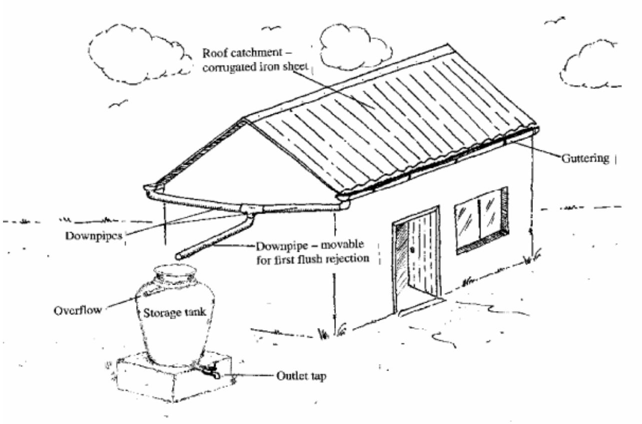
Earth & Subsurface Water System

1. Domestic Rainwater Harvesting (DRWH)



Technical Description:

Primary use: Domestic Water Supply

Domestic rain water harvesting has been successfully utilized by people all over the world for many centuries. A domestic rainwater harvesting system consists of the following component: The catchment (roof), conveyance mechanism (guttering and down pipes), first flush device and storage tank (masonry, ferrocement or plastic) The roof catchment area determines the quantity and to some extent the quality of water available throughout the year. GI sheet roofs are by far the best due to their relative smoothness and the sterilising effect of the metal roof heating under the sun. Conveyance is by guttering and down pipe made normally of PVC or folded metal (GI) sheet. DRWH systems normally include 'first flush' water diversion so that it does not enter the storage tank. The size the storage tank will depend on local rainfall spreading (number of dry days) and HH consumption rates. The storage tank can either 1) be above the ground with variation in size from 1 m3 to more than 40 m3 for households and up to 100 m3 or more for schools and hospitals or 2) below the ground. The benefit of above the ground tanks is that water can be extracted easily through a tap just above the base of the tank. Underground tanks offer a cheaper alternative due to its lower construction costs, but it is necessary to pump (lift) water and there is risk of contamination and sedimentation.

Useful design guidelines (for drinking purpose only):

Average *minimum* HH daily consumption Q_{HH} = 10 + (n x 5) litres (n = number of people in HH)

Average *sufficient* HH daily consumption Q_{HH} = 30 + (n x 7) litres (n = number of people in HH)

It is recommended to utilize minimum Q_{HH} in areas with only one rain season and a dry period between 6-8 months and sufficient Q_{HH} in areas with two or more rain seasons and a dry period between 3-5 months.

Annual consumption Q_A = 365 x Q_{HH}

Roof Area A = Q_A/(runoff coefficient x lowest annual rainfall within 5 years)

Storage requirement V = Dry Days x Q_{HH} x Evaporation loss (if storage closed considered zero)

Type of roof	*Runoff coefficient*	*Notes*
GI Sheets	*> 0,9*	*Excellent quality water. Surface is smooth and high temperatures help to sterilise bacteria*
Tile (glazed)	*0,6 – 0,9*	*Good quality water from glazed tiles. Unglazed can harbour mould. Contamination can exist in tile joins*
Organic (Thatch)	*0,2*	*Poor quality water (>200 FC/100ml)* *Little first flush effect* *High turbidity due to dissolved organic material which does not settle*

Useful in: Domestic RWH systems are suitable for individual household use, and use in schools and other institutions where sufficient impermeable roof cover exists. It is generally accepted to be most useful in areas with rainfall between 200 and 1000 mm. It has been found useful particular in the following situation: • Limited water resources for water supply – e.g. no perennial water sources and groundwater potential are low (low yield) or problematic (quality unacceptable). • Unreliable water supply - caused by seasonal variation in normal water availability. • In areas with 2 rainy seasons with dry spells limited to 3-4 months. • Remote and difficult to reach areas. Generally sufficient information exists on DRWH to incorporate these systems into regular WSS project as occasional, intermittent, partial or full scale water supply.	**Limitation:** In areas with rainfall below 200 mm, the roof area and storage requirement become as a rule too large and often financial unattractive (note that this highly depend on the fresh water scarcity situation and in severe cases DRWH can be a feasibility option even in areas with rainfall below 200 mm). In areas, where rainfall exceeds 1000 mm, water availability is normally sufficient to cater for conventional water supply techniques (rivers, lakes, sub-terrain aquifers etc.)
Geographical extent of use: Africa: Kenya, Tanzania, Uganda, Mali, Mauritania, Benin, Burkina Faso, Botswana and Ethiopia.	**Effectiveness:** The intensity and distribution of rainfall will determine the feasibility of a DRWH system. The intensity of rainfall will determine the catchment areas needed – whereas the spreading with determine the storage requirement. The effectiveness of rain water collection systems depends on the type of roofing material used. For example, thatched grass gives lower yields than corrugated iron sheets.

Cost:

Data and experiences from numerous references shows that the capital cost for a DRWH system with a above the ground tank in Africa would be approximately 50 USD/m3 storage inclusive gutters and other minor components. DRWH with **underground tanks** would be considerably cheaper (7-16 USD/m3).

Example:

Q_{HH} = 30+(6x7) litres (6 = people in HH) = 72 litres

V = 120 days (dry days) x 72 litres = 8,64 m^3

Approximately cost per HH = 432 USD

Approximately cost per capita = 72 USD

Note that this DRWH system will supply 12 litres per each individual (6) in the HH during the 120 dry days.

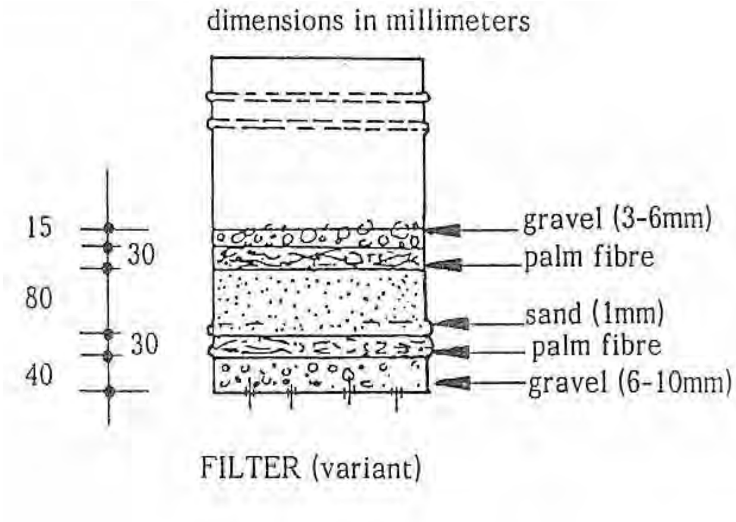
A climate where rain falls regularly throughout the year will mean that the storage requirement is low and hence the system cost will be correspondingly low and vice versa. Drinking water supply through rainwater harvesting can often be twice or triple the cost (per capita) compared with regular water supplies (e.g. piped water supplies) – but only if potable water is easily available.

