major external challenges.

Feeder Roads

Overview

Ethiopia is a country of great geographical, climatic and cultural diversity. The country's diverse topography, high mountains to low-lying depressions, has the effect of causing a wide variation to the country's climate, livelihood and ease of accessibility. Ethiopia's high plateaus and mountain ranges are characterized by precipitous edges and dissection by numerous streams. Communities are often left isolated and without access, particularly during periods of rains. These areas are inhabited by higher population proportion, the majority engaged in small scale crop livestock mixed farming system. While the lowland areas, located in the north-west, east and south with vast majority of these areas support nomadic and semi-nomadic pastoralism. The descent to the southwest and west leads to the semi–humid lowlands.

The reason for wide spread poverty in the rural areas in the country is generally associated with low growth, low productivity of subsistence agriculture and a reliance on rain-fed cultivation vulnerable to the vagaries of weather conditions. Problems are aggravated by the country's minimum level of basic access roads, affected by rugged terrain, its uneven geographic distribution of population and the predominance of isolated rural settlements with poor spatial integration. Isolation and unreliable or non-existent access to markets stifles economic activity and further adds to the rural poverty burden. Without a minimum of reliable and efficient access to locations of basic social and economic activities, rural life as a whole stagnates, local development prospects remain limited and the whole economy suffers. Drought adds a significant risk and can threaten to take the lives of millions of rural people.

Providing and maintaining a minimum level of basic access is therefore an essential element of any rural and economic development strategy. Improved logistics to support trade and communication, the location of services, and the provision of cost-effective transport infrastructure and services are key.

Road network classification: The functional classification of roads in Ethiopia is based on five classes:

- **Link roads**: connecting centers of national and international importance such as principal towns and urban centers;
- **Main access**: connecting centers of provincial importance;
- **Collectors**: connecting locally important centers to each other or to a more important center or to a higher-class road; and
- **Feeder roads**: connecting minor centers such as a market to other parts of the network.

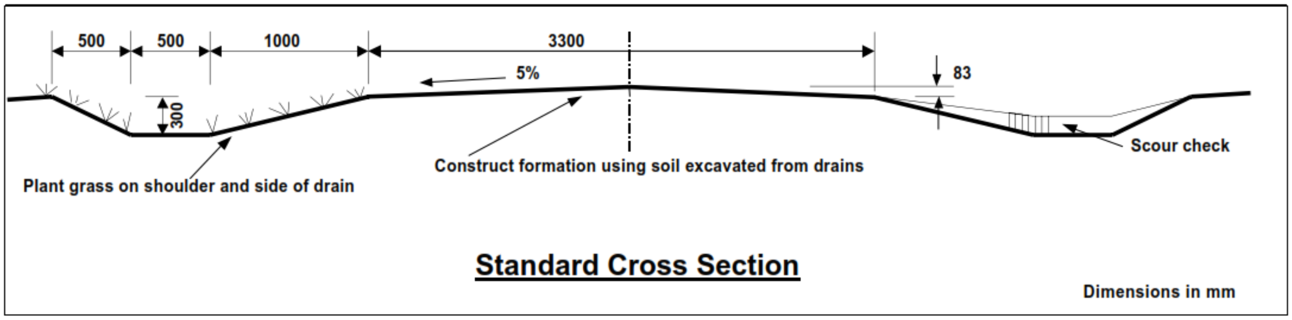
Roads in Ethiopia can be further divided into three categories depending on ownership and the authority responsible for them. These are: Federal (the responsibility of the Ethiopian Roads Authority) predominantly design class DC5 and above; Regional (the responsibility of the Regional or Rural Roads Authorities) for roads in design classes DC4 – DC1;.and Other rural roads (the responsibility of local authorities at Wereda or Kebele level or communities).

Basically, the Ministry of Agriculture is not tasked to construct roads, however based on the ownership and mandate for managing them districts (Wereda) and sub-districts (Kebele) are engaged in the construction of substantial networks of unpaved gravel and earth roads. As a grass root front line implementer, the Ministry of Agriculture through programs, projects, community programs, and cooperative ventures helps woredas and kebeles to construct feeder roads of low volume of design class (DC1), level of service D (Service level is geared to provision of access rather than efficiency) and average annual traffic <25. Hence the following info-tech as feeder road construction thematic area is included in this manual to be used as a short reference info-tech for woreda and kebele level experts.

1. R1 Earth road on flat and rolling terrain – stable soils
2. R2 Earth road on mountainous terrain–stable soils
3. R3 Graveled road on flat and rolling terrain – sandy or weak soils
4. R4 Graveled road on mountainous terrain – weak soils
5. R5 Graveled road on flat and rolling terrain– black cotton soils
6. R6 Road on escarpment

Community Road R1 Earth Road on Flat and Rolling Terrain – Stable Soils

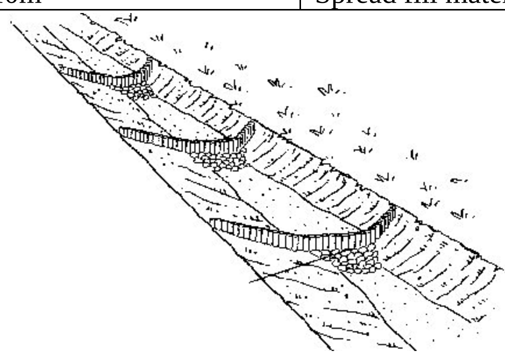
Description of the technology	This is the standard design recommended by ERA for community feeder road with design class 1 (DC1) on flat and rolling terrain (the natural ground slopes perpendicular to the ground contours are 0-25%) with stable soil

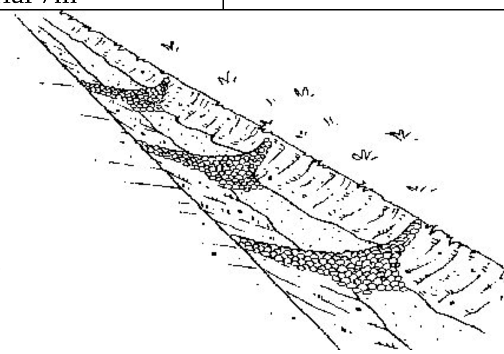


Recommended Standard Design		**Daily Work Norm**	
Minimum horizontal curve radius	50 m	**General norm 3000pd/km**	
Maximum gradient	7%	Clear grass & shrub (light) $150m^2$	Compact by hand $100m^3$
Maximum spacing of passing Bays (20m long x 5m wide)	500m	Clear grass & shrub (heavy) $50m^2$	Collect stone (near) $1m^3$

Scour Checks			
Gradient	Spacing	Excavation (soft soil) $3m^3$	Collect stones (far) $0.5m^3$
		Excavation (Hard soil) $2m^3$	Break rocks $0.5m^3$
3% - 5%	20m	Excavation (rock) $0.5m^3$	Score checks 2pd
5% - 7%	10m	Spread fill material $7m^3$	

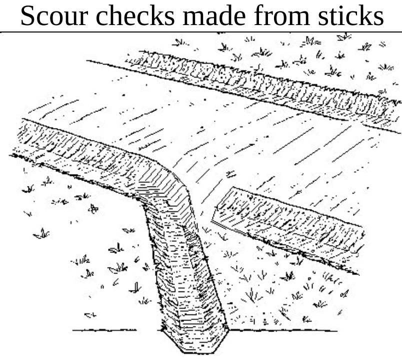
For Scour checks made from sticks use about 3cm diametre and 40cm long sticks and hammer stics into ground 25cm and provide aprone of stones or grass sodes. Dito for stone scour checks.

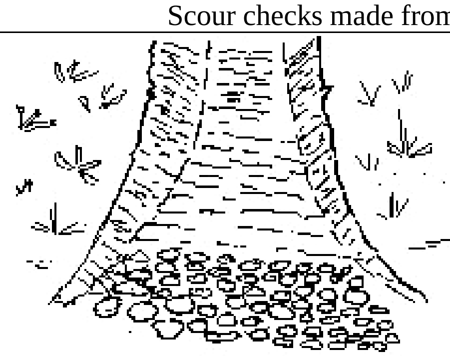

Scour checks made from sticks


Scour checks made from stones

Turnout Ditch

Gradient	spacing
<4%	100m
4%-6%	80m
6%-7%	60m



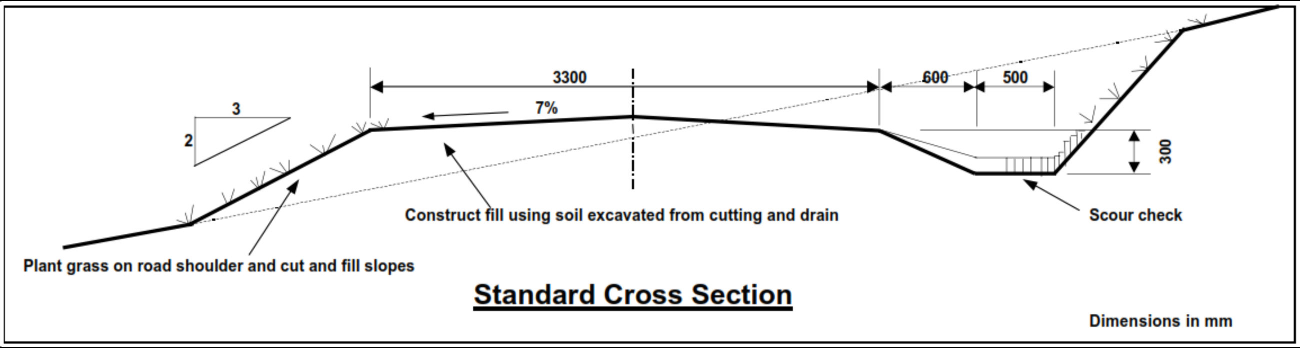


Turnout detail minimum 10 meters long and provide stones at the end of turnout to prevent scouring

Reference	ERA manuals for Low Volume Roads

Community Road R2 Earth Road on Mountainous Terrain – Stable Soils

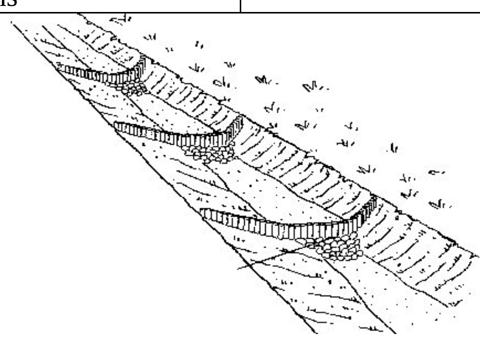
Description of the technology	This is the standard design recommended by ERA for community feeder road with design class 1 (DC1) on mountainous terrain (the natural ground slopes perpendicular to the ground contours are >25%) with stable soil

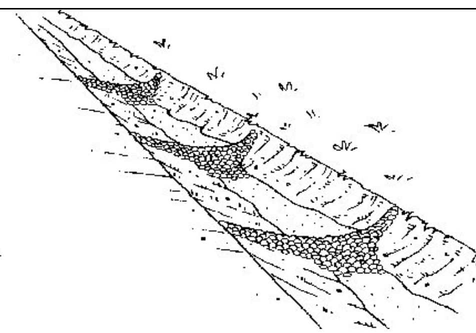


Recommended Standard Design		**Daily Work Norm**	
Minimum horizontal curve radius	30 m	**General norm 4000pd/km**	
Maximum gradient	14%	Clear grass & shrub (light) 150m²	Compact by hand 100m³
Maximum spacing of passing Bays (20m long x 5m wide)	200m	Clear grass & shrub (heavy) 50m²	Collect stone (near) 1m³

Scour Checks			
Gradient	Spacing	Excavation (soft soil) 3m³	Collect stones (far) 0.5m³
3% - 5%	20m	Excavation (Hard soil) 2m³	Break rocks 0.5m³
5% - 10%	10m	Excavation (rock) 0.5m³	Score checks 2pd
>10%	Lined drains	Spread fill material 7m³	

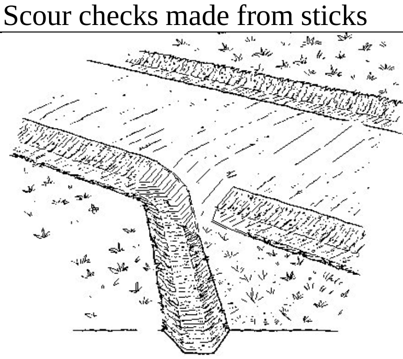
For Scour checks made from sticks use about 3cm diametre and 40cm long sticks and hammer stics into ground 25cm and provide aprone of stones or grass sodes. Dito for stone scour checks.

