Guided Learning on Roads Water Management

First Version – December 2016

MetaMeta Research facilitates policy discussion, supported by stakeholder engagement and applied research on water and natural resource management. This work has been accomplished under the program Roads for Water with the support of the Global Resilience Partnership (GRP).

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The first version of the training modules have been developed in the winter of 2016 and it will be revised and adapted to take into account the remarks from national experts, international experts, but most importantly to include the feedback of the first trained practitioners.

1st version – Winter 2016

Contents

1 Module 1: Roads for water – Introduction and design considerations

The way roads are now built often causes considerable damage and undermines climate resilience. Roads cause erosion, sedimentation and flooding – thus worsening the effect of storms and droughts. Investigation shows that typically there are 13 - 25 problem spots along a 10 kilometers stretch of road.

This does not need to be. Roads can be turned around into instruments of climate resilience. Roads can be used to systematically harvest water and to mitigate floods. This can be done with modest additional investments as is already done at scale in some countries. In Ethiopia more than 1 Million people have benefitted from the road water harvesting programmes. Managing water with roads can bring income increases of more than 30 %, increase the resilience of local communities to droughts, and minimize road damages.

Roads have a major impact on climate resilience because they determine the way water moves across the terrain: roads impede the flow of water, concentrate it in a few places or roads may convey water and act as a drain. On the other hand, water from roads can be used for multiple productive uses to the benefits of rural communities.

The training

This training course has been established to familiarize participants with roads water management approaches and technologies. The participants will be enabled to apply the acquired knowledge and skills in their woreda to find possibilities to improve the present situation and plan for the future.
At the end of the course participants will be able and have practiced with the development of road water management solutions. They will also be able to include these solutions in the Woreda and Zone planning cycle, but also to open doors for innovative funding models and to create linkages with on-going planning activities. The specific **learning objectives** are:

- Be able to recall the design principles for feeder roads in different terrain and soil types
- Describe how road water damages roads and downstream land and how this damage can be reduced
- Be able to assess, plan and implement road rehabilitation works which are resilient and beneficial to roadside communities
- Describe how to better harvest, store and utilised road water for the benefit of roadside communities
- Describe the benefits of roadside vegetation

The course follows an innovative approach of guided joint learning, where participants can access training modules, resource materials and resource persons, in different ways (internet, flash drives, and paper). Participants will learn in their work environment and have some face-to-face contact with fellow participants, course moderators and resource persons as well as email and telephone support. The modality of the training is shown in Figure 1.

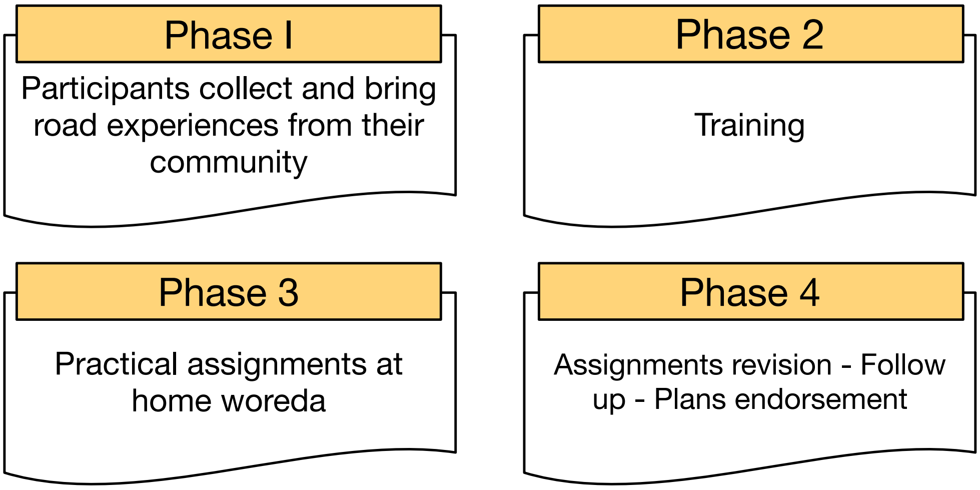

Figure 1: Training modalities – The four phases of guided learning on road water management

This training is shaped to fit the necessities of local water and land practitioners that want to introduce a new and visionary approach in their working area.

Phase 1: The participants are asked to collect pictures/videos of road water related challenges in their woreda of origin. The collected material is a main inputs of the subsequent phases of the training.

Phase 2: A week long training with a well balanced mix of theoretical, interactive and practical sessions takes place. The participants intensively interact with facilitators and key experts.

Phase 3: The participants go back to their woreda and work in groups to make **road water inventories** and come up with **solutions to road/water problems.**. The facilitators will offer distance support by phone, email and provide written feedback to the training participants.

Phase 4: The participants come back together to discuss the identified solutions, share experiences and discuss the uptake of road water management measures in their woreda.

The content of this training is shaped in three modules

1. Feeder road design
2. Road water harvesting and utilization
3. Roadside vegetation

In the annex you can find some practical formats to be used in phase 3 to:

- **prioritize roads where** to intervene (Annex 4); and
- Make an **inventory of road/water problem spots** and make an early identification of possible solutions (Annex 3)

1.1 From problem to solution

Roads **concentrate runoff** within watersheds. As well as runoff, roads also influence **soil moisture** and in some cases **groundwater**. When driving in Ethiopia, gullys starting from road culverts and side drains are a common sight (Figure 2). This is especially common when the drainage system downslope of the road is not carefully designed and protected to safely dispose of runoff, especially in sloping areas. Together with soil loss, the eroded land suffers from decreased capacity to store water in the form of soil moisture and/or groundwater. Gullys act as drains removing water from the system.

Figure 2: Road culverts concentrate in a point big amounts of water runoff and commonly cause erosion damages

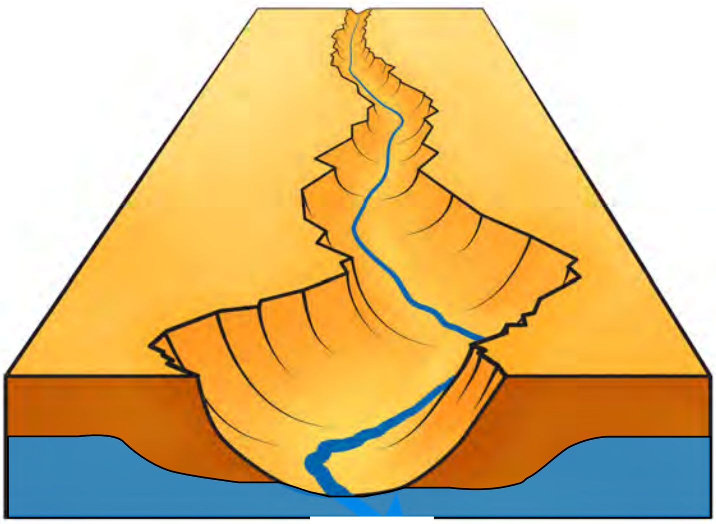

Figure 3: Gullys may act as soil moisture and groundwater drainage (See the lowering of the shallow aquifer)

It can also happen that road construction – because of heavy compaction – decreases **groundwater flow** under the road, which reduces the water-table level on the downside of the road. Furthermore, runoff may cause **flooding and sediment transport** which negatively impact downstream communities (see Figure 4). Sedimentation may block irrigation and drainage channels, deposit coarse sand in the fields and reduce design life and capacity of reservoirs and clog wetlands. Where drainage from roads is inadequate, this may cause waterlogging (Figure 5), damaging crops and roads. Flooding can also happen when too much water is concentrated in too few culverts and the water not well managed.


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Figure 4: Road flooding in West Hararghe, Oromia

Figure 5: Flooding and water logging along roads is a common sight in the rainy season

All these problems are mostly caused by too much water in a very short period of time. Nevertheless, when it doesn't rain many areas are still suffering from water scarcity. This is the turning point where road water challenges can be turned into an opportunity for road managers and roadside communities. The excess road water can be managed and diverted to storage structures such as ponds, and cisterns on the side of the road or spread on the land to increase soil moisture and shallow groundwater recharge. This results in reduced road management costs and additional water resources for roadside communities.
To initiate and sustain a long lasting change, it is a must to involve all stakeholders in the road sector: agriculture, road and water practitioners, local governments and roadside communities. By working together integrated **solutions** deliver the following benefits:

- **Moisture levels in soils** will increase
- **Shallow groundwater** levels will increase
- **Gully** expansion will be halted
- Reduction in **flooding** of dwelling houses and farmlands
- Reduction in **damage to roads**

Many solutions (Figure 6) are available and can be adapted and applied to most situations. When all these measures are combined and with the right considerations and management in place, roads become a flexible tool for resilience (Figure 7).

Adapting to the road

Adjusting the road

Figure 6: Road water management solutions

Figure 7: From dysfunctional road water management to roads for resilience

1.2 Design considerations: Terrain, climate, soils and road class

The main factors influence road design are

- Terrain
- Soils
- Climate
- Road class

1.2.1 Terrain

Slope is critical to road design. Roads on steeper slopes are more expensive to construct and maintain and are more prone to road-water damage and landslides. Adjacent, downslope land is more prone to erosion especially gullies downslope of culverts. The Ethiopian Road Authorities classifies slopes in 4 categories based on number of 5m contours/km on a line drawn between 2 points and slope perpendicular to line. Flat, rolling and mountainous are useful categories for understanding road erosion and water harvesting potential (Figure 8). With GPS recorders it is relatively cheap and easy to map and catalogue the road inventory of woredas. Mapping the slopes and condition of road infrastructure and drainage along a road and points of vulnerability is the first step to developing an effective and preventative road management plan. Tracking roads on google earth allows the slope and terrain classification to be quickly calculated.

Flat	0 to 10 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally below 3%.
Rolling	11 to 25 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally between 3 and 25%.
Mountainous	26 to 50 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally above 25%.
Escarpment	Escarpments are geological features that require special geometric standards because of the engineering risks involved. Typical gradients are greater than those encountered in mountainous terrain.

Figure 8: Terrain classification in the Ethiopian road sector

Figure 9 shows how road design varies according to slope and soil type according to the ERA design manuals. As slope increase (>15%) upslope drains are used and lined to prevent erosion. The optimum slope for a side drain or ditch in most soil conditions is 3%. Above 3% slope, runoff can erode the drain. Scour checks prevent/reduce this erosion. As slope increases, the spacing between scour checks reduces. Between 3-15%, rolling dips can be used to transfer runoff (from the upper catchment and road surface) from the upper to down slope. Above 15% slope, culverts or drifts should be used. As slope increases the frequency of culverts increases. Checks catch sandy sediment which can be profitably harvested. As slopes increase roads require measures such as spring capture/seepage drainage, ditches, benches to prevent landslides.

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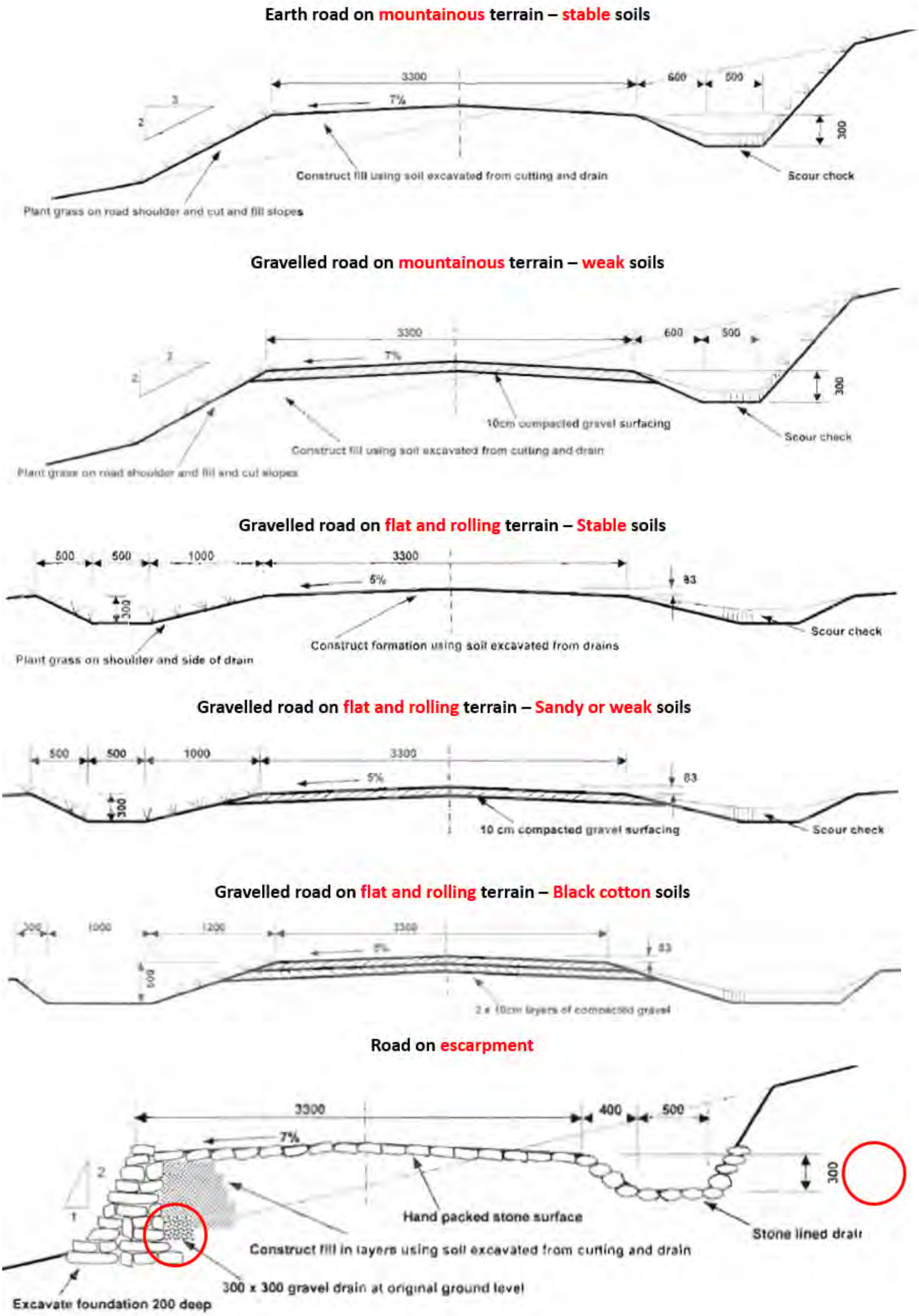
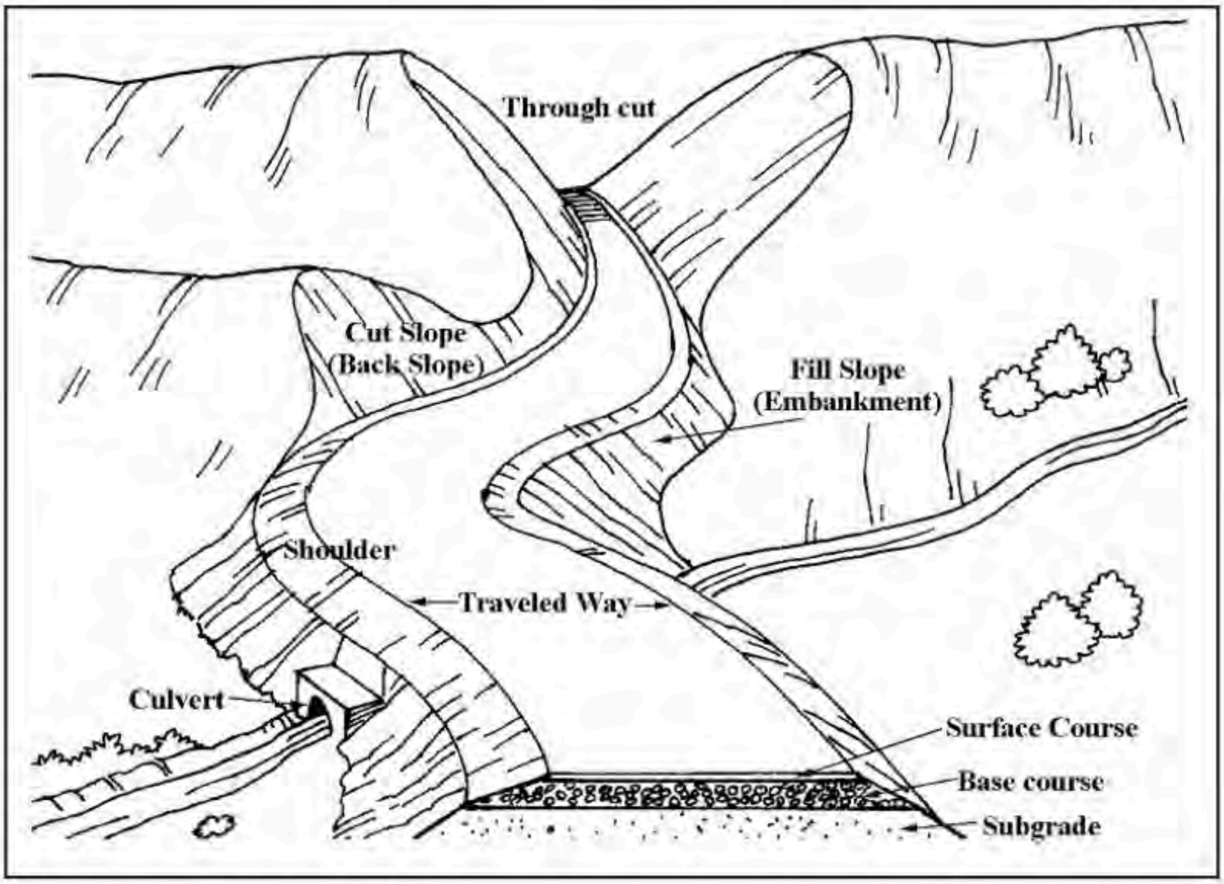


Figure 9: Road cross-sections showing how road design and drainage vary with slope and soil type



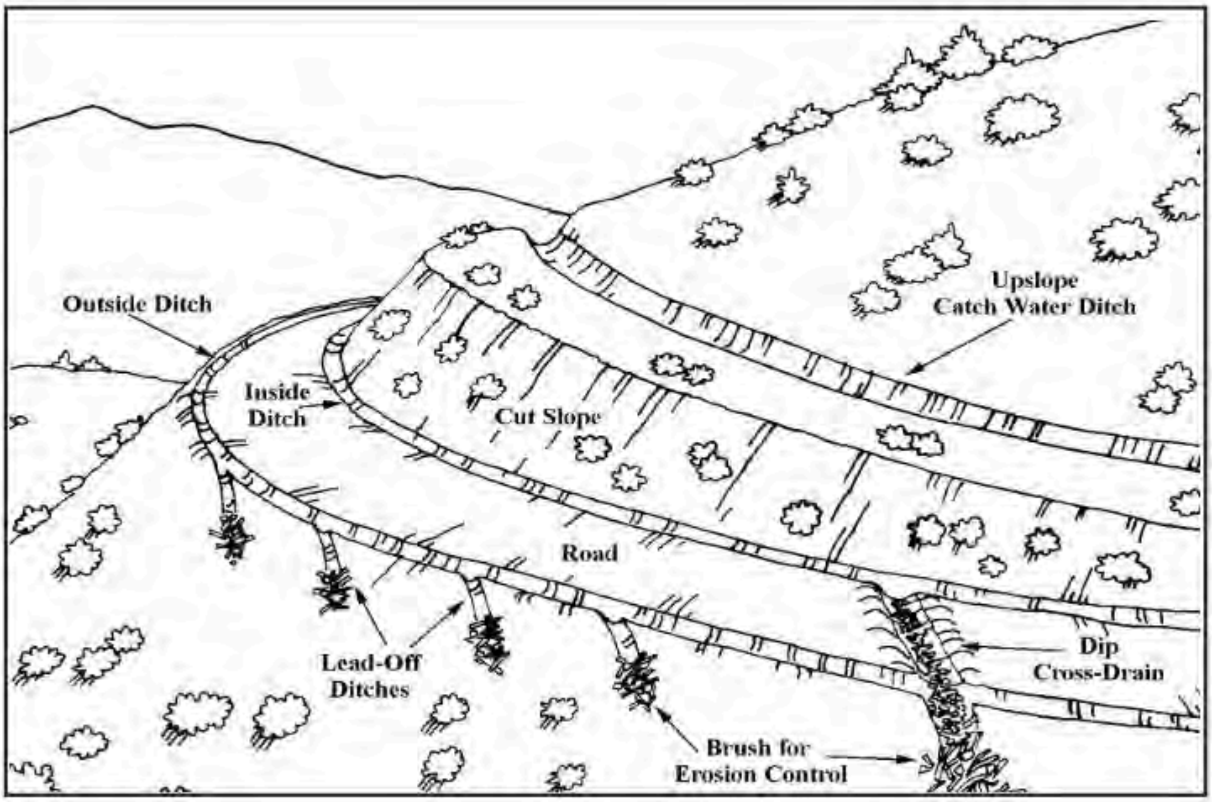


Figure 10: Typical road layout showing the key features and terminology used in road design

1.2.2 Climate

Part B of the ERA design manual describes the factors and methods for estimating drainage flows. Figure 12 shows how the ERA classify Ethiopia according to 5 climate zones characterised by rainfall and evapotranspiration and Figure 11 shows zones of rainfall-intensity-duration frequency. These classifications are very broad and consequently have a significant margin of error. Local knowledge and experience should always be sought: ask local people about water scarcity and flooding especially in extreme (El Nino) years. Convectional storms in semi-arid regions often produce the greatest peak design runoff and offer the greatest road water harvesting potential.

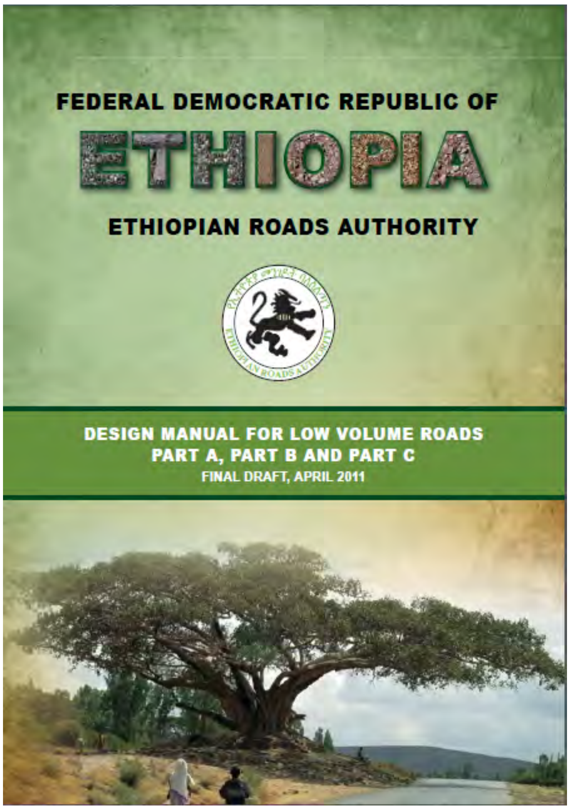
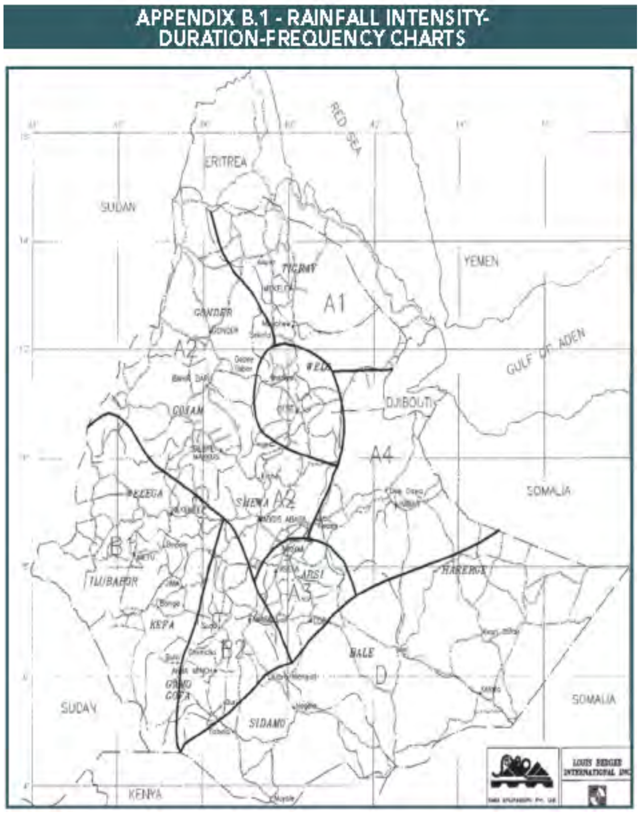


Figure 11: Map showing the rainfall zones used by ERA to estimate the design storm intensity used to design road drainage systems



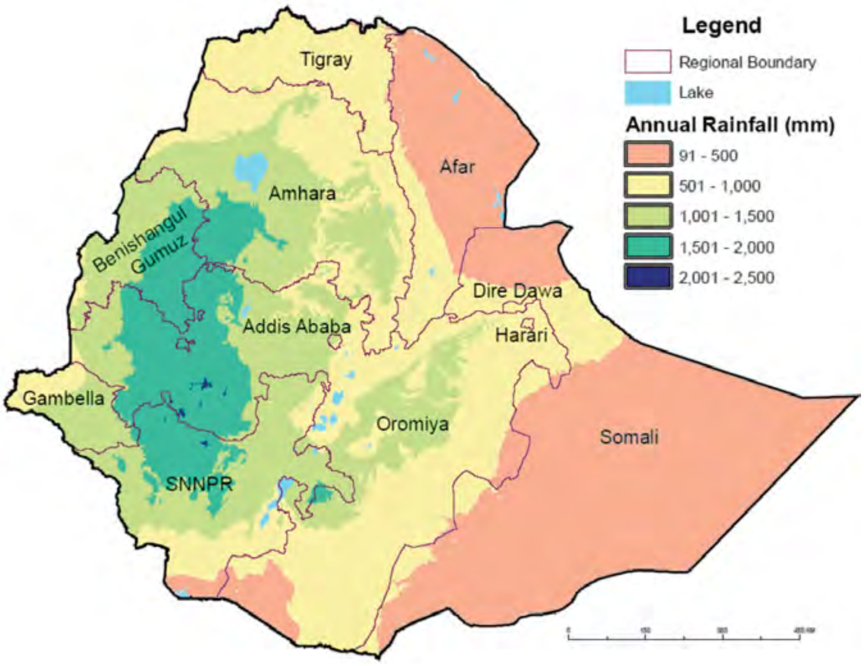


Figure 12: Annual rainfall distribution

1.2.3 Soils

Soil type determines how vulnerable a road and the surrounding land is to landslides and erosion. Soils with low clay content are described as weak and have less internal cohesion. They will therefore slide at a lower slope angle and are more prone to erosion. Compacted gravel is used as a road pavement on weak, erosive soils: 1 x 10 cm layer on weak, sandy soils and 2 x 10 cm on swelling black cotton soils / vertisols.

1.2.4 Road Location, alignment and surveying

It is much better to have a bad road in a good location than it is to have a good road in a bad location. A bad road can be fixed. A bad location cannot. Most of the investment in the bad road can be recovered, but little, if any, can be recovered from a bad location!

Road location ensures a road accesses a desired area whilst minimizing costs, distance between locations and problems related to drainage and erosion. Road location influences both problems arising from drainage and potential benefits.

Road survey, design, and construction are the steps in the process where road designer needs are combined with geometric factors (which are the specific measures and shapes that each road component has) and terrain characteristics. A road or site survey is needed to identify the terrain characteristics, such as drainage, rock outcrops and slope and to design road geometry: how the road is positioned in relation to the landscape and slopes. A survey may be very simple and accomplished with compass and cloth tape for a rural road, or it may be very detailed using sophisticated instruments and a high level of precision in difficult terrain or for a high standard road. Elements of design include:

- Road geometry
- Design speed
- Drainage
- Stream crossing structures

- Slope stabilization needs
- Structural sections (materials type, use, and thickness)
- Road grades

Error! Reference source not found. Fig. 13 shows how road alignment in the same sloping landscapes can drastically change the amount of excavation needed. The best alignment is achieved with precise survey work to understand the topography of the area and thus avoid unnecessary costs. At the same time alignment and road positioning influences road drainage and the straightness and undulation of the road. Road surveys should identify areas of historic or potential vulnerability, such as geologically unstable materials or areas, areas subject to flooding, landslides or areas with steep slopes, high volcanic or seismic hazards. Avoid problematic areas and road locations in areas of high natural hazard risk, such as landslides, rock-fall areas, steep slopes (over 60-70%), wet areas, and saturated soils. Avoid or minimize construction in narrow canyon bottoms or on flood plains of rivers that will inevitably be inundated during major storm events. Minimize changes to natural drainage patterns and crossings to drainages. Drainage crossings are expensive and potentially problematic, so they must be well designed. Changes to natural drainage patterns or channels often result in environmental damage or failures.

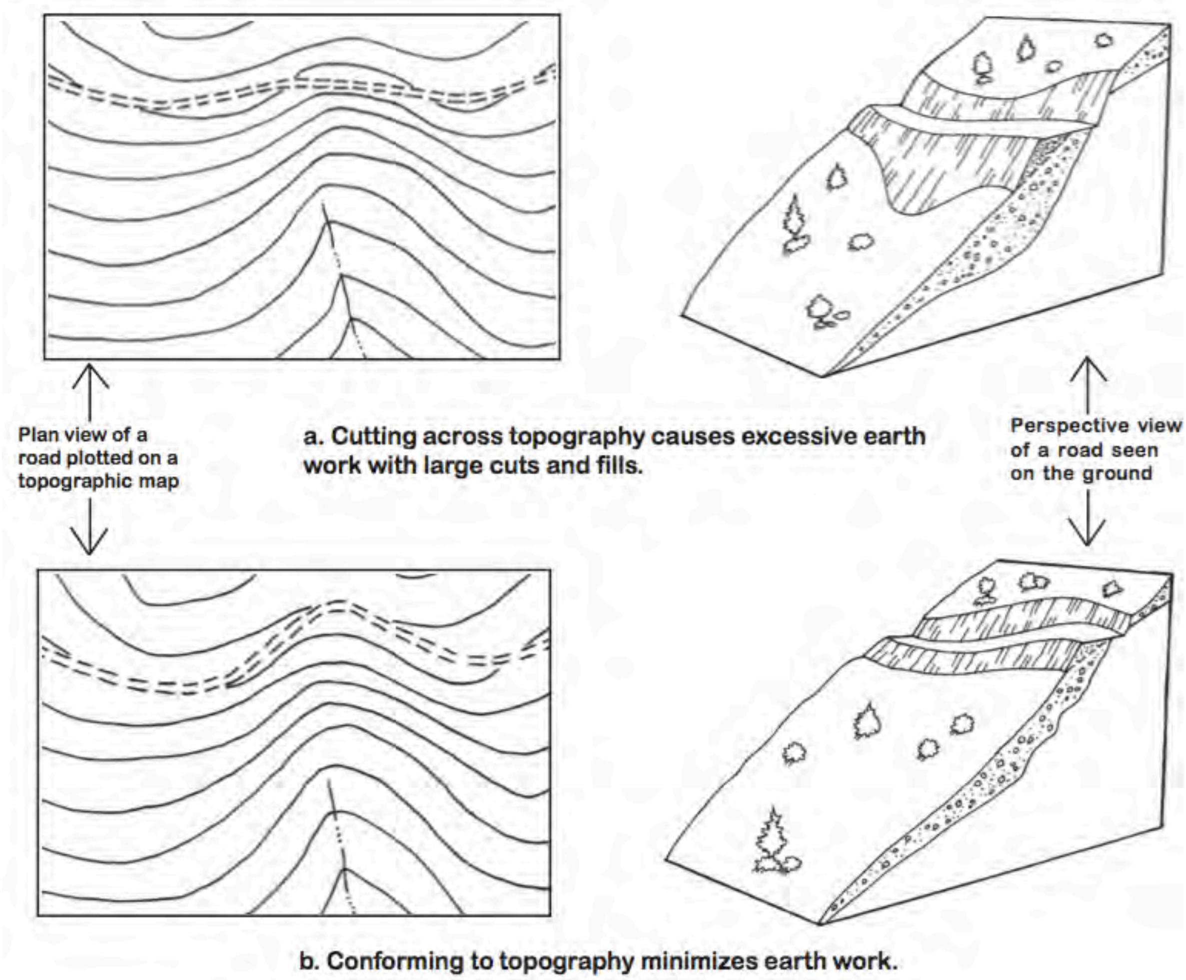


Figure 13: Above: the road cuts through contour lines and thus require excessive earth work. The road is straighter allowing for higher speeds but also more expensive. Below: the road design follows the topography and minimizes earth work

Construction involves all aspects of implementation of the design and implementation on the ground. A key link between design and construction is the use of standard plans and drawings that show how the work should look, and specifications that describe how the work is to be done (Refer to ERA guidelines). Another key part of construction is quality control and inspection to ensure that the work is done in accordance with the plans and specifications. Sampling and testing is typically specified to ensure that the materials used in construction meet specifications.