In addition, domestic rainwater harvesting suffers from strong diseconomies of scale in terms of supplying water needs. A small tank (1,000 litres) may supply 70% of a households water needs over the year (mainly in the wet season) whereas a tank 5 times the size will supply 90%, only a 20% improvement. Nonetheless, the technology can be highly cost-effective if gutters, down pipes, filters and storage tanks can be constructed using low cost locally available materials.

Operation and maintenance:

Limited regular maintenance of gutters, and removal of leaves and other debris from the catchment surface, is required. Cleaning of the tanks is necessary before and after the first rains. All of these activities can be handled by the community. Water is drawn by bucket or taps fitted to the storage tank. Note that training and information on O&M for DRWH systems is often forgotten, which leads to deterioration and unsafe water quality.

Water quality in stored RWH system has been investigated through several studies /IWA, 2006/ and these consider the growth of pathogenic bacteria in rainwater storage tanks for unlikely. Furthermore there is a die-off behaviour of micro-organisms during storage /DTU 2001/. In addition, successful practices applicable for rural setting can be used to ensure potable water – e.g. solar disinfection using UV rays and heat (see www.sodis.ch), boiling (5-20 minutes), filtering (see right or treatment with chlorine.



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Enabling Environment:

- Domestic RW harvesting must be supported and included as a key option within regular water supply programmes as part of the demand responsive approach.
- Policies and legislation that recognize rainwater as the source of water.
- Including the DRWH in the institutional curriculum – in design norms and educational institutions.
- Political acceptance and support

Level of beneficiary involvement:

Any intervention using DRWH must employ demand responsive approaches, user contribution towards capital cost either in kind or cash, community participation and ownership. Lastly beneficiaries should be properly trained in O&M.

Environment benefits:

The capture of rainwater on roofs eases the pressure on existing water sources. In addition, it minimizes the erosion damages around the domestic building during torrential rain showers.

Cultural acceptability:

Rainwater has generally a high level of acceptance among communities in respect to taste and appearance. Household with DRWH systems even act as water vendors during periods of water shortages. No negative cultural factors have been observed.

Advantages:

- Water is provided at the point of consumption
- The recurring costs for operation and maintenance of the system include regular cleaning and leak prevention which can be easily undertaken by the

Disadvantages:

- Medium to high per capita cost
- Lack of reliability as a source of water – periods of drought.

2. Rock and other surface catchment systems

Primary use:

Domestic Water Supply and Livestock

Technical Description:

Rock catchments are simple systems for the collection of rainwater. The placement of these structures should take into account ease of access of the users and the geological structure of the site. The best sites are found on the lower reaches of bare rock (without fractures or cracks), where runoff losses to the soil, vegetation and structures is minimised. The retention of runoff is made in natural hollows or a valley which is made into reservoirs by constructing a simple masonry wall. The reservoir should have a relative high depth to surface ration to minimize evaporation. Stone and mortar gutters may be built across the rock face to channel the runoff into the dam. Storage may be provided in dams or open tanks. Other surfaces can also be used as catchment – e.g. concrete, plastic sheets, treated soils etc.

Useful design guidelines:

Average *minimum* HH daily consumption Q_{HH} = 10 + (n x 5) litres (n = number of people in HH)

Average *sufficient* HH daily consumption Q_{HH} = 30 + (n x 7) litres (n = number of people in HH)

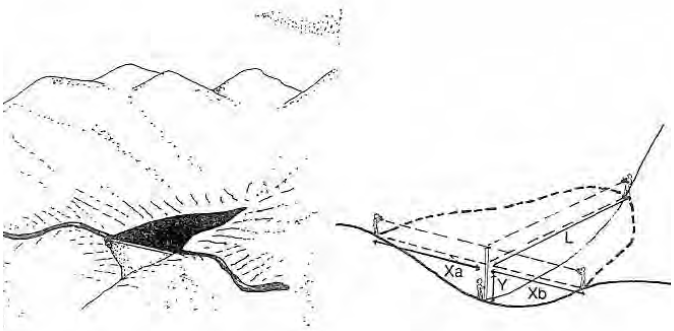
Annual consumption Q_A = 365 x Q_{HH}

Runoff = Rock catchment Area x runoff coefficient (0,8) x lowest annual rainfall within 5 years (LAR)

Required Catchment = (Q_{HH} x No. of HH + evaporation loss)/(runoff coefficient (0,8) x LAR)

Storage volume requirement V = Dry Days x Q_{HH} x No. of HH

Storage volume V = 1/6 x L x Y x (Xa + Xb) – see below.



After Lee, M.D. and J.T. Visscher, 1992

Useful in: Rock catchment systems are suitable in areas with geological suitable rock outcrops (granite, basalt or any other hard rock). It has been found useful particular in the following situation:

- Limited water resources for water supply – e.g. no perennial water sources and groundwater potential are low (low yield) or problematic (quality unacceptable).
- Unreliable water supply - caused by seasonal variation in normal water availability.
- Remote and difficult to reach areas.

Information and experiences with technical institutions on rock catchment might not exist in a given area/country.

Limitation:

In areas with rainfall below 200 mm, the required catchment area/rock face can become too large and difficult to locate.

In areas, where rainfall exceeds 1000 mm, water availability is normally sufficient to cater for conventional water supply techniques (rivers, lakes, sub-terrain aquifers etc.)

Geographical extent of use:

Africa: Kenya and Tanzania.

Effectiveness: The intensity and spreading of the rainfall and the catchment area will determine the efficiency of the rock catchment system. Substantial amount of rainwater can be harvesting under the right geomorphologic situation – but consideration on distances to user should also be taken into account.

Cost:

The cost will be highly depending upon local condition and availability of local material for construction. Nonetheless where technical feasible, this technique can compete with conventional WS techniques.