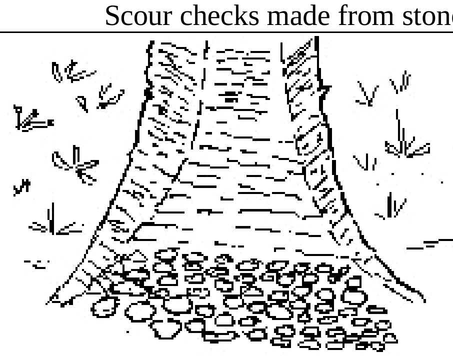

Scour checks made from sticks


Scour checks made from stones

Turnout Ditch

Gradient	spacing
<4%	100m
4%-6%	80m
6%-8%	60m
8%-14%	40m



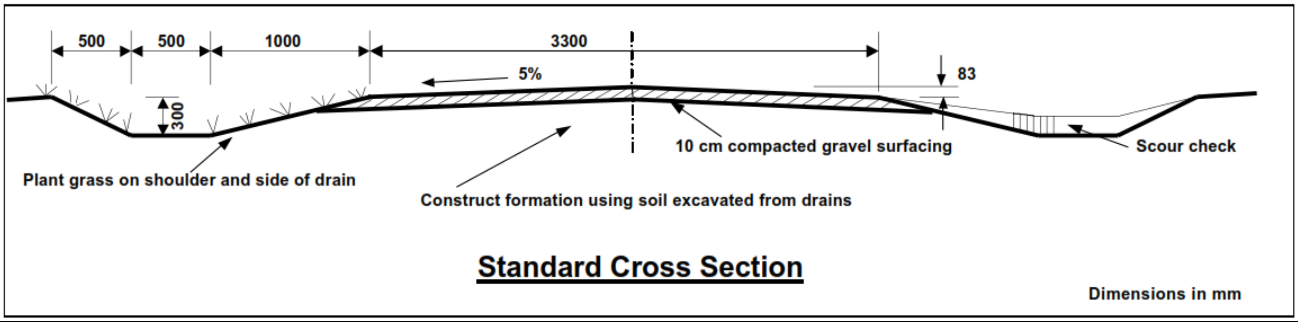


Turnout detail minimum 10 meters long and provide stones at the end of turnout to prevent scouring

Reference	ERA manuals for Low Volume Roads

Community Road: R3 Gravel Road on Flat & Rolling Terrain – Sandy/Weak Soils

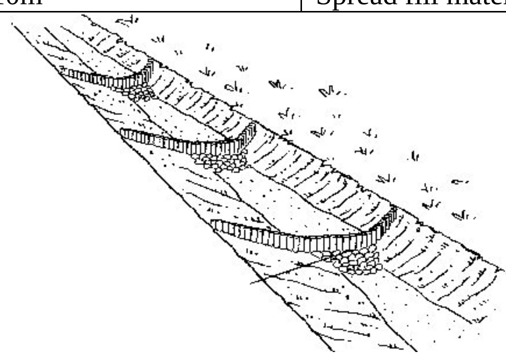
Description of the technology	This is the standard design recommended by ERA for community feeder road with design class 1 (DC1) on flat and rolling terrain (the natural ground slopes perpendicular to the ground contours are 0-25%) with sandy or weak soil



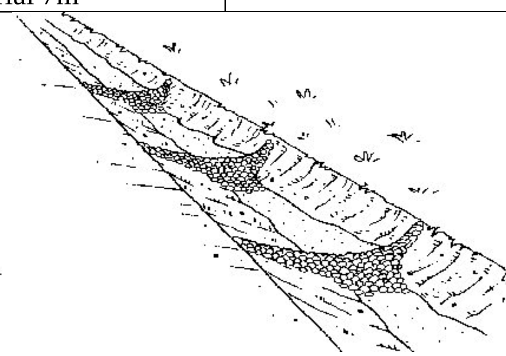
Recommended Standard Design		**Daily Work Norm**	
Minimum horizontal curve radius	50 m	**General norm 3000pd/km**	
Maximum gradient	7%	Clear grass & shrub (light) 150m^2	Compact by hand 100m^3
Maximum spacing of passing Bays (20m long x 5m wide)	500m	Clear grass & shrub (heavy) 50m^2	Collect stone (near) 1m^3

Scour Checks			
		Excavation (soft soil) 3m^3	Collect stones (far) 0.5m^3
Gradient	Spacing	Excavation (Hard soil) 2m^3	Break rocks 0.5m^3
3% - 5%	20m	Excavation (rock) 0.5m^3	Score checks 2pd
5% - 7%	10m	Spread fill material 7m^3	

For Scour checks made from sticks use about 3cm diametre and 40cm long sticks and hammer stics into ground 25cm and provide aprone of stones or grass sodes. Dito for stone scour checks.



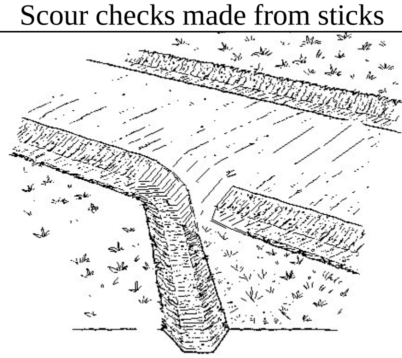
Scour checks made from sticks

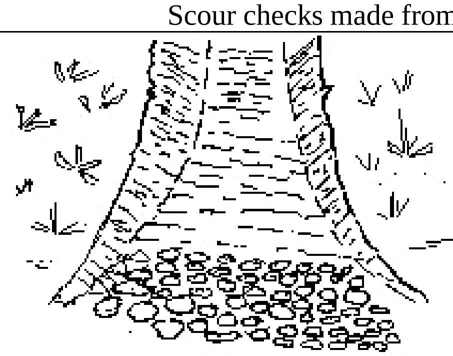


Scour checks made from stones

Turnout Ditch

Gradient	spacing
<4%	100m
4%-6%	80m
6%-7%	60m



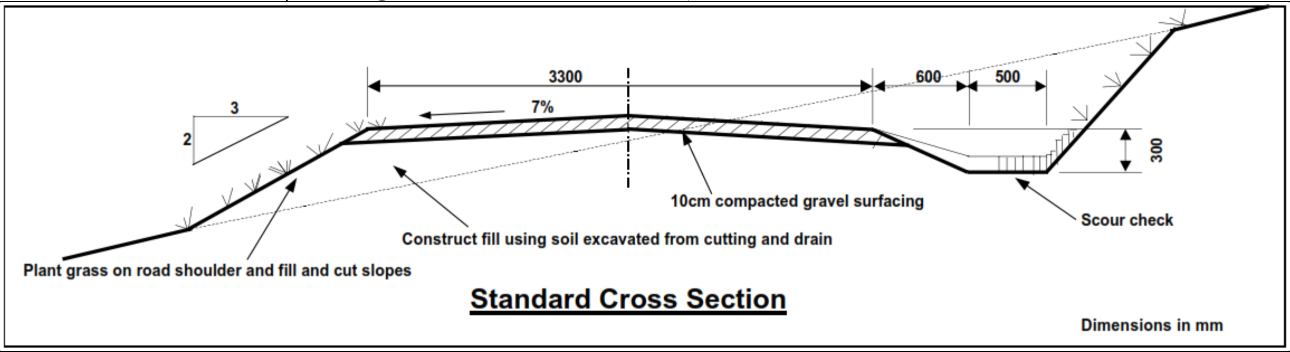


Turnout detail minimum 10 meters long and provide stones at the end of turnout to prevent scouring

Reference	ERA manuals for Low Volume Roads

Community Road: R4 Gravel Road on Mountainous Terrain – Weak Soils

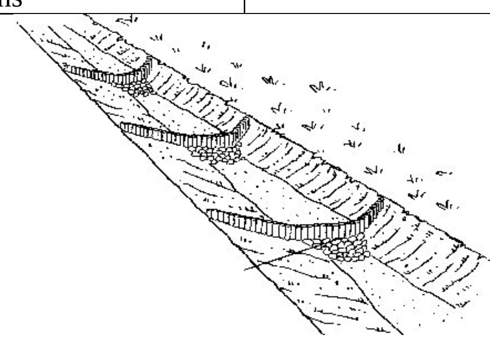
Description of the technology	This is the standard design recommended by ERA for community feeder road with design class 1 (DC1) on mountainous terrain (the natural ground slopes perpendicular to the ground contours are >25%) with weak soil



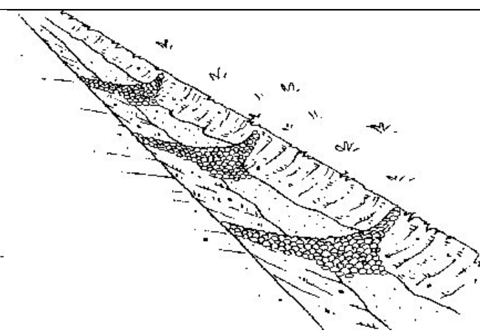
Recommended Standard Design		**Daily Work Norm**	
Minimum horizontal curve radius	30 m	**General norm 4000pd/km**	
Maximum gradient	14%	Clear grass & shrub (light) 150m^2	Compact by hand 100m^3
Maximum spacing of passing Bays (20m long x 5m wide)	200m	Clear grass & shrub (heavy) 50m^2	Collect stone (near) 1m^3

Scour Checks		Excavation (soft soil) 3m^3	Collect stones (far) 0.5m^3
Gradient	Spacing	Excavation (Hard soil) 2m^3	Break rocks 0.5m^3
3% - 5%	20m	Excavation (rock) 0.5m^3	Score checks 2pd
5% - 10%	10m	Spread fill material 7m^3	
>10%	Lined drains		

For Scour checks made from sticks use about 3cm diametre and 40cm long sticks and hammer stics into ground 25cm and provide aprone of stones or grass sodes. Dito for stone scour checks.



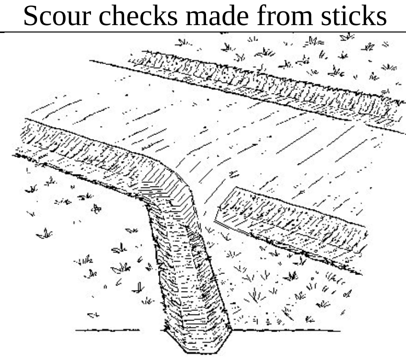
Scour checks made from sticks

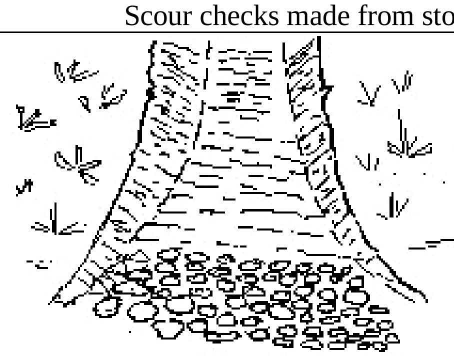


Scour checks made from stones

Turnout Ditch

Gradient	spacing
<4%	100m
4%-6%	80m
6%-8%	60m
8%-14%	40m



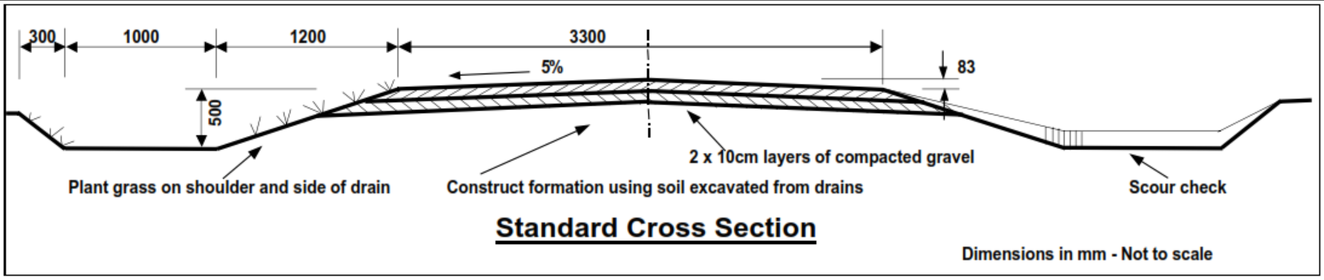


Turnout detail minimum 10 meters long and provide stones at the end of turnout to prevent scouring

Reference	ERA manuals for Low Volume Roads

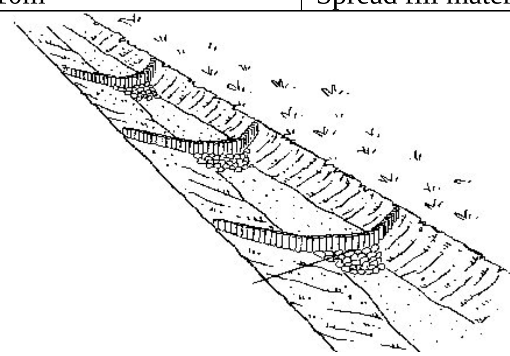
Community Road: R5 Gravel Road on Flat and Rolling Terrain – Black Cotton soils

Description of the technology	This is the standard design recommended by ERA for community feeder road with design class 1 (DC1) on flat and rolling terrain (the natural ground slopes perpendicular to the ground contours are 0-25%) with sandy or weak soil

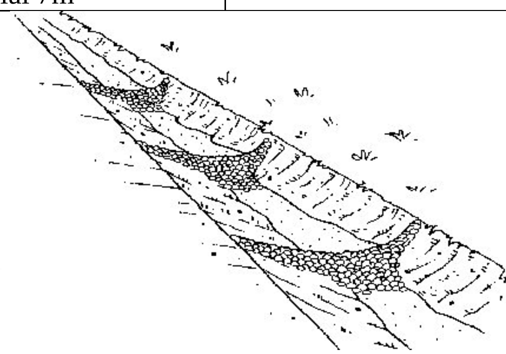


Recommended Standard Design			**Daily Work Norm**	
Minimum horizontal curve radius		50 m	**General norm 4500pd/km**	
Maximum gradient		7%	Clear grass & shrub (light) 150m^2	Compact by hand 100m^3
Maximum spacing of passing Bays (20m long x 5m wide)		500m	Clear grass & shrub (heavy) 50m^2	Collect stone (near) 1m^3
Scour Checks			Excavation (soft soil) 3m^3	Collect stones (far) 0.5m^3
Gradient	Spacing		Excavation (Hard soil) 2m^3	Break rocks 0.5m^3
3% - 5%	20m		Excavation (rock) 0.5m^3	Score checks 2pd
5% - 7%	10m		Spread fill material 7m^3	

For Scour checks made from sticks use about 3cm diametre and 40cm long sticks and hammer sticks into ground 25cm and provide aprone of stones or grass sodes. Dito for stone scour checks.



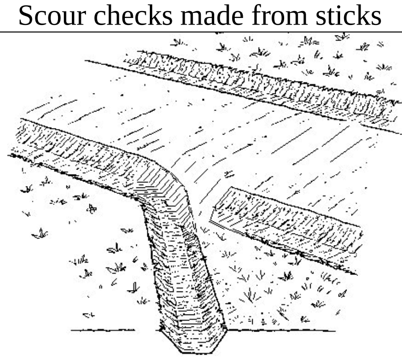
Scour checks made from sticks

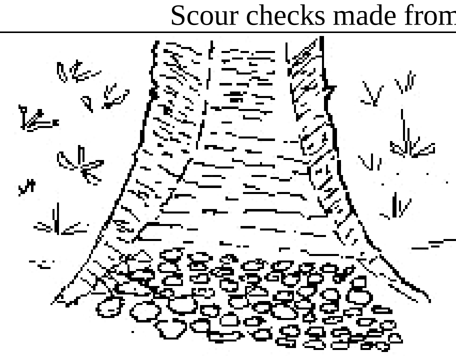


Scour checks made from stones

Turnout Ditch

Gradient	spacing
<4%	100m
4%-6%	80m
6%-7%	60m



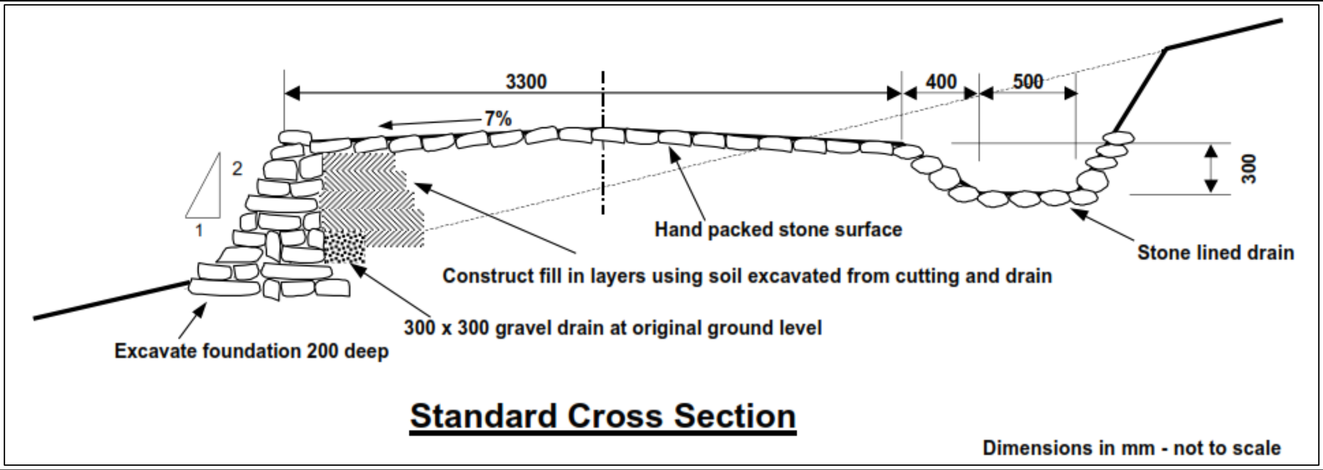


Turnout detail minimum 10 meters long and provide stones at the end of turnout to prevent scouring

Reference	ERA manuals for Low Volume Roads

Community Road R6 Road on Escarpment

Description of the technology	This is the standard design recommended by ERA for community feeder road with design class 1 (DC1) on escarpment.