1.2.5 Road Class

Road construction costs are most influenced by the standard or class of road to be built and the steepness of the terrain. In Ethiopia there are the following main classifications of road:

- A Class: Trunk Roads
- B Class: Link Roads
- C Class: Main Access Roads
- D Class: Collector Roads
- E Class: Feeder Roads

The initial classification defined Classes A to C as Federal Roads and thus directly under the responsibility of ERA, with Classes D to E as Regional Roads which were to be looked after by Regions or local administrative bodies. However, in reality the current role the ERA requires it to become involved in the lower two classes of road. Through District Maintenance Offices (DMO) ERA maintains certain Class C and D roads plus some that are unclassified. The road class determines the standard minimum design specifications for a road, particularly the road geometry, width and type of surfacing.

A higher class of road will be straighter, wider and flatter compared with lower class roads and they will have permanent bridges as river crossings rather than drifts. This increases the amount of cut and fill required especially on steep slopes and this greatly increases the cost and time of construction and the amount of excavation, earthworks, clearing and revegetation required. Feeder roads that are not required to be as fast or straight as A Roads and so in hilly terrain, they often follow the contour closely. This reduces the amount of cut and fill required and hence the costs, but significantly increases the overall length of the road and hence the length and number of road drainage structures.

1.2.6 Road cost estimates

Estimates are important in both the planning process and the overall project budgets to ensure that adequate funds are available to properly build the road. Good design and construction techniques require relatively high initial costs but can greatly reduce future maintenance needs and avoid costly failures, repairs, and adverse environmental impacts. In many cases roads are not provided with a sufficient number of cross drainage structures and properly shaped side drains. This might decrease the cost of construction, but in time it will make the road very expensive to maintain. In Ethiopia for instance, 35% of all road damage is caused by water. Therefore when looking for solutions to reduce road maintenance costs and negative impacts of road drainage, look at increasing the number of culverts and rolling dips and reducing runoff in the road catchment.

1.2.7 Slope stabilization

Keep cut and fill slopes as flat as possible and well covered (stabilized) with vegetation to minimize slumping as well as minimize surface erosion. However, near-vertical slopes that minimize the exposed surface area may best resist surface erosion for well-cemented but highly erosive soils. Use deep-rooted vegetation for biotechnical stabilization on slopes. Use a mixture of good ground cover plus deep-rooted vegetation, preferably with a native species, to minimize mass instability as well as offer surface erosion control protection.

1.2.8 Road drainage design

Provide good roadway surface drainage and rolling road grades so that water is dispersed from the road frequently and water concentration is minimized. Out slope roads whenever practical and use rolling dip cross drains for surface drainage rather than a system of ditches and culverts that require more maintenance and can easily be blocked during major storm events (Photo 3.4). Use simple fords or drifts for small or low-flow stream crossings instead of culvert pipes that are more susceptible to plugging and failure. With fords, protect the entire wetted perimeter of the structure, protect the downstream edge of the structure against scour, and provide for fish passage where needed.

1.3 The road management process

The management of road-water greatly depends on roads characteristics, their design and management. It is therefore of upmost importance to have a clear understanding on how roads are planned, located, designed and constructed. These steps are all part of the road management process and are quickly described in this section:

Road Planning

Road planning and analysis are key to make sure that a road meets the current needs of the users, that it is not overbuilt, that it minimizes impacts to the environment and to the people along the road, and that it considers future needs of an area. Road management objectives help define and document the road purpose, standards, and how a road will be used, managed, maintained, and funded, as well as applicable best practices for the road.

Road Maintenance

Rural roads must be maintained during active use, after periodic operations have been completed, and after major storm events, to ensure that the drainage structures are functioning properly. Routine maintenance is needed on any road to keep the road serviceable and its drainage system working properly. Perform scheduled maintenance to be prepared for storms. Ensure that culverts have their maximum capacity that ditches are armored and cleaned, and that channels are free of debris and brush than can plug structures. Keep the roadway surface shaped to disperse water rapidly and avoid areas of water concentration.

A well-maintained road will reduce road user costs, prevent road damage, and minimize sediment production. Research by the ILO shows that management costs are optimized when 80% of roads maintenance budgets are spent on periodic and routine maintenance and 20% on emergency repairs (Table 1). However, the same research found road authorities in SE Asia neglect preventative maintenance and spend up to 80% on emergency repairs. When it comes to roads maintenance **prevention is better than cure**.

Table 1: Budget allocation for Road maintenance and repairs. Typical situation vs Optimum

	Optimum	Typical
Emergency repairs and reconstruction	20%	80%
Periodic maintenance	40%	10%
Routine maintenance	40%	10%

In hilly terrain, landslides after heavy rains will cause cut slope failures that block ditches and cause water to flow and erode the road surface and fill slopes. Debris washed down natural channels and blocks drainage structures, causing water to overtop the road and erode the fill. Ruts, washboards, and potholes in the road surface will pond water, weaken the roadway structural section, accelerate surface damage, and make driving difficult.

How road maintenance will be accomplished should be resolved before the road is built or reconstructed. Maintenance work can be conducted either by state or local agency personnel, by contractors, or by local community groups. Funding for maintenance may be allocated directly from agency funds, from taxes, from road user fees, or from donated local labor by interested road users.

1.4 The investment case for the road sector

Roads are a major global investment. There is an estimated annual investment of 1-2 Trillion USD in roads – with the bulk of this amount in low and middle income countries. With the rapid expansion of low volume roads these investments are present everywhere.

Authorities should rethink roads to promote climate resilience. Investing funds and resources in road water management has multiple benefits:

1. Management of water with road infrastructure presents a triple win: reduced road maintenance costs; reduced degradation of the landscapes; productive and consumptive use of water harvested with the roads.

2. Minimal costs compared to the overall outlays for road repair/maintenance.

   Optimal option for climate resilient infrastructure. The costs associated with building roads that harvest water and manage floods better are considerably less than the costs of building larger infrastructure with higher design specifications. Well-designed road drainage reduces the size of the peak flood flow.

Investment in water buffering of roads:

Development of water harvesting structures:	USD 5,000-10,000/km
Modification to road design:	USD 8,000-80,000/km
Pay back in reduced road damage	1-4 years
Reduced erosion and flooding	++++
Water harvesting benefits	++++

1.5 Change in governance

In most cases, roads are imposed on the landscape and on the people without much local consultation. Increased community participation and inter-sectoral collaboration on the design leads to more adapted structures and lower construction and maintenance costs.

Design represents a technical activity reserved for experts from the ***woreda*** offices, regional or national roads departments. There is a natural connection between improved road water management, watershed management and mass mobilization efforts.

2 Module 2: Water harvesting from roads

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 (Figure 14):

- 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.

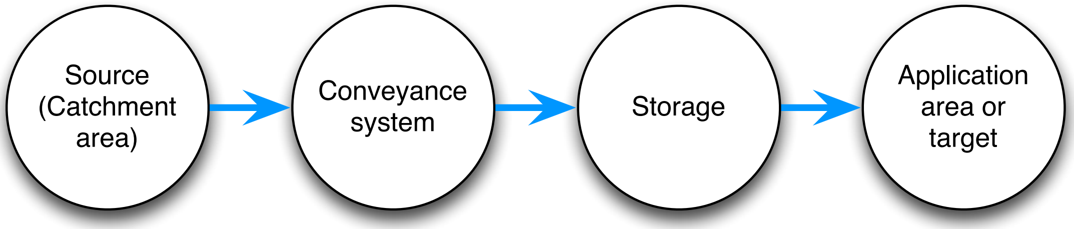


Figure 14: Main components of water harvesting systems

Water harvesting is practiced everywhere to a different extent and at different levels of sophistication. Some measures utilized in watershed management can also be considered water harvesting. For example an eyebrow micro basin is a small water harvesting system as shown in Figure 15.

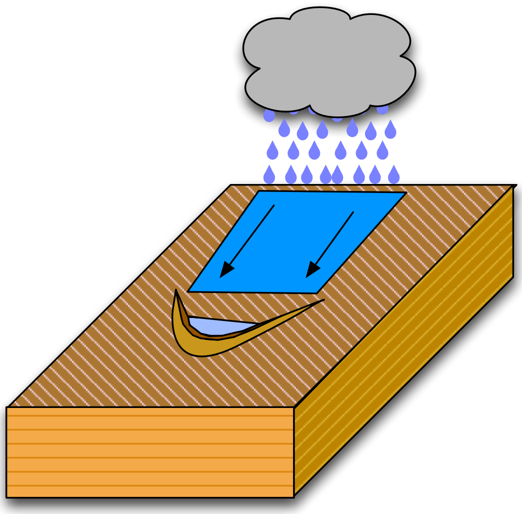


Figure 15: Eyebrow basins can be considered as small water harvesting systems when they collect water from a small catchment area (figure developed by Francesco Sambalino)

The water falling on roads and upslope of roads goes into the side drains and culverts to be disposed of safely and avoid damage to the road. Roads can also be seen as uncomplete water harvesting systems (Figure 16). The surface to generate runoff is already there, commonly together with some form of drainage ditches. What is missing most of the time is an appropriate storage infrastructure and a drainage systems adapted to divert water into it (Figure 17). Roads offer an immense opportunity to be developed into water harvesting systems for multiple uses.

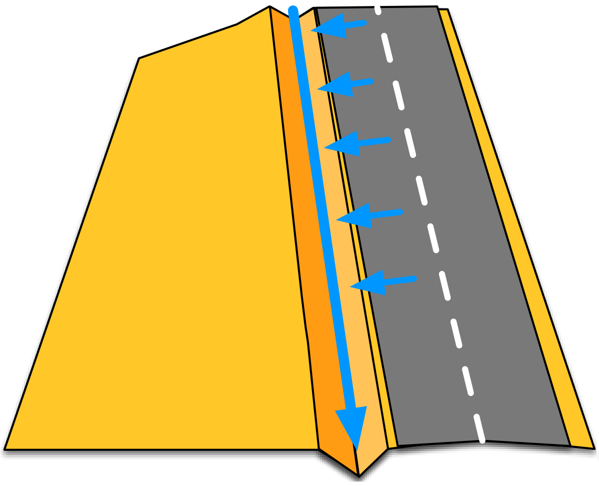


Figure 16: A road with drainage ditch (Figure developed by Francesco Sambalino)

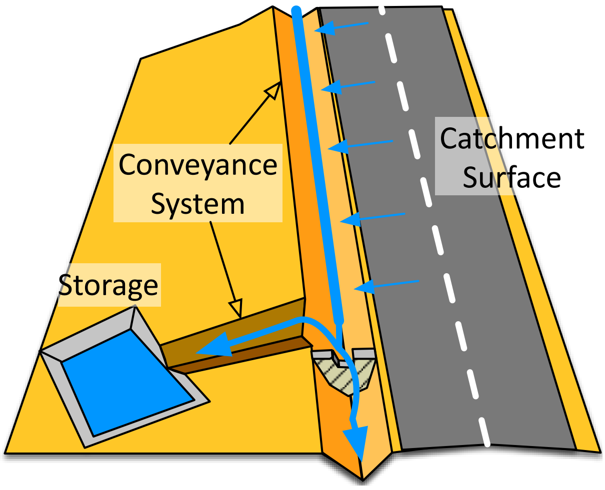


Figure 17: A road with drainage ditch adapted to become a water harvesting structure (figure developed by Francesco Sambalino).

To use the potential of roads for water harvesting there is a need to optimize road designs. Road development changes runoff patterns and roads generate runoff from their own surfaces as well.

Optimized designs can particularly improve water storage in the vicinity of the road, in open ponds and cisterns as well as in soil moisture and shallow groundwater. The availability of very shallow groundwater within the suction depth of low cost centrifugal pumps (i.e. Less than 7–10 m) is particularly important. More secure water availability at these shallow depths makes it possible to support local productive and consumptive uses by small farmers, especially supplementary irrigation that can protect a crop from periods of drought during the rainy season. With rainfall patterns projected to become more uncertain, this type of storage is vital to increased resilience amongst farmers. All over the Ethiopian highlands people are becoming successful commercial farmers thanks to small scale irrigation from shallow groundwater.

In Table 2 an overview of options to optimize water harvesting from roads in semi-arid environments is provided. 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.

Table 2: Roadwater management opportunities

Component	Design Options
Road Allignment	- Location within the catchment determined water harvesting opportunities from roads
Road Surfaces	- Harvest water directly from road surface from lead-off drains and rolling dips - In flat areas use low filtrating stone bunds - Storages and enhanced recharge structures on runoff paths
Cross-Drainage and Culverts	- Divide the road runoff into smaller flows - Use grade reversal and in- and out-sloping to keep runoff manageable - Direct the runoff to storage and recharge areas - Storages and enhanced recharge structures on runoff paths
Roadside Drains	- Storages and recharge structures on lead-off drains - Water spreading from mitre drains
Borrow Pits	- Use borrow pits for storage, recharge or as seepage ponds
Newly Opened Springs	- Collect newly opened spring flows in cisterns or storage reservoirs that are adequately dimensioned and have spillways facilities
Fords (Irish Bridges) and Flood-water Spreading Weirs	- Combine fords/Irish bridges with sand dams - Use fords to stabilize dry river beds - Use access roads to create flood water spreading weirs
Roadside vegetation	- Use vegetation (combined with micro basins and bunds) to slow down runoff, control erosion, and increase infiltration - Use vegetation to fix contaminants
Managing and Harvesting Sediments	- Controlled sand harvesting from fords with sand dams and from sand traps

2.1 Landslide prevention and water management in mountainous areas

2.1.1 Mapping and understanding landslides

Mekele University studied 54 landslide sites (Figure 18). The sites considered in study consisted of 4 **Types of landslides:** Rock falls: 4, Rockslides: 6; Debris/earth slides: 40 and Debris/ earth flows: 4. As shown in fig. 18, landslides are common in highlands and rift escarpment. In your woreda, map areas of greatest risk based on history and slopes and understand type and geometry of failure.

Indicators of landslides

- Bent over, tilted or bowed trees or utility poles
- Bulging earth and hummocky ground
- Cracks, particularly running parallel to a slope
- Cracks through the foundation or the walls of buildings.
- Seepage of water (the down slope area to become saturated)

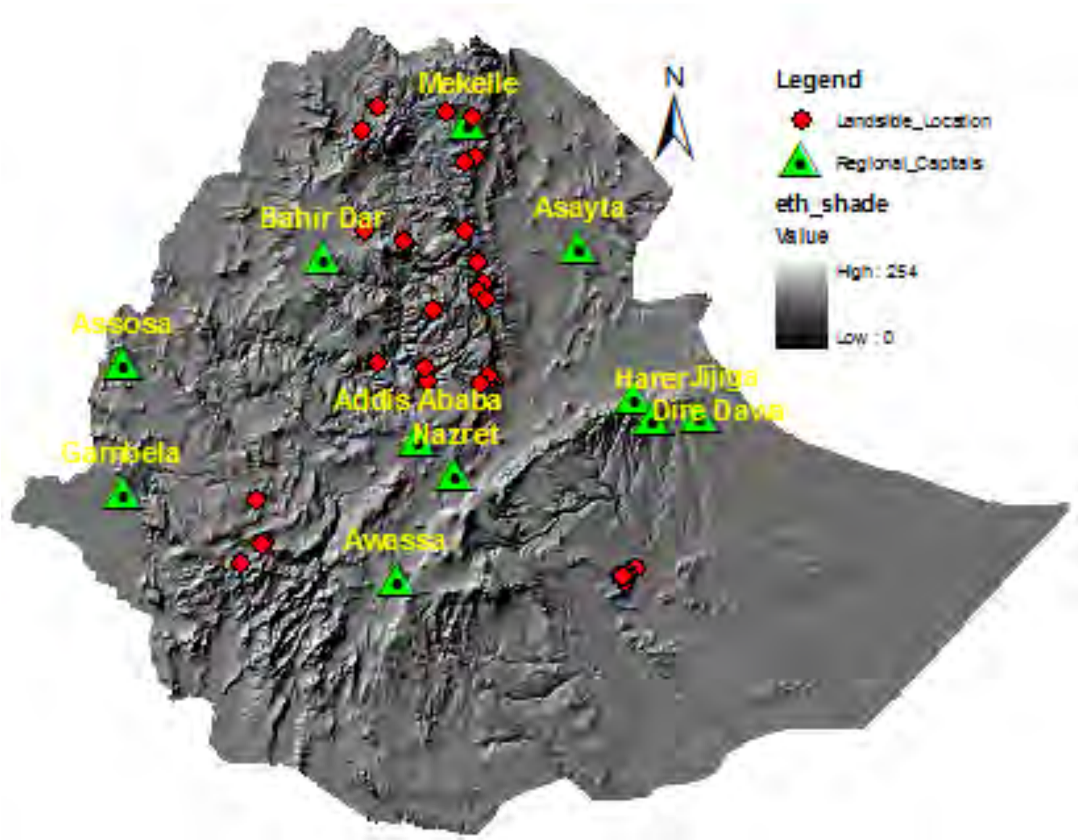


Figure 18: Location of road induced landslides

2.1.2 <u>Prevention of landslides</u>

Landslides occur after heavy rains when the soils become saturated. This increases the weight of the soil and reduces the internal friction leading to failure and slippage. Failure occurs at the interface of soil and bedrock where **water pressure develops**. Over 60% of the failures associated with streams or gully at the base of the slope. The solution is to identify areas of greatest landslide risk, usually where slopes are steepest and the geometry and type of failure. Catchment above the road should be protected by maintaining vegetation cover to minimise runoff and erosion (Figure 19). Bench terraces (at least 4m width) with drainage ditches (max 3% slope) above the road intercept runoff carry the runoff away from the zone of greatest landslide risk (Figure 20).

Sometimes when the road cutting is excavated, this will intercept groundwater flows. When this occurs an interception drain should be placed at the base of the slope at the interfaced with the bedrock to drain the seepage from the soil. This water can then be captured in spring capture box (Figure 21). The water above the road should be channelled along ditches to water courses perpendicular to the slope. On steep slopes these streams or channels may require protection and lining to prevent excessive erosion. Since this protection is expensive, it is often most cost effective to channel overland flow into a few well protected channels and culverts than increasing the frequency of culverts but having insufficient funds to line and protect these channels. Road alignment, which is the placement of the road within a landscape, is critical to managing both the cross and road slope. Roads often follow the valley bottom although beyond the flood plain of any river.

Figure 19: Terracing and vegetation stabilise slopes above road

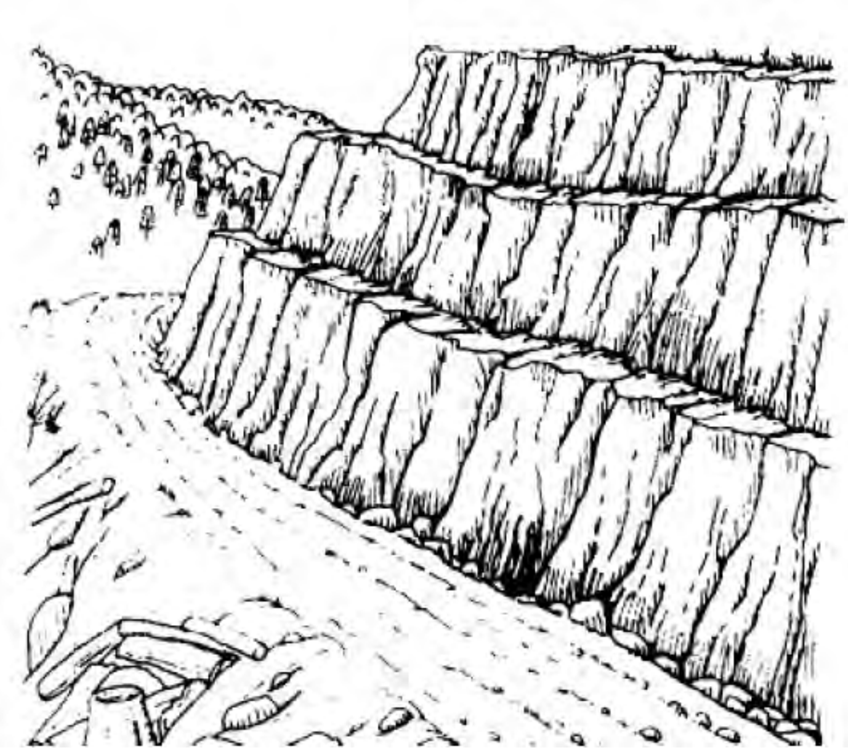


Figure 20: Bench terraces and ditches above the road intercept and channel runoff away


Figure 21 Intercept drains and spring boxes to capture

2.1.3 Failure of mitigation measures

Different efforts have been done but many are not effective

- For 60% of the sites, mitigation measures implemented could not achieve the intended purpose and often contribute to further instability.
- In 50% of the sites, road maintenance carried out up to 4 times in 5 years.
- Construction of retaining structures over a sliding mass.
- Construction of retaining structures not able to resist loads from upslope.
- Lack of proper design for drainage systems and shortage of design knowledge / capacity

2.2 Road water harvesting from road surface

Different road cross slopes and side drainage design is used depending on the terrain (Figure 22). In flat terrain a crown section is used. On rolling gentle cross slopes (less than 15%) the road is sloped downhill (at 4-6% slope) with no upslope drain. In steeper terrain the road is slope towards the upslope drain is used and then carried under the road by a culvert.

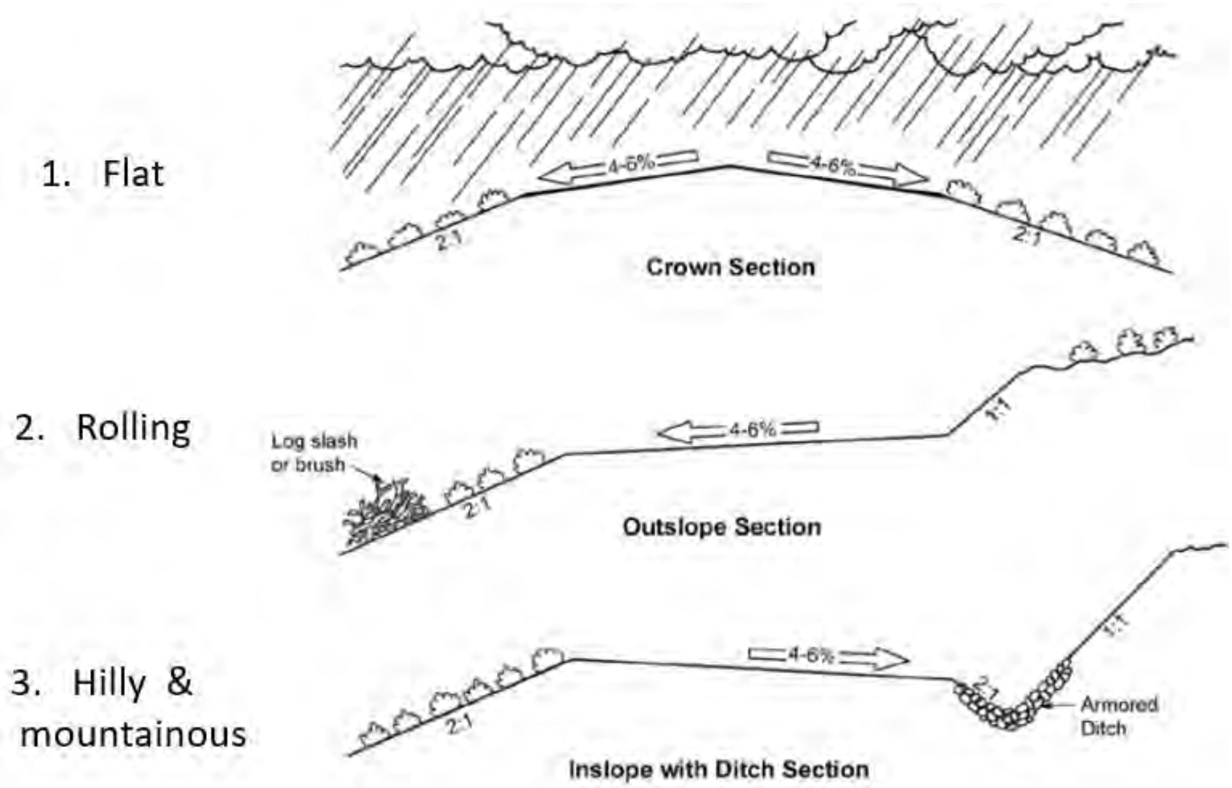


Figure 22: Different drainage is suggested for different types of terrains

Water can be harvested directly from the road surface itself. The amount of water generated from the road surface depends on the road grade or slope (Figure 23) as well as the width and surface of the road and the runoff coefficient of the road surface. A well graded and compacted surface will generate most runoff.

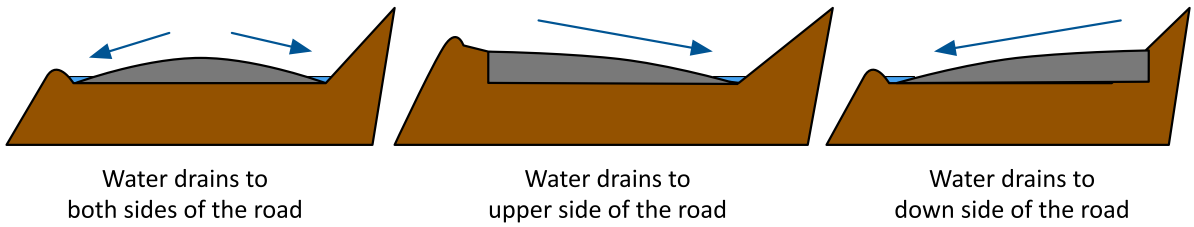


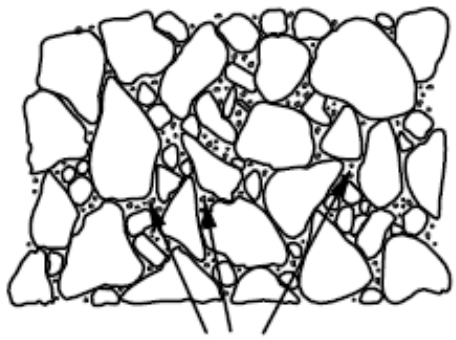
Figure 23: Three examples on how road grade influence road water drainage (Figure developed by Francesco Sambalino)

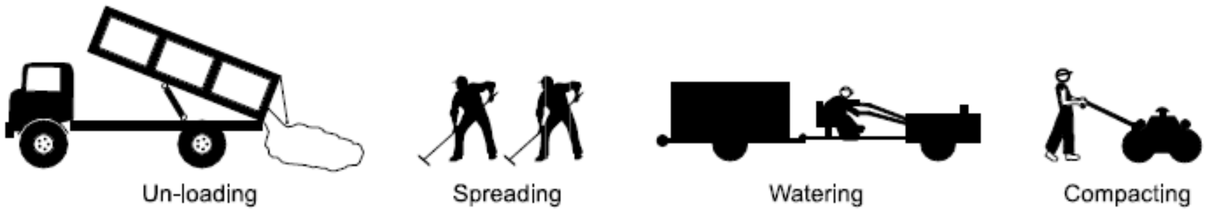
Experiments have shown that a concrete or asphalt paved highway will have a rainwater collection efficiency (RCE, or runoff coefficient) of 0.65 to 0.75. For an unpaved road, the RCE is more variable, ranging from 0.25–0.30 in semi-arid areas up to 0.80 during heavy storms. In humid or sub-humid areas, due to the frequent rain and higher soil moistures, the RCE from unpaved roads is high. Runoff generated by the road surface can be diverted to recharge areas or storage ponds through the use of drainage techniques. The most common road surface drainage methods are rolling dips, water bars and lead-off ditches.

2.2.1 Watering and compaction

ERA recommends that unpaved roads on sandy/weak soils and on swelling black cotton soils should by paved with a 10cm or 20cm layer of gravel. Good gravelling material should contain between 35 - 65% stones, 20 - 40% sand, and 10 - 25% clay. There are basically four methods of compaction:

- Manually or mechanically operated tampers or rammers,
- Deadweight rollers,
- Vibrating compaction, or
- Natural compaction.





2.3 Rolling dips

The function of a rolling dip is to collect surface runoff from the roadway and/or road ditch and direct the flow across and away from the roadway on the down slope. Rolling dips are a preferred technique in dirt roads (Zeedijk, 2006). The excavated material from the dip is used to create a higher area in the dirt road, making the road undulate slightly and so creating different drainage segments (see Figure 25 and 24). Rolling dips are excavated cross-drains at gentle gradients – between 2 and 5 per cent. Rolling dips collect road surface runoff and divert it away from the road. A rolling dip is a broadly angled dip drain with a cross slope of 4-8%, steep enough to flush away accumulating sediments. It is important to maintain slope and velocity of flow to prevent puddling and sedimentation. They additionally can drain upslope drainage water to the downside. Rolling dips are unsuited to terrain that is too flat (road grade less than 3% or cross slope less than 5%) or too steep (greater than 15%).