Cost of RCS are listed below:

Location	Volume (m^3)	Cost (USD)	USD/m3
Kimanjo, Kenya	100	5.000 (2002)	50
Musul, Kenya	450	30.000 (2001)	67
East Africa Mati, 2006	46-110 USD/m3		

Operation and maintenance: The rock (catchment area) should be kept clean; reservoir should be emptied at the end of the dry session if possible to remove silt and algae. The avoid mosquito breeding (and spread of malaria), Tilapia fish could be introduced to the reservoir. A community management committee should be established and caretaker should be appointed to assure preventive maintenance (repair of cracks, damage of channelling structures and replacement of water taps) and lastly ensuring reasonable water consumption per HH (e.g. 40 litres per HH).

Water quality in the stored tanks normally require no further treatment. To avoid contamination, a fence of thorn bush can be constructed around the catchment area or the reservoir edge. Nonetheless, if necessary, solar disinfection using UV rays and heat (see www.sodis.ch), boiling (5-20 minutes), filtering or treatment with chlorine can be applied.

Enabling Environment:

- Rock Catchment Systems must be supported and included as a key option within regular water supply programmes as part of the demand responsive approach.
- Policies and legislation that recognize rainwater as the source of water. Political acceptance and support
- Including the RCS in the institutional curriculum – in design norms and educational institutions.

Level of beneficiary involvement:

Intervention using rock catchment should employ demand responsive approaches, user contribution towards capital cost either in kind or cash, community participation and ownership. Lastly beneficiaries should be properly trained in O&M.

Environment benefits:

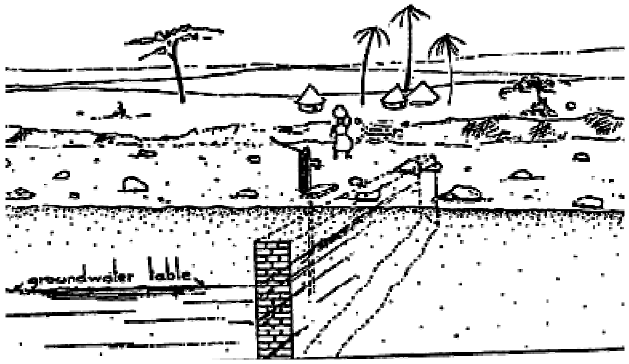
The capture of rainwater on bare rocks eases the pressure on existing water sources – e.g. groundwater and reduces runoff/soil erosion.

Cultural acceptability:

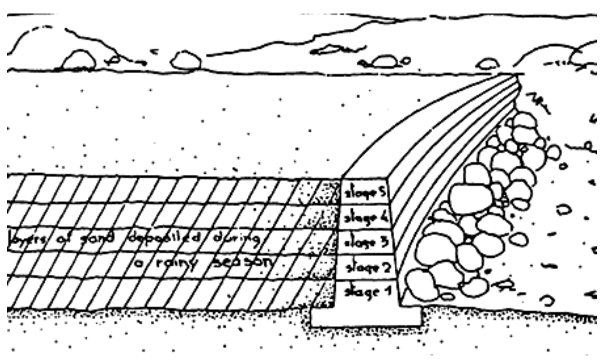
RCS generally has high level of acceptance in respect to taste and appearance. No negative cultural factors have been observed.

Advantages:	Disadvantages:
• Costs for operation and maintenance of the RCS include regular cleaning and leak prevention which can be easily undertaken by the communities. • If water is only available in deep groundwater aquifers/far away sources or in scenarios with water quality problems, the RCS solution will absolutely be price competitive.	• Lack of reliability as a source of water – periods of drought. • Unsuitable to supply water above 20 litres per capita (most African countries have adopted 20-35 l/c/d as basic water requirement).

3. Sub-surface Dams, Small Dams, and Sand Dams



Sub surface dam



A typical sand dam

Technical Description:

Primary use: Domestic Water Supply

A **sub-surface dam** consists of a vertical, impermeable barrier through a cross section of a sand- filled, seasonal river bed. A ditch is dug at right angles across the river and into each bank, preferably where a rock dyke protrudes. This provides a solid, impermeable base onto which a simple masonry wall can be built within the trench. In some situations, the wall is raised gradually as sand from upstream accumulates behind the structure, forming a **sand dam**. Water is taken out through a shallow well in the sand bed, or through a filter box, into a gravity pipe which runs through the dam to the point of use downstream. For water supply augmentation and soil conservation purposes, it is better to build a series of small dams along the same stream, rather than building one large dam. A sequence of small dams increases alluvial deposition and improves infiltration more than a single large dam.

Useful design guidelines (for drinking purpose only):

Average *minimum* HH daily consumption Q_{HH} = 10 + (n x 5) litres (n = number of people in HH)

Average *sufficient* HH daily consumption Q_{HH} = 30 + (n x 7) litres (n = number of people in HH)

It is recommended to utilize minimum Q_{HH} in areas with only one rain season and a dry period between 6-8 months and sufficient Q_{HH} in areas with two or more rain seasons and a dry period between 3-5 months.

Annual consumption $Q_A = 365 \times Q_{HH}$

Storage volume $V_{sanddam}$ = Height of dam/2 x (100 x Height of dam/slop of river (%)) x river width x porosity (0,3)

Useful in:

- Limited water resources for water supply – e.g. no perennial water sources and groundwater potential are low (low yield) or problematic (quality unacceptable).
- It is most suitable for use in sandy, seasonal rivers prone to sedimentation.
- Unreliable water supply - caused by seasonal variation in normal water availability.
- Remote and difficult to reach areas.

This technique seems to be restricted to Eastern Africa.

Limitation:

- Limited to areas with seasonal riverbeds with floods event during the wet season
- Rivers with less coarse sand will not have sufficient water storage capacity.
- River slope between 1 and 5 %.
- River bed should be solid rock without fractures
- Construction material should be local available.

Geographical extent of use:

Africa: Kenya and Tanzania

Effectiveness: This technology is an effective means of augmenting drinking water supplies, providing additional arable lands, and protecting watercourses from sedimentation.

Cost (examples from Kenya):

Type of dam	Water volume	Cost/year
Subsurface soil dam	1885 m3	9.000 Ksh/1997
Subsurface masonry dam	2411 m3	75.700 Ksh/1999
Sand dam rubble masonry	6717 m3	225.300 Ksh/1996
	900 m3	241.000 Ksh/2006

Operation and maintenance: Once constructed, recurring costs are negligible. The structures may be assumed to last for 30 years.

Water quality can be ensured or improved by introducing solar disinfection methods, encourage boiling (5-20 minutes) or treatment with chlorine.