Recommended Standard Design		**Daily Work Norm**	
Minimum horizontal curve radius	15 m	**General norm 6000pd/km**	
Maximum gradient	14%	Clear grass & shrub (light) 150m^2	Compact by hand 100m^3
Maximum spacing of passing Bays (20m long x 5m wide)	200m	Clear grass & shrub (heavy) 50m^2	Collect stone (near) 1m^3
Turnout Ditch or Culvert Spacing		Excavation (soft soil) 3m^3	Collect stones (far) 0.5m^3
Gradient	spacing	Excavation (Hard soil) 2m^3	Break rocks 0.5m^3
<4%	100m	Excavation (rock) 0.5m^3	Score checks 2pd
4%-6%	80m	Spread fill material 7m^3	
6%-8%	60m		
8%-14%	40m		
Reference	ERA manuals for Low Volume Roads		

References

Buzuayehu Tefera and Tariku Alemu. 2004. Physical Soil and Water Conservation Measures. Ministry of Agriculture and Rural Development - Managing Environmental Resources to Enable Transition to More Sustainable Livelihoods (MERET), Addis Ababa, Ethiopia.

Carucci, V. 2000. Guidelines on water harvesting and soil conservation for moisture deficit areas in Ethiopia: The productive use of water and soil. World Food Program (WFP), Addis Ababa, Ethiopia.

Critchley, W. and K. Siegert. 1991. Water harvesting. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.

Danano, D. 1996. Runoff management and erosion control measures in high rainfall areas. Ministry of Agriculture / World Food Program, Addis Ababa, Ethiopia.

ERA guidelines: http://www.fs.fed.us/eng/road_mgt/app2.shtml

Escobedo, J. 1988. Survey of soils for land classification. (ETH/85/016) MoA, Addis Ababa, Ethiopia.

Escobedo, J. 1988. Understanding soils in relation to SWC. (ETH/85/016), MoA, Addis Ababa, Ethiopia.

Escobedo, J. 1990. Land classification for use in SWC. (ETH/85/016) MoA, Addis Ababa, Ethiopia.

FAO (Food and Agriculture Organization of the United Nations) web: Dairy production system in Ethiopia.

FAO (Food and Agriculture Organization of the United Nations). 2004. Milk Producer Group Resource Book: A practical guide to assist milk producer groups. FAO, Rome

Francesco Sambalino and Ian Neal. 2016. Guided Learning on Roads Water Management, Meta Meta Research, Mekelle university, Mekele.

GIZ (Deutsche Gesellschaft fur Internationale Zusammenarbeit). 2011. Water Spreading Weirs (WSW) for the development of degraded dry river valleys. Bonn and Eschborn, Germany.

GIZ (Deutsche Gesellschaft fur Internationale Zusammenarbeit). 2014. Energising Development (EnDev) Ethiopia: Improved Cook Stoves (ICS), GIZ Energy Coordination Office (GIZ ECO), Gurd Sholla, Addis Ababa, available at http://endev.info/ethiopia

GIZ (Deutsche Gesellschaft fur Internationale Zusammenarbeit). 2011. Institutional Rocket Stove (IRS) Production manual. GIZ-ECO (Ethiopia), Production manual https://energypedia.info/index.php/File:Giz_ CIRS_Manual_eng.pdf; User guideline https://energypedia.info/index.php/File:IRS_ user_guide_english.pdf)

Habtamu, G. and Nega, H. 2005. Managing Land - Managing Water: a practical guideline for development agents in Ethiopia. Technical hand book No. 36. Nairobi: Regional Land Management Unit (RELMA in ICRAF).

Hudson, N. 1985. Soil Conservation. Batsford, UK.

Hune N. 2006. Rainwater Harvesting and Utilization techniques. Addis Ababa, Ethiopia.

Hurni H., Berhe WA., Chadhokar P., Daniel D., Gete Z., Grunder M., Kassaye G. 2016. Soil and Water Conservation in Ethiopia: Guidelines for Development Agents. Second revised edition. Bern, Switzerland: Centre for Development and Environment (CDE), University of Bern, with Bern Open Publishing (BOP). 134 pp.

John, B.C. 1984. Design and construction of hillside drains. (ETH/81/003) MoA, Addis Ababa, Ethiopia.

John, B.C. 1984. Design and construction of soil retention bunds. (ETH/81/003) MoA, Addis Ababa, Ethiopia.

John, B.C. 1984. Design and construction of stone and stone-faced bunds. (ETH/81/003) Ministry of Agriculture, Addis Ababa, Ethiopia.

Lakew Desta and Belayneh Adugna. 2012. Field Guide on Gully Prevention and Control. Nile Basin Initiative (NBI), Eastern Nile Technical Regional Office (ENTRO), Addis Ababa, Ethiopia.

Loïc Rakotojaona. 2013. Domestic Biogas Development in Developing Countries: A methodological guide for domestic biogas project holders in the early stages of setting up projects in developing countries, ENEA Consulting July 2013, Paris

Mercy Corps. 2010. Basic guide to fuel efficient stoves and emission testing, USA.

MoA (Ministry of Agriculture). 1986. Guidelines for Development Agents on Soil and Water Conservation and Community Forestry. MoA, Addis Ababa, Ethiopia.

MoANR (Ministry of Agriculture and Natural Resources). 2011. Training Materials for PSNP's Public Works (Training of Trainers for Community Training). Volume II: Technologies. SuDCA Development Consultants (SuDCA), Addis Ababa.

MoANR (Ministry of Agriculture and Natural Resources). 2018. Guideline for manual tube well drilling and installation for household irrigation in Ethiopia: A practical guideline for woreda experts and development agents in Ethiopia, second edition. Addis Ababa, Ethiopia.

Pacy, A. and Cullis, A. 1983. Rainwater harvesting. Collection of Rainwater and runoff in rural areas. Intermediate Technology publication, London

PRACTICA Foundation. 2006. Rope Pump Manual, Ethiopia: Hand dug well & Borehole model, Draft Final. Published by the PRACTICA Foundation, The Netherlands.

Regional Land Management Unit (RELMA). 2005. Water from ponds, pans and dams: A manual on planning, design, construction and maintenance, Technical hand book No. 32, Nairobi, Kenya

Seleshi Bekele Awulachew (IWMI), Philippe Lemperiere (IWMI), Taffa Tulu (Adama University), (not dated). Pumps for small-scale irrigation.

SNV Ethiopia (Netherlands Development Organization - Ethiopia). 2015. Implementation guide for improved stoves and biogas digesters integrated with PSNP. Climate Smart Initiative phase two (CSI II), Addis Ababa, Ethiopia.

Surash R. 2002. Soil and Water conservation Engineering. Bhargave printer, Delhi.

Tekalign Mamo, Abiye Astatke, K. L. Srivastava and Asgelil Dibabe (eds). 1993. Improved management of Vertisols for sustainable crop–livestock production in the Ethiopian highlands: Synthesis report 1986–92. Technical Committee of the Joint Vertisol Project, Addis Ababa, Ethiopia.

Thomas, D.B. 1999. Where there is no water: A story of community water development and sand dams in Kitui District Kenya. SASOL and Ufanisi, Nairobi.

USAID (United State Agency for International Development). 2010. Fuel-Efficient Stove Programs in Humanitarian Settings: An Implementer's Toolkit, prepared by Academy for Educational Development (AED) in collaboration with USAID

Volli Carucci. 2000. Guidelines on Rainwater harvesting and Soil Conservation for Moisture Deficit Areas in Ethiopia. WFP, Addis Ababa.

Wageningen UR Livestock Research. 2010. Performance of milk collection centres in Ethiopia: Assessment of the operation of milk collection centers in the central highlands of Ethiopia (Akaki, Asela, Chancho and Holeta). Wageningen - The Netherlands. Internet http://www.livestockresearch.wur.nl Reference: ISSN 1570 – 8616.

Wageningen UR Livestock Research. 2013. The Major Ethiopian Milksheds: An assessment of development potential. Wageningen - The Netherlands.

WLRC (Water and Land Resource Center). 2015. Energy Saving Stoves. Brief No. 5 June 2015; Design & Print by: Amlion Printing and Advertising: www.amlionads.com

ANNEXES FOR INFOTECHS

ANNEX 1: Estimation of Catchment Runoff

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

To start designing channels, ditches and other soil and water conservation structures to manage surface runoff one needs to know the probable quantity of discharge. If the objective is to impound or store the runoff then it may be sufficient to know the total volume of water to be expected, but the usual conservation problem is that of conveying water from one place to another, and in that case the rate of runoff is more important, particularly the maximum rate at which is likely to occur. This is the flow which a channel must be designed to accommodate.

In order, therefore, to design appropriate drainage structures such as diversion ditches, waterways or graded bunds, it is important to be able to make an estimate of runoff. The two most commonly used and relatively simple methods for this are the Rational formula and Cook's method. They are both applicable but will not give exactly the same result; they can both be used and the results compared to check the reliability of the estimate.

1.1 Rational Formula for Estimating Runoff Rate

Rational method is the oldest and the most famous hydrological model of predicting peak rate of runoff and expressed as follows:

$$Q = CIA/360$$

Where:

Q = runoff rate (m^3/s)
C = Runoff coefficient (between 0 and 1)
I = Rainfall intensity (mm/hr) = Rainfall amount over time taken.
A = Area of the catchment in ha

To use the Rational formula appropriately and meaningfully the following points need to be noted:

Runoff Coefficient: This is a proportion of total rainfall that is expected to become runoff during the design storm (**Runoff = Rainfall – Infiltration)**. It can be readily determined by referring to the watershed surveying results (Table 1.1 below). The assumption is made that the ground is already soaked and therefore the rate of infiltration is determined by the permeability of the soil, the surface roughness (whether there are furrows or depressions which can hold rain in-situ) and the ground cover, if any, which may impede the flow of water and increase the time of infiltration. A dense cover of fodder grass on a deep red soil may have zero runoff whereas a denuded grazing land may have a runoff coefficient of 0.75 or more. A tarmac road or parking area will have a runoff coefficient of just very closer to 1.0.

Table 1.1: Runoff coefficient values for use with the Rational formula

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

Source: *Adapted from Hudson (1995)*

Box 1.1: Find the runoff rate using the rational method for a runoff producing area of 80 ha of cultivated land having clay soil on a land slope of 8%. Assume a rainfall intensity of 30 mm/hr (using intensity curves prepared for the area under discussion).
Given: C from table 1above for clay soil and slope of 8% is = 0.6, I is = 30 mm/hr
Solution: Q = CIA/360 = (0.6 x 30 x 80)/360 = 4 m^3/s

To establish the C value of an area, it is necessary to properly explore and analyze the topography, vegetation cover and soil type. If the watershed is composed of various soil types under various land uses, it is necessary to estimate weighted C for computing runoff from the entire watershed. The weighted runoff coefficient (C_w) for a watershed can be calculated using the relation indicated below:

$$Cw = \frac{A1C1 + A2C2 + A3C3 + \cdots}{A}$$

Where: A_1, A_2, A_3, etc. = areas in ha under various land uses and soil types
C_1, C_2, C_3, etc. = corresponding values of runoff coefficient for A_1, A_2, A_3, etc.
A = Total area of watershed, ha

Rainfall Intensity and Time of Concentration:

The value of rainfall intensity in millimeters per hour for use in the Rational formula is the highest that can be expected in a 10 year return period for a time equal to the time of concentration of runoff at the outlet of the catchment. This is known as the d*esign storm*. The time of concentration is an important concept used in the rational formula in determining peak discharge (m^3/s) for designing diversion ditches/cutoff drains, waterways, etc. The time of concentration, or gathering time, is the longest time needed for surface water to flow from any point in the catchment to the outlet. This will usually be the time it takes to flow from the most distant part. In certain circumstances, however, it may take longer for the water to flow from a point nearer the outlet. This happens especially when the natural drainage system is less well developed or where there are various barriers in that section of the catchment.

The rationale behind the time of concentration is that it coincides with a storm condition in which all parts of the catchment are contributing simultaneously to discharge at the outlet. Maximum discharge will occur when the whole catchment is yielding runoff. For this to happen there must be a storm covering the entire catchment, the ground must be wet and all the minor depressions must be filled. Peak discharge is unlikely to occur at the beginning of the rainy season when the ground is dry and absorbent of rainfall but will occur after some days or weeks of continuous rainfall when the ground has become saturated.

The time of concentration is dependent on various factors such as the size of the catchment, the shape of the catchment, the topography or steepness of the catchment, the density of the drainage network and the ground cover. A short square watershed has a shorter gathering time than a longer narrow one. Because of the many variables contributing to the determination of the time of concentration, it is not easy to arrive at a precise figure. Estimates can, however, be made of the time of concentration for small catchments and approximate values are shown in Table 2 below.

Table 1.2: Time of concentration for small catchments

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

Another method for estimating the time of concentration is through the use of the Kirpich formula. This simply requires estimates of the maximum length of flow and the average slope of the ground: $\mathbf{Tc = 0.0195\ L^{0.77}\ Sg^{-0.385}}$

Where: Tc = time of concentration (min)

L = maximum length of flow (m)

S = average gradient (m/m)

Once the time of concentration has been determined, the rainfall intensity can be selected from a typical rainfall intensity duration curve for a 10 years' frequency (for SWC structures) provided there's such a curve has been developed for the particular area in question.