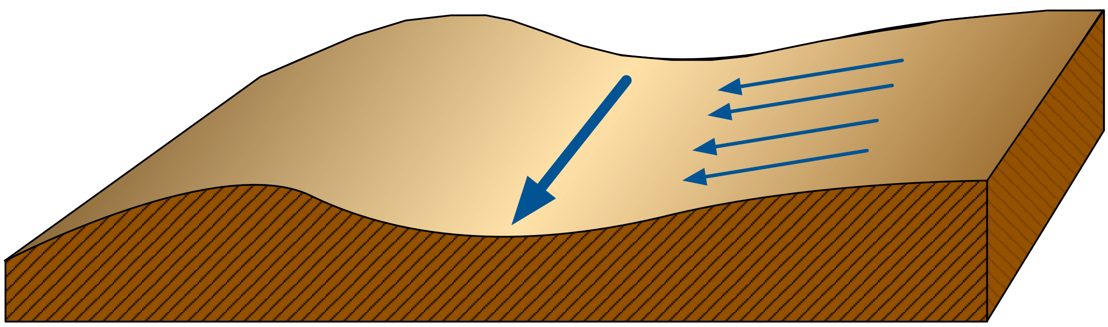


Figure 24: Drawing of a typical rolling dip layout

Rolling dips can be easily constructed into existing feeder roads and they are most appropriate on low speed roads (25-50 Km/h). At higher speed they can become dangerous to drive. Rolling speeds are one preferred option on roads with a maximum gradient of 8-10%. Sometimes they are built on steeper roads, but in that case the excavation work to construct them may become difficult (too deep – too much earthwork).

Rolling dips are built perpendicular to the road or ideally with an angle of maximum 25 degrees. On busier roads it is better to build the dip perpendicular road to avoid frame damage to transiting vehicles. The bottom of the dip must have an outward inclination of 2-5% to allow easy flow to the downside of the road. The whole rolling dip must be long enough to be comfortably driven on. Usually a length of 15-60 meters is suggested.

At the bottom of the dip it might be necessary to add some armoring in the form of broken stones rip-rap or gravel. This is a must when the excavation reaches softer soils beneath the road. Rolling dips are commonly constructed in multiples along the same road. In this case it is advised to keep a minimum and maximum distance between dips. In Figure 25 typical dimensions are provided. It is important to follow its indications and adapt them to the condition of the road in your specific woreda. The outlet of the rolling dip shall be carefully protected to avoid erosion. The collected water can be brought to reservoirs, recharge areas or spread over fields.

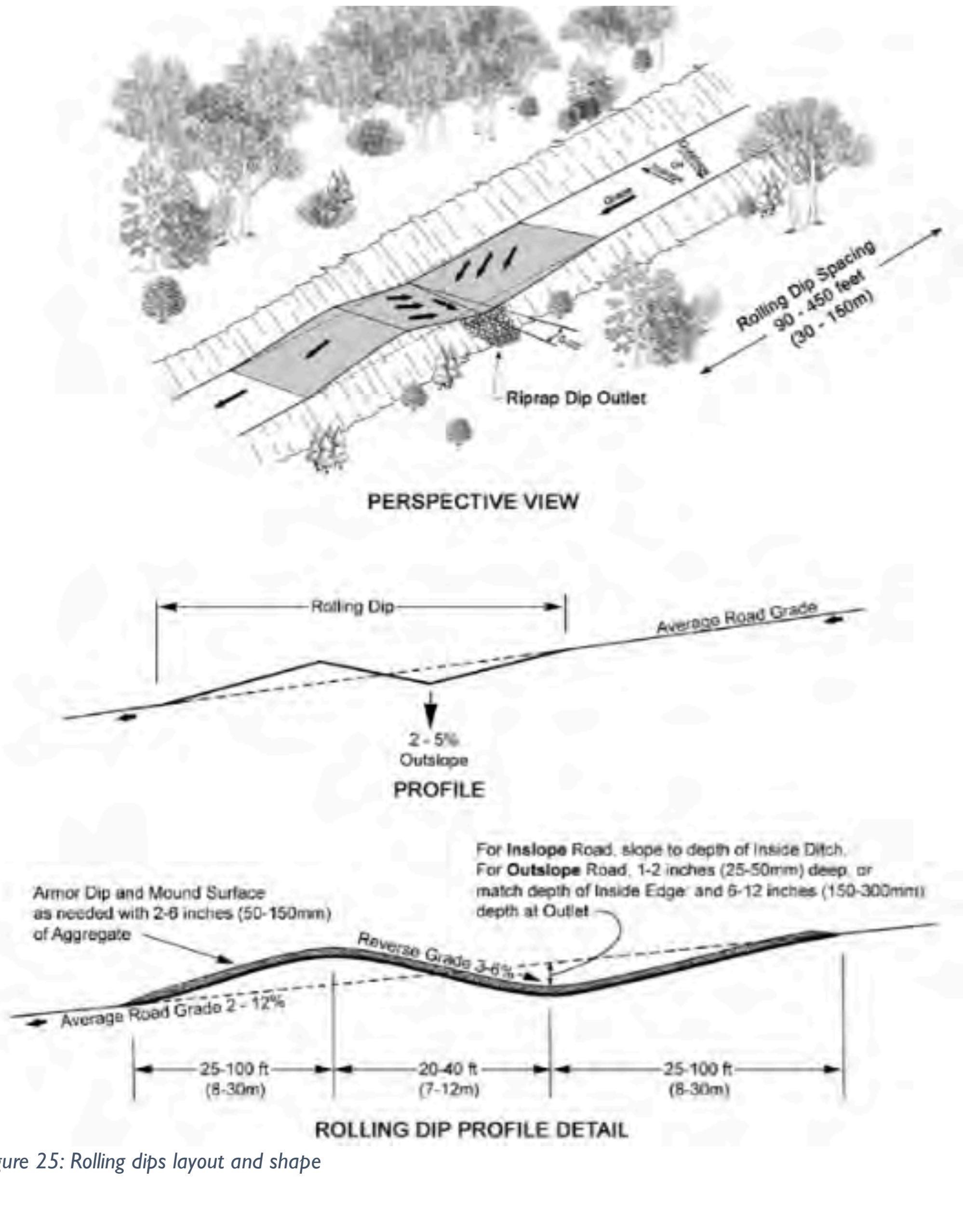


Figure 25: Rolling dips layout and shape

2.4 Water bars

Earth water bars are narrow, earthen bunds built across roads (Figure 26). They divert water off and away from roads or trails into vegetated areas before it causes erosion.

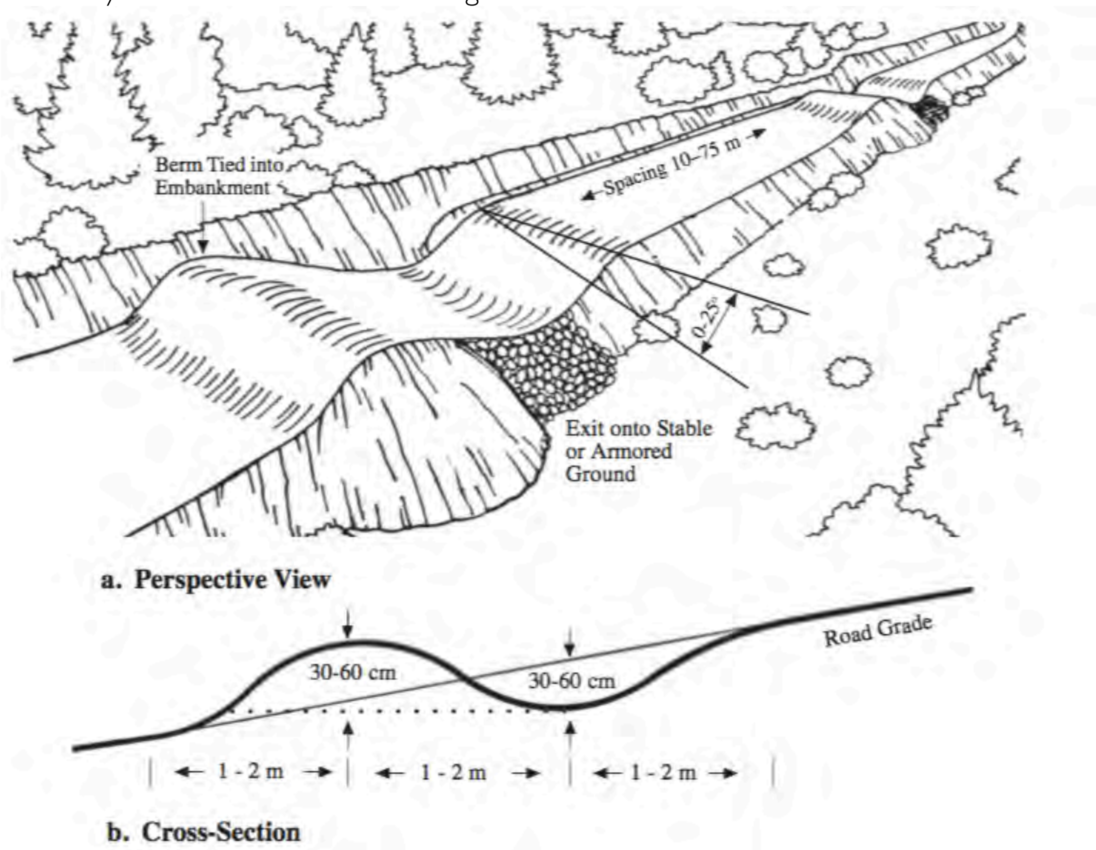


Figure 26: Water bar perspective view (a.) and cross-section (b.) (Source: Keller and Sherar, 2003)

To build an earth-berm water bar, excavate a trench at a 30- to 45-degree angle across the traffic surface. Use the excavated material to build a berm on the downhill side of the trench. Make the top of the bund at least 30 centimeters higher than the bottom of the trench. Make sure the outlet of the trench is at least 8 centimeters lower than the upper end.

Extend water bars slightly beyond both ends of the road to keep water from flowing around them. Direct diverted water into a stable, vegetated area, not into open water. To make a water bar easier to drive over, widen it by increasing the distance between the bottom of the dip and the top of the berm, maintaining the correct height.

Space water bars according to the grade. Table 3 provides an indication of the spacing between consequent water bars, according to soil type and grade.

Table 3 Spacing of water bars depend on the road grade

Recommended Water Bar Spacing (meters)		
Road/Trail Grade %	Low to Non-Erosive soils (1)	Erosive Soils (2)
0-5	75	40
6-10	60	30
11-15	45	20
16-20	35	15
21-30	30	12
30+	15	10

Note: (1) **Low Erosion Soils** = Coarse Rocky Soils, Gravel, and Some Clay
(2) **High Erosion Soils** = Fine, Friable Soils, Silt, Fine Sands

Adapted from Packer and Christensen (1964) & Copstead, Johansen, and Moll (1998)

Advantages
Properly water bars are very effective in diverting water off roads, trails, and landings.

Disadvantages
Water bars are hard to drive over and may be difficult to maintain. They don't work well for active traffic surfaces during most operations. Rocky soils may limit their use. Where there is considerable traffic it is better to use rolling dips.

Maintenance
Rebuild berms as needed if they are damaged by traffic, cattle or heavy rainfall.

2.5 Road water harvesting from 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 (Kubbinga, 2012).

Low volumes of flow and low velocities should be achieved at each discharge point to minimize erosion. To limit erosion, it is important to create regular mitre drains, by paving the drain with rip rap, by planting vegetation or by using scour check.

Water from the side drains should be discharged as frequently as possible. If the water can be discharged on the same side of the road as the drain, a turnout or mitre drain is used to lead the water onto adjacent land or structures (such as ponds). These solutions are covered in more details in chapter 2.6.

The advantage of connecting roadside drainage to such recharge and storage systems is that they help accommodate and store peak discharges. In areas with permeable soils, infiltration of runoff from these drainage systems can serve to recharge shallow aquifers. The recharge areas can also be 'enhanced' by the development of infiltration trenches, and micro-basins. When the water is applied to the field directly, moisture storage techniques common in spate irrigation are most appropriate: mulching and deep ploughing in semi-arid areas will ensure the availability of water later in the growing season (van Steenbergen et al., 2010).

2.6 Mitre drains

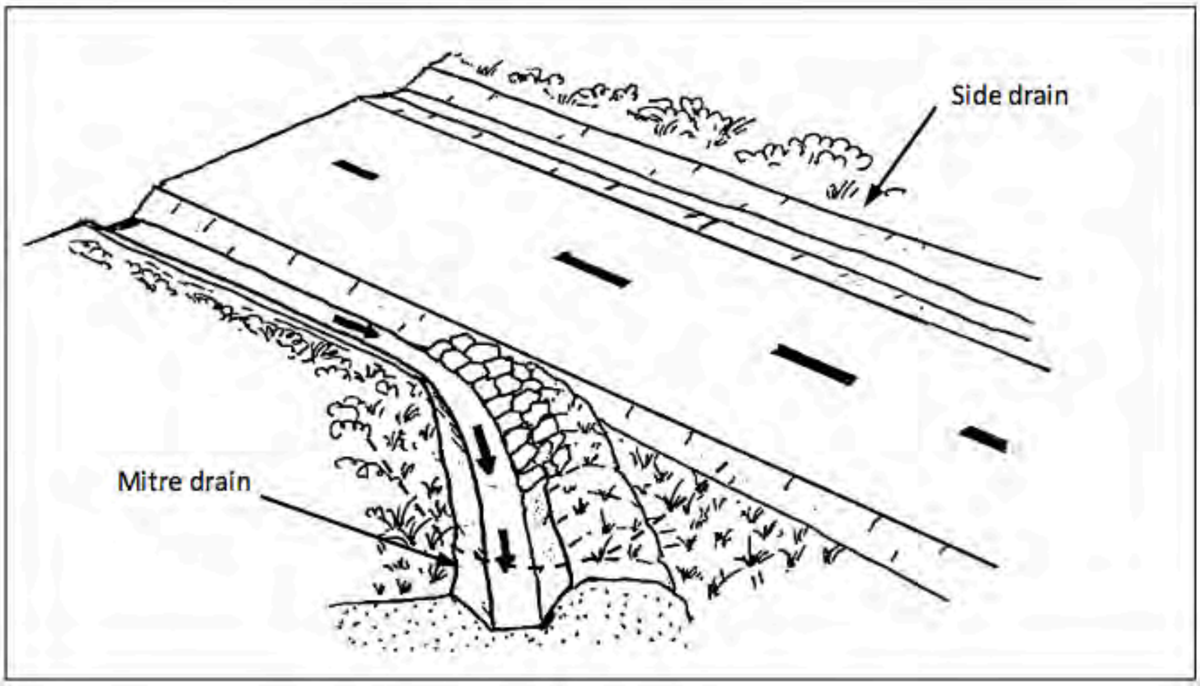


Figure 27: Mitre drain diverting water from main road side drain. This diverts water to a stable area. The water can also be diverted into storage or recharge structures.

A block-off (scour check) is required to ensure that water flows out of the side drain into the mitre drain (Figure 27). The angle between the mitre drain and the side drain should preferably be 30 degrees, but not greater than 45 degrees. Mitre drains are needed to reduce the amount of water accumulating in side drains and to unload it safely to the side of the road. They are commonly built in a sequence.

The desirable slope of the mitre drains is 2%. The gradient should not exceed 5% otherwise there may be erosion in the drain or on the land where the water is discharged. The drain should lead gradually across the land, getting shallower and shallower. Stones may need to be laid at the end of the drain to help prevent erosion.

Where soils are very erodible, it may be preferable to increase side drain capacity to convey runoff to the next available safe discharge point (could be a recharge or water harvesting pond) rather than to construct side drain turnouts or relief culverts on erodible slopes. With the extra volumes of water that this entails, the design of these less frequent safe discharge points will usually be more expensive.

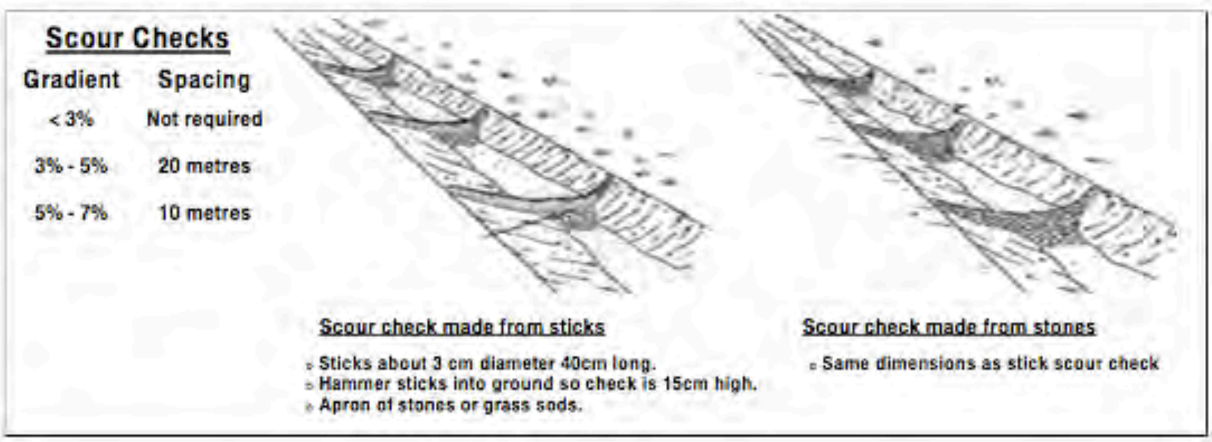
In mountainous terrain, it may be necessary to accept steeper gradients. In such cases, appropriate soil erosion measures should be considered.

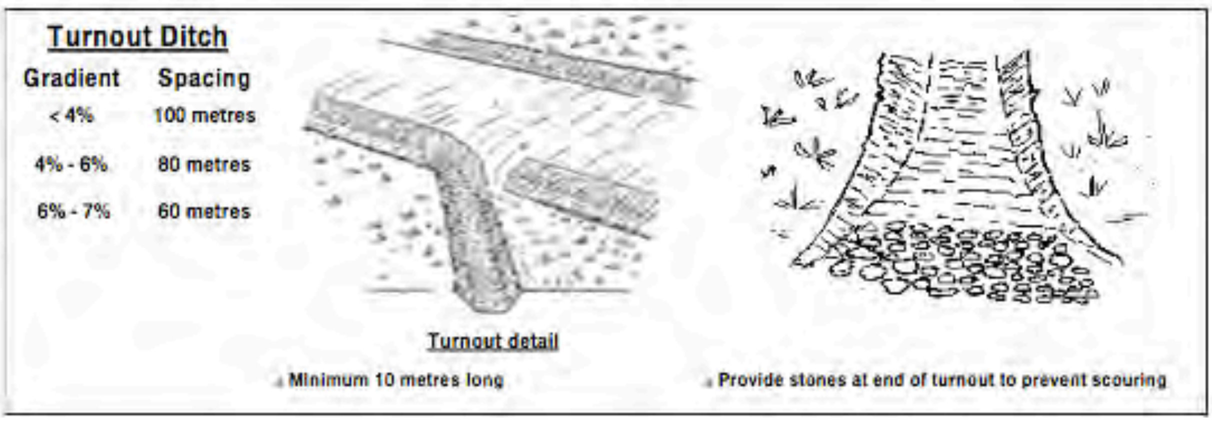
In flat terrain, a small gradient of 1% or even 0.5% may be necessary to discharge water, or to avoid very long drains. These low gradients should only be used when absolutely necessary. The slope should be continuous with no high or low spots. For flat sections of road, mitre drains are required at frequent intervals of 50m to minimise silting. It is therefore advised to always consult land owners before discharging water in their land.

Table 4: Maximum distance of mitre drains (Adapted from ERA guideline B)

Road gradient (%)	Maximum mitre drain interval
12	40
10	80
8	120*
6	150*
4	200*
2	80**
<2	50**
* A Maximum of 100 m is preferred ** At low gradient silting becomes the major issue	

The angle between the mitre drain and the side drain should not be greater than 45 degrees. An angle of 30 degrees is ideal.





On roads situated in flatter areas, such as alluvial plains and valleys, so-called **flat drains** can be used. Typically, in flat drain areas, where sheet flow runoff is more common than concentrated runoff, low stone bunds can be added along the roads, so as to reduce water velocity and increase infiltration. Low permeable bunds can be made of stones to decrease runoff speed and to spread runoff gently to the adjacent fields. This prevents the development of ruts and gullies, while at the same time improving moisture content in adjacent lands.

Ox drawn scopes (Figure 28) can be used to reduce labour needs for earthworks such as the construction of rolling dips, side drains, mitre drains and ponds

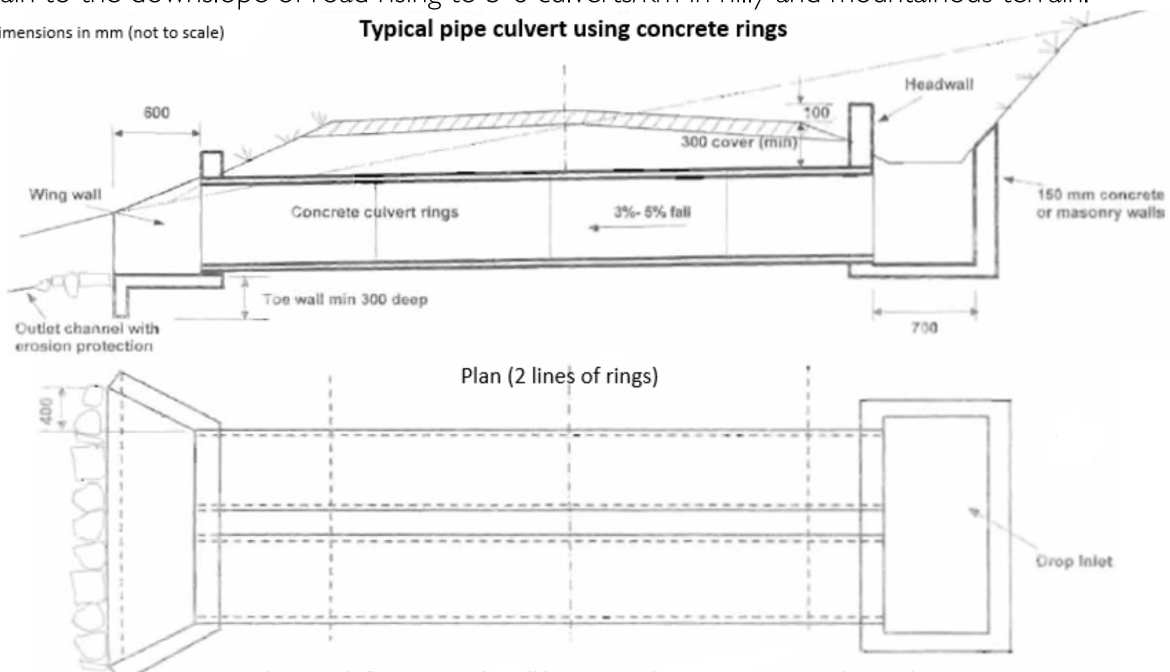
Figure 28: Ox drawn scoops reduce labour demand for earthworks

2.7 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. On roads prone to flooding use concrete drifts as shown in Figure 39. As a general rule 1-2 culverts/km are required on rolling terrain to carry water from upslope drain to the downslope of road rising to 5-6 culverts/km in hilly and mountainous terrain.

Dimensions in mm (not to scale)

Typical pipe culvert using concrete rings



Culvert or drift is required at all locations where water crosses the road

Advantages	Disadvantages
▪ Culverts provide a relatively cheap and efficient way of transferring water across a road ▪ Can be constructed and maintained primarily with local labour and local materials ▪ Culverts allow vehicle and foot passage at all times ▪ Culverts do not require traffic to slow down when they are crossed ▪ Culverts allow water to cross the road at various angles to the road direction for a relatively small increase in costs	▪ Regular maintenance is often required to prevent the culvert silting up, or to remove debris blockage ▪ Culverts act as a channel, forcing water flow to be concentrated, so there is a greater potential for downstream erosion compared with drifts ▪ Culverts are not suited to occasional high volume flows

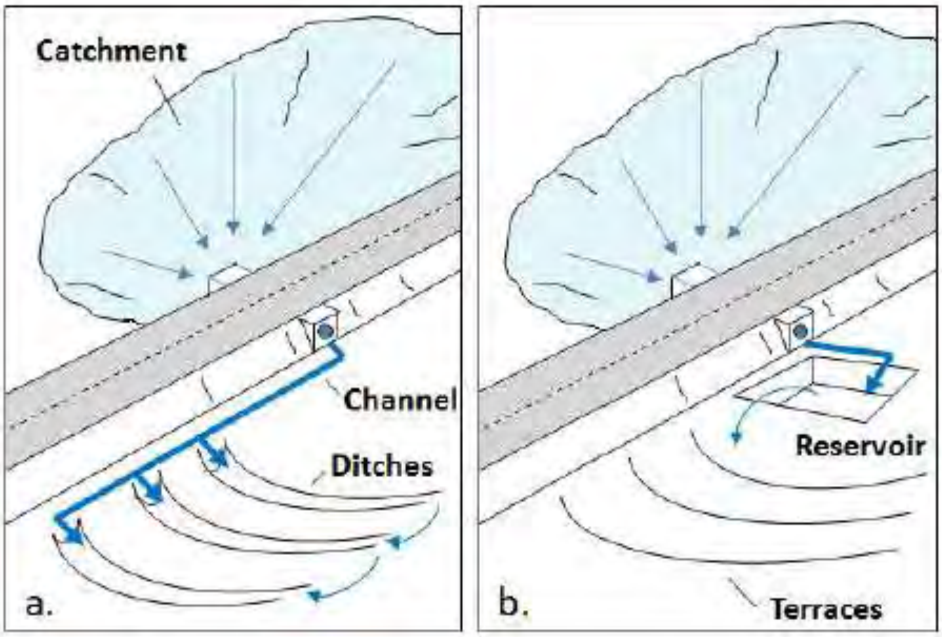


Figure 29: Options for spreading or storing water from culverts

2.8 Gully prevention and reclamation

Road construction through steep lands, without adequate provision for drainage systems, is a major cause of gully erosion. Inadequate drainage systems for roads (small number of culverts, insufficient capacity of road ditches, etc.) are a major cause of gullying. If road cuts and fill slopes are not re-vegetated during or immediately following road construction, gullys may form on both sides of the road. Related to roads, poorly managed and abandoned quarry sites are also potential sites for runoff generation and its concentration flow to low lying farmlands and drainage ditches.

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

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

Retention of water on the watershed that contributes to the road drainage system through mechanical and vegetative measures is useful for effective gully control. It is advisable to retain as much runoff water as possible in the gully catchment through different moisture retention techniques. Proper management of the runoff water and increasing the vegetative cover of the watershed improves the watershed hydrology, improves the watershed conditions, increases infiltration, reduces overland flow, and enhances the gully healing process. There is a very strong connection between road generated gullys and watershed management.

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

A. Improvement of gully catchments to reduce and regulate the run-off volume and peak rates;
B. Diversion of runoff water upstream of the gully area;
C. Stabilization of gullys by structural measures and accompanying re-vegetation.

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

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

Ethiopia has a very strong experience in watershed management and rehabilitation. Soil and water conservation practices such as soil bunds trenches and micro-basins are widely used and all contribute to check runoff speed and quantities before it become erosive. Community watershed management is therefore ideal in preventing excessive runoff water.

B - Diversion of runoff water upstream of the gully area

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

Cutoff drains and waterways (Figure 30) are drainage management structures which are commonly used to divert runoff before reaching gullies, cultivated lands and residences.

- Used to conduct run-off from cut-off drains to storage structures
- Grass waterways for slopes up to 25%
- Steeper slopes, channel lined with stones, masonry or reinforced concrete

- Dimension depends of the expected discharge
- Diagonally across de slope not recommended, if they break or overtop can cause serious damage
- The preliminary position should be determined from a reconnaissance field survey
- Where possible, it should be located in a natural depression or water way.

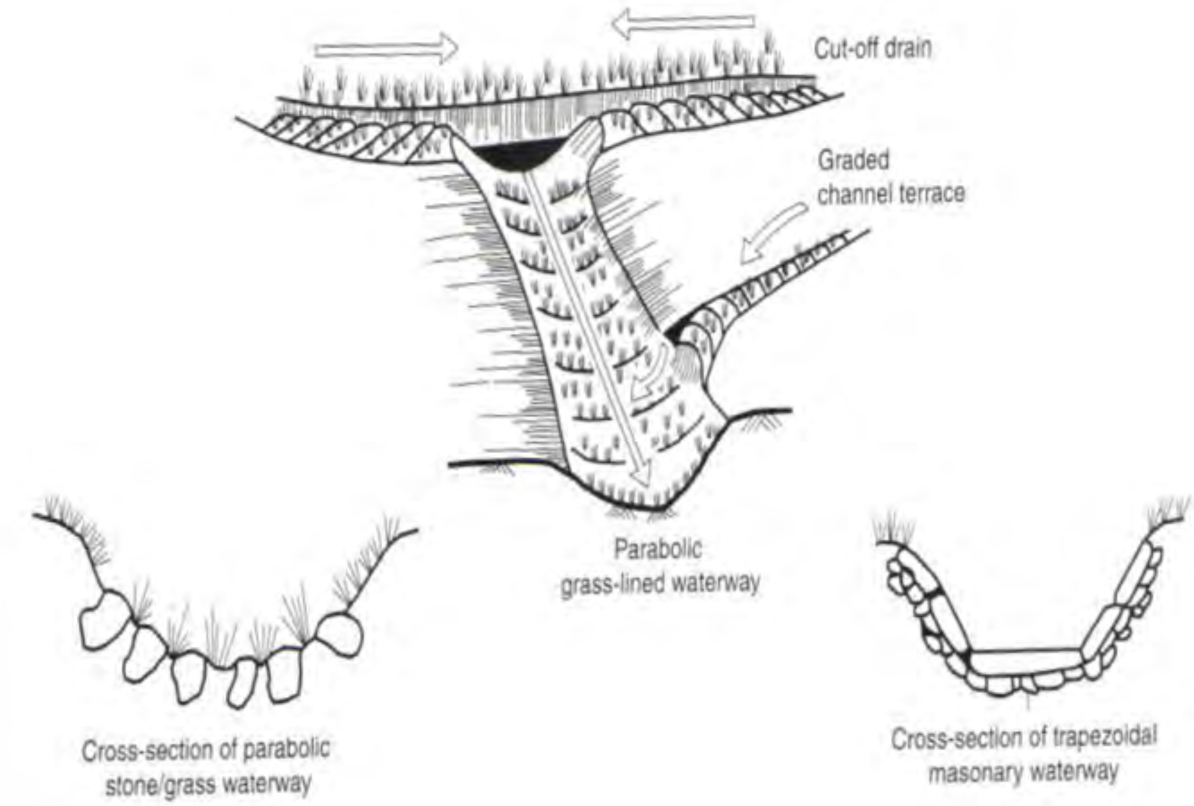


Figure 30: Cutoff drain and stabilized waterways

C - Stabilization of gullies by structural measures and accompanying re-vegetation.