Enabling Environment:

- Small dam RWH techniques must be supported and included as key water supply options as part of the demand responsive approach.
- Policies and legislation that recognize reservoirs created by small dams as the source of water.
- Including small dam techniques in the institutional curriculum – in design norms and educational institutions.
- Political acceptance and support

Level of beneficiary involvement:

The level of involvement depends on the extent of the project. Generally, small dam design and construction is within the capacity of local agencies. Often, governmental agencies and extension services are involved in the initial production of standardised designs for dissemination to communities. Demand responsive approaches, user contribution towards capital cost either in kind or cash and community participation and ownership must be adapted. Lastly beneficiaries should be properly trained in O&M.

Environment benefits:

Reduction of erosion, management of silt deposition within river basins, and increased moisture infiltration within the soil profile and into the groundwater are environmental benefits associated with sub-surface dams.

Cultural acceptability:

No negative cultural factors have been observed.

Advantages:

- Evaporation of stored water decreases.
- Siltation does not create a problem as topsoil particles and decries are cleared during flash floods.
- Contamination of water by insects, birds and animals cannot take place as water is not exposed.
- Downstream users not deprived as water only fills up behind the created dam in the sand reservoirs with floods when water is plentiful anyway.

Disadvantages:

- Limited to supplying drinking water only
- Unsuitable to supply water above 20 litres per capita (most African countries have adopted 20-35 l/c/d as basic water requirement).

4. Earth dams and water ponds/pans

Still water at the end of the dry period

Goats taken to reservoir

Highly unsafe water point

Technical Description:

Primary use: Domestic Water Supply, Livestock and some small scale irrigation

Earth dams are semi-circular or curved banks of earth, 3-4 meters high and 100 meters in length. Water ponds or pans are naturally occurring or excavated water storage structures (called charcos in Tanzania) without a constructed wall/dam.

The reservoir should have a high depth to surface ratio to store maximum water behind the smallest possible dam. The best catchment area would be a relatively steep and rocky landscape with no erosion – and the dam should be placed in gentle sloping land in a wide shallow channel or broad depression. It is preferred that these can be built by using manual labour and animal tracking. An outtake pipe system should be constructed to abstract drinking water from reservoir

Useful design guidelines (for drinking purpose only):

Average *minimum* HH daily consumption Q_{HH} = 10 + (n x 5) litres (n = number of people in HH)

Average *sufficient* HH daily consumption Q_{HH} = 30 + (n x 7) litres (n = number of people in HH)

Annual consumption $Q_A = 365 \times Q_{HH}$

Livestock consumption: cattle and camels 15 l/d, sheep and goats 3,5 l/d

Runoff coefficients used in catchment area:

0,25 for steep terrain with many rocky outcrops, 0,10 for gentle sloping hills mainly covered with soil.

Storage volume $V_{earthdam} = \frac{1}{2} \pi$ x W (width of dam) x D (maximum depth of reservoir)

Useful in:
- In arid and semi regions with limited water resources for water supply – e.g. no perennial water sources and groundwater potential are low (low yield) or problematic (quality unacceptable).
- Area with pastoral existence/pastoral herders
- Remote and difficult to reach areas.

Limitation:
- Areas with substantial soil erosion
- High probability of torrential rains/floods
- Construction material not local available.

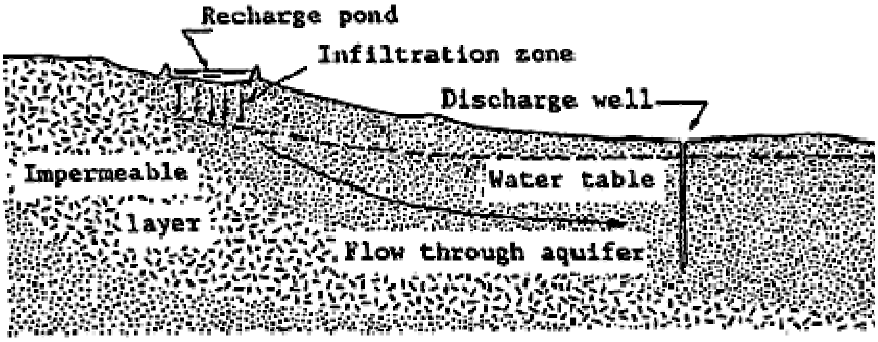
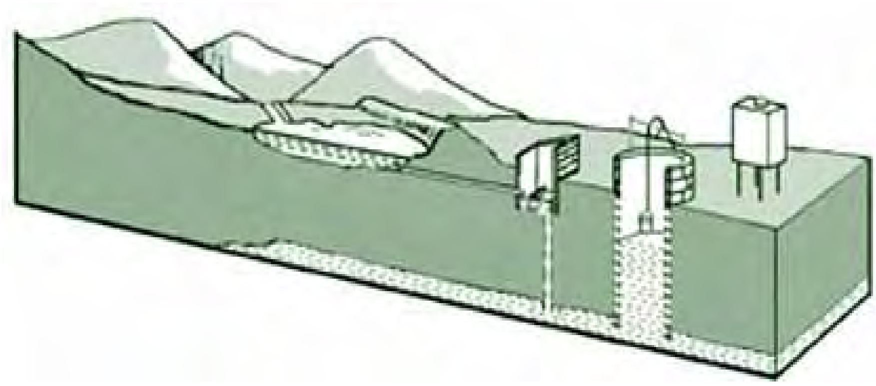
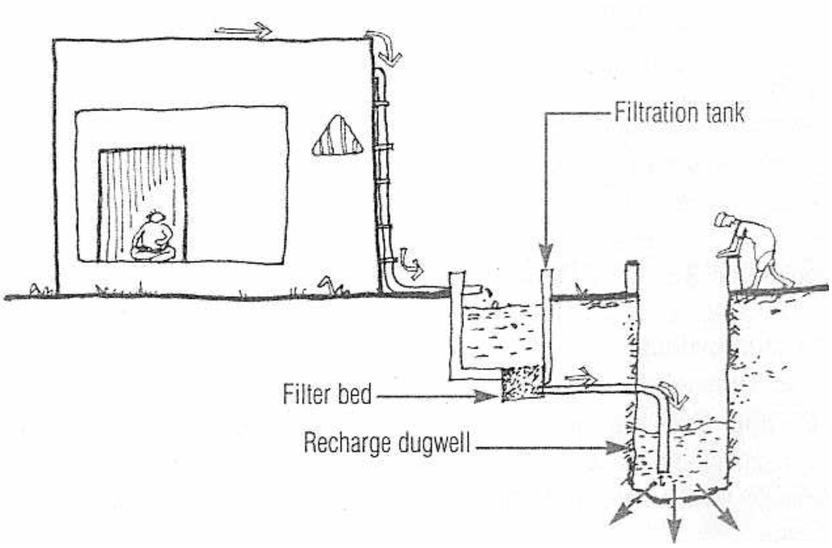
Geographical extent of use:

Africa: Kenya and Tanzania

Effectiveness: This technology is an effective and simple method to augment drinking water supplies to humans and livestock. The long term effectiveness (sustainability) depends on maintenance done/assured by the communities (protecting reservoir from sedimentation).