Area: The area of a catchment for which the rational formula is to be applied can be easily estimated by applying various methods such as measuring it on a topo map, on satellite imagery or through a GPS measurement.

1.2 Cook's Method for Estimating Runoff Rate

This method was developed by the United States Conservation Service and adapted for African conditions by Prof. Norman Hudson. The method is based on actual measurements of rainfall intensity and runoff rates from small catchments. It only requires that only the following three factors be determined; the catchment area, its shape and its characteristics. The shape is relevant because a short wide catchment will generally produce a higher peak runoff than a long narrow catchment of the same size. The catchment characteristics are based on observations of the vegetative cover, the soil type and the slope. A value is attached to each of these components as shown in Table 1.3. The sum of the three figures gives the total catchment characteristic. This method is simple to apply, but depends on the existence of data recorded from experimental watersheds.

Table 1.3: Catchment characteristics used for determination of runoff rate by Cook's method:

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

Source: Adapted from Hudson (1981)

Box 1.2: *Find the summarized characteristics for a land with the following surface conditions: The land is cultivated, having a loam soil on a 20% slope*

Solution: *For the cultivated land the value under the column vegetation, for the cultivated land is 20, from the second column of soil conditions you have the value of 25 for loam soils and from the third column of topography you have the value of 15 for a 20% slope .Thus the summarized catchment characteristics (CC) = 20 +25 +15 = 60*

Table 1.4 provides runoff rates for catchments of different sizes and characteristics. A simple approach to the use of this table is to assume that the basic data represent a catchment that is roughly square or round. Where possible however, the shape of the catchment should be taken into account as this affects the time of concentration and hence the design intensity and ultimately the peak runoff. In the case, therefore, of long narrow catchments the runoff values obtained from Table 1.4 should be multiplied by 0.8 and in the case of broad short ones, by 1.25. Where catchments are known to experience less intense rainfall, the values in Table 1.4 should be multiplied by 0.75.

Table 1.4: Runoff rates (m3/s) determined for small catchments by Cook's method

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

Box 1.3: *Find the runoff to be produced from a catchment with a square runoff area of 20 ha with the summarized characteristics calculated in box 2.*

Solution*:* *Use table 1.4 to read the runoff in m3/s.*
Runoff area = 20 ha, summarized characteristics from the preceding exercise is 60. Then from Table 1.4 read the value of 3.8, corresponding to the value of 20 for area and the value of 60 for summarized characteristics. Then, runoff (Q) of the given catchment can be reported as 3.8 m3/s. If the value of the CC is between the figures indicated in Table 1.4, do interpolation.

ANNEX 2: Surveying and Layout of Soil and Water Conservation Structures

2.1 Marking Contour Lines

Contour lines are horizontal lines across a slope, joining points of the same elevation. It is important to mark contour lines as precisely as possible when building soil and water conservation structures such as level bunds, moisture harvesting structures, and bench terraces that protect the soil from erosion. There are three simple ways to do this:

- **a)** The Line Level;
- **b)** The A-Frame Method; and
- **c)** The Water Tube Level.

a. The Line Level

This employs the same principles as the most modern levels and has the advantages that it is cheap to make, its use is easily learned, and it is a convenient tool for anyone, but especially by farmers, who wish to carry out their own leveling. A line level consists of two wooden posts of the same length (usually 2 m) and a plastic string about 11 m long of which 1 m is used to attach it securely to the poles leaving 10 m between the poles. The poles should be graduated and have marks made on them every 10 cm, or even better, every 5 cm. A spirit level is tied exactly in the middle of the string. Sticks or pegs are needed to mark the contours on the ground, and a stone or hammer is needed to drive the pegs into the ground. Three or four people are required to mark contours using a line level: two to hold poles at either end of the 10m string and maintain its tension; one person reads the line level and guides the movable wing person up and down the slope until the bubble in the level is cantered indicating that the line is level. The fourth person supports the survey team by making points with pegs. The

- **Marking contour lines with a line level**

1. Always start laying out contours at the top of the slope (not the middle or bottom), or immediately below the cutoff drain (if you have dug one). Drive a peg into the ground where you want the first contour to begin.
2. One person holds the first pole upright at this first peg. The other person walks roughly level with the other pole until the string is tight. The third person checks the spirit level in the middle of the string and directs the second person to move the pole up or down the slope until the bubble in the level is centered indicating that the line is also level (See Figure 2.1). A peg must then be driven into the ground at the exact spot where the second pole was located. It is essential of course to assure that the pole is absolutely vertical (i.e. at 90°to the string)
3. The two people holding the poles then both move forward until the first pole is at the location of the second peg. Keeping the string tight, the second person again moves his or her pole up or down the slope until the line is again level. Drive a third peg into the ground here. Repeat the process until the whole contour line is marked out.
4. To start a second contour line further down the slope, find a starting point by measuring the vertical interval you want. Then repeat the process for the new contour line.

In difficult topography, where there are barriers such as gullies, boulders, etc., it might be inconvenient to measure 10 m at a time. In that case, it is possible to reduce the length of the string.

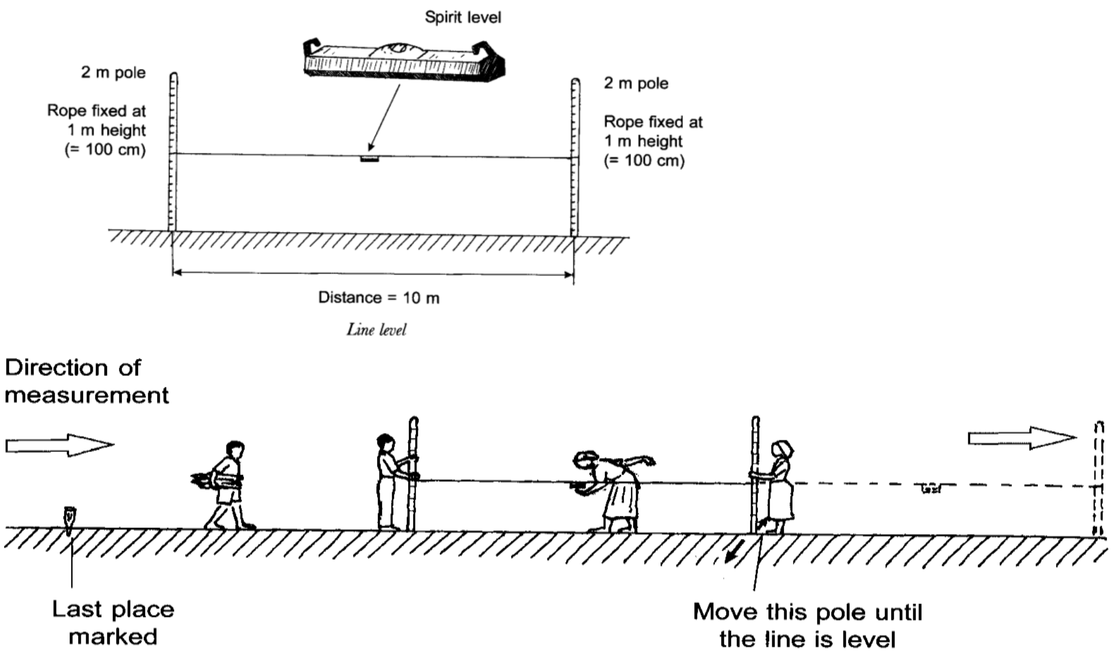


Figure 2.1: Marking contour lines with a line level

b. A-Frame

This can readily be made from local materials and consists of three poles fixed together to form a letter A. It requires: 3 wooden poles two of which should be 3 m long and have flattened ends and one of about 2 m length to use as a crosspiece; approximately 2 m of strong string is required to which a stone should be attached to act as a weight (plumb line); and tools - a hammer, nails and a knife.

- **Marking contour lines using an A-frame** (See Figure 2.2)
    1. Tie the two 3 m poles together at the top, as shown, then attach the 2 m pole horizontally about 1 m from the bottom to form an A. If possible, use nails rather than string to attach the poles as this makes a more rigid A-frame which is less prone to errors.
    2. Tie the stone to one end of the string and hang it from the top of the *A*. The stone should hang freely about 15 cm below the crossbar.
    3. Stand the A-frame on a level piece of ground. Mark the ground where the two legs stand. Make a small, temporary mark on the crossbar where the string crosses it.
    4. Turn the A-frame round (180 degree) so that each leg stands exactly where the other had stood. Make a second temporary mark on the crossbar where the string hangs past it.
    5. The two marks on the cross bar should be fairly close together. The point halfway between them indicates where the string would cross if the A-frame was standing on absolutely level ground. This point, midway between the two temporary marks, should be marked with a heavy final mark or notched with a knife. If the string hangs against this mark, the 2 feet of the A-frame are exactly level.

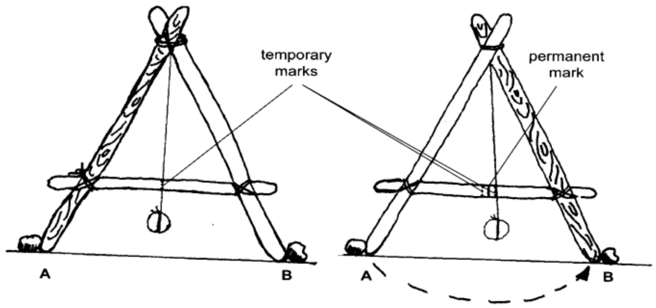


Figure 2.2: Calibrating an A-frame

Once completed, the A-frame can be used for marking contours. It is best, however, to only use the A-frame when calm conditions prevail, since the wind disturbs the string and can result in erroneous measurements.

Procedures to be followed during contouring (See Figure 2.3)**:**

1. Use a peg to mark the starting point and place one of the feet of the A-frame next to it. (Do not put the A-frame feet in holes, depressions, or on stones, ridges, humps or anthills).
2. Holding this leg in place, swing the second leg up or down the slope until the string hangs precisely over the heavy mark on the crossbar. Insert a peg into the ground here to mark it.
3. Keeping the second leg in place lift the first leg and pivot it around. Move it up and down the slope until you find a place where the string crosses the crossbar at the heavy mark. Drive another peg into the soil at this point too.
4. Continue pivoting along the contour, marking each pivot point, until the end of the field is reached.
5. Then move down the slope to where the next contour line should begin, and repeat steps 1 to 4
6. Once the contour lines have been established it is possible to dig ditches, construct terraces or plant trees along these lines using the pegs or stones as a guide

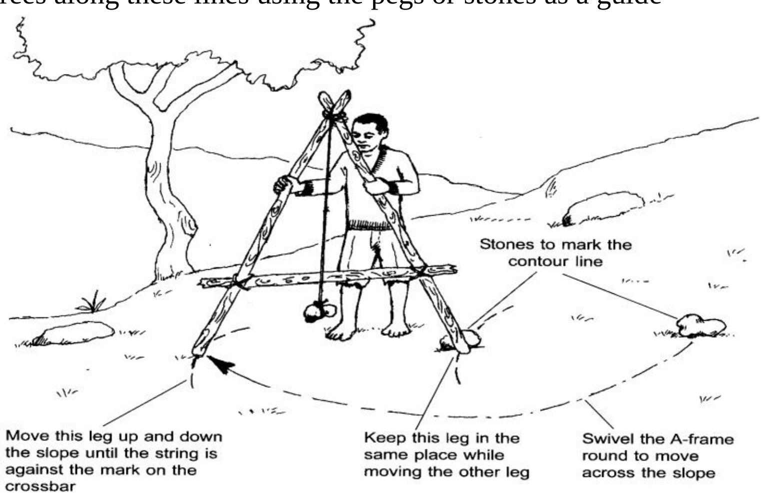


Figure 2.3: One person making contour lines using an A-frame

c. The Water Tube Level for Surveying

A very accurate and simple instrument for measuring the level differences of two points is the "tube water level". This is straightforward to use, and farmers can quickly be taught to layout contours using it. The concept itself – of matching up levels of water – is especially easy to understand. The advantages of the water tube level are that it can be operated by only two people and is more sensitive than the line level on very low slopes. It is, however, slightly less portable than the line level, and is not so simple to use for determining slopes or laying out graded contours.

The components of the water tube level consist of:

- A length of transparent plastic tubing, 6-10mm inside diameter and about 14m long.
- Two poles each about 2 m long.
- Four rubber straps (easily made from a bicycle inner tube) to attach the plastic tubing to the poles - one to two liters of water. Muddy or dyed water is preferable as it is more easily visible in the tube.

The plastic tubing is firmly attached to the poles using the rubber straps, or other securing devices. The ends of the tube should be about 10 cm from the top of each staff and the bottom fixing point about 20 cm from the bottom of each pole. The tube is then filled with muddy or dyed water until the water level is about halfway up each staff. It is essential that no air bubbles are trapped in the tube and, if necessary, they can be removed by tapping with the finger, wherever the two poles are set, the free water surfaces in each tube will now be at the same level.

- **Laying out a contour using a water tube level** (See Figure 2.4)

1. The two poles are placed back to back at the starting point, marked with a peg (**A**). After any air bubbles have been removed and the water has come to rest, a mark is made on both poles, indicating the exact water level in each tube.

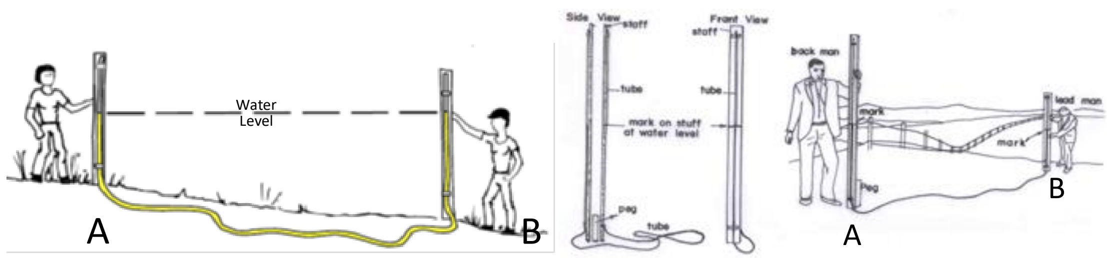


Figure 2.4: Establishing a contour line using a water-tube-level

2. The lead person then takes one pole and drags the tube in the general direction of the proposed contour line. When the tube is almost stretched out, the lead person moves slowly up and down the slope until his pole is situated in a position where the water level in the tube coincides with the mark. The staff is then at a position at which the ground level is the same as at peg **A**. A second peg (**B**) is placed at this point. The back man now moves from peg **A** to the other side of peg **B** where the lead man remains stationary. It is now the back man's turn to find the correct spot which is marked by peg **C**. This procedure continues until the end of the field is reached.
3. To start a second contour the operator's then measure, or pace, the horizontal distance required between the contours and once again follow the process described above.
4. The contour may then be "smoothed" by eye, according to the design specifications.