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

Typical measures/interventions are:

1. Gully reshaping (Figure 31): Gully wall reshaping is cutting off steep slopes of active gully flanks in to gentle slope (Minimum at 45% slope) and constructing small trenches along contours for re-vegetating the gully walls and beds

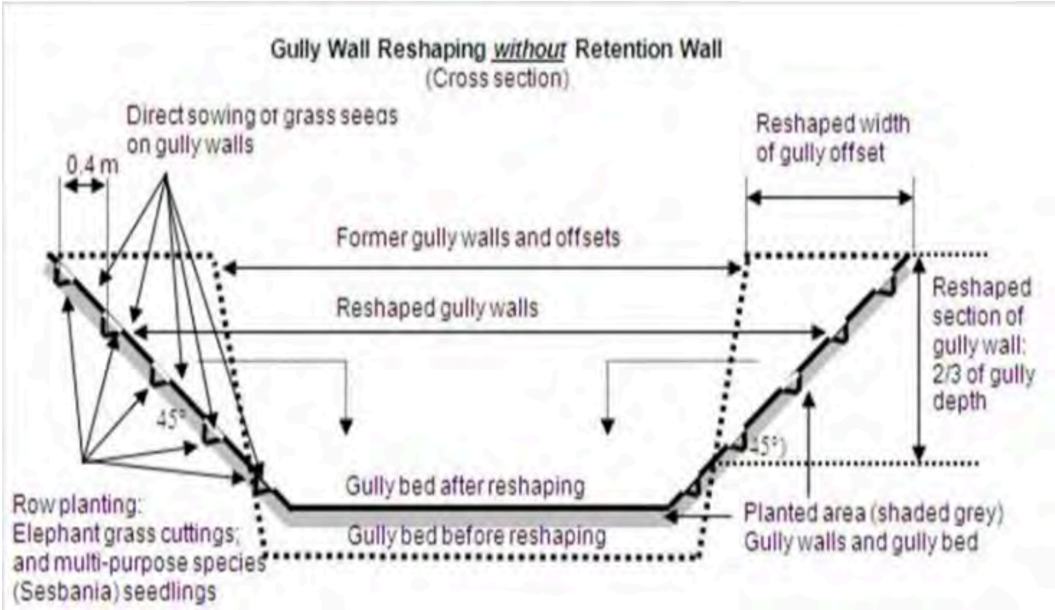
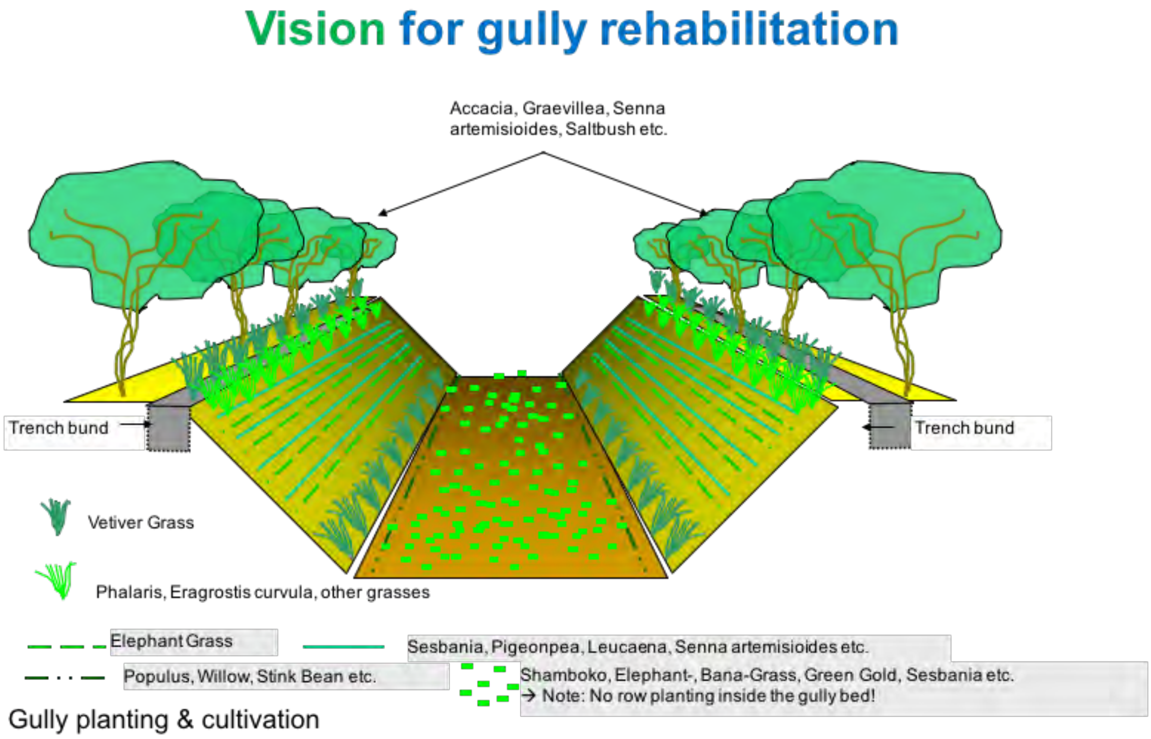


Figure 31: Stabilized gully with side walls cut and filled at 45 degrees

2. Check dams construction: check dams are temporary barrier that stabilize the gully, trap sediments and give time to the vegetation to claim back the eroded area. Several type of check dams are used and advised in Ethiopia:
    a. Gabion check dams (Figure 32)
    b. Brush and loose stone check dams, for small gullies. This fits well in small gullies in the road side drains.
    c. Arc-shaped check dams
    d. Plastered gabions check dams

Figure 32: Gabion check dam below road culvert

3. The use of vegetative material in gully control offers an inexpensive and permanent protection. Vegetation will protect the gully floor and banks from scouring. Grasses on the gully floor slows down the velocity of the runoff and causes deposition of silt. It can also be of economic value to the land users. Vegetation can be established in a gully by natural recovery or use of planting materials.



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

2.9 Solutions: spreading, storage and aquifer recharge

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 obtained water can be used in different ways. Many examples exist and a standardized design does not exist. It all depends on the landscape characteristics and the final use of the harvested water. Nevertheless some overall guidance principles can be drawn.

The obtained runoff water can be (see also Figure 33):

1. Spread over land to provide additional water for crop/grass/tree production. The water can also be directed to planting pits and trenches that are used to grow trees of different kinds. Water is stored in the soil and then directly used by plants
2. Collected in storage structures such as water harvesting ponds, small earthen dams, old borrow pits, cisterns. The water can be later reused for multiple purposes.
3. Spread over areas with high infiltration (recharge areas) to boost shallow aquifer recharge. Alternatively, the water can be directed in structures such as deep trenches and recharge pits/ponds. The water can be reused through shallow wells or revitalized springs.

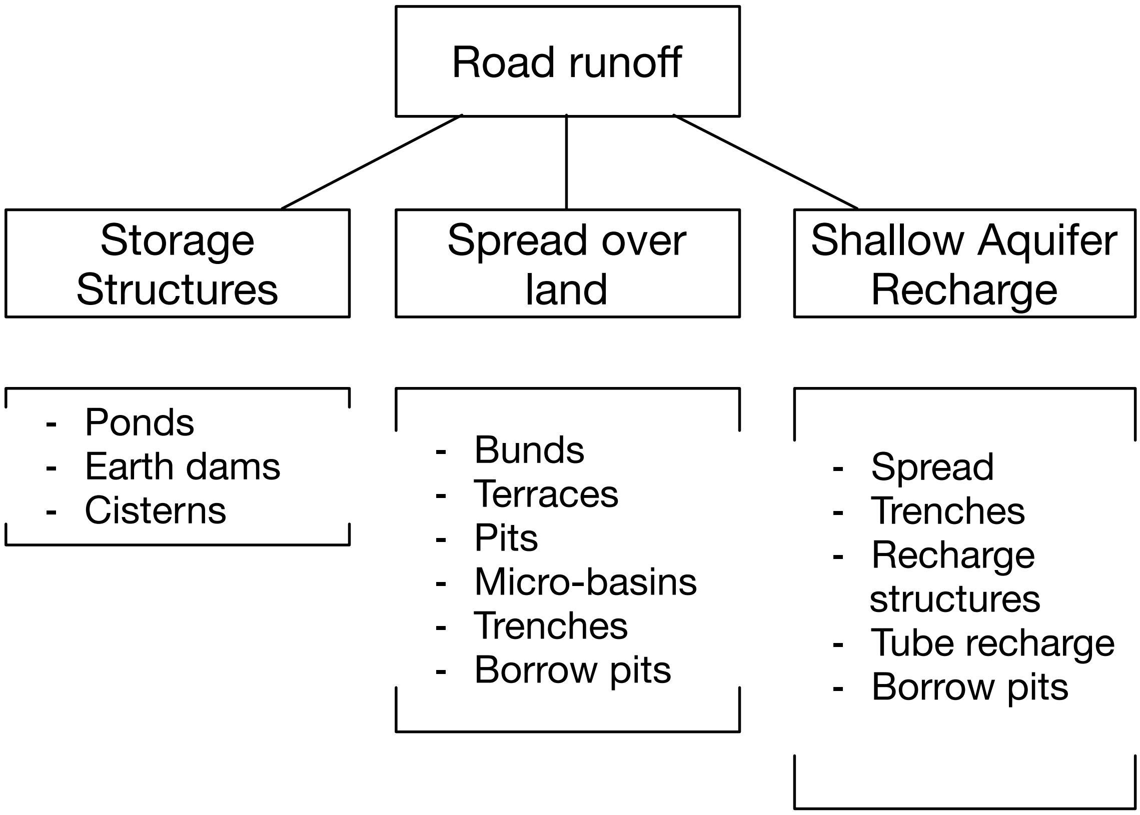


Figure 33: How can road runoff be managed

2.9.1 Spread water over land

- Use water to spread gently away from natural drain to avoid erosion
- Construct these culvert water spreaders early on so that no gully will develop
- Gently guide the water to agricultural land
- Reinforce the bund with stones when available

Runoff water spreading can start from either road side drains or culverts. The key element here is the construction of ditches and bunds with different sloping angles.

1. At first the water is brought to the target area using simple diversion structures from culverts and road side drains (Figure 34). The most simple diversion structures are loose stones barrier that slow down the runoff and divert it laterally in direction of the fields. A good example of this are mitre drains. Downstream of culverts, when the waterway reaches flat areas (0-5%) flood spreading weirs can be adopted.

Figure 34: Runoff water diverted from a culvert towards farming land

2. Afterwards the water can be directed to the fields/grazing area with small ditches with a very gentle side slope to avoid erosion. It is suggested to keep the gradient of the ditch to 3%.
3. Once reached the field there are many ways to apply water. Some typical methods are:
    a. A levelled ditch at the top of the field, homogenously spill water to the downstream field. Nevertheless, the field needs to have a very even and continuous gentle slope to avoid erosion and waterlogging;
    b. The field is divided in sub-basin (Figure 35). Water is allowed in the uppermost basin. Once filled its retaining bund is breached to allow water to enter the consequent field downslope.

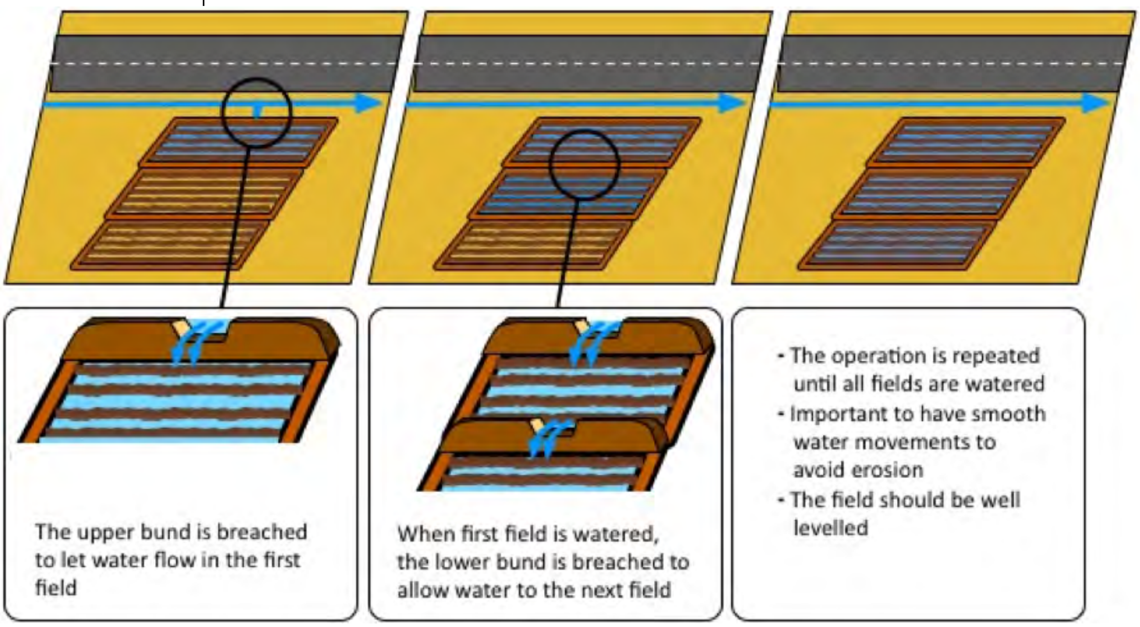


Figure 35: Flood irrigation sequence

c. Water is directed to planting pits which are connected to each other by ditches (Figure 36). Once a pit is filled water continuous to the consequent pit. This system is typically used to grow high value trees. In some areas the same principle is applied with long trenches.

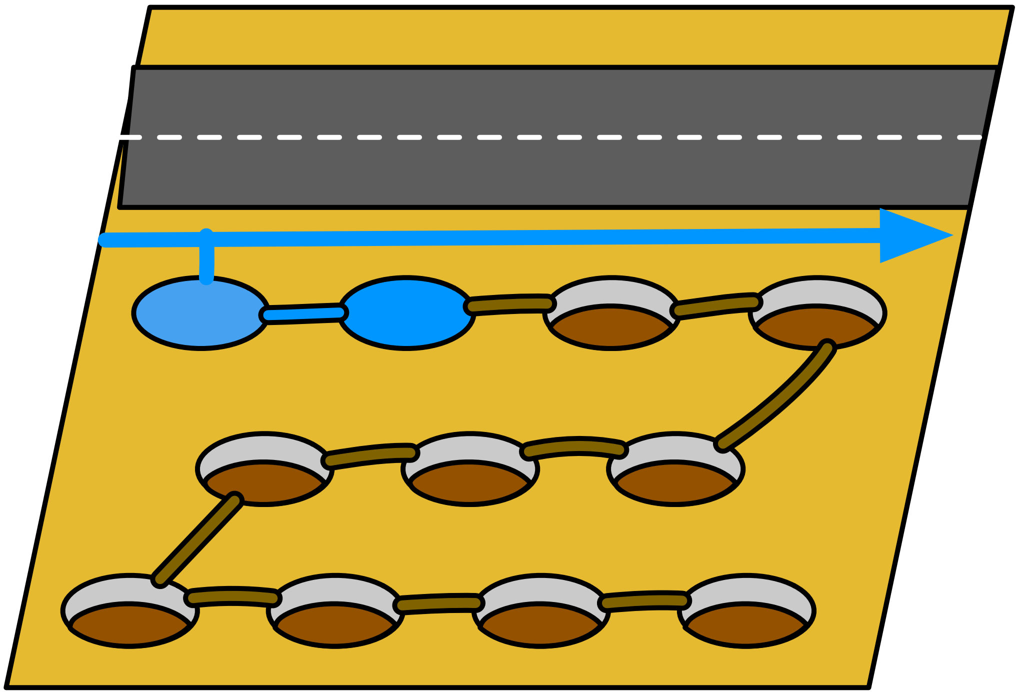


Figure 36: Road runoff is directed to inter-connected soaking pits

4. In grazing areas there are less concerns in the management of water. If there is a permanent vegetation cover and the area is flat, the water can be directly spread over the area without additional structures and/or earthwork. Alternatively when water can be spread in a controlled manner using low earthen or stone bunds along the contour or vetiver grasses

2.9.2 Collect water in storage structures

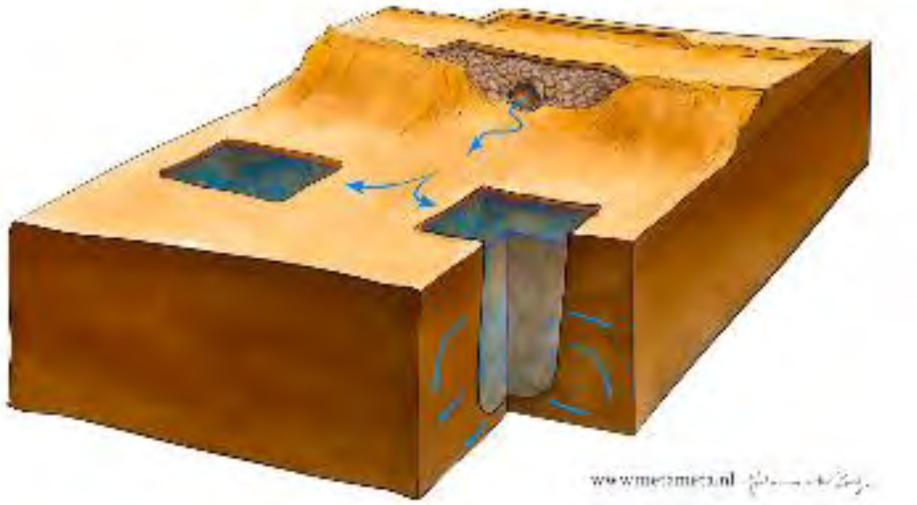
1. At first the water diverted from culverts and road side drains. The most simple diversion structures are loose stone barriers that slow down the runoff and divert it laterally in direction of the storage structure.
2. Afterwards the water can be brought to the target storage with small ditches with a very gentle side slope to avoid erosion (<3%).
3. Storage structures vary in shape, dimensions and construction material. Most of them can be classified as follows:
    a. Open storage: Ponds (Figure 37), small dams, hafir dams, armored reservoirs (cement, masonry). When using earthen structures it might be necessary to line the structure in order to reduce seepage losses.
    b. Closed storage (Figure 38): Cisterns of various shapes

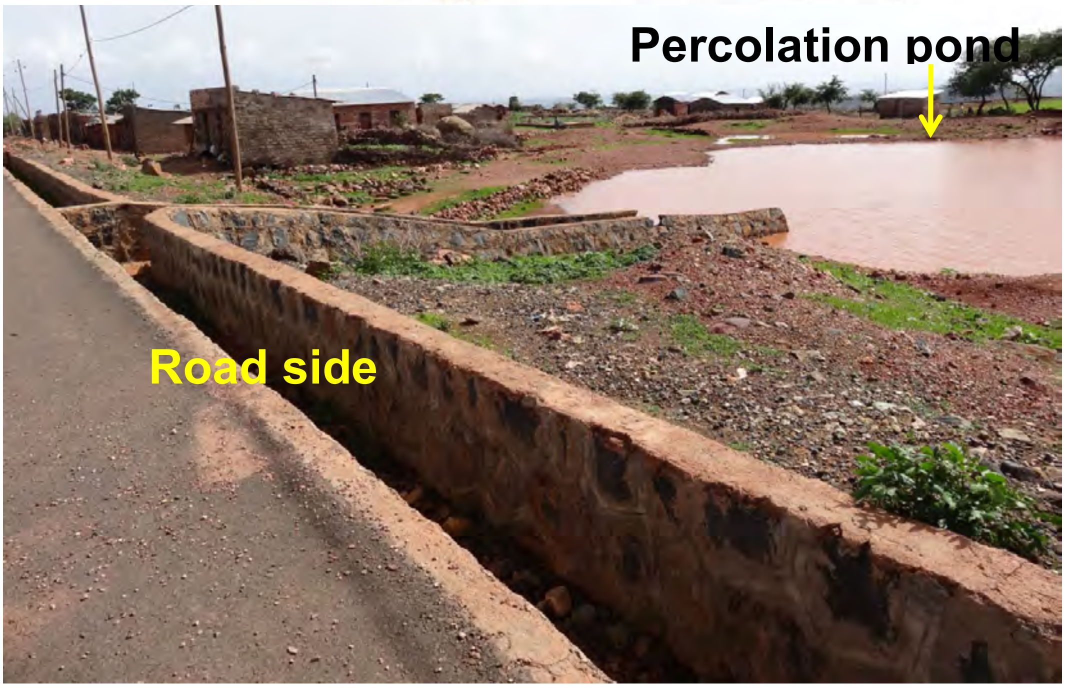

Figure 37: Road side runoff diverted into ponds for surface water storage and groundwater recharge.


Figure 38: Closed masonry cistern in Yemen

2.9.3 Enhance recharge

1. At first the water diverted from culverts and road side drains. The most simple diversion structures are loose stone barriers that slow down the runoff and divert it laterally in direction of the fields.
2. Afterwards the water can be brought to the target storage with small ditches with a very gentle side slope to avoid erosion (<3%).
3. For recharge two main options are available:
    a. Spread water over flat areas with high infiltration rate. Flow over the areas should be minimal to allow it to enter the ground. To spread the water homogenously is possible to use bunds laid precisely along the contour lines. Water spreading weirs can also be used.
    b. Use recharge structures such as:
        i. Old borrow pits that where dug to extract road materials
        ii. Deep trenches (technical details in Annex 1)
        iii. Recharge pits and recharge ponds (technical details in Annex 1)





2.10 Road-river crossings

Locate bridges and other hydraulic structures on narrow sections of rivers and in areas of bedrock where possible. Design critical bridges and culverts with armored overflow areas near the structure to withstand overtopping, or that have a controlled "failure" point that is easy to repair. Alternatively, over-size the structure and allow for extra Freeboard on bridges to maximize capacity and minimize risk of plugging. Also avoid constricting the natural channel.

Ensure that structural designs for bridges, retaining walls, and other critical structures include appropriate seismic design criteria and have good foundations to prevent failures during earthquakes. Place retaining structures, foundations, and slope stabilization measures into bedrock or firm, in-place material with good bearing capacity to minimize undermining and foundation failure, rather than placing these structures on shallow alluvial soil or on loose fill material that are scour susceptible and problematic or that otherwise require costly foundations. Avoid mid-channel piers.

Bridges (and large box culverts) are used on National roads that have higher speeds and continuous access. On low volume rural roads, drifts are the preferred design for road crossings across seasonal rivers. Culverts are prone to blockage. The paved area of the drift forms the spillway. Often this paved area does not extend sufficiently and as a result the river in flood can erode the river bank and cut a new river channel around the drift

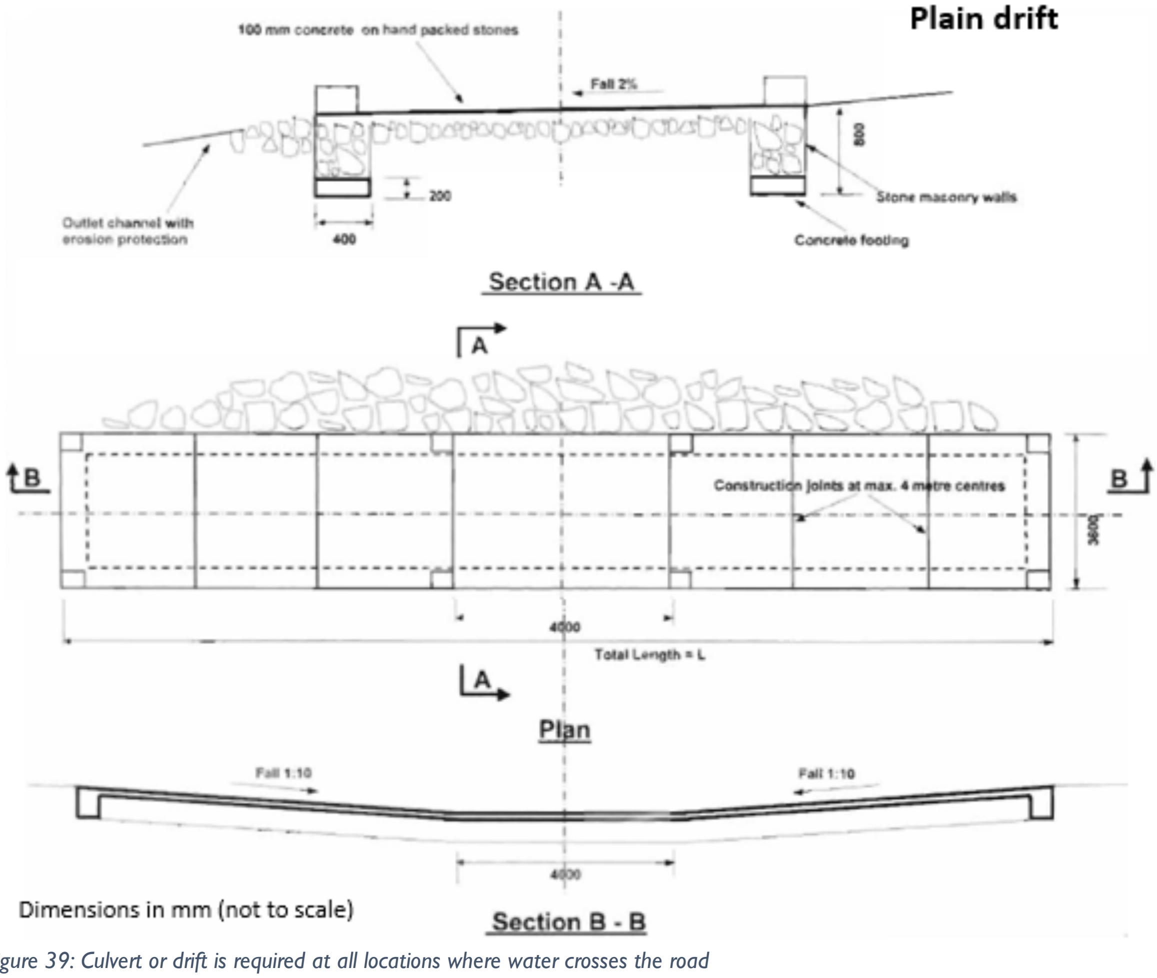
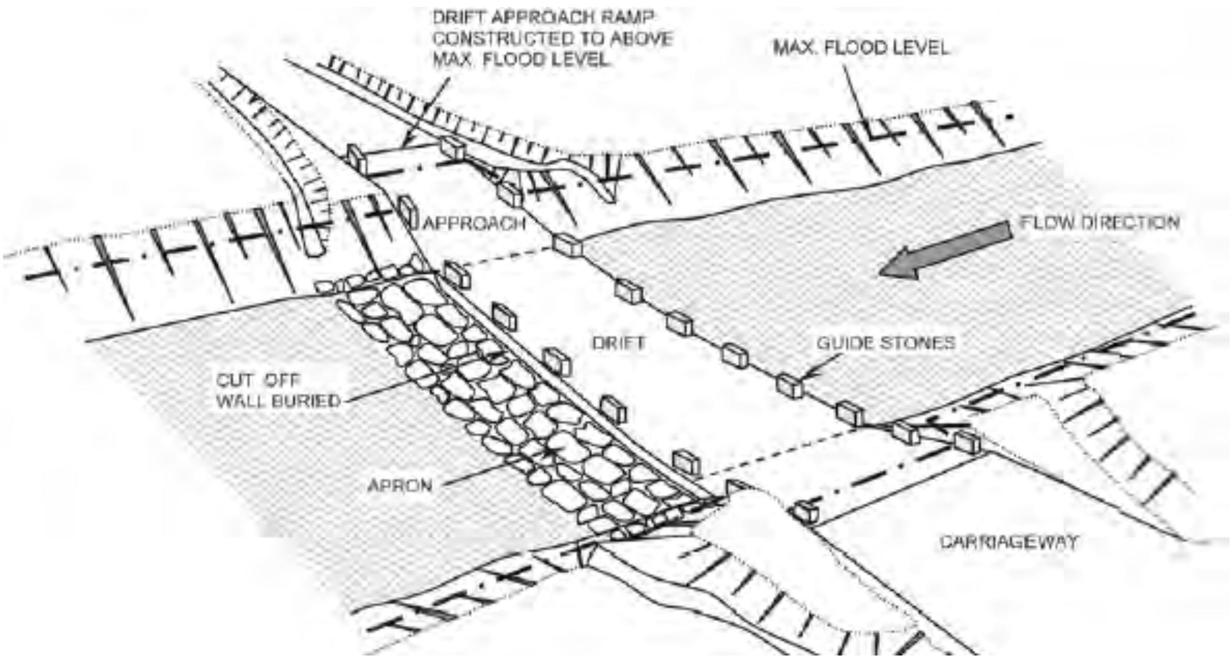
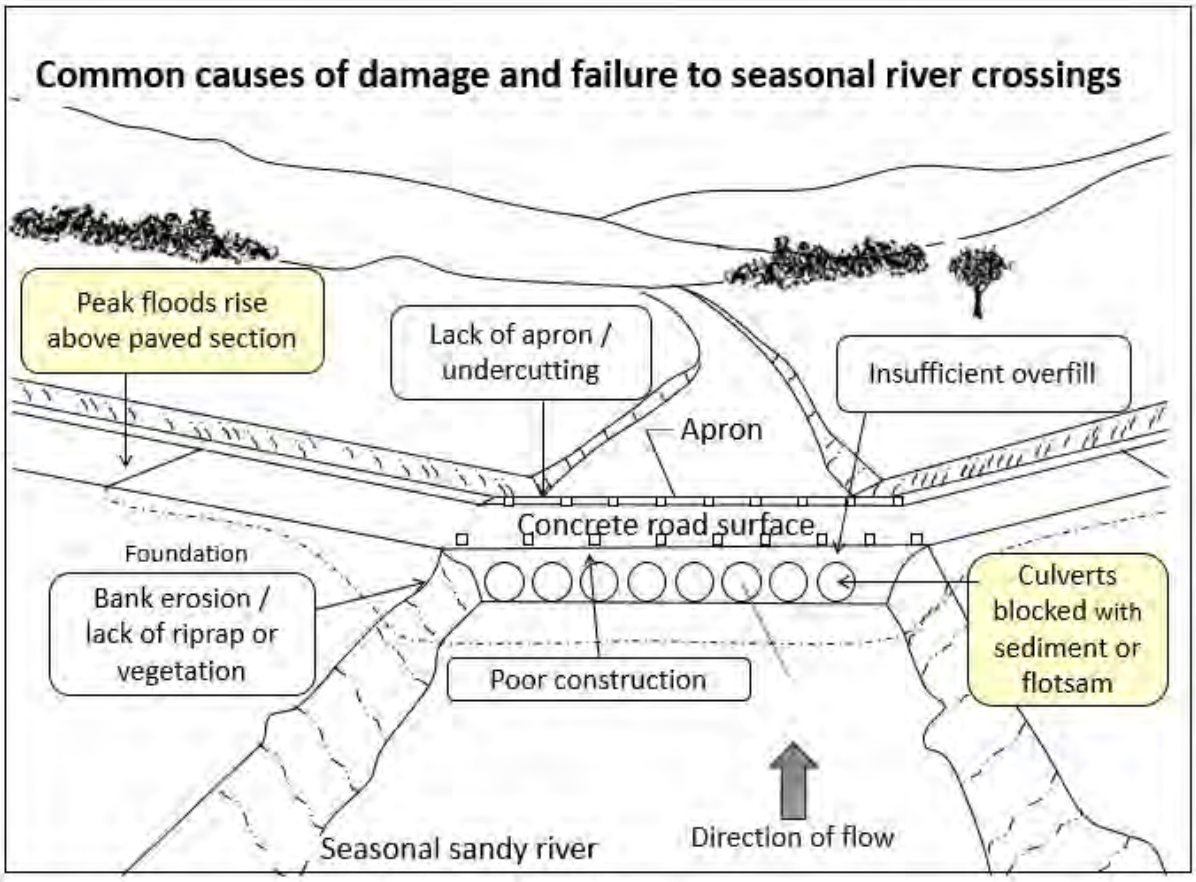


Figure 39: Culvert or drift is required at all locations where water crosses the road





In Kenya, there are examples of road drifts that have been raised. Provided the paved area extends sufficiently up the river banks that the spillway capacity remains unchanged, these raised drifts act as sand dams whilst retaining sufficient capacity to accommodate the peak design flood. River sediment collects behind the drift and water is stored in the sand. This water is protected from evaporation and contamination. An infiltration gallery and shallow well allows this water to be abstracted for domestic and productive purposes.