Cost: Highly depending upon user contribution and size. Data from AfDB Monduli project in Tanzania (earth dams constructed using of mechanical earth moving equipment and limited user labour contribution), provide average cost of 635 USD/HH and 10-16USD/m3 – based on preliminary estimates from 10 earth dam water supply schemes covering more than 5000 HH. Data from 1990 (IRC) indicate a much lower cost of around 2 USD/m3	**Operation and maintenance:** Erosion control in catchment area must be assured, silt traps must be annual emptied, cracks in the embankment should immediately be repaired and fence preventing primarily live stock to enter should be maintained. It is crucial that the maintenance of desiltation is given to the beneficiaries. The annual desiltation at the end of each dry season can be handled easily by communities, but requires mechanical earth moving equipment if this is left unattended for years. **Water quality** can be a severe problem, especially because livestock very often share the same water point as humans. So proper information and campaigning of water treatment methods like solar disinfection, boiling (5-20 minutes) or chlorine must be implemented.
Enabling Environment: • Earth dam techniques supported and included as key water supply options as part of the demand responsive approach. • Policies and legislation that recognize reservoirs created by earth dams as the source of water. • Including earth dam techniques in the institutional curriculum – in design norms and educational institutions. • Political acceptance and support	**Level of beneficiary involvement:** The level of involvement depends on the extent of the project. Generally, earth dam design and construction is within the capacity of beneficiaries with assistance from governmental agencies and extension services. Demand responsive approaches, user contribution in kind/labour and community participation and ownership must be adapted to assure the maintenance and sustainability of earth dams. Beneficiaries should be properly trained in O&M – especially annual desiltation.
Environment benefits: Reduction of erosion, management of silt deposition within river basins, and increased moisture infiltration within the soil profile and into the groundwater are environmental benefits associated with earth dams.	**Cultural acceptability:** No negative cultural factors have been observed.
Advantages: • Simple and well known technique/design • Multi purpose use – drinking, livestock, nurseries and even mud brick production • High potential for demand responsive approaches and user contribution (manual labour) – and thereby assuring better O&M.	**Disadvantages:** • The lifetime and reservoir capacity has tendency to decrease due to siltation unless O&M properly done annual by communities. • Human and livestock often end up drinking from same water point. • Difficult to avoid wildlife from entering water reservoirs. • Risk of increased cases of malaria (can be reduced by introducing Tilapia fish, that eat the mosquito larvae)

5. Recharge Structure

	Primary use:
 Recharge pond (UNEP, 1998)  Recharge well (Utthan Project, Gujarat, India)  Household recharge structure (CSE, 2003)	Domestic Water Supply and in some cases livestock

Technical Description:

Recharge structures is the use of infiltration basins or injection/infiltration wells to recharge groundwater resources. The concept is to collect rainwater typically from roofs, rock surfaces or established catchment areas and lead it towards the preferable well via a filtering arrangement. The filtering arrangement or the storage time in the aquifer normally is sufficient to assure water of drinking quality at the point of abstraction (borehole or open well).

Widely used now in urban settings but also used in rural areas throughout the world as a traditional approach as well as institutionally well accepted additional water supply structures /See key references below, GoK, 1999/.

Useful in: This practice is being increasingly utilized today as a consequence of problems with either depleted wells/groundwater aquifers or water quality (fluoride, arsenic or chloride). It has been found useful particular in the following situation:

- Limited groundwater resources for water supply – e.g. potential are low (low yield) and groundwater levels are low at the end of dry season.
- Problematic groundwater quality.
- Remote and difficult to reach areas.

Limitation:

- Presence of clay lenses covering parts of an aquifer can be a problem as they can prevent the infiltrated water from reaching the aquifer
- Groundwater recharge using infiltration basins in areas with high evaporation rates is not likely to be effective

Geographical extent of use:

Africa: Botswana, Egypt, Tunisia, and Algeria

Effectiveness: This technology is effective in arid regions with limited water sources. Since storage capacity in practice is unlimited, the more catchment area created – the more efficiency. Water reclaimed in this fashion may be used as an alternate source of drinking water.

Cost: Highly depending on available catchment area possibilities (roofs, smooth surfaces, bare rock etc.) and existing infiltration facilities (e.g. open well already existing)

Operation and maintenance: Limited regular maintenance of catchment areas and removal of leaves and other debris from the catchment surface, is required.

Enabling Environment:

- Recharge structure must be supported and included as part of a *water supply package* within regular water supply programmes as part of the demand responsive approach.
- Policies and legislation that recognize the need to apply recharging structure to water supplies.
- Including design of recharging structures in the institutional curriculum – in design norms and educational institutions.
- Political acceptance and support

Level of beneficiary involvement: Construction of recharge basins can be undertaken by local personnel with experience in well digging. Government assistance may be required to identify appropriate recharge sites. Demand responsive approaches, user contribution towards capital cost either in kind or cash, community participation and ownership must be employed.

Environment benefits:

The capture of rainwater/runoff and diversion to groundwater aquifers effectively replenish pressurized aquifers. In addition, it minimizes the erosion damages around the domestic building during torrential rain showers.

Cultural acceptability:

The technique is culturally acceptable.

Advantages:

- Storage capacity unlimited
- O&M is relatively easy and can be undertaken by

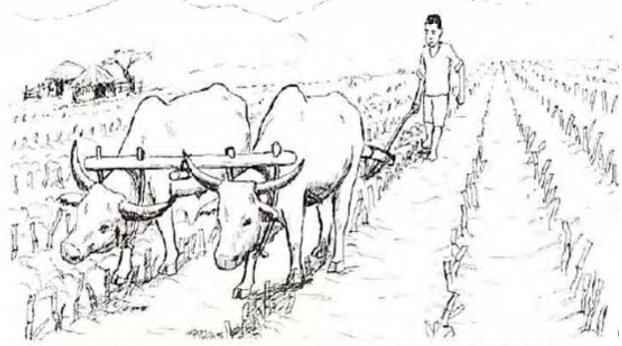
Disadvantages:

- The water from a recharged aquifer cannot be used without a system of abstraction.

the members of the household. • Groundwater recharge, especially using infiltration wells, conserves water through reduced evaporation. • Clean drinking water may be recovered from wells in the vicinity of the recharge field without using complicated treatment systems.	• Risk of polluting the aquifer with the recharged water. • Stored rainwater in aquifers might flow away and disappear from abstraction well.