❖ **Important Points to Remember**

- Work should be carried out during the coolest time of the day because heat causes the plastic tube to stretch and this affects the water levels, which may have to be re-marked.

➢ It is important to avoid spillage of water. If this does happen the water levels will have to be marked once again on the tubes. Water is usually spilled during movement of the poles which can be avoided by closing the ends of the tube with plugs during movement. It is, however, essential to remove the plugs while making measurements.
➢ The poles should always be held vertically.
➢ Minor depressions or isolated high spots in the field should be avoided.

2.2 Marking Graded Lines

Graded lines are lines of constant gradient (usually 0.25 to 2%), across a slope. They are used to plan conservation structures, such as cutoff drains and graded terraces which require a gentle slope that allows water to drain away safely. Graded lines can be marked out using a line level or an A-frame.

Preparing a line level to mark graded lines (see Figure 2.5)

The line level described previously for marking contours can also be used, but in this application the string should be fixed differently. The decision must first be made on the required gradient. For a 1% gradient, for instance, the height difference over 10 m (which is almost a standard) equals 10 cm. Tie the string on one pole at a height of 110 cm (1.1 m), whereas, on the other pole, tie it at 100 cm (1 m). When the bubble is at the center of the spirit level, the string will be level, but the bottom of the second pole will be 10 cm higher than the bottom of the first pole.

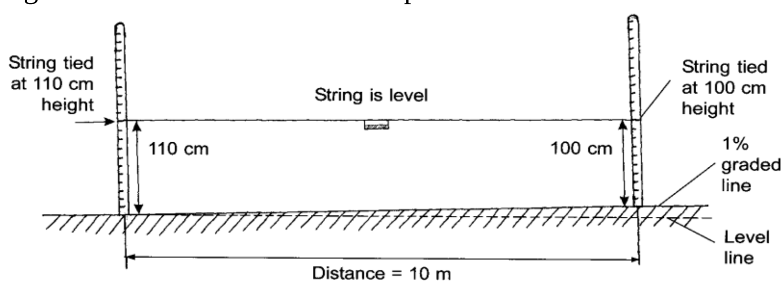


Figure 2.5: A 1% grade line

- ✓ For a 2% gradient, tie the string at 120 cm (= 1.2 m) on one pole, and the other end at 100 cm.
- ✓ For a 0.5% gradient, tie the string at 105 cm on one pole, and 100 cm on the other one.
- ✓ Make sure that the pole having the higher reading is always located towards the drainage way.

Procedures (See Figure 2.6)**:**

1. Always start marking graded lines at their lower end: for example, where you want a graded drainage line to meet a natural stream. Mark this place with a peg, and stand the pole with the string tied to it higher up (e. g, at 110 cm).
2. Move the other pole (tied at 100 cm height) roughly level and slightly upslope until it is 10 m away and the string is tight.
3. Check whether the bubble is in the center of the spirit level. Move the second pole up or down the slope until the bubble shows the string is exactly level. Mark this point with another peg.
4. Move both poles forward placing the first pole is at the second peg and the string between the two poles is once again taught. This second pole should then be moved up or down the slope until the string is level again (See Figure 2.6 – Step 2). Mark this point with a third peg. Repeat this process across the field until the whole graded line has been marked off.
5. Always start lining out at waterway or river and proceed slightly upslope.

6. Always use the pole on which the rope has been attached higher up, nearer to the waterway, and the pole with the rope attached lower down (e.g. at 100 cm if the 1% gradient is to be achieved) farther away, as shown in the figures below.
7. To start a second graded line, find a starting point by measuring the desired vertical interval and then repeat the process for the new line.

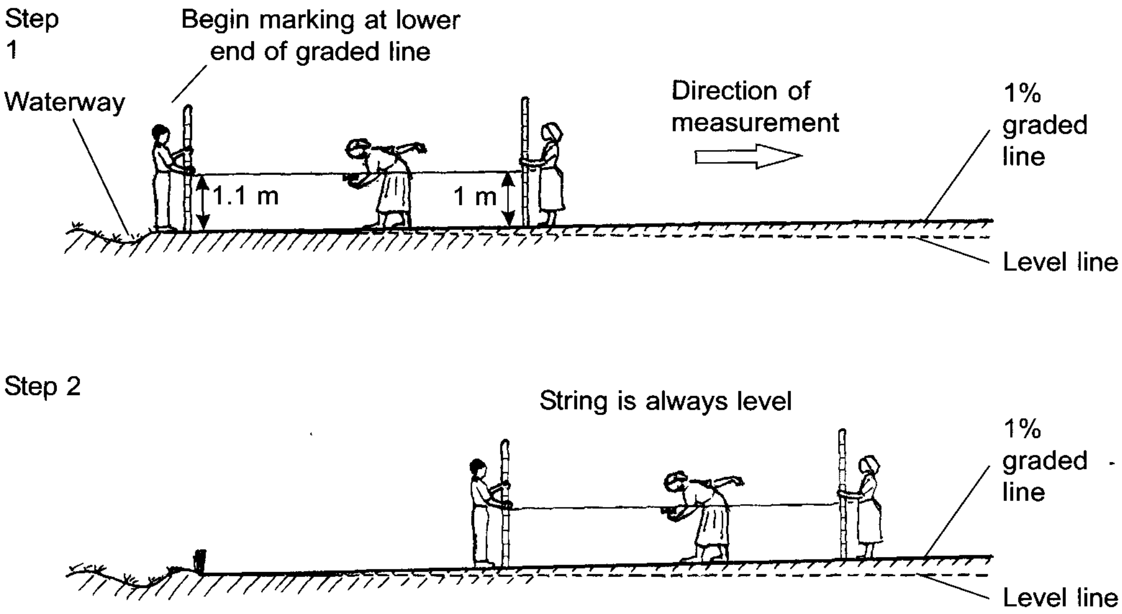


Figure 2.6: Marking 1% graded line using a line level

Preparing an A-frame to mark graded lines

To use an A-frame to mark graded lines, it is necessary to mark on the crossbar the point at which the vertical string touches the crossbar when the A-frame stands on a slope of the desired gradient (1%, 2% and so on). To achieve this do the following:

a. On a strong and completely straight plank of wood at least 2 m long mark a point exactly 2 m from one end.
b. Cut several small blocks of wood to different lengths: 1 cm, 2 cm, 4 cm, 6 cm, and so on to use for calibrating the gradient on the A-frame (See Figure 2.7).

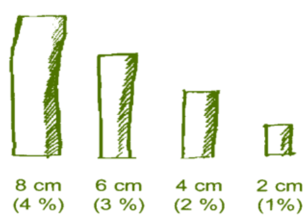


Figure 2.7: Blocks of wood used to calibrate the A-Frame at various slope

c. Put the plank on a level ground using the A-frame to check that it is level.
d. Put the small 2-cm block under the plank exactly at the 2m mark (The plank will now have a gradient of 1%, since 2 cm is 1% of 2m).

e. Place the A-frame on the plank (See Figure 2.8), being careful not to move the plank or the small block under it. Mark the point on the crossbar at which the string touches it and write a ‘1’ next to the mark.
f. Turn the A-frame around and again mark the point on the crossbar where the string touches it. Write a ‘1’ here as well.
g. To mark a 2% gradient, replace the small 2-cm block with the 4-cm block. Repeat procedures above, marking the points where the string touches the crossbar with a ‘2’
h. To mark a 0.5% gradient, a 1-cm block would be used and for a 3% gradient, a 6-cm block.

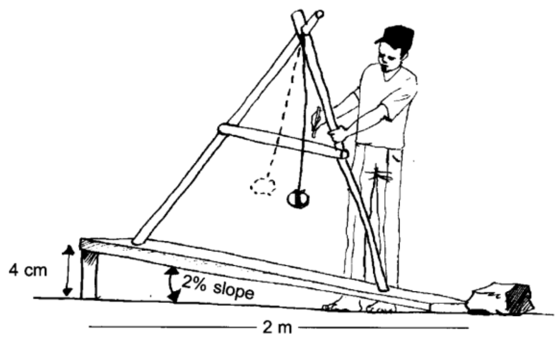


Figure 2.8: Calibrating the A-frame for preparing 2% graded line

Alignment Procedure (See Figure 2.9)**:**

1. Start at the lower end of the desired graded line (as with the line level). Mark the starting point with a peg, and stand one leg of the A-frame at this point.
2. The second leg of the A-frame should be placed in the direction of the desired graded line and slightly upslope such that the string hangs at the mark for the design gradient (i.e. 1 is 1% is the desired gradient). The point at which this second leg touches the ground should be marked with a peg.
3. Repeat the process, swiveling the A-frame around the second leg, until the string touches the other defined ‘1’ mark (always use the mark closest to the lower end of the graded line). Again mark this contact point with a peg.
4. Repeat this process until the whole graded line has been marked.

Figure 2.9: Marking grade lines with an A-frame

2.3 Measuring Vertical Intervals and Slope Gradients

A 'vertical interval' is the distance in height between two objects, such as two terraces or contour bunds. Conservation structures should be built at a small enough vertical intervals to prevent erosion.

- **Measuring vertical intervals with a line level** (See Figure 2.10)

1. To measure a vertical interval of 1 m, fix the string on one pole of the line level at 100 cm.
2. Have the person with the free end of the string hold it on the ground at the top of the slope.
3. A second person with the pole and string attached moves straight down the slope. The first person pays out enough string to keep the string taut. The third person watches the bubble in the spirit level.
4. When the bubble is in the center of its run, the string is level. The lower tip of the pole is now exactly 1 m below the free end of the string. Mark these two places with pegs or stones.

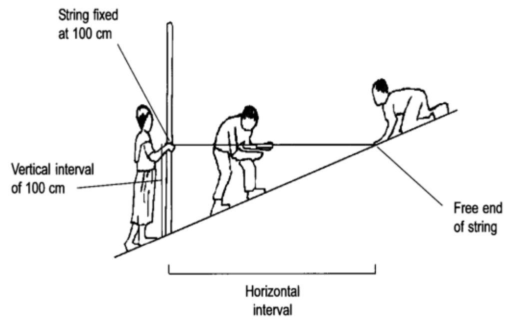


Figure 2.10: Measuring a vertical interval of 100 cm using the line level

5. Fixing a 1m vertical interval may not be achieved in one step (using 10 m string) particularly on gentle slopes. In this case, the vertical interval can be established after two or more rounds of measuring lower heights on the pole at which the 10 m string remains completely horizontal. On very steep slopes, 1m vertical intervals may be encountered at less than 10 m horizontal distance.
6. To mark a larger vertical interval of, say, 1.5 m, you can first measure a 1 m vertical interval, and then the remaining 0.5 m can be calculated.

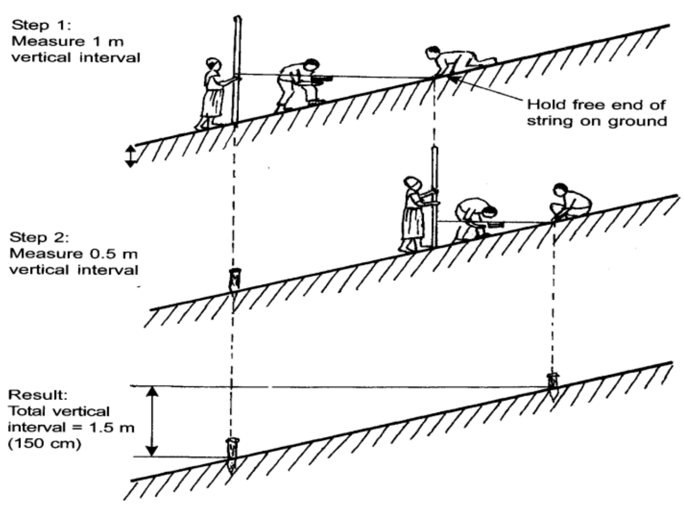


Figure 2.11: Measuring a vertical interval of 1.5 m using a line level

- **Measuring slope gradients with a line level and**

1. Measure a convenient vertical interval (in centimeters) of any distance

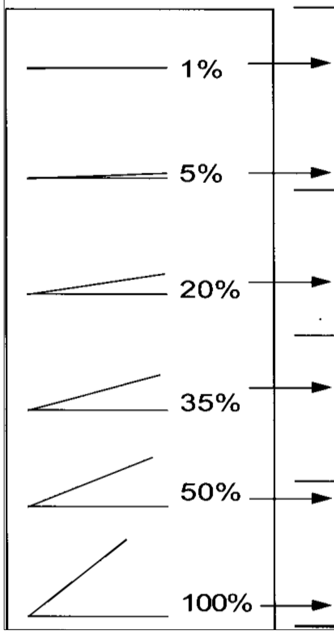
2. Measure the horizontal interval (the length of the horizontal string) in meters.
3. Divide the vertical interval by the horizontal interval

$$\text{Slope in \%} = \frac{\text{Vertical Interval in centimeters}}{\text{Horizontal Interval in meters}}$$

Slopes can also be measured in degrees, or as a ratio. See the table below to convert from one to the other:

Table 2.1: Slope conversion relations

Slope conversions



Percentage	Degrees	Ratio
0.5%	0.3°	1 : 200
1%	0.6°	1 : 100
2%	1.1°	1 : 50
3%	1.7°	1 : 33
5%	2.9°	1 : 20
10%	5.7°	1 : 10
15%	9°	1 : 6.7
20%	11°	1 : 5
25%	14°	1 : 4
30%	17°	1 : 3.3
35%	19°	1 : 2.9
40%	22°	1 : 2.5
45%	24°	1 : 2.2
50%	27°	1 : 2
60%	31°	1 : 1.7
80%	39°	1 : 1.3
100%	45°	1 : 1

ANNEX 3: Design Parameters for Graded Bunds

Vertical Interval (VI): Is the vertical difference (elevation difference) in meters that should be selected between two points on a slope when establishing the distance between two consecutive graded bunds. Its value depends on land slope, rainfall, soil infiltration and permeability data of the area. The formula for calculating it is:

$$VI = SX + Y$$

Where: VI = vertical interval between successive bunds (m);
S = gradient (%) or ground slope, to be changed into decimals for calculation defined;
X = is a variable which can take values from 0.4 to 0.8. The choice of values depends on rainfall with lower values for erosive rains
Y = is a variable with values from 1 to 2. The smaller value is used on erodible soils.
For sandy soils Y = 1.2, for moderately erodible soils Y = 1.5 and for less erodible soils Y = 2

In areas where there is adequate information on soil loss and the soil loss tolerance, terraces/bunds are spaced such that the soil loss is within the allowable limit for contour cultivation, using the most intensive land use and the expected level of management. For the purpose of this manual the formula given above (***VI = SX + Y***) is preferred. This is illustrated in Table 3.1 in which the different VI values have been prepared using a 'Y' value of 1.2 for sandy soils.