In flatter flood plains, water spreading weirs can be combined with road crossings. The weir spreads water (and river sediment.) onto the flood plains, recharging the shallow groundwater and allowing flood recession farming on the residual soil moisture. Water spreading weirs can be combined with road crossings as shown in Fig. 35.. They have the added advantage of stabilising the river bed upstream of the crossing. A stable river bed makes the construction of temporary offtake structures or bunds for upstream spate or flood diversion irrigation simpler and more predictable.

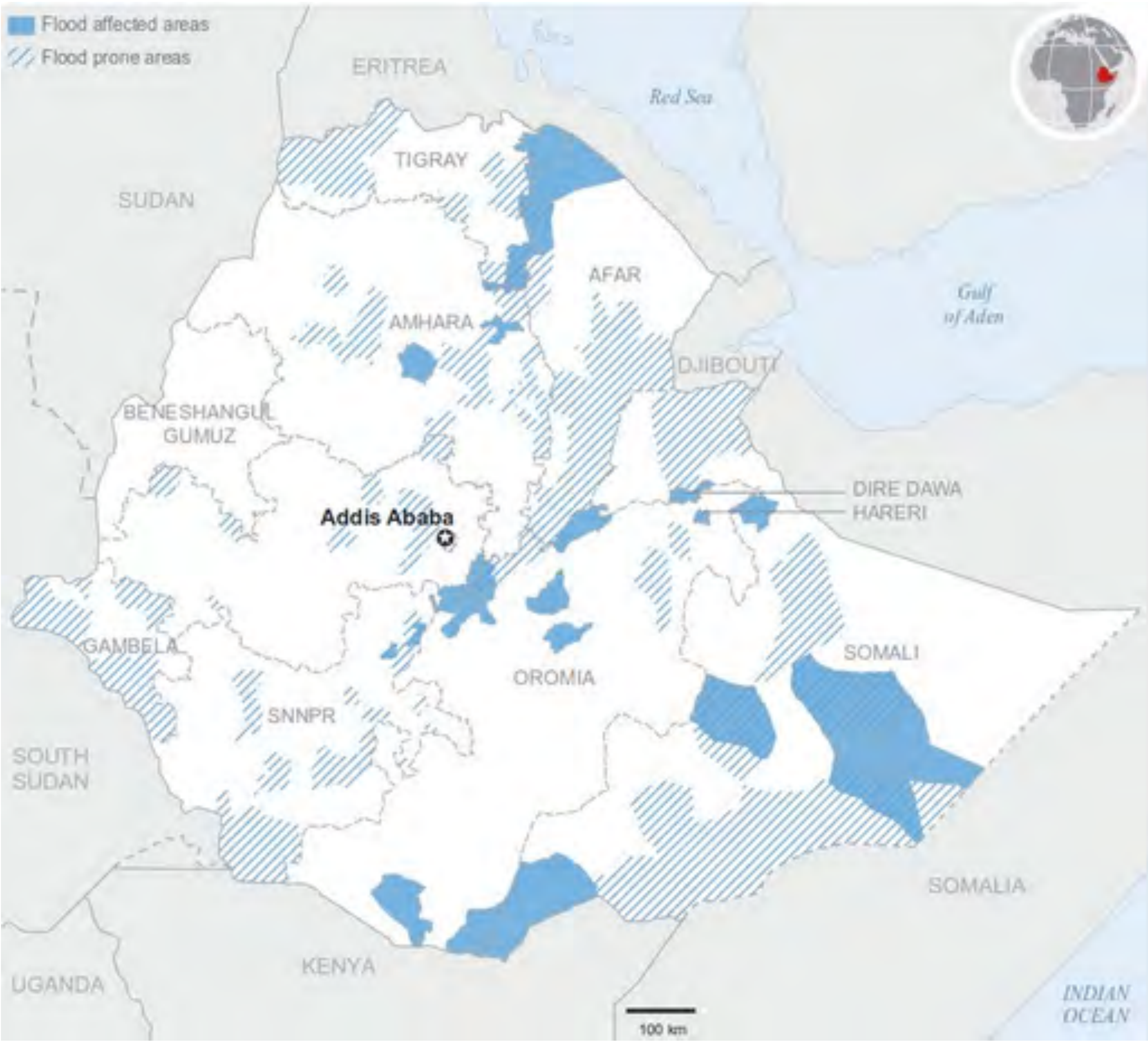
Figure 40: Water spreading weirs / spate irrigation, Niger

Figure 41: Combined flood spreading weir and road crossing, Niger

2.11 Floodplains and valley floors: Flood management and protection

Flooding has both costs and benefits. Costs include damage to infrastructure and houses, lost lives and crops and benefits include sedimentation provides fertile lands, flushing of stagnant water and pollutants and opportunities for flood based farming, distribution of moisture. The goal is to adapt to the constraints floods impose whilst maximising and taking advantage of benefits

Roads to control or contain floods. Roads are vital in evacuating people during floods. Road embankments act as dykes. Roads embankment when raised and reinforced act as a 'reservoir dam' storing floods. Flood plains cover more than 30 M ha in sub Saharan Africa. Roads fragment habitats and influence the flow of water, sediments, nutrients and aquatic life in wet season. Poor access hampers food distribution. Roads impact dry season activities by water storage and moisture availability which impacts burning of grazing land. Roads can affect the gradient of local streams and cause them to silt up. Roads in flood plains are in high danger of damage and disruption of traffic



2.11.1 To manage floods, we need to understand the following

- Map the extent of inundation in flood season and permanent and seasonal wetlands
- Frequency and annual variations in flood rise and recession patterns

- Impact of floods on livelihood systems and activities during flood and dry season: farming, pastoralism, fishing
- Emergency preparedness and response to floods
- Evidence of changes in rainfall patterns and sea level

There are 2 flood management strategies: resistance and resilience.

2.11.2 Resistance strategy:

Embankments and roads are constructed to protect areas from the influence of floods
Disadvantages:

1. Pressure on the structure can cause **damage** and high maintenance costs
2. Floodplain hydraulics are **disrupted**, which negatively impacts on the floodplain ecosystem
3. Water **quality problems** because dirt and polluted water are no longer removed by the flood waters

2.11.3 Resilience strategy:

- Creates safety against extreme river floods by widening river
- Situating dykes away from river or lower river forelands to reduce velocities and water levels by providing space for river.
- Requires properly designed flow-through structures that withstand high flow velocities.
- Minimizing the negative consequences of floods, whilst maintaining natural floodplain dynamics as much as possible.

- Better understanding and investment required but longer term costs (road damage and ecological impacts) lower.
- Important to locate bridges and culverts at best locations and only small additional construction costs.
- Preferable in low intensity flood plains

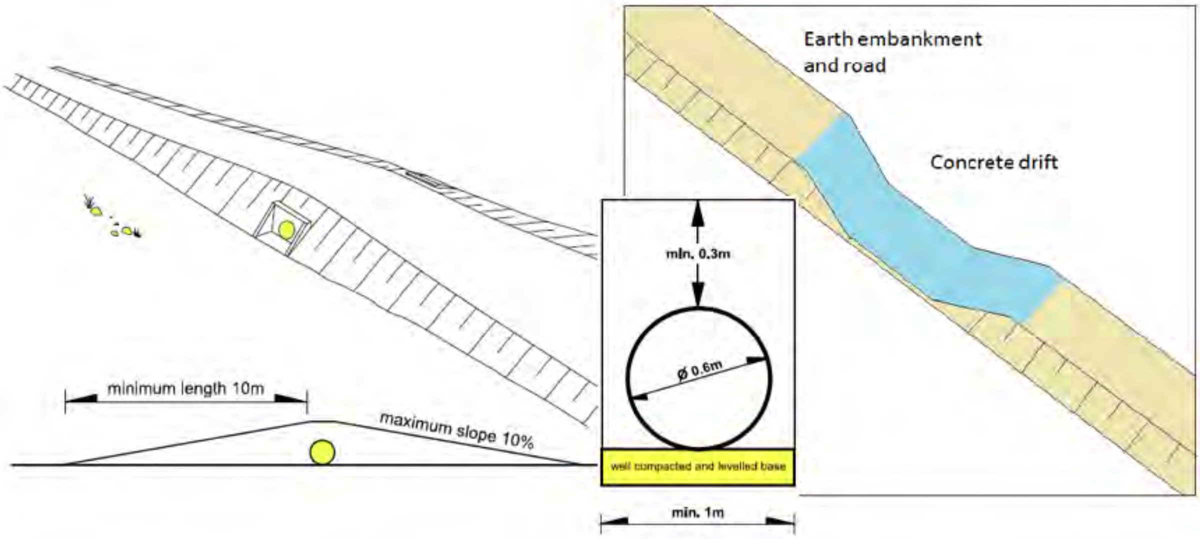


Figure 42: Culverts often have insufficient capacity and are prone to flood damage. Concrete drifts have greater capacity to transfer flood flows over the road

Often the capacity of culverts is insufficient resulting in the road being inundated by the flood and severely damaged by traffic. An alternative is to construct a concrete drift or ford would allow more water to flow over it safely.

The recommended crest level for National and Provincial roads is the highest recorded flood level plus 0.5 meters. For regional roads the crest level should correspond with 10 year flood plus 0.25 meters. For road embankments can be up to 4 meters high with a slope gradient of 1:3 Investigate top soils and remove inappropriate top soils. On National and major Provincial roads, embankment slopes should be protected using gabion mats or stone covers when flow velocities exceed 0.7 m/s and erosive soils. Use vegetation hedges to prevent wave erosion of the upper part of the embankment slope and shoulder. Main roads should be sealed with asphalt. Regional roads should be covered with minimum of coarse gravel on a draining (convex) clay substrate.

3 Module 3: Roadside vegetation, trees and dust control

Roadside vegetation is any vegetation growing on a road side. Planting trees, shrubs and grasses along the road alleviates the negative effect of roads on the local environment. Roadside planting is applicable in all agro- ecological zones with appropriate species which are suited to the given agro-ecology. In dry areas the technology should be supported by moisture conservation structures. Road water harvesting can be therefore efficiently used to favor the growth of vegetation, especially in dry areas.
At the same time, dust lifted by vehicles along roads (especially unpaved) has a direct effect on the environment and the health of people living near the roads. Road side plantations will not only check the deterioration of roads and make use of runoff, but will also create productive assets for local communities.
This module provides guidelines on how to plan, implement and monitor roadside revegetation activities without compromising road longevity and safety.

<table>
<tr><th colspan="2">Benefits of roadside planting</th></tr>
<tr><td>

Reduced soil erosion: holds soils in place
Remove dust and other pollutants from the air, protecting crops and road-side communities
Remove dust and other pollutants from the air, protecting crops and road-side communities
Remove dust and other pollutants from the air, protecting crops and road-side communities
Wind break
Flood control: slow and absorb road run-off

</td><td>

Improved water quality by ability of vegetation to trap sediment and increase water infiltration
Increased road stability: vegetation helps to lower local water tables that may affect the road formation and pavement
Safety: reinforcing road alignment, serving as crash barriers, protecting view planes and reducing wind speeds
Carbon dioxide sequestration
Defence against invasive weeks
Provide important pollinator habitat (honey production!)
Provide shade and keep the road cool for road users

</td></tr>
</table>

3.1 Criteria for site selection

The site must be highly visible for the driver to avoid roadway safety. Do not plant trees by the roadside where they will create visibility hazards at road intersections now or as they grow. Some site conditions are difficult to plant trees. An example is sites with excessive drought and vertisols, or sites that are severely degraded. Selecting planting sites not exposed to flooding is important to manage the wet season soil drainage problem in certain areas. The following criteria should be considered during selection of sites for roadside revegetation purposes:

- Sites shall preferably have access to water sources
- Sites with established animal paths shall not be considered
- Sites with nearby households engaged in farming or other activities shall be priorities
- Sites shall have access to nursery
- Sites shall not be severely degraded
- Sites shall have a community with positive attitude towards the project

3.2 Criteria for species selection

The plants selected to revegetate roadsides must be able to resist harsh conditions because the road side is often degraded. Native species have a higher survival rate since they are adapted to local conditions. The choice of species is based on the objectives of the plantation (economic or environmental) and influenced by height, growth rate, and density characteristics. For example, fodder, honey and timber species can be incorporated to provide additional benefits. If the purpose of the plantation is to trap dust, it is recommended to select species with pointed shape leaves such as conifer needles, or rough, hairy and sticky leaves.

Below are some criteria for selecting species:

- Tree species shall be evergreen or remain green over most of the period of the year
- Tree species shall have a crown architecture with more horizontal than vertical extension

- Tree and grass species shall be tolerant of seasonal drought and insect and pest harms
- Tree species shall be deep rooted to resist wind power, drought stress and to avoid damaging the road
- Tree species shall permits the growth of other plant species (avoid pine and eucalyptus species)
- Tree and grass species shall not be invasive
- Tree species shall be fast growing
- Grass species shall be capable of covering areas through rhizomes
- Tree species shall have one or more of social and economic values such as medicinal, food, fuel wood, fodder and shade.

Some species suitable for roadside planting in Ethiopia are provided in Table 5

Table 5: Some tree plant species that can be used in roadside planting in Ethiopia

No.	Species name	Amharic name
1	*Millettia ferruginea*	Berbra
2	*Gravellia robusta*	Gravelia
3	*Schinus molle*	Kundo berbere
5	*Casia spectabilis*	Kasia
6	*Jacaranda mimosifolia*	Yetemenja zaf
7	*Delonex regia*	Yedredawa zaf
8	*Spathodia nilotica*	Yechaka nebelbal
9	*Melia azedarach*	Meliya
10	*Azadiracta indica*	Neem
11	*Olea africana/europaea*	Weyra
12	*Callistamen citrinus*	Bottle brush
13	*Juniperus procera*	Yehabesha tsid
14	*Casuarina equisetifolia*	Shewshewe/Arzelibanos
15	*Acacia melanoxylon*	Omedela
16	*Ziziphus mucrocanta*	Kurkura

A more compreshensive list is provided in Annex xxx

3.3 Design of roadside plantations

The placement of trees along roads and foot paths must leave room for the safe passage of traffic, including animals, human and vehicles, and the trees must be compatible with adjacent land use, which include drainage ways, woodlands, croplands, pasture home compounds, village or markets. The average spacing between trees will be 3-4m. It can be planted on one side or two sides of the road. On the street road, trees should be planted at an average of 5-6 meters away from the road; but on curve road plantation should be done at 10-12 meters away. The following figures show the design of the road side plantation on street and curve roads
The target plant spacing is the chosen distance between established plants and trees. The selection of species will determine the plant spacing. Shrubs, for instance, grow at much closer spacing than trees, and this should be taken into consideration when determining the combination of species to be planted.

For row-plantings in general, larger trees are planted 3-4 m apart, larger shrubs 2.5-4 m apart and lower shrubs are placed 1.5-2.5 m apart.

The optimal time for tree planting in Ethiopia is at the start of the main rainy season. The sooner the planting can be started at the first regular showers, the better the survival of the seedlings during the coming dry season. The Plants should have their roots penetrating into the subsoil during the rains. Therefore, the recommendable planting season clearly ends before the completion of the rainy season; in fact, planting should be finished around 8 weeks before the dry -reason starts.
Within the planting season the schedule is usually so tight that planting must be carried out every day, from dawn to dusk. If it is possible to choose, it is preferable to plant when the sky is overcast, when humidity is high and wind velocity low. These conditions are met during the mornings and late afternoons, as well as after a shower.
Generally the following should be considered to have good seedling survival and growth after planting

- Time of planting is usually at the commencement of the rainy season.
- Plant trees when soil moisture levels have returned to field capacity
- Plant always on cloudy day
- Plant balanced plants which have been well watered before leaving the nursery.

3.4 Site preparation

Each planting area must be assessed for its unique site characteristics, such as rock content, soil depth, accessibility, steep slopes, and access to water resources. These characteristics will determine the selection of species and the method of planting.

The assessment should be finalized with the demarcation of each planting site. The demarcation can be done with wooden pegs or colored stones. The demarcation will tell the workers in which site to plant trees, shrubs and grasses.

Trees are commony planted in planting pits. It Ethiopia the standard pit for tree plantation so 40 cm in diameter and 40 cm in depth. The pit shall be dug a month ibefore the rainy season starts. This will alow the soil to adapt to the new condition, improve its structure and be ready to host the planted tree. The pit can be dug with tools such as spades, hoes, mattocks or pickaxes.

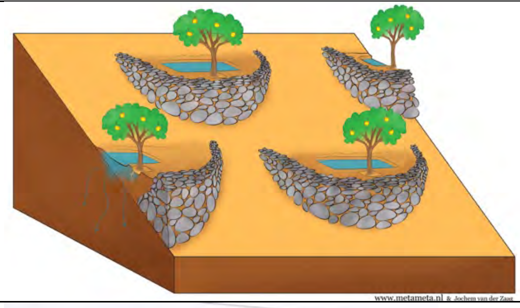
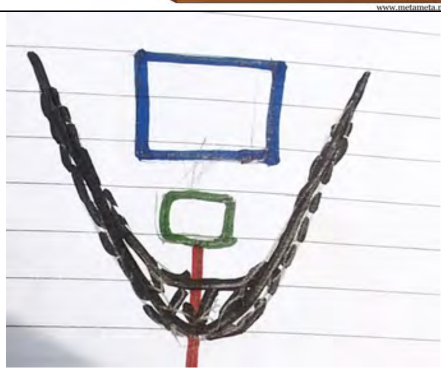
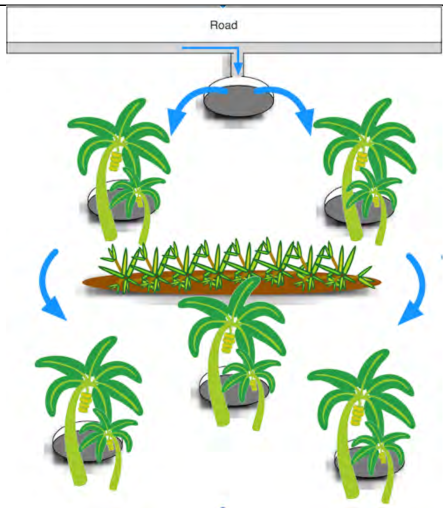
3.4.1 Combining road water harvesting with roadside planting

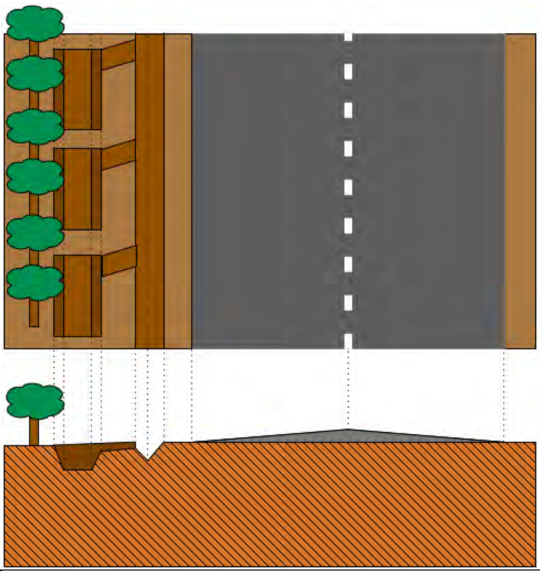
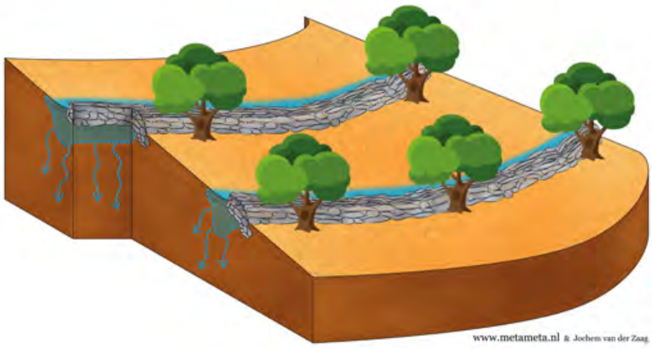
In arid and semi-arid areas the normal pit might not provide enough water to the seedlings and this will result in high mortality rates. It is in these cases that is suggested to link tree planting with road water harvesting. The standard pit can be coupled with Water harvesting and Soil and Water Conservation structures with the aim of providing more water to the young plants.

Small diversion channels can be constructed to slowly divert surface flow from roadside drainage system toward the tree seedlings and the complementary water conservation strucures.

Most micro-basin structures used for catchment rehabilitation can be adapted for roadside planting. The structures can be easily connected to the road drainage system and therefore benefit from additional water.

Many different designs can be used according to the topography, but there are always some key points to keep in mind:

Eyebrows (Semi circular bunds) Stone structures that contain a water soaking pit and a planting pit. Commonly used on steep land (>50%).	
Herring bones Are built of locally available stones. Two pits are dug inside the herring bone. The bigger pit collects water that slowly infiltrates and provide water to the plant that is grown in the smaller pit. Constructed on slopes <5% and with a soil depth of at least 50 cm.	
Soaking pits Soaking pits are bigger pits that are dug on the side of the planting pits with the ainm of collecting runoff. The water in the soaking pit will slowly reach the planting pits where the plant is grown. Soaking pits can be linked to each other in a way that when a soaking pit is full the water will pass to the next soaking pit	

Deep trenches can be easily connected to small mitre drains. When the trench is full the water will pass to the next trench or continue its way on the roadside drain. Plant the trees on the side of the trench. The trenches are also an excellent way to recharge the shallow aquifer	
Contour bunds (soil and stone) In very dry areas trees can be grown above the bund, in more humid areas it is better to plant them on the downside to avoid waterlogging risk. Stone & Stone faced soil bunds 3-35% Soil bunds 3-15%	

3.5 Retaining of fine dust by roadside vegetation

Dust is affecting the health of people living along the road and crop productivity (Figure 43). It was identified as a top three problem of unpaved roads by communities in Tigray.

Figure 43: Dust is a major problem to roadside communtities

Roadside vegetation can function as dust trap and windbreaker to impact dust movement and wind pattern. The height, width and porosity of vegetation are therefor important. Trees have the largest impact due to their size. A change in turbulence and wind speed has it's direct and the biggest effects on the levels of fine dust pollution.

When trees are planted with the additional function of wind break and dust barriers, it is necessary to plant several parallel rows. It is preferable to have plantations of 2 to 4 rows to protect a larger area (Figure 44). However, 1 and 2 row plantations are cost-effective options but require a uniform and high survival rate.

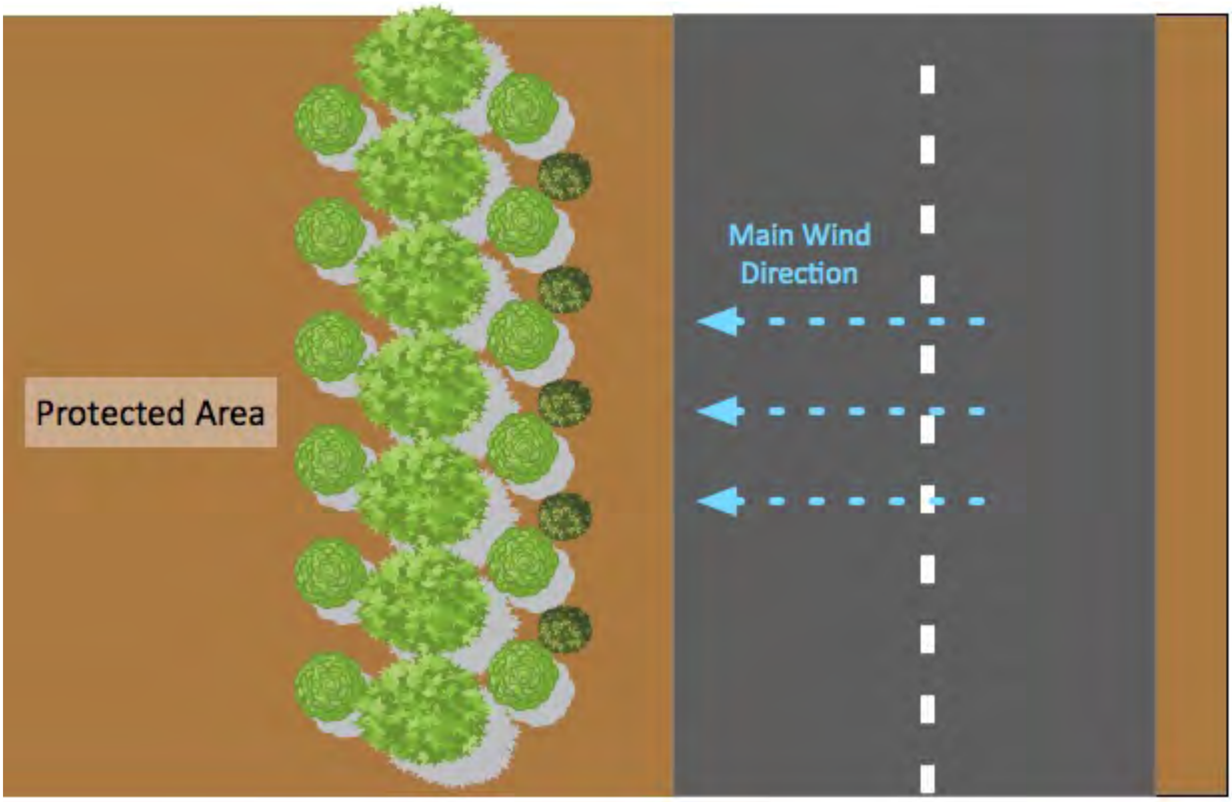


Figure 44: Roadside plantation act as dust and wind protection – especially when several lines of trees are planted parallel to the road and the dominant wind direction

A dense plantation provides higher protection over short distances, while a less-dense plantation provides less protection but over a greater distance. With a porous plantation, a large part of the airflow goes through it (SeeTable 6). Pollution is better trapped in porous plantations, because there is more contact with the leaves of the trees and shrubs. To accomplish a good degree of porosity, plantations should be approximately 5-20 meters wide consisting of tall trees with a bush layer underneath. The capture is enhanced by the turbulence in the plantation. This turbulence is caused by the presence of irregularities, such as branches, leaves and leaf structure. The more irregularities the structure contains, more dust, wind and pollutants will be trapped.

Table 6: The vegetation density greatly affects wind and dust movement

	Above: closed element (Diverse plant rows of different height, that create a thick edge)

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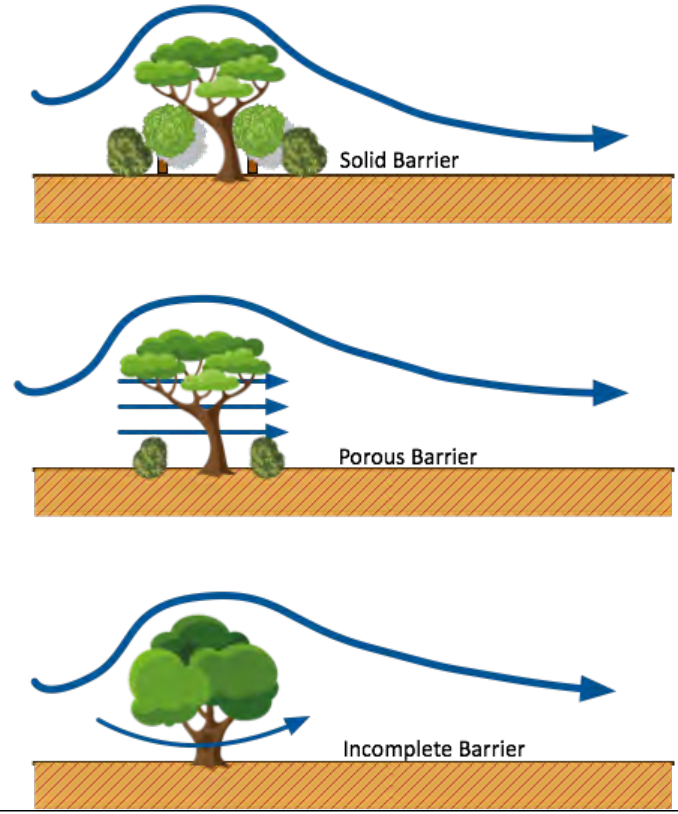
<tr><td rowspan="2">
</td><td>Middle: porous element (e.g. half open hedge or row of trees with undergrowth.)</td></tr>
<tr><td>Below: incomplete element (e.g. line of trees without undergrowth)</td></tr>
</table>

3.6 Maintenance

Maintenance is the most important element in planting survival. Do not establish a planting until all the necessary resources for maintenance have been planned and arranged. Plants often die because of animal damage, high surface temperatures, high evapotranspiration rates, lack of soil moisture, and competition with other vegetation.

Water

Water is a main element in the establishment of roadside plantations. If possible trees and shrubs should be watered after the rainy season ends. Sandy or rocky soils have low water-holding capacities. Less water but more frequent irrigations are recommended for these soils. On the other hand, finer textured soils, such as loams and clays, have a higher water-holding capacity. More water can be applied in these soil types and at less frequent intervals than sandy soils.

Moreover, when weeds and other undesirable vegetation is growing near planted seedlings, soil moisture is depleted sooner, requiring more frequent irrigations than if seedlings were free from competing vegetation.