6. Conservation Tillage

In-situ rainwater harvesting



With strip tillage, plough only the rows where the crop is to be planted

Technical Description:

Conservation tillage is a term used to describe any tillage system that conserves water and soil while saving labour and traction need. Conservation tillage aims at improving infiltration and water holding capacity through breaking up crust and pan formation but with minimum of soil disturbance and almost no inversion in order to minimise erosion. In addition the infiltration capacity and the water holding capacity are increased by an increased level of the soil organic matter and a largely undisturbed population of soil micro organisms which is important for the soil structure and its stability.

Conservation tillage applies four main principles: 1) zero or minimum soil turning, 2) permanent soil cover, 3) stubble mulch tillage, and 4) crop selection and rotations. An important aspect of conservation tillage practice involves ripping the land with tined implements or sub-soiling the land immediately after crops are harvested, to break the plough pans. Suitable equipment includes animal-drawn sub-soilers, rippers, “ridgers”, planters, and weeders. The following systems of conservation tillage has been developed for mechanised farming:

Stubble mulch tillage involves chopping crop residues and spreading them on the surface or incorporating them during tillage. Cultivation is usually done with a tined implement such as a such as a chisel plough. Herbicides are often used to control weeds. Equipment used for planting must have special furrow openers to avoid clogging with trash. Stubble mulch tillage reduces labour and farm-power requirements, and, as such, it is cost-effective. The system results in improved and stable soil structure, with reduced direct impact of raindrops on bare soil, thus minimizing soil erosion. Moisture retention capacity of the soil is also enhanced by the residues; hence crop survival is better during dry spells or drought.

Strip Tillage involves cultivating strips of only about 20 cm wide where the crop is planted (for example maize of cotton). Weeds are controlled with herbicides. The untilled land between the cultivated strips generates runoff which infiltrate in the tilled land.

Spot tillage refers to digging holes for seeds without cultivating the rest of the land. This is used with slash and burn agriculture.

Zero tillage or No-till: is a system with no primary or secondary tillage. Weeds are controlled entirely by herbicides such as Roundup and seeds are planted in a narrow slot with minimal soil disturbance. No-till has not been particularly successful in Kenya because of the need to loosen the soil to create a good seedbed and promote infiltration. However it is been strongly promoted in Zimbabwe to reduce erosion and improve the organic matter status of the soil

The small-scale farmer using a jembe is practising a type of minimum tillage. The soil is not inverted to the same

<table>
<tr><td colspan="2">extent with a jembe as with a mouldboard plough and residues are not so easily buried.

Contour farming is an important form of conservation tillage on slopes. All farm husbandry practices are done along the contour so as to form cross-slope barrier to the flow of water. Where this is not enough it is complemented with ridges which are sometimes tied to create a high degree of surface roughness to enhance the infiltration of water into the soil. The contour ridges are maintained for several seasons so that the work of construction is minimised. Preparation of a seedbed along the top of the ridges is carried out at the time of planting and in one operation. Residues are concentrated in the furrows where the water collects and most infiltration occurs.

Primary use:

Used for all kinds of row crops. Most of the here mentioned types are for mainly for mechanisation except contour farming and spot tillage which can be practiced with hand tools.</td></tr>
<tr><td>Useful in:
Areas where infiltration is more limiting than total amount of rainfall. Suitable on almost all soil types. Can be used and all types of slopes, from flat to steep. On flat land conservation tillage is used for RWH, on steeper slopes the main purpose is soil conservation.</td><td>Limitation:
Oxen drawn equipment is mostly required. Weeds are best controlled with herbicides.</td></tr>
<tr><td>Geographical extent of use:

Stubble mulch tillage has been used as a water conservation technique in Kenya, especially in the mechanized large-scale farms growing wheat and barley as found in Kitale and Timau in Kenya.

In the dry areas of East Africa, zero tillage has not worked well due to poor infiltration (as soils are easily self-sealing) and costs of herbicides being prohibitive. In Kenya, “no-till systems” used to be practiced mostly under large-scale mechanized wheat/barley systems, but smallholder farmers have recently started experimenting with this system with good results, as in Machakos, Laikipia and Nyando districts. Strip tillage has successfully been practiced in Tanzania. Minimum tillage by ploughing with a “magoye ripper,” which is adapted from Zambia has become popular among smallholder farmers in Kenya and Tanzania. Manual subsoilers have also been developed by innovative farmers.</td><td>Effectiveness:

In years with rainfall below normal it is observed that fields where conservation tillage has been practiced has a good yield compared to no yield with conventional tillage.

In Kenya, increased yields have been reported for stubble mulching, especially in marginal areas

In Arusha Region, Tanzania, where annual rainfall ranges from 400 mm-1,200 mm, the magoye ripper was found to reduce labour and enhance crop yields in the dry years.</td></tr>
<tr><td>Cost:

The cost of labour is less than for conventional tillage, but cost of ox drawn equipment and herbicides has to be included.</td><td>Operation and maintenance:

Breaking of plough pan every year after harvest. Regular application of herbicides.</td></tr>
<tr><td>Enabling Environment:

Information and demonstration. Development of locally appropriate tool. Support to buying of tools and herbicides.</td><td>Level of beneficiary involvement:

Beneficiaries are carrying out the work them selves</td></tr>
<tr><td>Environment benefits:

Build-up of organic matter in the soil as crop residues are left as mulch or incorporated in the soil and because the soil micro organisms are largely left undisturbed.</td><td>Cultural acceptability:

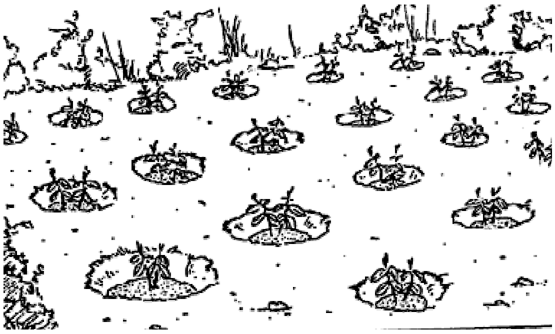
Generally accepted especially because less labour is used than for regular tillage. However, for small scale farmers the cost of tools, herbicides and an ox limits the adoption.