Table 3.1: VI in meters, for easily erodible soils (sandy soils)

Slope in percent (*decimal*)	**Vertical Interval values (meters)**		
	For a rainfall of < 1400 mm, (X = 0.65)	**For rainfall of 1400 – 1800 mm (X = 0.7)**	**For a rainfall of > 1800 mm, (X = 0.8)**
03 – 05 (*0.04*)	1.2	1.2	1.2
06 – 08 (*0.07*)	1.2	1.2	1.3
09 – 11 (*0.1*)	1.3	1.3	1.3
12 – 15 (*0.13*)	1.3	1.3	1.3
16 – 20 (*0.17*)	1.3	1.3	1.3
20 – 25 (*0.22*)	1.3	1.4	1.4
25 – 30 (*0.26*)	1.4	1.4	1.4
30 – 40 (*0.33*)	1.4	1.4	1.5
40 – 50 (*0.44*)	1.5	1.5	1.6

Using the above example, various tables can be prepared by applying different "X" values which should be selected with due consideration of the variations in soil sensitivity to erosion.

Box 3.1: *A farmer wants to construct graded structures on farmland of sandy soils having a general slope of 22%. The annual rainfall in the locality is 1500 mm. What is the value of VI does he need to use? Taking the given values of slope and soil characteristics, Table 3.1 gives the answer of VI = 1.4 meters.*

Horizontal Spacing: Is the horizontal ground distance or cultivable strip in meter between the successive bunds. It is measured by the land slope and calculated using the following formula:

HD = VI/S

Where: HD = Horizontal distance of the bund (m)
VI = Vertical Interval (m)
S = Land Slope (%)

In order to avoid calculation and for ease of work, use the information given in the following table for bund spacing (calculated from the above formulas).

Table 3.2: Spacing of bunds expressed in Vertical Interval (VI) and Horizontal distance (HD)

Slope (%)	**Soil with high infiltration and permeability**		**Soil with low infiltration and permeability soil**	
	VI (m)	**HD (m)**	**VI (m)**	**HD (m)**
3	1.0	34.4	0.7	23.4
4	1.1	28.1	0.8	19.1
5	1.2	24.4	0.8	16.6
6	1.3	21.9	0.9	14.9
7	1.4	20.1	1.0	13.7
8	1.5	18.8	1.0	12.8
9	1.6	17.7	1.1	12.0
10	1.7	16.9	1.1	11.5
11	1.8	16.2	1.2	11.0
12	1.9	15.6	1.3	10.6
13	2.0	15.1	1.3	10.3
14	2.1	14.7	1.4	10.0
15	2.2	14.4	1.5	9.8
16	2.3	14.1	1.5	9.6
17	2.3	13.8	1.6	9.4
18	2.4	13.5	1.7	9.2
19	2.5	13.3	1.7	9.1
20	2.6	13.1	1.8	8.9

ANNEX 4: Channel Size Determination for Drainage Structures

A. Using established tables

Once the runoff rate has been determined (as described in annex 1), it is then important to estimate the size of the channel that would be capable of handling the runoff. This may require the use of a complicated formula to calculate it the; to avoid to avoid this, simple tables can be used instead.

First step: To determine the size of the channel to all it is first necessary to know how fast water will be allowed to pass along it. This is referred to as the **maximum allowable or permissible velocity** and is defined as the velocity at which water is allowed to flow in a channel or ditch without causing damage.

In designing disposal channels care should, therefore, be taken to select the appropriate velocity, which does not initiate scouring and does not allow siltation of the channel. If the velocity is too slow then it is obvious that siltation will be a problem. If, on the other hand, if the velocity is too high the flowing water will erode sidewalls and the bed of the channel. The maximum permissible velocity is governed by soil type and degree of vegetative/grass cover and lining materials used in the channel. For each of these alternatives there is a maximum permissible velocity (as indicated in table 1) above which scouring can occur.

Table 4.1: Maximum allowable velocity in m/sec

Soil type	Vegetative/grass cover		
	Sparse	**Medium**	**Good**
Silty sand	*0.3*	*0.75*	*1.5*
Sand	*0.5*	*0.9*	*1.5*
Coarse sand	*0.75*	*1.2*	*1.65*
Sandy soil	*0.75*	*1.5*	*1.95*
Loam	*0.9*	*1.5*	*2.1*
Clay loam	*1.0*	*1.65*	*2.25*
Clay	*1.5*	*1.8*	*2.4*
Gravel	*1.5*	*2.1*	-

Second step: Once the velocity is determined, it is necessary to determine the **dimensions** of the channel (its **depth, bottom width and top width)**. The allowable velocity is taken from table 4.1 and the channel gradient is to be decided by the practitioner/expert. For the purpose of designing disposal structures for soil conservation, the gradient is to be limited. For cutoff drains and graded terraces it should not exceed 1%.

Table 4.2: Depth of a channel in meters

Channel slope/gradient (%)		Maximum allowable velocity (m/sec)								
Height: length	**(%)**	0.3	0.5	0.6	0.9	1.2	1.5	1.8	2.1	2.4
1:100	1	-	-	-	-	-	-	*0.4*	*0.5*	*0.6*
1:200	0.5	-	-	-	-	-	*0.5*	*0.7*	*0.9*	*1.0*
1:400	0.25	-	-	*0.3*	*0.4*	*0.6*	*0.9*	-	-	-

Note that values represented in *italics* in the table above are channel depth in meter.

Box 4.1*: For a channel slop of 0.5%, if the velocity is 1.5 m/sec the depth of the channel is 0.5 m (table 4.2 above).*

Third step: is to find the discharge per meter width, and this is obtained from table 3. These values are determined by the use of the channel gradient expressed in percent (%) and by the depth of the channel given in meters.

Table 4.3: Discharge in cubic meter/second per meter width

Depth of the 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*

Note that values represented in *italics* in the table above are discharge in m^3/sec.

Box 4.2*: If the channel depth selected is = 0.5m for a cutoff drain which is constructed at 0.5% slope, what will be the discharge per meter width?*
Considering the given values, the discharge is found from table 3 = 0.95m^3/sec

Fourth step: The remaining task is to establish the width of the channel. This is expressed in meters and for trapezoidal or parabolic sections can be calculated by dividing the estimated runoff in cubic meters per second (using Rational or Cook's method) by the value of the discharge obtained from table 3 above.

Box 4.3*: Find the size of a channel (cutoff drain) to be constructed at the foot of hilly grassland with an average slope of 20%. Soils for the catchment are clay. The runoff area has rectangular shape and is 200 meters long by 500 meter wide.*

Solution*:*

A*: calculate the runoff area*

The runoff producing area = 500 m x 200 m = 100,000 m^2 = 10 ha

B*: Find the summarized characteristics, use table 3*

- *The vegetation is grassland (medium cover) = 15*
- *Soils are clay = 40*
- *Topography = 15*
- → *The summarized characteristics are =70*

Using the runoff area value of 10 ha and the summarized characteristics value of 70, find the runoff from table 4 of annex 1. The reading for the runoff from the table is 2.8. Therefore, the runoff is 2.8 m^3/sec.

C*. Find the maximum allowable velocity.*

- *To find the velocity, use table 1. The velocity under clay soil and medium cover = 1.8 m/sec*

D*. Determine the depth of the cutoff drain*

- *In order to find the depth use table 2, by the help of maximum velocity (1.8 m/sec) from table 1 and using gradient estimate of (1 %), depth is 0.4 m.*

E*. Find the discharge in m^3/sec/m*

- *To find the discharge, use table 3. The reading for the value of discharge is made by the use of a depth of the channel, which is 0.4 m and the gradient is 1%. So the discharge value from table 3 is 0.9 m^3/sec/m.*

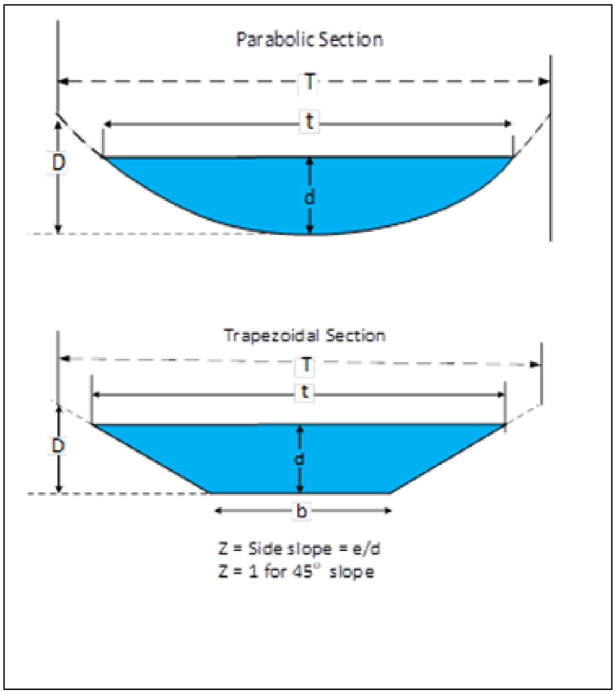
F*. Find the width of the cutoff drain*

- *In this case there are two conditions to be considered:*
  1. *If the channel is to have a trapezoidal or parabolic section, Width = Runoff from the runoff producing area/discharge in to the channel = 2.8/0.9 = 3.2 m*
  2. *If the channel is to have rectangular section, Width = 3.2 – 1/3x3.2 = 1.9 m*

❖ ***Remark****: If the procedures given above are clearly understood, then it will be easy to estimate runoff to be produced from small catchments, and find appropriate dimensions of the channel.*

In general, cutoff drains and waterways should be designed to have, wherever possible, a wide and shallow cross section, in order to minimize the risk of erosion and allow easy crossing by humans and livestock. The channel dimensions are dependent on types of cross-sections to be used. The formulas to be applied and the relationship among the different dimensions for the most commonly used channel cross sections (trapezoidal and parabolic) are indicated in Figure 4.1 below.

Figure 4.1: Channel Dimensions



Channel Parameters

Parabolic Section

Area (A) 2td/3

Wetted Perimeter t + 8d2/3t)

Hydraulic Radius (R = A/P) $t^2d/1.5t^2 + 4d^2$ (Also = Approx 2d/3)

Top width

(t) t = 3A/2d

(T) $T=t\ (D/d)^{0.5}$

Trapezoidal Section

Area (A) $bd + Zd^2$

Wetted Perimeter $B = 2d\sqrt{1 + Z^2}$

Hydraulic Radius (R = A/P) $\frac{bd + Zd^2}{b + 2d\sqrt{1 + Z^2}}$

Top width

(t) t = b+2dZ

(T) T = b = 2DZ

Table 4.3: Channel dimensions and relationships for different cross-sections

Channel type	Area (A)	Hydraulic radius R=A/P	Top width
Trapezoidal y d b	$bd + zd^2$	$\frac{Bd + 2d^2}{B + 2d\sqrt{z2 + 1}}$	t =b+2dx T=b+2Dz
y b	By	$\frac{by}{b+2y}$	b
Parabolic z y	Zy^2	$\frac{Zy^2}{2\sqrt{1+z^2}}$	2zy
c D d	2/3td	$2t^2d/3t^2$ + 8d2	3d/2d t=9/0.67d $T=t(D/d)^{1/2}$

Note that free board = D – d for both cross-sections

The dimensions of trapezoidal shape sections can be determined by combining the formulas given above, using the manning equation and the permissible velocities provided in Table 4.1 as demonstrated here below.

The following two equations are considered in determining the sections of open channels.

i) $Q = AV$; ii) $Q = AR^{2/3} S^{1/2} /N$

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

A = area of flow, m^2

V = mean velocity, m/s

R = hydraulic radius, m, R= A/P; P is the wetted perimeter.

S = bed slope, m/m

N = Manning roughness coefficient = 0.03 for open drains

$A = bd + Zd^2$; $P = b + 2d\,(1+Z^2)^{1/2}$; $t = b + 2dz$; $T = b + 2Dz$

Where, Z is the side slope of a trapezoidal channel. In any case Z should not be steeper than 1.5: 1 (Horizontal: Vertical); b = bottom width of the drain, d = depth of water

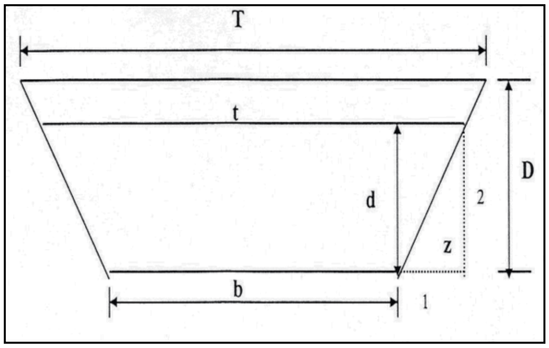


Figure 4.2: Cross section of a trapezoidal channel

<u>Remark</u>: *Various kinds of geometric formulae can be drived using logical assuptions: E.g: Assuming that the channel sidewalls are inclined **45 % (1:1)** and the water depth in the channel is **1/3** of the channel bottom width, the following equations can be formulated:* ***d^2 = ¼ x A, b^2 = 9/4 x A, D = d + free board, t = b + 2d and T = b + 2D***

Table 4.4: 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, plowed and harrowed channels	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 diameter	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

B. Design Steps – For fixing flow depth & bottom width using trial and error method

Step 1: Compute the peak discharge Qp, (use rational formula or Cook's method). The procedure is already discussed in the previous sections (A return period of 5 to 15 with 10 is most commonly used for SWC measures).

Step 2: Compute the hydraulic radius R, (use Manning's formula for which data are provided in Table 4.3 above). The Manning's roughness coefficient is dependent on the channel condition and discharges so the specific conditions and dissipated or existing must be assessed before looking up the coefficient in Table 4.3 above.

Step 3: Compute flow area, from continuity equation . Q = A x v

Step 4: Compute wetted perimeter, P, from the hydraulic relation: R = A/P.