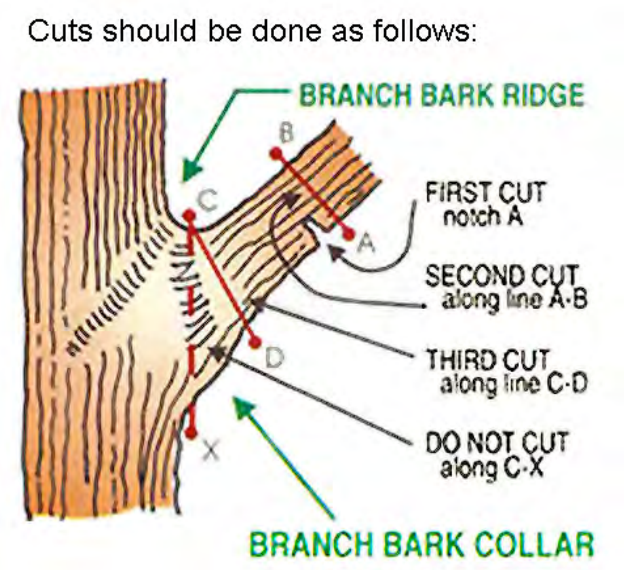
Mulch

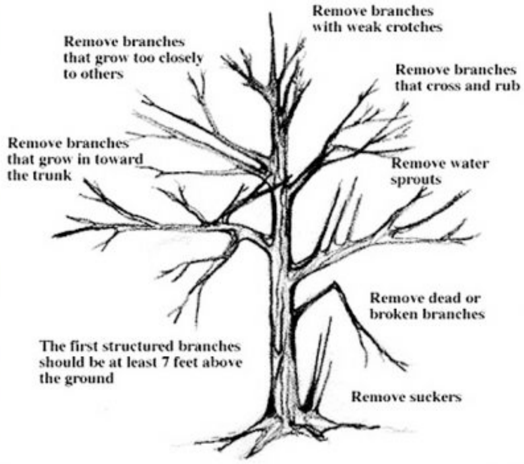
Mulch is a protective material placed on the soil surface to prevent evaporation, decrease surface temperatures, avoid weed establishment, enrich the soil, and reduce erosion. Applying mulch immediately after planting, and maintaining it for several years helps hold moisture in the soil and suppresses weed germination. There are several materials that can be used as mulches such as wood fiber, erosion mats, hay, straw and composts.

Mulching around seedlings is specially recommended for hot and dry sites and sites with competing vegetation.

Pruning

It is important to develop well-spaced structural branches early in the life of a tree. Branches that are growing close together when the trees are young will grow into each other, and they will not be able to develop their full structural strength. Once the structural branches have been established, little pruning should be needed. Uncontrolled growth of trees and shrubs could cause problems for vehicles such as reduced sight distance, vehicle or personal injury. Trees also need to be pruned to remove dangerous hanging branches or to prevent lower branches from blocking a path or obstructing visibility.





Protecting the seedlings

In free-grazing areas and places subject to damage, fencing will be necessary. Social fencing is sometimes considered an alternative to a physical fence. If all the residents of the area agree to keep their cattle off the roadside plantation, and if there is no risk of cattle from other villages encroaching upon it, it is possible to establish the plantation without a physical fence.

When selecting fencing materials, it is preferable to use materials that allow sufficient sunlight for photosynthesis. Individual trees can be fenced by surrounding them with wood sticks made with small branches from nearby trees.

A plastic netting can be installed to protect seedlings from browsing animals over each seedling. The netting acts as a barrier to foraging of foliage, stems, and even root systems, without impeding plant growth. Netting must be installed as soon after planting as possible to ensure immediate protection.

Tree shelters are translucent plastic tubes placed around seedlings after planting. They create a favorable growing environment while protecting the seedling against animal damage. Tree shelters enhance plant growth by creating a microclimate, which has lower light intensities, higher temperatures, and higher humidity. Tree shelters should be considered for sites where the potential for animal damage is very high. Tree shelters are not suitable for all species or site conditions. Tree shelters must not be removed until a portion of the seedling crown has grown out of the shelter. If the tree shelter is removed while it is still growing inside the shelter, the seedling will not be capable of supporting itself. Tree shelters are more effective than other methods, but they are also more costly.

3.7 Monitoring of the plantations

Regular visits to the project to evaluate progress, and to intervene if required, are vital for the revegetation process. Routine visual inspections of trees after planting should be carried out to identify damages and undertake replanting of damaged trees and maintenance.

Normally, several seedlings die during the first dry season, and the replacing of dead seedlings with new ones is compulsory (the process is also called beating up). Beating up needs to be done twice and sometimes three times as follows:

1. The first beating up is done at the end of the rainy season during which the initial planting takes place. About 5 to 10 % of the seedlings in the nursery should be reserved for this purpose.
2. The second beating up takes place in the second year after the planting.
3. The third beating up is done at the beginning of the second main rains after the planting.

When monitoring the success of the planting efforts it is suggested to use a form as shown in

Table 7: example of survival count form

Site	**healthy**	**Damaged sick**	**dead or missing plants No,**
	plants No.	**plants no.**	
1	27	6	7
2	20	8	5
3	12	10	3
Sum	**59**	**24**	**15**

From the information in Table 7 is possible to easily calculate the survival rate (percentage). The following equation can be used:

$$Survival\ \% = \frac{(Healthy + Sick\ or\ Damaged)}{(Healthy + Sick\ or\ Damaged + Dead\ or\ Missing)} \times 100$$

It is also important to have a monitoring strategy in order to be able to intervene in a timely manner and to allocate the right resources. A monitoring strategy should have the following components:

1. Summary of objectives: the purpose for monitoring and the project objectives.
2. Monitoring area map: the monitoring area map locates and identifies all monitoring areas in the road project area.
3. Summary of monitoring protocols: the strategy summarizes the general type of monitoring, including scope, location, timing, frequency, and sampling methods for monitoring each revegetation unit.
4. Consolidated timelines: a comprehensive timeline should be developed for the entire project, detail the schedule for how each revegetation area will be monitored.
5. Monitoring supervision: one person must have oversight of all monitoring activities. This person is responsible to ensure that the protocols are being implemented within the timelines that were developed.

4 Annex: technical sheets of single solutions

Solutions to divert and spread water

1. Graded diversion canal
2. Permeable dam (Flood spreading weirs)
3. Graded soil bund
4. Field water management

Solutions to store water

1. Low Cost micro-ponds
2. Underground cisterns
3. Farm ponds
4. Farm dam

Solutions to recharge shallow aquifers

1. Percolation pits
2. Percolation ponds
3. Trenches

4. CUT-OFF DRAINS

Planning steps for constructing cut-off drains or diversion ditches	Definition
I. Preparing technical design for constructing cut-off drains: The design for cut-off drain should include all dimensions; top width, bottom width, depth, side and channel slopes, shape and length of the ditch. The design should be supported by diagrams/sketches of the cut-off drain drawn on the development map the area in relation to the location of the runoff generating catchment. The steps for estimating dimensions of cut-of drains are outlined below under minimum technical standards. II. Estimating the labor requirement (PDs) for constructing cut-off drains: The total labor requirement in PDs can be estimated by calculating the total volume of the cut-off drain over its total length and dividing it by the work norm which is 0.42 m3/PD; adjusted for pastoral areas. III. Estimating the PW resource/budget for constructing cut-off drains: The budget for constructing a cut-off drain can be estimated by multiplying the total PDs estimated in step ii by the rate of payment per PD in pastoral areas. IV. Preparing work schedule for constructing cut-off drains: The work schedule should show the starting year and month, duration of the work, break down of the work by months and weeks and ending year and month of the work.	Cut-off drain is a graded ditch, with small gradient (a maximum of 1%), and an embankment of earth or stonewall on the lower side, constructed across the slope of a land to intercept and safely drain runoff water to a desired outlet, a waterway, safe disposal area or water storage place (Figure. 13). Its main purpose is to intercept and divert surface runoff water generating from upslope either to protect downstream assets from damages by flood, or to collect runoff water in a reservoir/storage for future productive uses or to directly divert flood water to irrigable field. Two different names, cut-off drain and diversion ditch, are commonly used in literatures for the same structure. Technically, cut-of drain and diversion ditch are essentially the same, and both names are used here.
Planning and implementation arrangements	**Steps for constructing cut-off drains**
Planning follows community/user groups' agreement on layout and management requirements. Groups of 5-20 PW participants work together to increase efficiency.	I. Make sure that there is a proper outlet such as a waterway or safe disposal area or water storage II. Mark the top and bottom widths of the cut-off drain or diversion ditch on the ground keeping the survey marks (pegs) at the center III. Dig the ditch 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 channel and the embankment to prevent the embankment soils from sliding into the channel. IV. In digging the ditch/channel, proceed by first cutting rectangular sections to the desired depth and then shape the sides later to give it either trapezoidal or parabolic shape V. After the channel is formed, check that the slope of the channel is correct and place the necessary score checks, aprons and drop structures. VI. Plant suitable grasses or fodder shrubs on the embankment to make it firm.

Marking/laying-out the graded path for cut-off drain or diversion ditch with line level

I. Select the slope, width and depth of the cut-off drain or diversion ditch. The slope should range from 0.25 to 1% depending on the expected amount of runoff in the ditch. Bigger drains/ditches are needed for larger catchments and if larger amount of runoff is expected. An alternative approach for determining channel slope/gradient is 0.8 - 1% for 1 – 10ha; 0.5% for 10 – 30ha; and 0.25% for 30 – 50ha. Typical values for small hand-dug cut-off drains or diversion ditches are top width 1.5 m, bottom width 0.9 m and depth 0.6 m.

II. Remove/clear obstacles such as tall grasses and shrubs from the path/general direction of the survey.

III. Tie each end of the nylon string on the two graduated poles, as done on marking out of the contour lines, but with height difference in this case. The difference in height should be equal to the vertical interval (VI) of the selected slope of the cut-off drain or diversion ditch. For example, if the selected slope for the cut-off drain is 0.5%, (slope = VI x 100)/Horizontal Interval, HI). Thus, 0.5% = VI x 100/HI, or VI = 0.5 x HI/100. But HI is 10 m i.e the length of the nylon string between the two poles. Therefore, VI = 0.5 x 10 m/100, or 0.05 m or 5 cm. So the difference in height between the two poles should be 5 cm. That is, if one end of the string is tied at 1 m height on one of the poles, the other end of the string needs to be tied at 1.05 m height on the other pole.

IV. Once the string is tied on the poles with the desired height difference, the survey starts from the outlet (lower) end of the cut-off drain or diversion ditch, and should proceed to the higher end with the person holding the pole tied at 1 m height leading in front. The man attending the line level needs to direct the front man while the fourth man hammers the pegs into the ground to mark out the path of the cut-off drain. Repeat the process (like the survey for contour lines) until the upper end of the path of cut-off drain or diversion ditch is reached.

Minimum technical standards for constructing cut-off drains

To design a cut-off drain or diversion ditch properly, the planer needs to have basic knowledge on open channel flow. It has to be also realized that most of the available empirical formulae give rough estimates of runoff discharge and require reliable information/data on rainfall and/or the physical characteristics of the catchment area generating runoff water.

i. Estimate the peak rate of runoff (Q) from the runoff contributing catchment area. This requires knowledge of the size (area) and characteristics of the runoff generating catchment, the intensity of rainfall in the area, and the coefficient of runoff, i .e the portion of rainfall that goes as runoff. Table 1 gives coefficient (C) of runoff for different land uses/covers which can be obtained from field observation. If rainfall intensity (I in mm/hr) and area (A in ha) of the runoff catchment are known, discharge (Q in m3/sec) can be estimated by Rational method as: Q = CIA/360. Cook's method (see appendix II) can be used as alternative, especially when rainfall intensity is not available.

ii. The cross-sectional area (A) of the channel of the cut-off drain to be constructed to safely convey the estimated peak runoff (Q) can then be expressed using the basic flow equation: Q = AV, then A = Q/V, Where; Q = The peak discharge in cubic meters per second, m3/sec, (estimated Q in step i. above); A = Cross-sectional area of the ditch in square meter (m2); and V = Maximum permissible velocity in meters per second (m/sec).

iii. Common values of permissible velocity include: stable earth: velocity = 1 m/sec; close growing grass in channel: velocity = 2 m/sec; hard stone/rock: velocity = 4m/sec; Concrete: Velocity = 5.5m/sec. Maximum permissible velocity can also be obtained from table 2 by entering with appropriate slope of the channel which ranges 0.1 – 1%. (If V is known, A can be calculated as Q/V = A)

iv. Decide on the shape (trapezoidal or parabolic) and gradient of the channel and keep side slopes 1:1. Common values of channel gradient include: (0.1 – 0.2% for light soil (sand, silt, sandy loam); 0.4 – 0.5% for heavy soil (clay and clay loam) and 1% slope as upper limit for earth channel.

v. Obtain depth in m from table 2 entering with the selected channel slope/gradient (step iv)

vi. Find the discharge in the channel per unit of width (Q m3/sec/m) from table 3 entering with depth (step v) and channel gradient (step iv).

vii. Find top width by dividing the discharge Q (step i) by the discharge per unit width (step vi)

viii. Determine the bottom width of the channel from the side slopes relation. For alternative direct use, typical dimensions of channel/ditch under small holders' situation are:

Depth: 0.5 – 0.6 m; Bottom width: 0.9 – 1.5 m with side slopes 1 : 1

Limitations	**Management requirements**
Erosion risk at the outlet as well as in the channel due to improper provisions of score checks, aprons and drop structures.	Households/interested groups with crop fields, pastures or other assets to be protected by the cut-off drain should follow-up the construction and ensure its maintenance. Community/interested groups should follow up the construction of cut-off drains and should ensure its maintenance.
Institutional responsibility	**Implementation period**
Fully on individuals/groups +/- community (commitment to proper mgt.). DAs and woreda experts - technical support and follow-up/mgt.	Flexible; preferably when the soil is friable and during the period not interfering with activities of agriculture and/or normal/customary mobility.

Minimum design standards

Table 10: Values of Runoff Coefficient

Land Use/Cover	Runoff Coefficient		
	Slope (0-5%)	Slope (5-10%)	Slope (10-30%)
Cultivated land			
Open sandy loam	0.25 – 0.30	0.4	0.52
Clay & silt loam	0.5	0.6	0.72
Tight clay	0.6	0.7	0.82
Pastures			
Dense cover	0.1	0.16	0.22
Medium cover	0.3	0.36	0.42
Open pasture	0.4	0.55	0.6
Forest/woodland			
Dense cover	0.1	0.25	0.3
Medium cover	0.3	0.35	0.5
Scattered	0.4	0.5	0.6

Table 11: Depth of a Channel in meters

Channel Slope % Slope	Maximum allowable velocity (m/sec)					
	0.6	0.9	1.2	1.5	1.8	2.1
1					0.4	0.5
0.5				0.5	0.7	0.9
0.25	0.3	0.4	0.6	0.9		

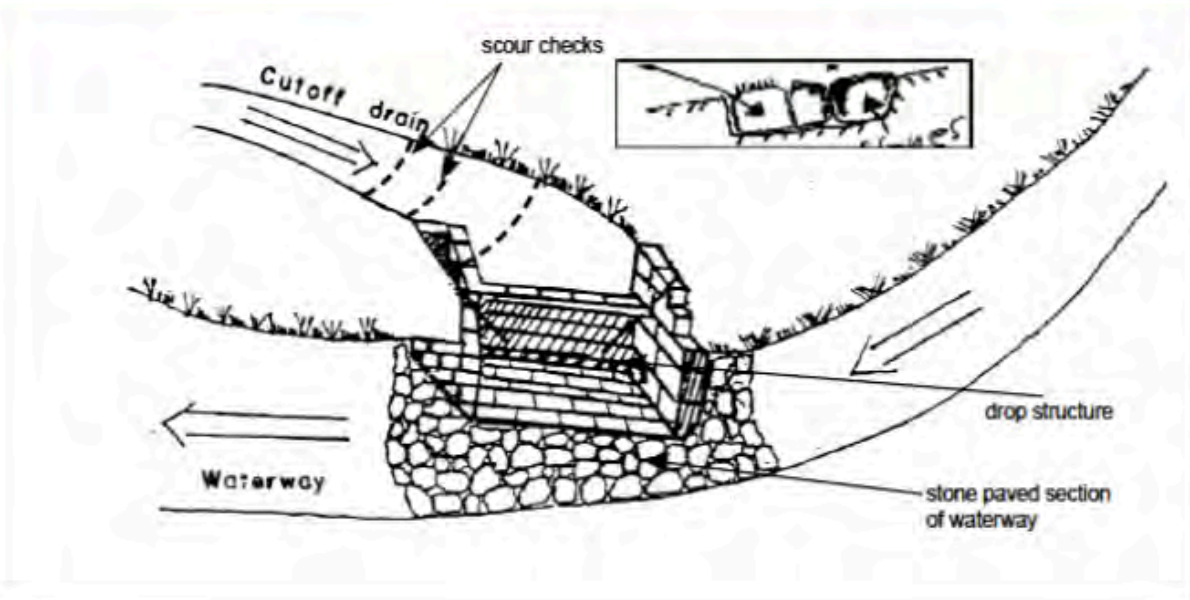
Table 12: Discharge in m3/sec/meter width

Depth of Channel	Slope (%)		
	0.8 – 1	0.5	0.25
0.3	0.6	0.4	0.25
0.4	0.9	0.65	0.45
0.5	1.3	0.95	0.65
0.6	1.8	1.3	0.95
0.7	2.25	1.7	1.2
0.8	2.8	2.15	1.5
0.9	3.4	2.65	1.8

Source: Lakew Desta (etal). 2005

Work norms	Hand tools
Construction of a cut-off drain or diversion ditch involves clearing (removal of vegetations from the place of embankment), excavation of soil from the ditch, shaping and compaction of embankment. The average work-norm used as National norm for constructing cut-off drain is 0.7m3/PD. If this is adjusted by 40% to pastoral areas considering the harsh climatic condition and short working hours per day (5 hrs as compared to 8 hrs in the highlands), the average work-norm for constructing cut-off drain in pastoral areas will be **0.5m3/PD.**	Tools for constructing cut-of drain include crowbars, sledge hammers, shovels, pick axes, axes, big knife, wheelbarrows and wooden compactors.

Figure .13 Cut-off drains



TECHNICAL INFORMATION KIT

RIVER-BED OR PERMEABLE ROCK DAMS

(1) Period/phases for implementation

. Only during dry season and min. one month before rains likely to occur.

(2) Objectives/remarks

. River bed dams are a floodwater farming techniques where runoff waters are spread in valley bottoms of seasonal riverbeds, large gullies or natural water courses for improved crop and forage produodtion using a long, low structure, made from loose stone (occasionally some gabion baskets may be used). Developing gullies are healed at the same time. Occasionally it is required to raise the riverbed in order to guide spate floods into irrigation canals of spate irrigation schemes, or to accumulate river sediments for riverbed cultivation. In such a case, very strong dams are required that can resist powerful spate floods.

.It is a relatively low cost structure especially designed to resist heavy flooding. The structures are typically long, low dam walls across valleys. The large amount of work involved means that the technique is labor intensive and needs group approach.

(3) Suitability, agro-ecology and adaptability based upon local knowledge

River bed dams for crop production can be used under the following conditions: Rainfall: 200 – 750 mm; from arid to semi-arid areas; Soils: all agricultural soils – poorer soils will be improved by treatment;Slopes: best below 2% for most effective water spreading; Topography: wide, shallow valley beds; Traditional structures similar to river bed dams are common in several parts of Ethiopia (Dire Dawa, Tigray/Erob, Wollo, , Hararghe, etc). As the flood subsides ring planting is practiced.

(4) Main land use

. Suitable in river/valley bottoms for improved crop production. They can also be used for forage production using the residual moisture of the riverbed sediment. Is more effective in areas where villagers have some experience in spate irrigation or flood farming.

(5) Technical preparedness

. Training required (DAs and HHs)
. Agree with farmers on location, user rights, size,production area, catchment protection works and on-the-job training. Test measure first.

(6) Potential to increase/sustain productivity and environmental protection

. Very high - for cereal as well as cash crops, introduction of fruit trees in gullies, valuable trees, etc.
. Provide opportunities for income generation to small land holders and landless.
. Drought proof activity - even when rainfall is low river bed dams collect sufficient moisture.
. Promotes fertility management (compost, etc) and watershed protection, raise water table.

(7) Minimum surveying and tools requirements

. Survey: long rope and wooden pole, measuring tape or marked string Tools: crow bars, shovels, pick axes, local stretchers (barella) to carry soil, sledge hammers.
. Volume of stone work per ha varies from 70 - 280m3 based on slope.

(8) Layout

A) Site Selection: site selection depends both on the beneficiaries and the technicians. Theoretically it is best to start at the top of the valley, though this may not always be people's priority. After site identification it is necessary to determine whether the structure needs a defined spillway: as a rule of thumb no spillway is required if the gully is less than one meter deep. For greater depths, a spillway is recommended. Gullies of over two meters depth poses special problems and should be only tackled with caution.

B) Catchment: Cultivated Area ratio: the calculation of the C:CA ratio is not necessary as the catchment area and the extent of the cultivated land are predetermined. However, the catchment characteristics will influence the size of structure and whether a spillway is required or not. Usually, because it is a permeable rock dam, if the depth is less than one meter then there is no need to include spillway. When required gabions are best for spillways, as loose stones easily destabilized by heavy floods. As the soils become heavier behind the bunds water logging could be a problem and selection of crop taken into account.

C) Design/size: the main part of the dam wall is usually about 70cm high although some are as low as 50cm (fig 1-4). However, the central portion of the dam including the spillway (if required) may reach a maximum height of 2m above the gully floor. The dam wall or "spreader" across the valley beds normally range from 30 to 100 meters. Sites requiring greater than this size technical assistance may be consulted. The dam wall is made from loose stone, carefully positioned, with larger boulders forming the "framework" and smaller stones packed in the middle like a "sandwich". The side slopes are usually 3:1 or 2:1 (horizontal : vertical) on the downstream side, and 1:1 or 1:2 on the upstream side. With shallower side slopes, the structure is then more stable (Fig 2). For all soil types it is recommended to set the dam wall in an excavated trench of about 10cm depth to prevent undermining by runoff waters. In erodible soils, place a layer of gravel, or at least small stones, in the trench.

D) Quantities and labor: the quantity of stone, and the labor requirement for collection, transportation and construction depends on a number of factors and vary widely. Table below gives the quantity of stone per cultivated hectare for a series of typical river bed dams under different slopes.

Land slope (%)	Spacing between dams* (m)	Volume of stone/ha cultivated (m3)
0.5	140	70
1.0	70	140
1.5	47	208
2.0	35	280

*vertical interval between adjacent dams = 0.7m, the above figures are calculated for a river bed dam with an average cross section of 0.98m2, 70cm high and base width of 2.8m and a length of 100m. The vertical interval between dams is assumed to be 0.7m, which is equal to the dam ht.

Fig1. Riverbed dam dimensions

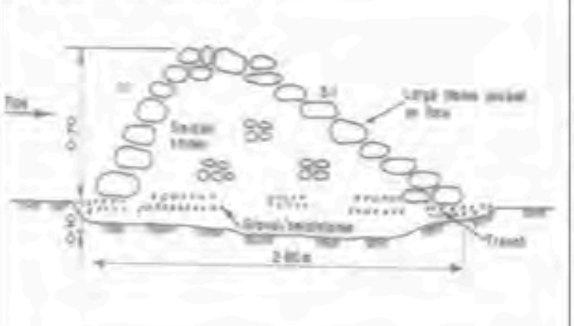
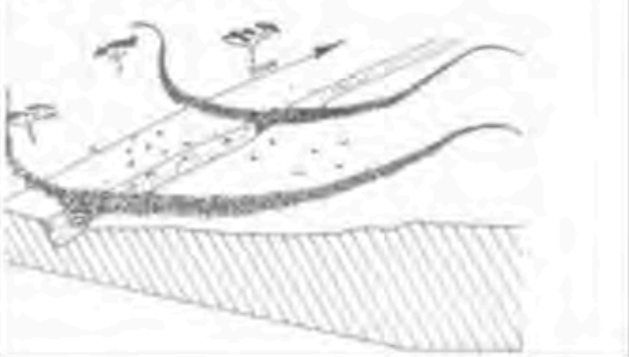


Fig2. Riverbed dam: general layout.

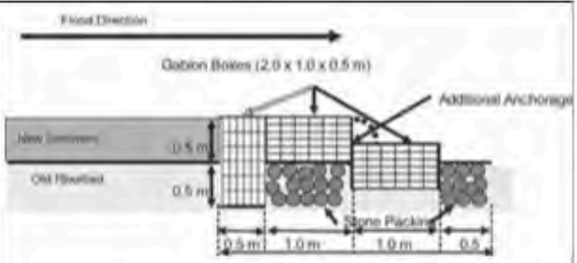


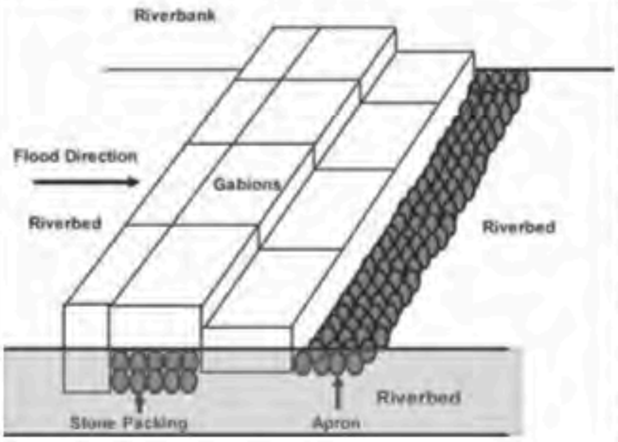
F) Example on how to determine spacing of riverbed dams:

for dams of 70cm height, the VI should theoretically be 70 cm. However in practice this may not be practicable due to the amount of stone and labor involved. As a compromise, a V.I. of 100 cm might be more realistic. Even wider spacing could be determined most easily by the use of a line-level.

The horizontal spacing between adjacent dams can be determined from the selected VI and the prevailing land slope according to the formula: HI = (VI x 100)/(% slope)

Where: HI = horizontal interval (m)
VI = vertical interval (m)
Slope in % = land gradient expressed as a percentage
For example, for a VI of 0.7 m and a 1% land slope,
HI = (0.7 x 100)/1 = 70 meters
For a VI of 0.7 m and a 2% land slope,





G) Layout and construction steps:

1) A foundation of small stones, set in a trench, is required.

2) An apron of large rocks is needed to break the erosive force of the overflow (fig1-4).

3)The downstream banks of the watercourse should be protected by stone pitching to prevent gully enlargement.

4)The alignment of the main dam walls can be marked out, starting at the center of the valley (where there may/may not be a spillway).

5)The arms end when they turn parallel to the watercourse. The contour can be laid out simply using a water tube or line level.

6)The first action after aligning the extension arms of the dam is to dig a trench at least 10 cm deep and 280 cm wide (according to the base width of the bund). The earth should be deposited up slope and the trench filled with gravel or small stones.

7)The skill of construction is in the use of large stones (preferably of 30cm diameter or more) for the casing of the wall.

8)This should be built up gradually following the required side slope, and the center packed with smaller stones and the whole length of the bund should be built simultaneously, in layers.

9) If a series of permeable rock dams is to be built, and appropriate vertical interval (VI) should be selected.Technically it is correct to: start at the top of the valley and work down; and use a VI equal to the height of the structure.

(9) Work norm

Estimate about requirements based on the following work norms:

. The work norm for the **Riverbed dam embankment** (inclusive of all elements) is estimated as 0,75 m³ of volume work (earth and stone fill) per person/day.

. The work norm for the **spillway** is **0,5 m³** of spillway excavated soil and stone work (including drop structure and rip rap if necessary) per person per day.

.More explanation is also given on the front page under design section "D). Quantities of labor".

(10) Integration opportunities/requirements

. Riverbed dams are part of a watershed treatment. The dams improve conditions for plant growth by spreading water, where moisture availability is a limiting factor. In additon, sediment, which will build up behind the bund over seasons, is rich in nutrients, and this will further improve crop growth.

.This techniques is used exclusively for annual crops. In the sandier soils, which do not retain moisture for long, the most common crops are millet and groundnuts.

.As the soils become heavier, the crops change to sorghum and maize. Where soils are heavy and impermeable, waterlogging could be a problem and therefore, within one series of permeable rock dams, several species of crop may be grown, reflecting the variations in soil and drainage conditions.

.Gullies leading into the main riverbed dams should be treated with check-dams or SS dams. Spillways could be necessary as required.

(11) Management requirements

. The river bed dam based on the design given above should not require any significant maintenance work provided the described construction method is carefully applied. It will tolerate some overtopping in heavy flods.

.There may be some stones wahsed off, which will require replacing, or tunneling of water beneth the bund and need packing with small stones.

.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 gully.

.Sample soil profile cuttings to check soil/parent material conditions in order to decide best placement of the dam.

.After 1-3 years try hand-dug well close to lower side of embankments (2-3 meters from the wall). Make sure that each households owning/using their own dams along a common dry water course/gully agree to form a group for management river bed dams (mutual help).

(12) Planning and implementation arrangements

. Large quantities of stone needed
. Outside assistance could often be necessary for transport of stones
. Siting is often determined by the people rather than the technicians
. As the structures may not be made by individual farmers, it is necessary to cooperate in construction.

(13) Limitations

.The main limitation of riverbed/permeable rock dams is that they are particularly and require considerable quantities of loose stone as well as the provision of site-specific, transport.. Labour intensive and needs thorough follow-up - difficult in areas with limited expertise. Limited number of direct beneficiaries.

Not suitable in sandy and sodic soils.

(14) Institutional responsibility

. Fully on groups/individuals +/- community (commitment to management)
. DAs and wda experts - technical support and follow-up/management

TECHNICAL INFORMATION KIT	(1) Period/phases for implementation	(2) Objectives/remarks
GRADED SOIL BUNDS	. Only during the dry season and period not interfering with land preparation	. Graded soil bund is similar in description with level soil bund. However, graded soil bund is upto 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 inculde tied ridges smaller in height within the channel of the terrace. The stored water within the ties can infiltrate into the soil while any above that height is drained out. . Graded soil bunds can be made to gradually develop in to benched type terraces through careful maintenace. Any integration of other measures such as stabilization and composting can be applied as it can be applied on level bunds.

(3) Suitability, agro-ecology and adaptability based upon local knowledge

. Suitable mostly in high rainfall and humid areas of wetter agroecologies and specially 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).