In dry areas where all organic matter is used as fuel or</td></tr>
</table>

	fodder it is difficult to convince the farmers to leave plant residues on the soil surface.
Advantages: • Less labour than conventional tillage • Improved infiltration, reduced runoff • Improved soil organic matter content • Reduced soil erosion	**Disadvantages:** • Conservation tillage allows more weeds to grow so more labour is needed for weeding. • In conservation tillage weeds are best controlled with herbicides – which may be to expensive for small scale farmers • Funds are required for tools, herbicides and an ox • Proper handling of herbicides requires training

7. Planting Pits (Zai, Zay, Chololo, Matengo, Ngoro)

Micro Catchment Technique



Planting pits, or *Zai* (Lee and Visscher, 1990).

Zai, Burkina Faso

Technical Description:

The planting pit system is a Micro catchment technique. Planting pits are made on land which low permeability to allow for runoff collection. Planting pits are holes dug to catch runoff and allow time for infiltration and they are usually fertilised with organic matter in the form of plant debris or compost.

Primary use:

Annual and perennial crops for example sorghum, maize, millet, cowpeas, sweet potatoes, groundnuts and bananas.

Useful design guidelines:

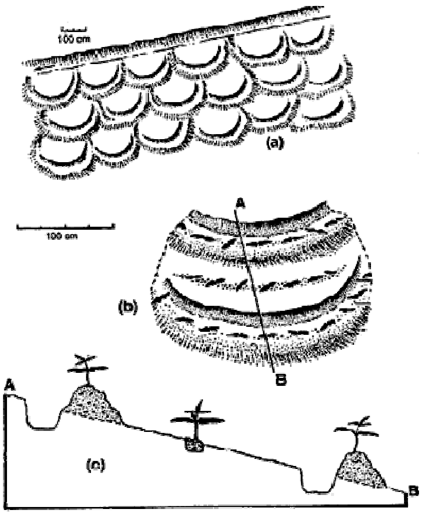
The Zai form are dug with approximately 80 cm apart to a depth of 5 to 15 cm, with a diameter of between 15 and 50 cm, but the planting pits also exists in much greater size and with different spacing.

Useful in:	**Limitation:**
The planting pits are suitable for semi-arid area to enable crops to survive dry spells. They are used on a wide variety soil types but most suitable on silt and clay soils where runoff can be generated due to limited permeability. The technique works on sloping land from 1-15%.	The planting pits will not maintain runoff water in sandy soils.
Geographical extent of use:	**Effectiveness:**
The planting pit technique is used in Mali, in Burkina Faso (locally it is called Tassa) and in Tanzania where it is called Chololo, Matengo or Ngoro. It can be used in all Sahelian countries. Tumbukiza is a special variation recently introduced in Kenya, Uganda, and Tanzania. The pits are used for fodder grass, are as deep as 1,2 m and watered 20 l per pit per day in the dry season to support dairy cows (IWMI research).	It has been noticed that the earth around the plants remains damp for a considerable length of time after each rainfall compared to the surrounding catchment. In Tanzania the yield of millet has been observed increasing from 124 kg/ha to 360 kg/ha. Planting pits are also use to vegetate abandoned or unused ground. Thus, crop yields resulting from this practise bring a benefit of 100%. Yields range between 0.7 and 1.0 t/ha for sorghum.
Cost:	**Operation and maintenance:**
The cost of the planting pits is corresponding to the time it takes to dig the holes and fill them with organic matter. Depending on the hardness of the ground, the input required is between 30 and 70 person days per hectare for the digging of the holes and 20 person days per hectare for fertilisation with manure and composting. Taking into account the wear and tear	The pits are easy to maintain. However, it is important to make sure that the holes are correctly dug and that the debris is evenly placed in each hole. The holes must be checked each year before planting to make sure that they are in good conditions, and they must be filled with organic matter as required. .

cost of materials used by the farmers, the cost may be estimated at approximately $8/ha. (1998) and the cost of the labour can be estimated to $ 1,5/day.	During a storm where a lot of water will collect the debris placed in the pits usually soaks up the excess water, but after a heavy storm the pits have to be checked and repaired if required.
Enabling Environment: Information campaigns and demonstration is usually sufficient as the technique is easily understood. If there is no local tradition for using organic matter to fertilise the soil, and the available organic matter already has a purpose as fodder or fuel, it may require more through demonstrations of the obtainable yield with and without organic matter in the pits	**Level of beneficiary involvement:** Planting pits is a very simple and flexible technique which needs no other equipment than what is usually already available and they can be fine tuned to many different localities. Information and awareness campaigns are necessary and the experience shows that after a few pilot projects the technique is accepted and spreads quickly due to its simplicity and effectiveness.
Environment benefits: Planting pits also limit the volume of runoff and, hence, the extent of soil erosion. With time the growing plants will also rebuild a more porous soil structure which will further limit runoff and erosion. Planting pits do probably improve groundwater recharge.	**Cultural acceptability:** The different kinds of planting pits have met no reservations in the countries where it has been introduced. Thus, it is apparently not contradicting with any socio-cultural practices.
Advantages: • Planting pits increase infiltration into the ground. After several years of employing this practise, the soils may re-acquire its porosity and permeability. Thus there is a dual purpose of cultivation and regeneration of the soil. • The design is flexible and can be adapted to the local conditions. • The technique is easily accepted in most places.	**Disadvantages:** • The only major disadvantage of planting pits is the labour requirements for construction as well as the maintenance. The farmer has to watch over the state of the holes, deepen them and refill them with manure before each wet season and check them after heavy rainfall. • Planting pits may be subject to water logging in very wet years.

8. Katumani Pitting

Micro Catchment Technique



Stylised representation of Katumani pits in plan (a and b)
and cross sectional views (c).

Technical Description:

This locally adapted manual pitting system is originally developed at the Kenyan Agricultural Research Institute (KARl) at Katumani, in the Machakos District of Kenya, and resembles the small zai-pit. The technique is also used in the Njombe District of southern Tanzania, where the pits are made bigger and deeper (at least 0.6 m deep), and a 20-litre volume of manure is added.

The pits are constructed as small, interlocking mini-catchments using a pitting and ridging technique coupled with reseeding with native grasses and legumes. Pitting should start at the top of an eroded slope below a cut-off drain which will intercept runoff from above. Pits should be dug to form interlocking catchments, each about 2 m2 in area, varying in shape with the micro topography.

Pitting can be extended down the slope as convenient and necessary. Final embankments should be about 30 cm high, around crescent-shaped trenches, 15 cm deep and 20 cm wide. Cow peas, or other ground cover crop, should be sown on the ridges, and cattle excluded, during the first growing season to allow vegetation cover to establish and soil to compact.