Step 5: Compute flow depth, the two expressions are derived as follows:

- The spillway channel is assumed to be trapezoidal in shape.
- Side slope H: 1 (i.e. H units horizontal and 1 unit vertical).

Box 4.4: *Sample calculations for determining dimensions/channel sections of a trapezoidal cutoff drain: The calculation is to be made by trial and error method.*

Data

Q,m³/s	*3.84*	*$Q_{10\ years}$*
bed Slope, m/m	***0.0005***	*(Initially, start with .05%)*
Side slope	*1:1*	
Max V, m/s	*0.75*	*For a sandy loam*
N	*0.03*	
Trial b, m	***3.9***	*(Start with wider b)*

d	***A***	***P***	***R***	***V test***	***Q test***
m	*m^2*	*m*	*m*	*m/s*	*m^3/s*
1.3	*6.76*	*7.6*	*0.88*	***0.68***	***4.6***

Step 1. Fill the Data Values above.
Step 2: Apply a trial Value for b
Step 3: Apply a trial Value for d
Step 4: Check whether the Q test is =or > Given value of Q. If yes, go to step 5
Step 5: Check whether the V test is < or = Given value of V. If no,
Step 6 Reduce bed slope and go to step 2 and follow the procedure again

Determinations of the dimensions of a parabolic section:

- Estimate discharge (Q) using the Rational or Cooks method
- The Slope is assumed to be the natural slope (for the waterway) or decided in the case of a cutoff drain;
- Select the maximum permissible velocity depending on channel material and condition of the cover;
- Select (N) roughness coefficient from Table 4.3;

- From Manning's equation calculate the hydraulic radius - $r = (vn/s^{0.5})^{1.5}$;
- Calculate the cross-sectional area of the channel - A = Q/v;
- For parabolic section use the design depth (d) = 1.5r;
- For a parabolic section use the design to width (w) = A/0.67d;
- Set the values of the design criteria depth = d meter, and width = w meter;
- Check whether the capacity of the channel is adequate or not;
- For a parabolic section Q = Av = 0.67wdv;
- Final design criteria are depth = design depth + 20% free board.

Box 4.4: The design of an artificial waterway:
Using the maximum permissible velocity method, design a parabolic grassed waterway to convey 6 m^3/sec on a 1 percent slope over an erodible sandy soil with Bermuda grass vegetation in a good stand cut to 6 cm.

1. Discharge (Q) = 6m^3/s;
2. Slope (s) = 0.01;
3. Select maximum permissible velocity (v) = 1.5m/s from table 5;
4. Select Manning's roughness coefficient (n) = 0.034 from table 8;
5. Calculate the hydraulic radius using Manning's equation; $r = (vn/s^{0.5})^{1.5}$;
   $r = (1.5*0.034/0.01^{0.5})^{1.5}$; r = 0.364m;
6. Calculate the required cross-sectional area (A) of the channel; A = Q/v = 6/1.5 = 4m^2;
7. For a parabolic section, the design depth (d) = 1.5r; d = 1.5*0.364; d = 0.55m;
8. For a parabolic section, the design top width (t) = A/0.67d; t = 4/0.67*0.55; t = 10.86m;
9. Design criteria are; depth = 0.55m; width = 10.86m;
10. Check that the capacity of the channel is adequate; for a parabolic section, Q = Av = 0.67*t*d*v; Av = 0.67*10.86*0.55*1.5 = 6m3/s which is adequate;
11. Final design criteria are; depth = design depth + 20% free board = 0.55+0.11 = 0.66m; top width = 10.86m.
12. As a result of the freeboard, the Top Width (T) = $t(D/d)^{1/2}$, $10.86(0.66/0.55)^{1/2}$ = 12m.

Remark: *For quick decision, the dimensions of a waterway can be determined using tables 5 and 6 below*

Table 4.5: Relationship between drainage area and width of waterway

Runoff area	Width of the waterway (m)		
	Slope gradient (0 -5%)	**Slope gradients (6 - 12%)**	**Slope gradient (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

Table 4.6: Relationship between depth (m) and width (m) of waterway

Width in meters	Depth in meters
0 – 3	0.3
4 - 6	0.4
More than 6	0.5

ANNEX 5. Assessment of Gully Erosion: A Field Form for Data Collection

Observer: ________________________ Name of the area: _________________ Gully size: _______________________ Date: ___________________________	1 Number of gullies	2 Av. Length (m)	3 Av. Width (m)	4 Av. Depth (m)	5 Av. Gully gradient (%)	6 Field/ watershed size(m^2)	7 Gully Density (m/m^2) or Km/km^2	8 Soil loss M^3	9 Possible reasons for gully formation	10 Recommendation for rehabilitation
Land use type /site name/location name										
Grazing land										
Cultivated land										
Bush covered										
Miscellaneous (footpaths, cattle trafficking lines…)										

Instructions to use the above table:

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

ANNEX 6. Spillway Design and Apron Installation for Check-Dam

a) Spillway design:

The spillway of a check-dam should be designed to safely convey the peak runoff. It has to be designed to carry the maximum flow without overtopping or breaching the check-dam. Therefore, it must be big enough to accommodate the maximum flow expected once in ten years. For a rough estimate of a peak flow, the watermarks visible on the gully banks or debris deposits give a good indication of its magnitude and the dimensions required for the spillway. A better and more realistic approach to calculating the discharge to be accommodated through the spillway is to use the aforementioned discharge formula and then to calculate the width and depth of the spillway using the following and spillway formula.

$$Q = Cld^{3/2}$$

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 = Length of spillway in meters;

d = depth of spillway in meters;

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

Box 6.1*: The catchment area of a 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-dam's spillway?*

*The spillway dimensions can be calculated by the spillway formula (**$Q = Cld^{3/2}$**) as follows:*

Q: 9.675 cubic meters/second, is given and C: 3.0 coefficient for rock and brush structures
D: Depth of spillway varies from 0.5 to 1.5 m in general. (0.8 m is tried as shown below).

$9.675 = 3*l*0.8^{3/2} = 3*l*0.71$
$l = 4.54$ m

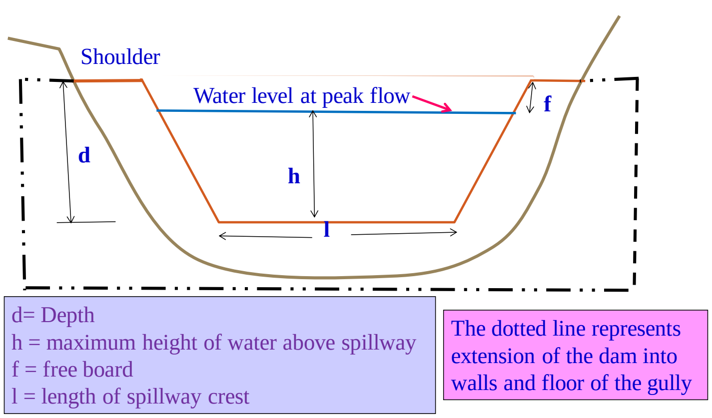


Figure 6.1: Cross section of a check-dam spillway

Spillway dimensions can also be determined using table 6.1 below. The depth of the spillway can be determined on the basis of the discharge entering into the gully from the gully catchment upstream and the width of the spillway, which is proportional to the gully bottom width. Note that the numbers in *Italics* in the table below are discharge values.

Table 6.1: Depth of spillway required for different widths and discharges Runoff Volume (m3)

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

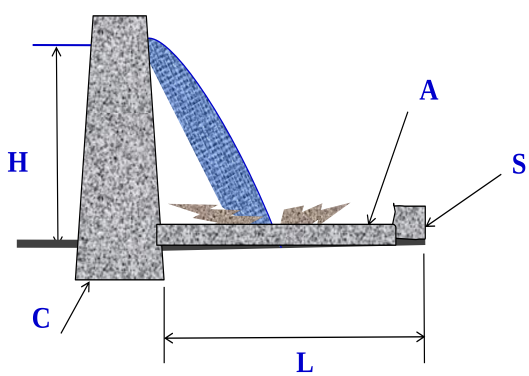
Source Wenner, 1984

Box 6.2: *If the runoff entering into the gully is 1.5m*^{3}*/s, assume the spillway width of 2.4 meter; from the table above, the depth of spillway is 0.6 meters.*

b) Installing apron:

An apron is to be designed to dissipate the energy of falling water passing through the spillway. It can be made from stone riprap, strong enough to withstand pressure of falling water and a surface wash. To prevent surface wash the voids between the stone riprap must be filled with gravel. In conditions in which there is a high spillway, the apron should be constructed from gabion box filled with stone.

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



A = Apron
S = Sill
L = Apron length
C = Check dam
H = Dam height

c) Figure 6.2: Waterfall passing through the spillway and falling on the apron

ANNEX 7: Determination of the Number of Checkdams and Checkdam Spacing

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

(i) Calculating number of check-dams using compensation gradient:

$$NOCD = \frac{a-b}{H}$$

Where:

- NOCD = 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 the 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 foundations, to be constructed in that portion of the gully bed.

The formula above assumes that the spaces between check-dams can be determined according to the compensation gradient and the effective height for the check-dams. The gradient between the top of the lower check-dam and the bottom of the upper one is called "compensation gradient" which is the future or final gradient of the gully channel. It is formed when material carried by flowing water fills the check-dams to spillway level.

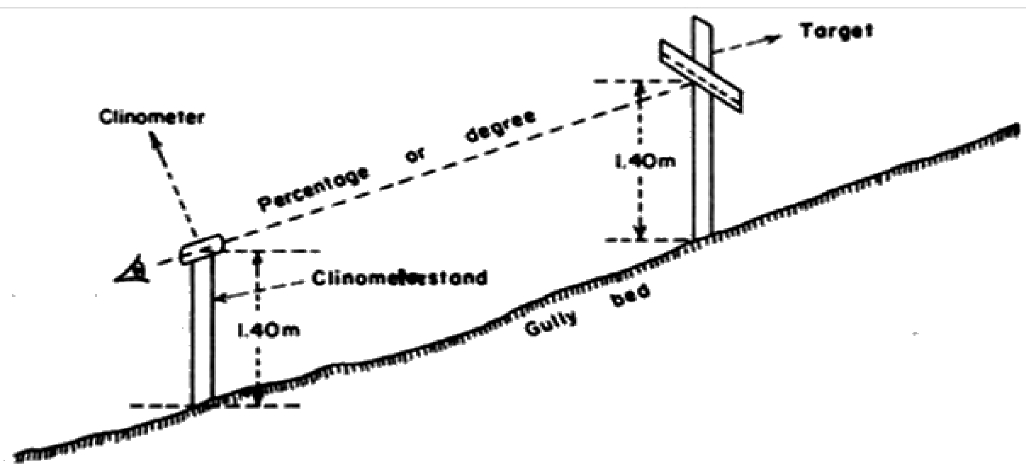


Figure 7.1: shows how to use a clinometer

Figure 7.1: shows how to use a clinometer, a clinometer stand and a target in order to locate the position of the second check-dam in a gully bed. At the location of the second check-dam its effective height should be marked at the edge of the gully taking into account the depth of the gully, the depth of the spillway and the maximum height of the check-dam.

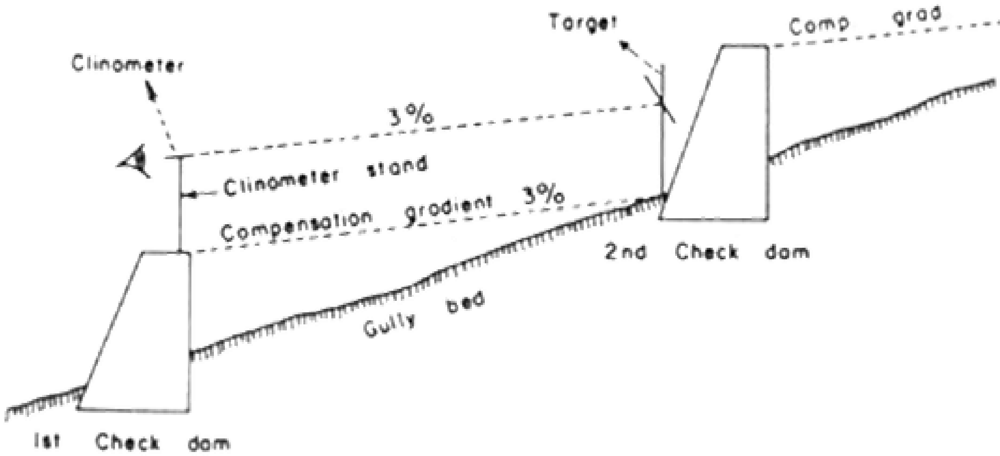


Figure 7.2: Measuring the gradient of the gully between check-dams.

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

$$S = 1.2H/G$$

Where:

S is the spacing in meters;
H is the effective height of the check-dam (spillway height in m);
G is the gully gradient.

Box 7.1:	What will be the spacing of the check-dam, if the effective dam height is 1.5 m and gully gradient is 15%?
Solution:	Using the empirical formula above: Spacing = 1.2 x 1.5/0.15 = 12 m. (i.e. the check-dams will be installed 12m apart along the gully)

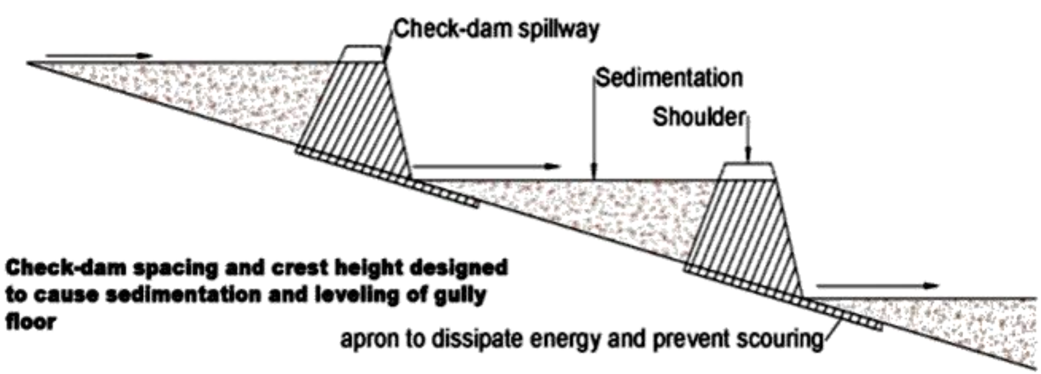


Figure 7.3: Check-dam spacing and sedimentation

ANNEX 8. Estimating Water Demand for Domestic Purposes, Livestock and Irrigation

Water demand estimation is central to planning, design and construction of water harvesting structure in general. To determine the water requirement for any particular household or community, information on the number of people, livestock and any irrigation requirements needs to be gathered. Then the demand for water for domestic purposes, livestock and irrigation can be simply estimated as follows.