(4) Main land use	(5) Technical preparedness
. 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.	. Land use, soil and topography assessed . Discuss/agree with farmers on design and layout + provide on-the-job training . Precise layout and follow-up/adaptations

(6) Potential to increase/sustain productivity and environmental protection	(7) Minimum surveying and tools requirements
. High in high rainfall, humid and water logged areas. There is high potential of integration with bilogical measures. More siutable in areas where runoff becomes excess as a result of high rainfall and poor infiltration of the soil. The tied ridges retain moisture in case of rainfall/runoff is minimum.	**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**: shovels, pick axes and wooden compactors (the proportion of shovels and pick axes depend on type of soil)

(8) Min. technical standards	(9) Layout and vertical intervals (VI)	(10) Work norm
. The artificial or natural waterway should be constructied one year before the graded bund. The channel is graded upto a maximum of 1% (10cm for every 10 meter lay out of the line level) . Height: min. 60 cm after compaction. . Base width: 1-1.2m in stable soils (1 horiz: 2 vertical) and 1.2-1.5m in unstable soils (1 horiz: 1 vertical). 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 e.g. from 25cm depth and 50cm width to 50 and 100cm, respectively. Ties (if appropriate): tie width with dimension as required, placed every 3-6 m interval along the channel.	. 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 (only exceptional cases - reinforced) (**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 coutours but with 1% gradient using line level. Ddiscuss spacing with farmers. Make bund length max 50-80m the > the slope the < the length. Proper link and stone pitching of the area when bund meets the waterway.	. Precise layout along contours with 1% gradient (graded) using line level, . Scratching or removal of grasses from where embankment is constructed for better merging & stability, . Excavation channel, and ties along channel (as necessary), . Embankment building, shaping and compaction (essential), . Leveling and compacting the top of bund with an A-frame. **WORK NORM: 150 PDs/Km**

(11) Integration opportunities/requirements (see also WHSC guideline)	(12) Modifications/adaptation to standard design
1. Integration with artificial or natural waterways and apron (in case of sharp falls) is a must. 2. Integration with **bund stabilisation**: 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 practices: contour plowing and **compost** (start first year applying 2-3m strips above the bunds - where soil is deeper and moisture is higher). 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.). 5. **Control grazing** - avoid animals to graze between bunds for at least 1 year.	1. At the out let to the waterways, in case of sharp falls, apron should be considered. 2. Upgrading graded soil bunds and application of COMPOST (Same as level soil bunds) **(14) Management requirements** . Graded soil bunds may need to be upgraded to become level terraces - the upgrading should use soil from the lower part of bund (fanya juu principle, to avoid fertile deposited soil to be used for the embankment. . Apply cut&carry for grass/legumes growing on bunds (not uprooted).

(13) Planning and implementation arrangements	(15) Limitations
. 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).	. If the gradient is high scouring and if low flow blockage and overtopping is a problem. . Limited stability if not integrated with revegetation - requires regular maintenance

(16) Institutional responsibility

. Fully on individuals/groups +/- community (commitment to mgt.)
.Common mangt. of the waterways and adjoining lands required
. DAs and wda experts - technical support and follow-up/mgt.

Field- water distribution	
Steps	Implementation
I. The flow from the road side drain or culvert outlet is diverted to fields with earthen/stone bunds. II. When the upstream field is irrigated, water is released by making a cut in the downstream field bund to release water to the next field. III. This process is repeated until all the fields in command have been irrigated. IV. If the spate continues after all fields have been irrigated, the block-off is broken to avoid excessive irrigation.	I. The fields need to be levelled and homogenous. If there is a slope is important to construct flat terraces. II. Each field should be bunded. Construct a solid bund on the edge of the field to retain water. III. The land shall be prepared before the rains or as soon as the soil becomes workable. IV. Farmers need to monitor their land closely and run to the field when runoff starts. V. Farmers should be ready to divert and stop diversion to their fields. VI. 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. VII. When all fields are full the upper diversion structure (at the culvert or end of mitre drain) must be broken to stop irrigation.
Danger	Tools needed
I. To avoid damage the farmers should learn gradually to use this technique. The system can be enlarged in the years. II. Constant monitoring is necessary when it rains to divert and stop diversion. III. Monitor for early erosion/breaching signs	Layout: Line level, range poles, 10 m string Work: digging tools, compacting tools to stabilize the bund

TECHNICAL INFORMATION KIT	(1) Period/phases for implementation	(2) Objectives/remarks
LOW COST MICROPONDS (MP)	. Only during dry season and min. one month before rains likely to occur.	. Supplementary irrigation to high value crops (horticulture, fruit trees, etc.). . Water for livestock for a few months. . Microponds allow to use surface runoff from small catchment areas within and between homesteads (foot paths, small grazing land areas, rocky areas, etc.). Can also collect water from feeder roads, graded bunds, spillways, etc.) . Water collected can be used during the rainy season as supplementary irrigation (during dry spells) or after (1-2 months max) for additional support to horticulture crops, fruit trees, compost, small livestock, beekeeping, etc.

(3) Suitability, agro-ecology and adaptability based upon local knowledge

. Suitable in most agroclimatic zones except in areas with excessive dryness (below 400 mm rainfall) as not cost effective. They are suitable when hand-dug wells are not possible, even after watershed treatment (water tables too low). MPs need demonstration before expansion - also need support in terms of tools for increasing depth and deal with rocky subsoil, stone shaping, seepage, etc.

(4) Main land use	(5) Technical preparedness
. Mostly around homesteads. . Possible to apply on open fields to collect water from graded bunds,and waterways. . At the foot of hillsides to increase recharge of water tables. . Inside large gullies and at the foot of treated hillsides.	. Training required (DAs and farmers) . Discuss/agree with farmers on location, size, production area, catchment areas and on-the-job training. Test measures first.

(6) Potential to increase/sustain productivity and environmental protection	(7) Minimum surveying and tools requirements
. Assist grow of high value/cash crops especially high value trees in areas with low rainfall. Can support income generation activities of small land holders and assist landless with homesteads. Assists controlling runoff and can promote keeping of livestock near residences. . Can promotes better fertility management (compost, etc) and agronomic practices.	**Survey**: pegs, 10-15 meters string, measuring tape Construction: crow bars, pick axes, shovels and wooden compactors Labour group: min 5 people per micropond to increase efficiency

(8) Design & technical standards (fig 1)

Main Types:

1) Microponds (cemented): Useful for small-scale irrigation both during (supplementary) and few months after the rainy season.
2) Microponds (not cemented): Useful mostly during the rainy season as supplementary irrigation during dry spells and to recharge ground water.
Design:
A) Round shaped micro-ponds (cemented and not cemented) --> For detail design procedures consult guidelines provided by the MoARD/BoARD in each region: Usually 4-6 meters radius and 3-4 meters deep. The cone of the pond is truncated at its bottom, allowing for 2-3 meters diameter flat bottom. Volume calculated approx as fig 1-a based on small micro-catchments (400-1000m²), supply of excess runoff from feeder roads, footpaths, small closures, grazing areas, compounds, etc. Use pole and string with knots placed at different diameters based on size of pond to facilitate excavation. The bottom and sides of ponds should be tightly stone paved/faced using mortar (cement/sand 1:4), reinforced with mesh and plastered (cement/sand ratio 1:2-3). Moist the cemented wall /bottom for 2-3 weeks after construction to avoid cracks.
B) A lower cost micropond measure applicable in areas with medium textured soils is to apply clay blankets (20-30 cm) lined and compacted at the bottom to decrease vertical seepage. While applying the clay blanket moisturize and compact every 3 cm. Walls can also be stone faced and plastered using local mortar ("chika") mixed with teff straws, dung and cement (cement: soil ratio is 1: 6-8). This can only reduce lateral seepage and cracks need to be filled every year. A second option is that in addition to clay blankets side walls could be built stone stepped to facilitate access. In this case, the stone masonry work should be carefully done, and space between stones filled with mortar. Test this measures at small scale first.
C) Square or rectangular microponds: depth (2.5m to 3.5m) - may be larger in size. Side slope 1:1. Size of pond and volume as in **fig 1-b**. Rectangular ponds are usually cheaper, not cemented and used mostly to supplement water during rainy season (during dry spells). To reduce seepage a system of stone paving + a clay blanket (10-15cm layer) and/or plastic sheets can be used. Alternatively use local bricketing and seal gaps with mortar as above. Side walls (faced or stone stepped can also be built) to increase stability and reduce lateral seepage.

NOTE:All microponds need to be shaded to prevent malaria. A low cost shade is made out of a central pole placed in the middle of the pond linked to "tukul" like wooden frame covered by thatch (using straws) or mats.

(9) Integration opportunities/requirements	(10) Work norm	(11) Use of microponds from different sources of runoff
1. Construct small silt traps before water enters the MP (2mLx2mWx1mD). More than one silt trap may be required (especially for microponds collecting water from erodible soils - check first year and add one if necessary). 2. Provide each MP with a stone ladder, or a wood ladder, or hard soil hewn steps, to facilitate fetching water. 3. Microponds integrated with proper seedbed preparation for horticulture crops, compost making, beekeeping, watering of fruit trees, improved water lifting systems, etc. 4. Build the shade as indicated in (8)	(1) Excavation (1PD/0.5 m³) (2) Stone collection and shaping PD/0.5 m³) for stone stepping/facing of walls (3) Shading (thatched roof, etc) (4) Others as required (such as small cutoff drains and waterways see other infotechs).	1. Illustration of Microponds using microcatchments - figure 2. 2. Example of Microponds using overflow from springs (single or as relay structure based on amount of flow) - figure 3. 3. Example of Microponds placed as relay system along paved waterways (with drop structures and graded bunds) - figure 4. 4. Microponds receiving water from small cutoff drains (single or in series of relay cutoff drains) - figure 5.

(12) Planning and implementation arrangements	(13) Management requirements
. Planning follows groups and individual owners' agreement on location, source of runoff to exploit, purpose, type of crops and management. Groups of 3-5 households work together to increase efficiency. Skilled mason required for cemented structures.	. Removal of silt from reservoir/silt trap as required (can be used for seed beds if fine). Check the shading is effective (mats, others). Check fence for safety (aware children of hazards).

(14) Limitations	(15) Institutional responsibility
. Not suitable in unstable soils, e.g. sandy/sandy loam or very expandable soils. . Water not suitable for domestic drinking purposes. May induce water borne diseases. . Limited efficiency - only for supplementary irrigation of small plots.	. Fully on individuals/groups for management. . DAs and wda experts - technical support and follow-up/mgt.

Fig 1 Design of microponds

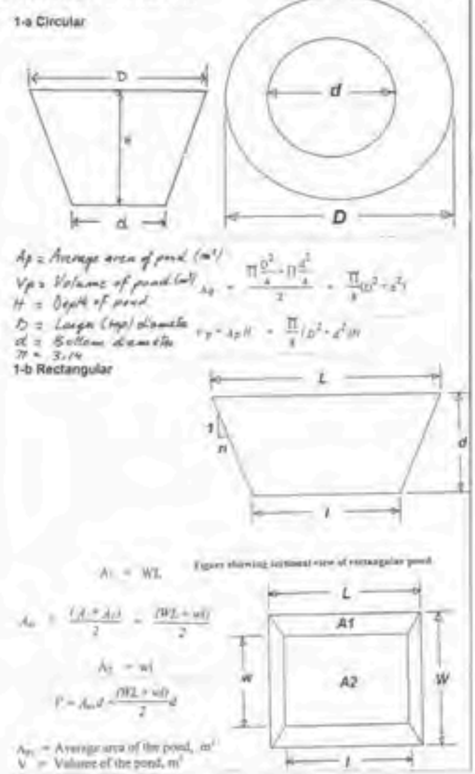


Fig 2 Example of micropond below microcatchments

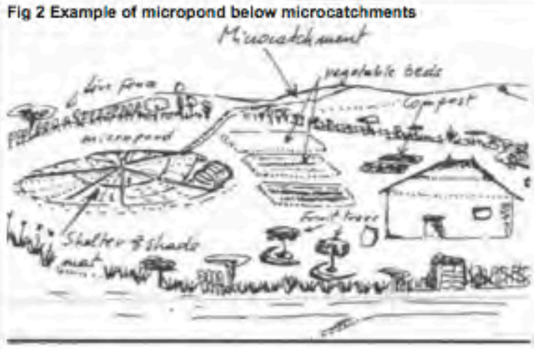
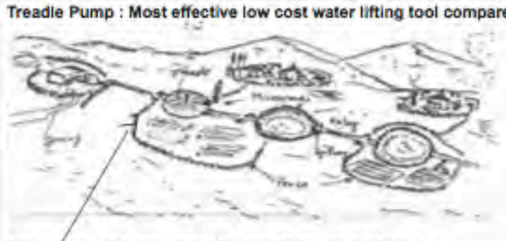


Fig 3 Microponds constructed to use overflow from

Collects overflow (especially night flow)

Treadle Pump : Most effective low cost water lifting tool compared to other



Relay microponds storing high overnight flow (linked by stone paved waterways)

Fig 4 Microponds as relay system along paved waterways (receiving water from graded bunds). Cultivation of cash crops near pond (during rainy season dry spells)

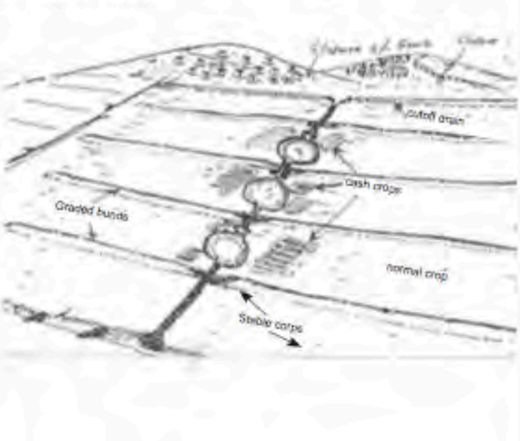


Fig 5 Microponds collecting water from small cutoff drains

a) Single cutoff drain (linked to small catchment/closure)

b) Relay small cutoff drains and microponds

TECHNICAL INFORMATION KIT

UNDERGROUND CISTERNS (Hemispherical, Dome cap, Bottle shapephere, Sausage shape)

(1) Period/phases for implementation

. Only during dry season and min. one month before rains likely to occur. But if water for mixing and curing of cement is a limitatin moist season is ok.

(2) Objectives/remarks

. Supplementary irrigation to high value crops(horticulture, fruit rees, small livestock, etc.)

. Water for livestock for a few months

.Water for raising seedlings in dry seasons

. Microponds allow to use surface runoff from small catchment areas within and between homesteads (foot paths, small grazing land areas, rocky areas, etc.).

. Water collected can be used during the rainy season as supplementary irrigation (during dry spells) or after (1-2 months max) for additional support to horticulture crops, fruit trees, compost, small livestock, beekeeping, etc.)

(3) Suitability, agro-ecology and adaptability based upon local knowledge

. Low at introduction stage - b/c could require purchased inputs (cement, chicken mesh, reinft.bars, pipes, etc.) - may need support in terms of long-term credit, skilled labor, tools, seepage and evaporation control, etc.
. Suitable to enhance horticultral production that can be used as cash crops (particularly less or non perishable crops, vegetables, fruit trees, etc.). Stable/average soils than sandy or heavy clay soils.

(4) Main land use

. Mostly around homesteads.
. Possible on open fields to collect water from graded bunds, and waterways. Can also collect water from feeder roads, cutoff drains, waterways, spillways, etc.

(5) Technical preparedness

. Training required (DAs and farmers)
. Discuss/agree with farmers on location, size, production area, catchment areas and on-the-job training. Technical assistance required.

(6) Potential to increase/sustain productivity and environmental protection

. Assist grow of high value/cash crops especially high value trees in areas with low rainfall.
. Can support income generation activities of small land holders and assist landless with homesteads. Assists controlling runoff and can promote keeping of livestock near residences.
. Can promotes better fertility management (compost, etc) and agronomic practices.

(7) Minimum surveying and tools requirements

Survey: pegs, 10-15 meters string, measuring tape, Construction: crow bars, pick axes, shovels, mason's hand tools, ladder, metal hack saw, barrel, plumbob, pliers, carpenter's tools, Labour group min 5 people per cistern to increase efficiency

(8) Design and technical standards (see figs 1 to 6 at the back)

Main Types by shapes: Hemishpherical, Dome cap, Bottle shape, Spherical, Sausage, etc.
1) Hemispherical: Useful to small-scale irrigation during (supplementary) and after the rainy season, easy construction, takes up space
2) Dome/Sphere/bottle/Sausage: Relatively requrie stable soils,if properly done less seepage/evaporation loss, take less space.
Design: Sizing a water tank: If the monthly rain data of an area is available , and monthly water demand for any activity in the same area is known, the required size of the tank can be estimated easily as shown below :
Step 1 Obtain average monthly rain fall of an area for a minimum of 8-10 years.
Step 2 Rank rain fall data of the months starting with the highest rainfall.
Step 3 Select the catchement type and size that will be available for use:
Step 4 Calculate the monthly runoff amount (in flow) that can be generated from the given catchement area.
Step 5 Calculate the monthly water demand (out flow) for each type of use.
Step 6 Calculate the cumulative in flow (supply) for each month.
Step 7 Calculate the cumulative out flow (demand) for each month.
Step 8 Compute the difference between total water available (inflow) and demand (outflow) for each month (step 6 minus step 7)
Step 9 Subtract the smallest negative difference from the largest posetive difference (from step 8). The value obtained will be the required water tank size for the annual water demand.
Siting conditions: 1. Locale the tanks where the largest amount of water can be stored. 2. Avoid sites near unstable ground, such as gullies, landslides or neer deep-rooted trees. Do not plant trees with deep roots near the tanks.
Under ground cisterns as compared to above ground tanks can store more water at lower cost b/c the ground supports the weight. This means walls can be thinner than for above ground tanks. Water is relatively colder, the water to be stored may come from the ground surface or from rooftops. The tank fills quickly.

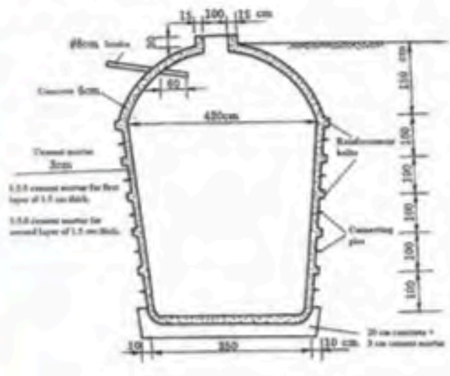
(9) Integration opportunities/requirements	(10) Work norm	(11) Use of microponds from different sources of runoff
1. Construct small silt traps before water enters the MP (2mLx2mWx1mD), see fig 6. More than one silt trap may be required (especially for microponds collecting water from erodible soils - check first year and add one if necessary). 2. Integration with low-cost lifting and drip systems to facilitate fetching water and water application to each plant. 3. Cisterns should be integrated with proper seedbed preparation for horticulture crops, compost making, beekeeping, watering of fruit trees, small livestock, etc. 4. Fencing in the case of the hemispherical and proper lid	(1) Excavation (1PD/0,5 m³) (2) Stone collection and shaping (1PD/0,5 m³) for stone pavement/facing of walls (3) Shading (thatched roof, etc) (4) Others as required (such as small cutoff drains and waterways see other infotechs)	1. Illustration of cistern hemispherical shape - fig 1 2. Sketch of emispherical cistern - fig 2 3. Illustration of cistern - dome cap - fig 3 4. Illustration of cistern - spherical - fig 4 5. Illustration of cistern - bottle shape - fig 5 6. Illustration of the silt trap - fig 6

(12) Planning and implementation arrangements	(13) Management requirements
. Planning follows groups and individual owners' agreement on location, source of runoff to exploit, purpose, type of crops and management. Groups of 3-5 households work together to increase efficiency. Skilled mason required for cemented structures.	. Removal of silt from reservoir/silt trap as required (can be used for seed beds if fine). Check the shading is effective (mats, others). Check fence for safety (aware children of hazards).

(14) Limitations	(15) Institutional responsibility
. Not suitable in unstable soils, e.g. sandy/sandy loam or very expandable soils. . Water not suitable for domestic drinking purposes. May induce water borne diseases. . Limited efficiency - only for supplementary irrigation of small plots. Credit facility required.	. Fully on individuals/groups for management . DAs and wda experts - technical support and follow-up/mgt.

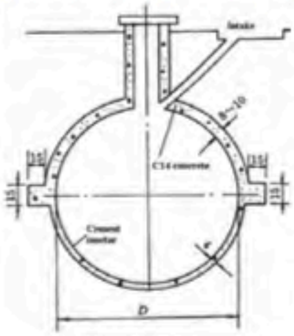
1. Illustration of cistern hemispherical shape - fig 1

3. Illustration of cistern - dome cap - fig 3



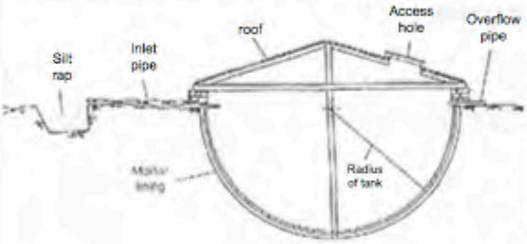
Concrete dome tank

4. Illustration of cistern - spherical - fig 4

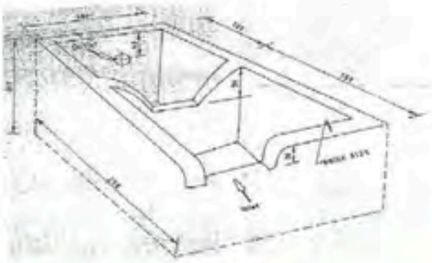


Spherical tank (Unit in cm)

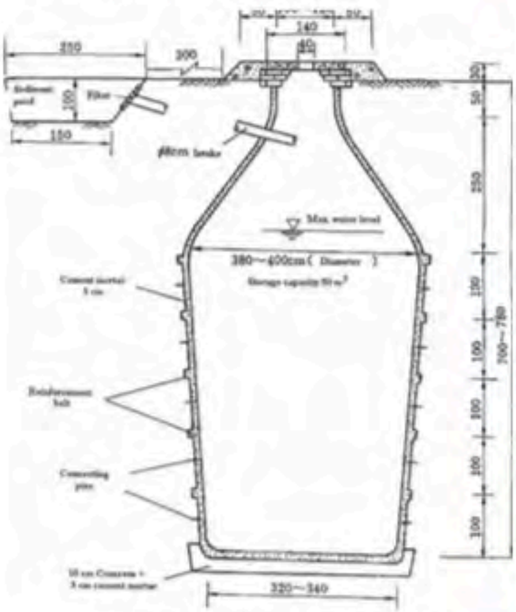
2. Sketch of hemispherical cistern - fig 2



6. Illustration of the silt trap - fig 6



5. Illustration of cistern - bottle shape - fig 5



Underground tank lined with cement mortar (Unit in cm)

Competed silt trap

TECHNICAL INFORMATION KIT

Farm Pond Construction

(1) Period/phases for implementation

Construction of ponds should be during, dry season before rainfall occurs

(2) Objectives/remarks

.To store surface water for use during dry seasons for the purpose of domestic use, human consumption, irrigation or for fish production.

(3) Suitability, agro-ecology and adaptability based upon local knowledge

A suitable site for a pond is where a limited amount of excavation is required to contain, or hold back a large volume of water. A valley were a dam can be constructed at a narrow pass is a good example.
The designer or expert should also think about the size of the catchment area to get enough runoff to fill the pond.
(1) Ponds should be located at a point where maximum volume of water can be collected with least digging or earth fill. (2) Ponds for livestock should be well spaced as the livestock should not travel more than one km. (3) To avoid pollution, the site should be away from farm drainage and sewage lines. (4) The drainage area should be sufficient to provide adequate runoff.

(4) Minimum tools required

(1) Wooden pegs, measuring tape or marked string.
(2) Sledge hammers, crow bars, shovels, pick axes, wheel barows and barella (to carry out soil), backets
(3) Workers or labourers

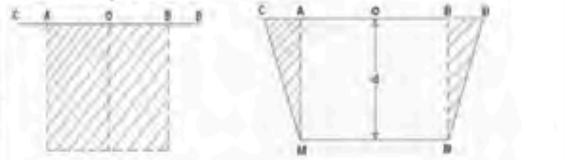
(5) Worknorms (WN)

Average worknorm is 0.5 m3/pd. The WN invloves surface clearing, digging, disposing or removal of soils and excavation works.

(6) Construction Procedures (layout)

1. Mark the pond on the ground
2. Start digging the pond
3. Keep the soil 3 m away from the edge of the pond
4. Consider point O as the center of the pond
5. If the side slopes are considered to be same in both sides, the distance of points AC and BD are equal. Similarly, distances of points OA and OB are as well equal.
6. Start excavating or digging AMNB first and then shape CAM and DBN as shown above.
7. Excavate similar dimensions on the width wise direction

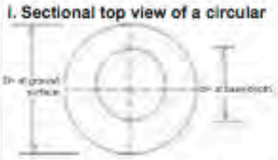
Construction procedures



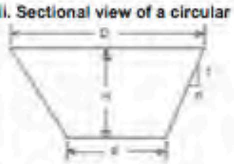
(7) Design and determination of volumes

To determine the volume of water to be stored in the pond, the volume of expected water use should be calculated.
Volume of a pond is calculated based on the shape of the pond.
(a) Volume of a **circular pond** can be calculated by multiplying the average area of the pond by its depth. (1) To avoid collapsing or sliding of the sides of ponds, it should have a certain permissible side slope. (2) The volume of the sloping sides therefore should be deducted from the total volume of the pond.

i. Sectional top view of a circular



ii. Sectional view of a circular



The average area of a circular pond is calculated using the following formula

$$A_s = \frac{\Pi D^2}{4} \qquad A_b = \frac{\Pi d^2}{4}$$

π = 22 / 7 = 3.1428.

Where, As = Area at the surface of the pond, m2
Ab = Area at the base of the pond, m2

$$A_{av} = \frac{A_s + A_b}{2} = \frac{\Pi(D^2 + d^2)}{8}$$

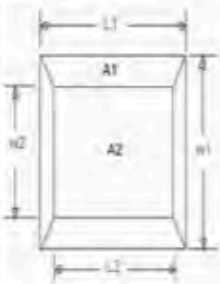
Where, Aav = Average area of the pond, m2
The average volume or capacity of a pond can be calculated by using the following formula:
Vav = =Aav x H = {π (D2+d2)/8} x H
Where,
Vav = Volume or capacity of the pond, m3
H = Depth of the pond, m.
D = Diameter of the pond at the surface, m.
d = Diameter of the pond at the bed of the pond, m.

(11) Modifications/adaptation to standard design

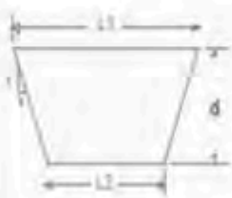
(b) Volume of a **rectangular pond** can be calculated by multiplying the average area of the pond by its depth.

The surface area (A1) and area at the bottom of the pond (A2) is calculated as follows:
A1 = W1 x L1
A2 = W2 x L2
Aav = (A1+A2)/2 =
= {(W1 x L1) + (W2 x L2)}/2
Where,
Aav = is the average area of the rectangular pond, m2
A1 = Area at the surface of the pond, m2
A2 = Area at the based of the pond, m2
W1 = Width of the pond at the surface, m
W2 = Width of the pond at the base, m
L1 = Length of the pond at the surface, m
L2 = Length of the pond at the base, m
Volume of a rectangular pond can be calculated by using the following formula,
Vav = Aav x d = {(W1 L1+W2 L2) x d}/2
Where,Vav = average volume or capacity of the rectangular pond, m3
d = Depth of the pond, m

iii. Sectional top view of a rectangular pond



iv. Sectional view of a rectangular pond



TECHNICAL INFORMATION KIT	**(1) Period/phases for implementation**	**(2) Objectives/remarks**
Farm dam Construction A body of water created either by excavation or by earth filling across a depression or stream course. Earth fill farm dams are storage dams. All earth fill farm dams are non-over flow dams. Some of the general water sources of a farm dam are surface flow and	Construction period for embankment or earth fill farm dams should be during dry seasons, usually January to May.	Storage farm dams are mainly to store surface runoff water and to use it when required for various uses such as for human and animal consumption, small scale or supplementary irrigation, fish production.

(3) Suitability, agro-ecology and adaptability based upon local knowledge

A suitable site for a farm dam construction is where a watercourse or river valley has a neck formation. A valley which has a large storage capacity on the upstream side of the proposed dam site is probably the best. The general paramount considerations in the choice of the dam are geology of foundations, hydrologic considerations, availability of construction materials and general know how. The geology of the foundations needs to be fully investigated before the choice is completed. The investigations are to be conducted not only at all selected alternate dam sites but also over the entire reservoir area to identify the potentially weak strata which are likely to give way under the pressure. The designer or expert should also think about the size of the catchment area to get enough runoff to fill the farm dam. Moreover, farm dams should be located at a point where maximum volume of water can be collected with least excavation or earth fill; farm dams for livestock should be well spaced as the livestock should not travel more than one km; to avoid pollution, the site should be away from farm drainage and swage lines; and the drainage area should be sufficient to provide adequate runoff.

(4) Minimum tools required

(1) Surveying equipment (such as water level, theodolite), range poles, measuring tape or marked string. (2) Sledges, crow bars, shovels, digging hoes, pick axes, wheel barrows, soil compacting tool, soil dumper, etc. (3) Workers or laborers

(5) Worknorms (WN)

The average worknorm for small farm dam is 0.40 m3/pd. The work norm for a farm dam is calculated in terms of volume of fill materials. The worknorm refers to soil and stone movement, placement of stones for a spillway rip rap, sodding of grasses on down stream face, stone riprap on upstream face, placement of sand and toe filters

(6) Design and Construction Requirements for an earth fill farm dam

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. The zoned section is the most popular type used nowadays in which cross sections of the farm dam is divided into zones. The outer zones are more pervious to have a free draining property while the inner zone or the core zones are made up of an almost impervious clayey soil to check seepage.

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 and remove the excess water to a safe outlet, a properly designed spillway is very essential

(7) Design of small scale farm dam

The design of a farm dam is based on existing experiences and performance. For preliminary design of a farm dam, selecting suitable values of top width, height of the dam, free board, upstream and downstream slopes, drainage arrangements, etc. are required. Free board is the vertical distance between the maximum reservoir level and the top of the dam. To avoid over topping of a farm dam, there must be sufficient free board. In most cases, the recommended values of a free board for an earth fill dam are indicated in the table below.

Width :- The top width of large earth fill dams should be sufficient to keep the seepage line well within the dam, when reservoir is full. For small dams, this top width is generally governed by minimum road way width requirement. The top width (b) of the earth dam can be selected according to the following recommendations.

$$b_1 = \frac{H}{5} + 3 \qquad b_2 = 0.55\sqrt{H} + 0.2H \qquad b_3 = 1.65(H + 1.5)^{1/3}$$

Where:
H is the height of the dam.

Note:- Formula b1 is used for low earth fill farm dams; formula b2 is used for earth fill farm dams lower than 30 m and formula b3 is used for earth fill farm dams higher than 30 m.
The down stream 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

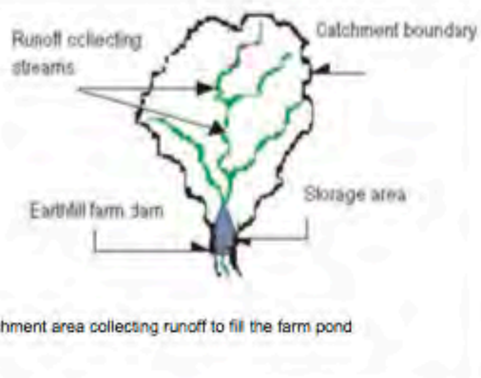
Type of construction material	Upstream slope (H:V)	Downstream slope (H:V)
Homogeneous wellgraded	2.5:1	2:1
Homogeneous Course silt	3:1	2.5:1
Homogeneous Silt clay: 1. Height less than 15 2. Height more than 15	2.5:1 3:1	2:1 2.5:1
Sand & gravel with a central clay core	3:1	2.5:1
Sand & gravel with R.C diaphragm	2.5:1	2:1

Height of dam

The Height of a farm dam should be designed so that it is not over topped any time. Thus, after studying the wave height, wind setup, likely maximum water elevation, etc. the free board varying between 3 m to 5 m 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:

Height of dam, m	Max. free board m	Top width, m	Upstream slope, H/V	Downstream 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



Catchment area collecting runoff to fill the farm pond

TECHNICAL INFORMATION KIT	(1) Period/phases for implementation	(2) Objectives/remarks
RIVER-BED OR PERMEABLE ROCK DAMS	. Only during dry season and min. one month before rains likely to occur.	. River bed dams are a floodwater farming techniques where runoff waters are spread in valley bottoms of seasonal riverbeds, large gullies or natural water courses for improved crop and forage production using a long, low structure, made from loose stone (occasionally some gabion baskets may be used). Developing gullies are healed at the same time. Occasionally it is required to raise the riverbed in order to guide spate floods into irrigation canals of spate irrigation schemes, or to accumulate river sediments for riverbed cultivation. In such a case, very strong dams are required that can resist powerful spate floods. .It is a relatively low cost structure especially designed to resist heavy flooding. The structures are typically long, low dam walls across valleys. The large amount of work involved means that the technique is labor intensive and needs group approach.