8.1 Human and Livestock water demand

Human water consumption varies widely across Ethiopia, ranging from a low of 5 liters per person per day l/p/d) for some rural communities, to a high of 120 l/p/d for urban dwellers with more sophisticated water facilities (Teka, 1982). The average rural consumption in 1973 was estimated to be
15 l/p/d (Ministry of the Interior, 1973). This figure is unlikely to be exceeded where water has to be carried. The calculation of future human demand should take into account population growth and the increased use per person which will result from improved supplies. Suitable design consumption for human population in rural areas of Ethiopia is 10 - 20 l/p/d.

Livestock require 20–30 liters per tropical livestock unit (TLU2) per day (EWRA, 1976; Hofkes, 1983). Further details of human and livestock water requirements are given in Table 8.1 below.

Table 8.1: Water demand for various types of consumers

No.	Category	Demand (liters/day)
1	Human use	
	• Water source > 1000 m distant	10
	• Water source 500-1000 m	15
	• Water source < 500 m but	20
2	Cattle	25
3	Horses	20
4	Sheep and goats	10
5	Donkeys	20
6	Camels	50
7	Poultry (l/100/day)	15
8	Pigs	15

These values are indicative but, as each rural community will differ in use patterns; where possible a field survey should be made to assess water use. Daily water use per person data can be used to make a rough estimate of a community's water demand; although per household water use may be more accurate since much of the water is shared by members of a family. It is often the case that once a large new water supply is built within a community, people will bring their animals to drink rather than go to other sources further away.
The water demand for domestic use can be calculated/estimated using the following formula:

Wd = (Po x Dc x T)/ 1000

Where:

Wd = Domestic water supply during the dry period in m^3

Po = Users of the reservoir

Dc = Average rate of water consumption in l/day/person

T = Duration of the dry period in days

The water demand for livestock can also be estimated using a similar kind of formula:

WL = (NL x Ac x T)/1000

Where,

WL = Water needed for livestock during the whole dry period in m^3

Nl = Number of animals to be watered from the reservoir

Ac = Average rate of animal water consumption in l/day/animal

T = Duration of the dry period in days

Depending on the estimated water consumption figure for people and livestock in a certain area, the water requirement for a month or year can be estimated using the following equation.

D = (**Wd + WL) x 1.2**

Where,

Wd = Domestic water supply (water for people) during the dry period in m^3

WL = Water needed for livestock during the whole dry period in m^3

1.2 = Extra allowance for number of people and number of livestock in a household and increased consumption due to close access

8.2 Irrigation water demand

To estimate the water requirement for irrigation, consider the main factors, such as the irrigation method used (furrow, sprinkler or drip), the soil type (sandy, loamy, clay), climate, type of crop and its growing period. FAO manuals can further be referred for estimating irrigation water requirement of major crops to be grown in the area (For CROPWAT See http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1026559/).

- Determine ETo for the area using CROPWAT software using climate data available;
- Calculate evapotranspiration of the crop ETc as $Et_c = Et_o * Kc$;
- Calculate the net irrigation water requirement by subtracting effective runoff that is $In = Et_c - Eff\ R$;
- Calculate the gross irrigation water requirement by considering the efficiency of application as $I_g = I_n/Eff$;
- Find I_g for the whole growing season (LGP) and multiply it for a given area;
- Total irrigation water demand =Ig*A

ANNEX 9: How to Size A Rainwater Harvesting Tanks

In order to decide the size of water tank required for a household or small group, follow the steps below:

Step 1. Obtain average rainfall data for the area of interest covering the last 10-20 years;

Step 2. Rank the rainfall data in terms of months with highest rainfall;

Step 3. Select the catchment that will be available and determine its type and size;

Step 4. Calculate the amount of runoff from the catchment (inflow) on a daily, or if data is not available, monthly (basis;

Step 5. Calculate the daily or monthly (depending on data availability) water demand (out flow) for each use (domestic or irrigation or both);

Step 6. Calculate the amount of inflow (supply) and out flow (demand) for each month;

Step 7. Calculate the cumulative inflow and out flow;

Step 8. Compute the difference between total water available (inflow) for year and demand (out flow) per yea;

Step 9. Subtract the smallest negative difference from the largest positive difference (from step 8);

Step 10. The maximum difference between the highest value and the subsequent lowest value of the accumulated difference is the required storage tank.

Box 9.1: A farmer living in moisture stressed area needs to construct underground rainwater tank. The farmer has a total size of 300m2 compacted soil catchment area at his homestead. The monthly rainfall distribution in the area and the monthly water demand (out flow) of the farmer is given as follows:

Determine the required capacity of the storage tank that can satisfy the yearly demand of the farmer.

Solution

1. Rank rainfall data in terms of months with highest rainfall (column 1 & 2 Calculate the monthly runoff amount (inflow) is cubic meter (column 4).

   Remember Q = P x A x K, and use, K = 40%
2. Put the monthly demand (out flow) as shown in column 6. The expected monthly water loses due to seepage, evaporation, and increased consumption (20% of the demand) is included in the monthly demand.
3. Find the cumulative of inflow and outflow as shown in column 7 & 8, respectively.
4. Calculate the difference (column 7 - column 8 of Table 9)
5. Identify the maximum and lowest value of the accumulated difference (column 8).

Therefore, the required capacity of the storage tank will be = 43.6 - (-9) = 53m^3

Month	Rainfall (mm)	Outflow (m^3/month)- demand
July	210	6
August	105	5
September	80	4
October	46	6
November	0	15
December	0	14
January	0	16
February	40	5
March	60	4
April	14	5
May	0	4
June	100	4

Table 9.1 Data and computations for tank capacity

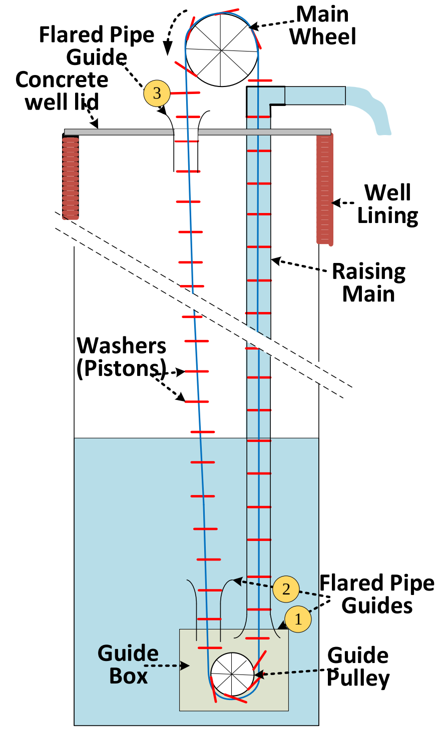
Month	Rainfall (mm)	Rank	Catchment Size (m^2)	Inflow (m^3/month)	Outflow (m^3/month) -demand	Cumulative Inflow (m^3)	Cumulative Outflow (m^3)	Difference (m^3)
[1]	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**	**[9]**
July	210	1	300	25	6	25	6	19.2
August	105	2	300	13	5	38	11	26.8
June	100	3	300	12	4	50	15	34.8
September	80	4	300	10	4	59	19	40.4
March	60	5	300	7	4	67	23	43.6
October	46	6	300	6	6	72	29	43.1
February	40	7	300	5	5	77	34	42.9
April	14	8	300	2	5	79	39	39.6
May	0	9	300	0	4	79	43	35.6
November	0	10	300	0	15	79	58	20.6
December	0	11	300	0	14	79	72	6.6
January	0	12	300	0	16	79	88	-9.4

ANNEX 10. Installation of Rope and Washer Pump

Installation

Before going into the field, check all tools and materials needed for the installation. As it is essential to have a good indication on the water level in the well before purchasing the PVC parts, one of the first things to do is to measure the depth to the water level and the total depth of the well. At least two people, preferably the new owner and/or some of the users are needed for installation. There is also the need for a sufficient number of people to lift the well cover halves, in situations where the rope pump is placed on a hand dug well.

Figure 10.1
Rope & Washer Pump



Making Flares

Flares have to be made on those ends of the PVC pipe, where rope and pistons enter:

- On the guide box: rising main and catcher pipe
- On top of the well where the rope and pistons pass through the well cover

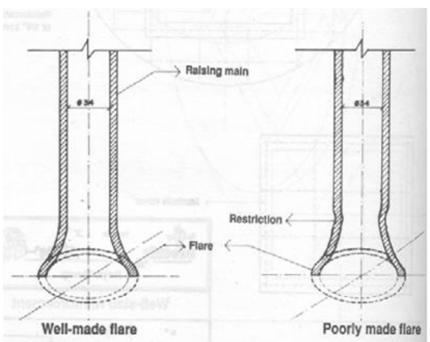


Figure 10.2. The Flare

The flare is made by heating the end of the pipe and then opening it up with a flaring tool (for example a V-shaped stick or soft drink bottle).
Don't heat up the pipe-end too much! This will create restrictions which hamper the entry of the pistons.

Connecting Pipes

To connect the PVC pipes of the rising main a socket has to be created. To make a centralized socket, a simple tool (1) can be made out of two pipes; one of which fits the inside diameter of the rising main while the other has the same diameter as the rising main.

Figure 10.3 – Creating a socket. Heat up the end of the rising main. Insert the tool. Cool the end of the rising main with water (turn the tool around to prevent it from getting stuck). Remove the tool from the rising pipe. The socket is created.

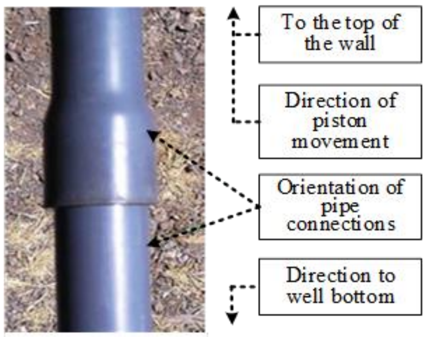
Figure 10.4 – Making the connection. Roughen up the inside of the female and the outside of the male part with sandpaper. Glue the pipes together When glue the pipes together, only glue the male part. NOT the inside of the female part. If you do so, the male part will push the glue inside the female part forward, creating a rim on the inside, which could block the pistons.

Step by step Installation

Step 1 Preparing the rising main

Measure the depth of the well. Glue the riser main together to the appropriate length. This should be the total depth to the bottom of the well less approximately 1m (the allowance to the base of rope pump).

Step 2 Connecting the Riser Pipe



Take a short piece of riser main and make a flare. Insert the flare into the GI pipe. Glue a female part of the riser pipe on top **(Figure 10.5)**. Make sure during installation that all connections are constructed with the male parts towards the bottom of the well and the female parts towards the top of the well. This ensures that the moving pistons will not get stuck behind the male the end of the male (rim) inside the pipe.

Figure 10.5 Connect Rising Pipe

Step 3 Pulling the rope through the pipe

Figure 10.6 Guide Box with Rope and Pistons running through it

To pull the rope with pistons through the pipe making sure that the PE pistons will move in the right direction do the following: Take a thin rope and connect a heavy bolt to it. Drop the bolt and the rope through the pipe. Connect the rope with pistons on the thin rope and pull it through **(Figure 10.6)**. Connect both ends of the rope temporarily together on the top end of the riser main to prevent the rope from dropping into the well during installation.

Step 4 Marking the top end of the riser main

Mark the top end of the riser main on the side on which the catcher pipe of the guide box is to be situated. This is needed to ensure that the guide box (at the bottom) and the pump (on top) are properly aligned after installation. If this is not done carefully the rope and pistons might become entangled around the riser main and get stuck.

Step 5 Installing the guide box with rising main and rope into the well

Figure 10.7 Installing the Guide Box with Rising Main and Rope

Lower the guide box and rising main to the bottom of the well. Ensure there is adequate clearance between the guide box and the bottom of the well to avoid sediment being pumped. For HDW this clearance is 10 cm. For tube wells the re ommended clearance is at least 50 cm.

When lowering of the rising main into the well it should be bent as little as possible so as to prevent it from cracking or even breaking.

The rising main should not be rotated during installation so as to prevent the rope from winding around the rising main and becoming entangled on it. It must therefore be kept at all times on the same side of the raising main.

Step 6 Cutting the riser main

When the guide box and rising main have reached the correct depth, the rising main has to be cut approximately 5 cm above the well cover. Especially in case of a tube well, make sure that a can or bucket will fit under the outlet so that it will later be possible to fill such receptacles with. If this cannot be done, the rising main should be cut higher above the well cover.

While cutting the riser main, hold the rope on the opposite site of the cutting line. So as to ensure that the rope is not cut or damaged.

Step 7 Aligning the pump

When the pump is being installed in a tube well and as part of final installation the pump wheel must be aligned with the rising main and/or the hole in the well cover for the raising main.

Put a plumb line (string with a weight at one end) over the wheel. The string should be aligned with the middle of the raising main. When a concrete slab or concrete well cover with bolt connections for the pump is installed, alignment should take place during construction of the slab (to position the bolts in the concrete).

Step 8 Connecting PVC Parts

Figure 10.8 Connecting PVC Pipes

Roughen up with sandpaper:

- The top outside of the riser main;
- The outside of the reducer;
- All three insides of the T-piece;
- One side of the outlet;
- One side of the top pipe;
- Glue all parts together.

Make sure all parts fit each other exactly.

Step 9: Making a Loop by Threading the Rope Back

Figure 10.9 Make a loop on one of the rope ends by threading the rope three times back, through its own base.

Put the other rope end through the loop and check the rope tension.

There should be little play on the rope. If not, the pistons get stuck in the guide box and the rope might slip on the wheel. Take the rope between thumb and forefinger.

Figure 10.10 Checking the Tension

Turn your hand. If the turn can be completed between 90 and 180 degrees, the rope tension is ok.

Figure 10.11. Create the Second Loop

When the rope tension is ok, create a second loop with the other rope end.

Figure 10.12 Seaming the End of a Nylon Rope Loop

If nylon rope is used instead of PP, it is recommended to seam the end of the loop to avoid disconnection of the loop (nylon tends to slip)
Make sure the length of the full loop does not exceed 30 cm. As the loop consists of a double threaded rope, this part will not fit the V-shaped wheel very well. A long which is too long might slip on the wheel.
Just after installation the rope tends to stretch a bit, making the rope longer. Check the rope tension again after the pump is tested. Make sure the users will check the tension periodically.