(3) Suitability, agro-ecology and adaptability based upon local knowledge

River bed dams for crop production can be used under the following conditions: Rainfall: 200 – 750 mm; from arid to semi-arid areas; Soils: all agricultural soils – poorer soils will be improved by treatment;Slopes: best below 2% for most effective water spreading; Topography: wide, shallow valley beds; Traditional structures similar to river bed dams are common in several parts of Ethiopia (Dire Dawa, Tigray/Erob, Wollo, , Hararghe, etc). As the flood subsides ring planting is practiced.

(4) Main land use	(5) Technical preparedness
. Suitable in river/valley bottoms for improved crop production. They can also be used for forage production using the residual moisture of the riverbed sediment. Is more effective in areas where villagers have some experience in spate irrigation or flood farming.	. Training required (DAs and HHs) . Agree with farmers on location, user rights, size,production area, catchment protection works and on-the-job training. Test measure first.

(6) Potential to increase/sustain productivity and environmental protection	(7) Minimum surveying and tools requirements
. Very high - for cereal as well as cash crops, introduction of fruit trees in gullies, valuable trees, etc. . Provide opportunities for income generation to small land holders and landless. . Drought proof activity - even when rainfall is low river bed dams collect sufficient moisture. . Promotes fertility management (compost, etc) and watershed protection, raise water table.	. Survey: long rope and wooden pole, measuring tape or marked string Tools: crow bars, shovels, pick axes, local stretchers (barella) to carry soil, sledge hammers. . Volume of stone work per ha varies from 70 - 280m3 based on slope.

(8) Layout

A) Site Selection: site selection depends both on the beneficiaries and the technicians. Theoretically it is best to start at the top of the valley, though this may not always be people's priority. After site identification it is necessary to determine whether the structure needs a defined spillway; as a rule of thumb no spillway is required if the gully is less than one meter deep. For greater depths, a spillway is recommended. Gullies of over two meters depth poses special problems and should be only tackled with caution.

B) Catchment: Cultivated Area ratio: the calculation of the C:CA ratio is not necessary as the catchment area and the extent of the cultivated land are predetermined. However, the catchment characteristics will influence the size of structure and whether a spillway is required or not. Usually, because it is a permeable rock dam, if the depth is less than one meter then there is no need to include spillway. When required gabions are best for spillways, as loose stones easily destabilized by heavy floods. As the soils become heavier behind the bunds water logging could be a problem and selection of crop taken into account.

C) Design/size: the main part of the dam wall is usually about 70cm high although some are as low as 50cm (fig 1-4). However, the central portion of the dam including the spillway (if required) may reach a maximum height of 2m above the gully floor. The dam wall or "spreader" across the valley beds normally range from 30 to 100 meters. Sites requiring greater than this size technical assistance may be consulted. The dam wall is made from loose stone, carefully positioned, with larger boulders forming the "framework" and smaller stones packed in the middle like a "sandwich". The side slopes are usually 3:1 or 2:1 (horizontal : vertical) on the downstream side, and 1:1 or 1:2 on the upstream side. With shallower side slopes, the structure is then more stable (Fig 2). For all soil types it is recommended to set the dam wall in an excavated trench of about 10cm depth to prevent undermining by runoff waters. In erodible soils, place a layer of gravel, or at least small stones, in the trench.

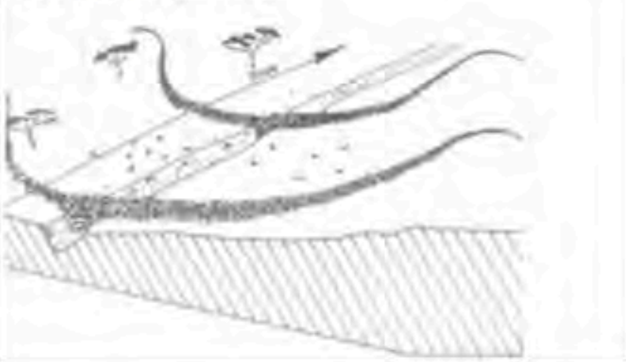
D) Quantities and labor: the quantity of stone, and the labor requirement for collection, transportation and construction depends on a number of factors and vary widely. Table below gives the quantity of stone per cultivated hectare for a series of typical river bed dams under different slopes.

Land slope (%)	Spacing between dams* (m)	Volume of stone/ha cultivated (m3)
0.5	140	70
1.0	70	140
1.5	47	208
2.0	35	280

*vertical interval between adjacent dams = 0.7m, the above figures are calculated for a river bed dam with an average cross section of 0.98m2, 70cm high and base width of 2.8m and a length of 100m. The vertical interval between dams is assumed to be 0.7m, which is equal to the dam ht.

Fig1. Riverbed dam dimensions

Fig2. Riverbed dam: general layout.

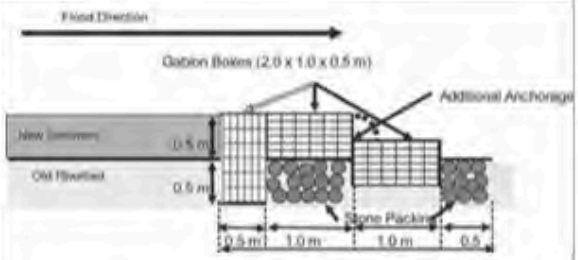


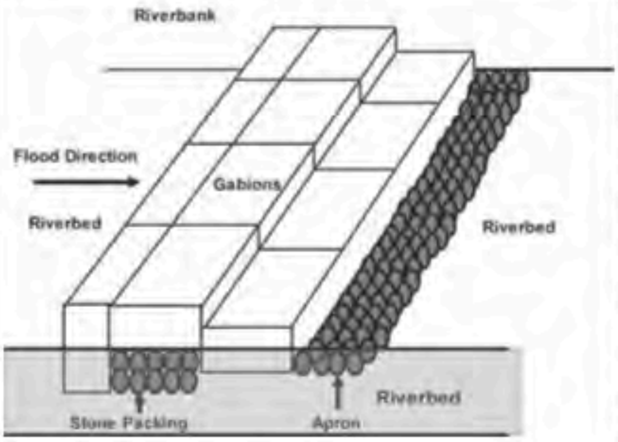
F) Example on how to determine spacing of riverbed dams:

for dams of 70cm height, the VI should theoretically be 70 cm. However in practice this may not be practicable due to the amount of stone and labor involved. As a compromise, a V.I. of 100 cm might be more realistic. Even wider spacing could be determined most easily by the use of a line-level.

The horizontal spacing between adjacent dams can be determined from the selected VI and the prevailing land slope according to the formula: HI = (VI x 100)/(% slope)

Where: HI = horizontal interval (m)
VI = vertical interval (m)
Slope in % = land gradient expressed as a percentage
For example, for a VI of 0.7 m and a 1% land slope,
HI = (0.7 x 100)/1 = 70 meters
For a VI of 0.7 m and a 2% land slope,





G) Layout and construction steps:

1) A foundation of small stones, set in a trench, is required.

2) An apron of large rocks is needed to break the erosive force of the overflow (fig1-4).

3)The downstream banks of the watercourse should be protected by stone pitching to prevent gully enlargement.

4)The alignment of the main dam walls can be marked out, starting at the center of the valley (where there may/may not be a spillway).

5)The arms end when they turn parallel to the watercourse. The contour can be laid out simply using a water tube or line level.

6)The first action after aligning the extension arms of the dam is to dig a trench at least 10 cm deep and 280 cm wide (according to the base width of the bund). The earth should be deposited up slope and the trench filled with gravel or small stones.

7)The skill of construction is in the use of large stones (preferably of 30cm diameter or more) for the casing of the wall.

8)This should be built up gradually following the required side slope, and the center packed with smaller stones and the whole length of the bund should be built simultaneously, in layers.

9) If a series of permeable rock dams is to be built, and appropriate vertical interval (VI) should be selected.Technically it is correct to: start at the top of the valley and work down; and use a VI equal to the height of the structure.

(9) Work norm

Estimate about requirements based on the following work norms:

. The work norm for the **Riverbed dam embankment** (inclusive of all elements) is estimated as 0,75 m³ of volume work (earth and stone fill) per person/day.

. The work norm for the **spillway** is **0,5 m³** of spillway excavated soil and stone work (including drop structure and rip rap if necessary) per person per day.

.More explanation is also given on the front page under design section "D). Quantities of labor".

(10) Integration opportunities/requirements

. Riverbed dams are part of a watershed treatment. The dams improve conditions for plant growth by spreading water, where moisture availability is a limiting factor. In additon, sediment, which will build up behind the bund over seasons, is rich in nutrients, and this will further improve crop growth.

.This techniques is used exclusively for annual crops. In the sandier soils, which do not retain moisture for long, the most common crops are millet and groundnuts.

.As the soils become heavier, the crops change to sorghum and maize. Where soils are heavy and impermeable, waterlogging could be a problem and therefore, within one series of permeable rock dams, several species of crop may be grown, reflecting the variations in soil and drainage conditions.

.Gullies leading into the main riverbed dams should be treated with check-dams or SS dams. Spillways could be necessary as required.

(11) Management requirements

. The river bed dam based on the design given above should not require any significant maintenance work provided the described construction method is carefully applied. It will tolerate some overtopping in heavy flods.

.There may be some stones wahsed off, which will require replacing, or tunneling of water beneth the bund and need packing with small stones.

.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 gully.

.Sample soil profile cuttings to check soil/parent material conditions in order to decide best placement of the dam.

.After 1-3 years try hand-dug well close to lower side of embankments (2-3 meters from the wall). Make sure that each households owning/using their own dams along a common dry water course/gully agree to form a group for management river bed dams (mutual help).

(12) Planning and implementation arrangements

. Large quantities of stone needed
. Outside assistance could often be necessary for transport of stones
. Siting is often determined by the people rather than the technicians
. As the structures may not be made by individual farmers, it is necessary to cooperate in construction.

(13) Limitations

.The main limitation of riverbed/permeable rock dams is that they are particularly and require considerable quantities of loose stone as well as the provision of site-specific, transport.. Labour intensive and needs thorough follow-up - difficult in areas with limited expertise. Limited number of direct beneficiaries.

Not suitable in sandy and sodic soils.

(14) Institutional responsibility

. Fully on groups/individuals +/- community (commitment to management)
. DAs and wda experts - technical support and follow-up/management

TECHNICAL INFORMATION KIT

PERCOLATION PIT

(1) Period/phases for implementation

. Only during the dry season and period not interfering with Agriculture

(2) Objectives/remarks

A percolation pit is a structure, constructed on any marginal land with perviouos soil, with the following objectives:

1. Recharge the ground water
2. Enhance biomass production through improved water availability in the soil profile.
3. Reduce runoff and subsequently erosion and land degradation.

(3) Suitability, agro-ecology and adaptability based upon local knowledge

. Suitable in all areas where there is no drainage problem or where the grounnd water table is deep.
. Suitable in areas where the ground is pervious
. Can be constructed on any topography with adequate runoff.
. It should be considered only as an element of an inegrated watershed development.

(4) Main land use

.Marginal lands
.Gullies

(5) Technical preparedness

. Land use, soil and topography assessed
. Discuss/agree with farmers on design and layout + provide on-the-job training
. Precise layout and follow-up/adaptations

(6) Potential to increase/sustain productivity and environmental protection

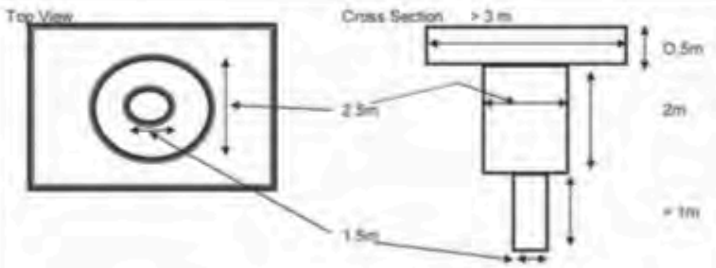
. Enhanced ground water availability for human and livestock use and irrigation.
. Water stored in the upper 1-3 m of the soil profile can sustain vegetative growth.
. Capturing the runoff by a series of ponds and related structures would retard surface runoff and subsequently avert land degradation.

(7) Minimum surveying and tools requirements

Layout: The pit can be circular or take the shape of the available land. Mark the top 0.5m deep pond and again mark the 2.5m pit.

Work: Dig the first 0.5m deep pond. Then dig the 2m deep pit. Next dig the 1.5m diameter pit. Fill the lower portion with 4cm stone.

(8) Layout



(10) Work norm

WORK NORM: 1 m3 / Personday for the first 1m depth; 0.5 m3 /PD therafter.

The worknorm involves digging, disposing of spoil, excavation of diversion canal

Gravel and stone collection

0.5 m3 / Personday

(9) Minimum Technical Standard

Percolation pits could be constructed in a wide range of conditions; (1) at any marginal land.(2) at outlets of cutoff drains/water ways (3) at abandoned quarries and depressions. There should be ample runoff that is free from pollution.

1) Excavate a 50 cm deep pond of any shape with either sides ranging from 2.5 to 10 meters.

2) Inside the o.5m pond, excavate a pit with a diameter of 2.5m and depth of 2 m.
3) Inside the pit excavate another pit with a dia. of 1.5m to a minmum depth of 1m or more.

4) The upper most portion of the pit is covered with an artificial filter to prevent suspended materials from entering in to the aquifer with recharged water.

The filter consists of 0.4m thick coarse sand, 0.5 m thick gravel (diameter 20mm) and stones of 40 mm size starting from 1m below the surface up to the bottom end.

(12) Modifications/adaptation to standard design

. The larger the pond sizes the better the recharge of the underground water.
. Spacing between two pits shall be about 50 meter.

(14) Management requirements

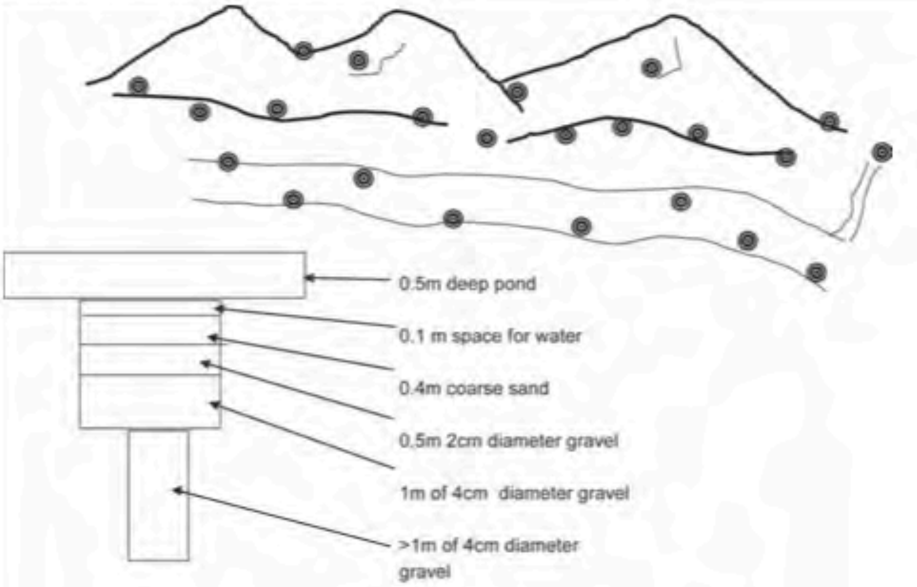
. Percolation pits require proper regular follow-up and maintenance through user groups.
. Silt deposited in the pit prevents water from percolation. Thus, it has to be removed 3 to 4 times during the rainy season.
. It is also necessary to ensure adequate runoff is diverted to the pond.

(13) Planning and Implementation arrangements

. Planning follows community/groups and individual owners' discussion/agreement on layout, spacing and management requirements.

(15) Limitations	(16) Institutional responsibility
Percolation pits shall not be excavated under the following conditions: 1) Little or no runoff 2) Weathered limestone/alkaline soils - as it would increase PH of the water; 3) Catchment with high concentration of manure or animal wastes - as it would increase the nitrate content of the groundwater; 4) Close to deep gorges - as the recharged water becomes unavailable easily; 5) Clay or impermeable geological formation - as it does not allow fast percolation of water	.To be implemented as part of an integrated watershed development intervention. . Fully on individuals/groups +/- community commitment to management. . DAs and wereda experts - technical support and follow up/ mgt.

Possible locations of a Percolation pit/pond



Excavation	Backfilling	Gravel on top of the small stones Coarse sand on top of the gravel
		

TECHNICAL INFORMATION KIT

PERCOLATION POND

(1) Period/phases for implementation

. Only during the dry season and period not interfering with Agriculture

(2) Objectives/remarks

A percolation pond is a structure, constructed on any marginal land with perviouos soil, with the following objectives:

1. Recharge the ground water
2. Enhance biomass production through improved water availability in the soil profile.
3. Reduce runoff and subsequently erosion and land degradation.

(3) Suitability, agro-ecology and adaptability based upon local knowledge

. Suitable in all areas where there is no drainage problem or where the grounnd water table is deep. Suitable in areas where the ground is pervious Can be constructed on any topography with adequate runoff.It should be considered only as an element of an inegrated watershed development.

(4) Main land use

. Marginal lands

(5) Technical preparedness

. Land use, soil and topography assessed
. Discuss/agree with farmers on design and layout + provide on-the-job training
. Precise layout and follow-up/adaptations

(6) Potential to increase/sustain productivity and environmental protection

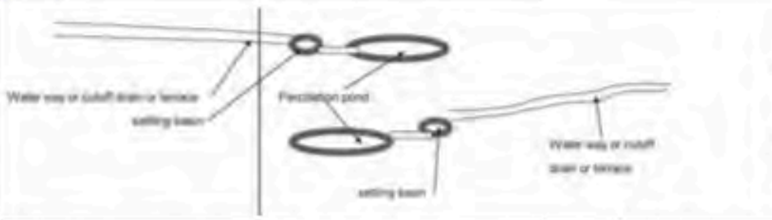
. Enhanced ground water availability for human and livestock use and irrigation.
. Water stored in the upper 1-3 m of the soil profile can sustain vegetative growth.
. Capturing the runoff by a series of ponds and related structures would retard surface runoff and subsequently avert land degradation.

(7) Minimum surveying and tools requirements

Layout: The pond can be trapezoidal or take the shape of the available land. Mark the top and bottom edges by pegs.

Work: Dig vertically following the mark of the bottom edge. Then trim the earth to join the bottom and top edges.

(8) Layout



(10) Work norm

WORK NORM: 1 m3 / Personday for the first 1m depth; 0.5 m3 /PD therafter

The worknorm involves digging, disposing of spoil, excavation of diversion canal and at a later stage removal of silt deposition from the pond surface.

(9) Minimum Technical Standard

Percolation ponds could be constructed in a wide range of conditions;

(1) at any marginal land.
(2) at outlets of cutoff drains/water ways
(3) at abandoned quaries and depressions.There should be ample runoff that is free from pollution.

(11) Modifications/adaptation to standard design

. The larger the sixe the better the recharge of the ground water
. Minimum Spacing between two percolation ponds shall be about 50 meters.

(12) Planning and Implementation arrangements

. Planning follows community/groups and individual owners' discussions/agreement on layout, spacing and management requirements.

(13) Management requirements

. Percolation ponds require proper regular follow-up and maintenance through user groups.
. Silt deposited in the pond prevents water from percolation. Thus, it has to be removed 3 to 4 times during the rain season.
. It is also necessary to ensure adequate runoff is diverted to the pond

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Percolation ponds shall not be excavated under the following conditions:
1) Little or no runoff
2) Weathered limestone/alkaline soils - as it would increase PH of the water;
3) Catchment with high concentration of manure or animal wastes - as it would increase the nitrate content of the groundwater;
4) Close to deep gorges - as the recharged water becomes easily unavailable;
5) Clay or impermeable geologicalformation - as it does not allow fast percolation of water

(15) Institutional responsibility

.To be implemented as part of an integrated watershed development intervention.
. Fully on individuals/groups +/- community (commitment to mgt.)
. DAs and wereda experts - technical support and follow-up/mgt.

Percolation Pond Lined with stone riprap to prevent erosion of the sides

Percolation ponds constructed in rocky terrain may not need protection of the sides

8. TRENCHES

Planning steps for constructing Trenches

i. Preparing technical design for constructing trenches: The design for trenches should indicate depth, width and length of each trench; spacing between trenches across and along the slope; average slope of the area and total number of trenches to be constructed in the planned area. The design should be supported with diagrams/sketches of trenches shown on the development map of the area. The possible dimensions for trenches are indicated below under minimum technical standards.
ii. Estimating the labor requirement (PDs) for constructing trenches: The total labor requirement in PDs can be estimated at two stages: (a) grouping the trenches by length (2 – 3 m long and 3 -5 m long) and then multiplying each group by its appropriate work norm. The work norms are 2PD/1.8 trenches for trenches of 2 – 3 m long and 1PD/0.6 trenches for trenches of 3 – 5m long; both PDs adjusted for pastoral areas. (b) Summing up the PDs of the two groups gives the required PDs for constructing the planned trenches.
iii. Estimating the PW resource/budget for constructing trenches: The budget for constructing the trenches can be estimated by multiplying the total PDs estimated in step ii by the rate of payment per PD in pastoral areas.
iv. Preparing work schedule for implementing trenches: The work schedule for constructing trenches should show the starting year and month, duration of the work, break down of the work by months and weeks and ending year and month of the work.

Hand tools

Tools for constructing trenches include crowbars, sledge hammers, shovels, and pick axes.

Planning and implementation arrangements

Planning follows community/user groups' discussions/agreements on the layout and management requirements.

Definition

Trenches are large and deep ditches/pits constructed along a contour with the purpose of collecting and storing rainfall-water to support the growth of trees, cash crops, and grass or various combinations of these species (Figure. 18 a & b). They are useful structures in moisture stressed areas for harvesting rainwater to meet the water requirement of grazing reserves, pastures, etc.

Work Norm

Construction of trenches involves excavation of soil, building embankment and compacting and digging plantation pit(s). The average work-norms used as National norms for constructing trenches are 2PDs/3 trenches of 2 – 3 m long and 1PD/trench of 5 m long with 2 - 3 ties/pits. When these are adjusted by 40% to pastoral areas in view of the harsh climatic condition and subsequent short working hours per day (5 hrs as compared to 8 hrs in the highlands), the average work-norms for constructing trenches in pastoral areas can be **14PD/15 trenches** of 2 – 3 m long and **7PD/5 trenches** of 5 m long with 2 – 3 ties/pits.

Management requirements

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.

User groups should ensure proper management and maintenance.

Implementation period

Flexible; during the dry season, preferably one month before rainy season (to enable plantation pits to weather) and during the period not interfering with activities of agriculture and/or normal/customary mobility.

Institutional responsibility

Individuals/groups +/- community (commitment to proper management and use.

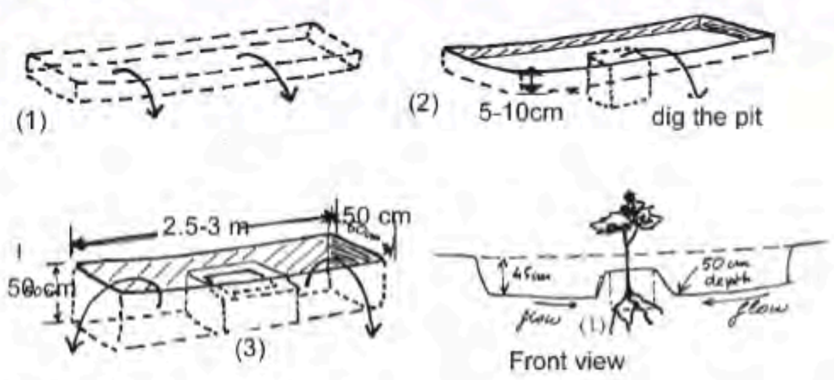
DAs and wda experts - technical support and follow up/management.

Minimum technical standards and designs for constructing Trenches

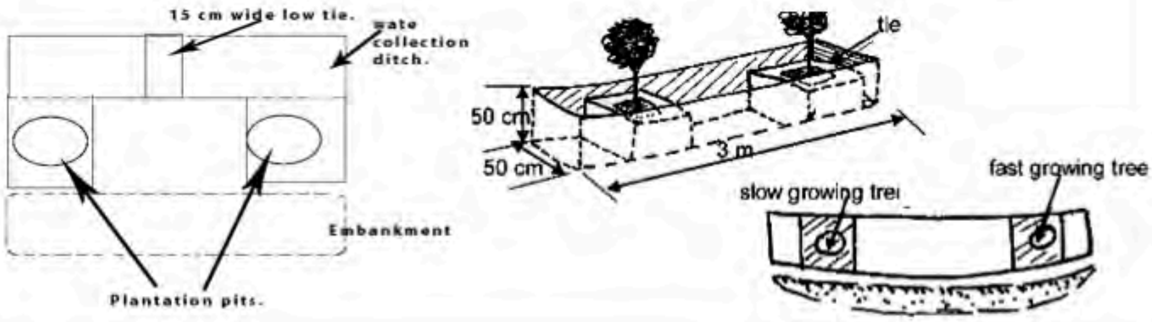
i. Select/determine the size of the trench and mark it on contour on the ground, starting from the top of the slope,
ii. Dig the trench/ditch and form the embankment on the lower side maintaining the recommended spacing between consecutive trenches.
iii. Trenches can have flexible size to accommodate the requirements of different plant species. Typical trenches have the following dimensions: Length: 2.5 – 3 m; Width: 0.5 m; Depth: 0.3 – 0.5 m
iv. Trenches should be spaced 0.5 m apart along the contour and 2 – 3 m along the slope with staggered position
v. If the plan is to plant a tree in the trench, leave undisturbed soil in the middle of the trench during its construction. After the trench is constructed, dig a pit of 0.5 m by 0.5 m in the middle of the remaining undisturbed soil. The pit should have a tie of 10 cm on the sides and the bottom should be 10 – 15 cm lower than the bottom of the trench.

Figure. 18. Trenches

a. **Layout of trenches**



b. **Planting trees in the middle of the trench**



Annex 2: Road prioritization tool

Here is an example of a simple way to rank the road where is more urgent to intervene. Some simple steps need to be followed. B

1. Draw a table in a flipchart/paper:

Road name	Start/end	Importance for the community (0=low; 5 = High)	Water related problems with the road (0= low; 5 = High)	Roadwater problems in nearby land (0= low; 5 = High)	Totals

2. In the first column write the name of the roads in your woreda

Road name	Start/end	Importance for the community (0=low; 5 = High)	Water related problems with the road (0= low; 5 = High)	Roadwater problems in nearby land (0= low; 5 = High)	Totals
Gaiuls road					
Matapi road					
Boiadeh road					

3. In the second column write all roads start points and end points (name)

Road name	Start/end	Importance for the community (0=low; 5 = High)	Water related problems with the road (0= low; 5 = High)	Roadwater problems in nearby land (0= low; 5 = High)	Totals
Gaiuls road	From Antani to Gaiuls				
Matapi road	From Kircha to Antani				

Boiadeh road	From Boiadeh to Antani				

4. In the third suggest what are the most important roads for their community (0= low; 5 = High);

Road name	**Start/end**	**Importance for the community (0=low; 5 = High)**	**Water related problems with the road (0= low; 5 = High)**	**Roadwater problems in nearby land (0= low; 5 = High)**	**Totals**
Gaiuls road	From Antani to Gaiuls	3			
Matapi road	From Kircha to Antani	5			
Boiadeh road	From Boiadeh to Antani	4			

5. In the fourth Column ("Water related problems with the road") rank what is the road that get more problems during the rainy season.

Road name	**Start/end**	**Importance for the community (0=low; 5 = High)**	**Water related problems with the road (0= low; 5 = High)**	**Roadwater problems in nearby land (0= low; 5 = High)**	**Totals**
Gaiuls road	From Antani to Gaiuls	3	4		
Matapi road	From Kircha to Antani	5	3		
Boiadeh road	From Boiadeh to Antani	4	5		

6. In the fifth column ("Roadwater problems in nearby land") rank what is the level of damage that road water causes to the nearby land (farmland, grazing land, Houses).

Road name	**Start/end**	**Importance for the community (0=low; 5 = High)**	**Water related problems with the road (0= low; 5 = High)**	**Roadwater problems in nearby land (0= low; 5 = High)**	**Totals**
Gaiuls road	From Antani to Gaiuls	3	4	3	
Matapi road	From Kircha to Antani	5	3	3	
Boiadeh road	From Boiadeh to Antani	4	5	4	

7. In the last column sum up the numbers in column 3, 4 and 5. This is the number that will suggest the priority for road-water interventions. The higher the number the higher is the need for R4W interventions. The road with higher number will be the first in line to get detailed planning and consequent interventions.

Road name	**Start/end**	**Importance for the community (0=low; 5 = High)**	**Water related problems with the road (0= low; 5 = High)**	**Roadwater problems in nearby land (0= low; 5 = High)**	**Totals**
Gaiuls road	From Antani to Gaiuls	3	4	3	**10**
Matapi road	From Kircha to Antani	5	3	3	**11**
Boiadeh road	From Boiadeh to Antani	4	5	4	**14**

Annex 3: Road Inventory Tool

Woreda name		**Kebele name**		**Sketch box**
Community catchment name		**Road name**		
Road length		**Change in elevation (metres)**		

No	**coordinates**	**Observed feature**	**Intervention to protect road**	**Productive use of water**
1	N E	**(Photo number)**		Yes/No How:
2	N E	**(Photo number)**		Yes/No How:
3	N E	**(Photo number)**		Yes/No How:

Annex 4: Further reading

ERA guidelines: http://www.fs.fed.us/eng/road_mgt/app2.shtml
LOW-VOLUME ROADS ENGINEERING Best Management Practices Field Guide (USAID)
PIARC Road Maintenance Handbook
Desta et al 2005, Productivity safety net programme Pastoral area public works: A guideline
GIZ, 2011, Water-spreading weirs for the development of degraded dry river valleys.