Primary use:

Re-vegetation of degraded grazing land and cultivating of crops for example bananas in area with rainfall as low as 300 mm/year and maize in wetter areas.

Useful in:

This technology is appropriate for the rehabilitation of grazing lands or cultivating of crops over a wide moisture regime.

Limitation:

Labour requirements and protection from livestock

Geographical extent of use:

Different forms of the system are widely adopted in some parts of Kenya and Uganda. Some progressive farmers in Tanzania and in the semi-arid Southern Province of Zambia have also adopted the system.

Effectiveness:

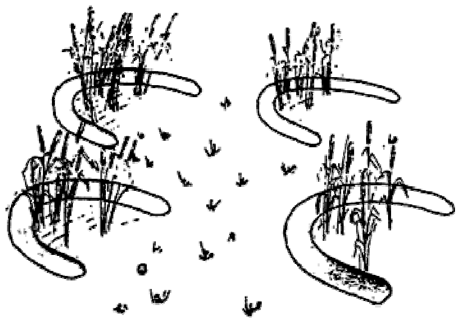
Cow peas, grown during the first season, have been reported to yield 750 to 900 kg /ha. Notwithstanding, weeds and grasses tend to dominate in the second season, unless additional management practices are adopted. Pasture yields of 3 to 4 t/ha/season are achievable, with a legume content up to 50%. Total dry matter production on Katumani-treated land increased by a factor of 5 to 10 compared to untreated land

Maize has yielded more than double of that on

	conventional tilled land in an area with an annual rainfall close to 1,000 mm where 15-20 seeds of maize were planted per pit.
Cost: Costs are primarily related to labour costs of about $100 to $150/ha. To establish a ground cover crop, fertilisers may be needed, especially where severe loss of topsoil has occurred.	**Operation and maintenance:** There are limited operation and maintenance requirements. In particular, over-grazing should be avoided so as not to cause a return to a previously denuded condition. Cut-off drains also are to be maintained.
Enabling Environment: Motivation, demonstration, assistance for designing and maybe initial support for example as food/cash for work.	**Level of beneficiary involvement:** Local community inputs or hired labour is generally used to construct the pits and cut-off trench. If hired labour is used and no local ownership is achieved maintenance will be a problem.
Environment benefits: Decreased runoff and erosion, rehabilitation of degraded lands, and stabilisation of soils.	**Cultural acceptability:** No adverse cultural problems have been recorded, but spreading has been limited probably due to the labour requirement.
Advantages: • Surface runoff is reduced with the result that soil moisture content is greatly increased. • Improved production of fodder and some suitable crops	**Disadvantages:** • The technology is labour-intensive.

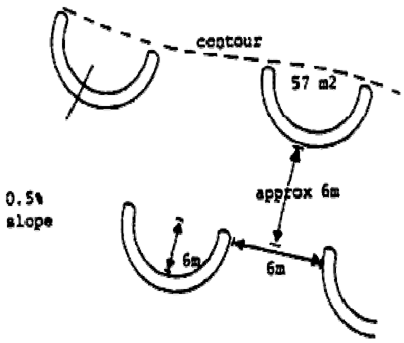
9. Semi-circular bunds or hoops, Demi-lunes, or half moons

Micro Catchment Technique



Demi-lunes from Niger (Critchley *et al*., 1991).

Demi-lunes implementation in Burkina Faso (photo from PDRDP-B/K)



Dimensions as used in Kenya. A cut off drain may be cut along the contour. (Critchley *et al*., 1991).

Technical Description:

Semi-circular bunds are earth embankments in the shape of a semi-circle with the tips of the bunds on the contour. The semi-circular bunds are constructed in staggered lines with runoff producing catchments between structures. Semi-circular bunds (the term "demi-lune" is used in Francophone Africa), are recommended as a quick and easy method of improving rangelands in semi-arid areas. Semi-circular bunds are more efficient in terms of impounded area to bund volume than other equivalent structures - such as trapezoidal bunds for example. Surprisingly, this technique has never been used traditionally.

Depending on the location, and the chosen catchment: cultivated area ratio, it may be a short slope or long slope catchment technique. The examples described here are short slope catchment systems. C:CA ratios of up to 3:1 are generally recommended for water harvesting systems used for rangeland improvement and fodder -production. A detailed calculation is not required. The reasons for applying low ratios are that already adapted rangeland and fodder plants in semi-arid and arid areas need only a small amount of extra moisture to respond significantly with higher yields. Larger ratios would require bigger and more expensive structures, with a higher risk of breaching.

Primary use:

Semi-circular bunds, of varying dimensions, are used mainly for rangeland rehabilitation or fodder production. This technique is also useful for growing trees and shrubs and, in some cases, has been used for growing crops.

Useful design guidelines:

Semi-circular bunds can be constructed in a variety of sizes, with a range of both radii and bund dimensions. Small radii are common when semi-circular bunds are used for tree growing and production of crops. A recommended radius for these smaller structures is 2 to 3 metres, with bunds of about 25 cm in height. Soil for the bund is either drawn from within the hoop thus levelling the land, or by creating a furrow inside or outside the hoop.

Design "a" in the table below has a C:CA ratio of only 1.4:1, and does not require provision for overflow. Design "b" has a C:CA ratio of 3:1, and therefore provision for overflow around the tips of the bunds is recommended, though occurrence of overflow is usually rare. A larger C:CA ratio for design "b" is possible but it should not exceed 5:1.

QUANTITIES OF EARTHWORKS FOR SEMI-CIRCULAR BUNDS

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

Useful in:

Semi-circular bunds for rangeland improvement and fodder production can be used under the following conditions:

Rainfall: 200 - 750 mm: from arid to semi-arid areas.
Soils: all soils which are not too shallow or saline.
Slopes: below 2%, but with modified bund designs up to 5%.
Topography: even topography required, especially for design "a" (see table above).

Limitation:

The main limitation of semi-circular bunds is that construction cannot easily be mechanized.

Geographical extent of use:

While widely promoted and accepted in Niger (where several thousand hectares are cultivated using this technology) and demonstrated in several areas of Kenya, neither country reports the spontaneous adoption by the technique by the community.

Effectiveness:

The semi-circular bunds are used mainly for increasing pasture production and rehabilitation of degraded lands and more seldom for crop production. The technique has resulted in dramatically improved vegetation growth within the bunds, but in most cases production has not been measured.

Cost:

The cost of this technology can be approximated as $150/ha for labour.

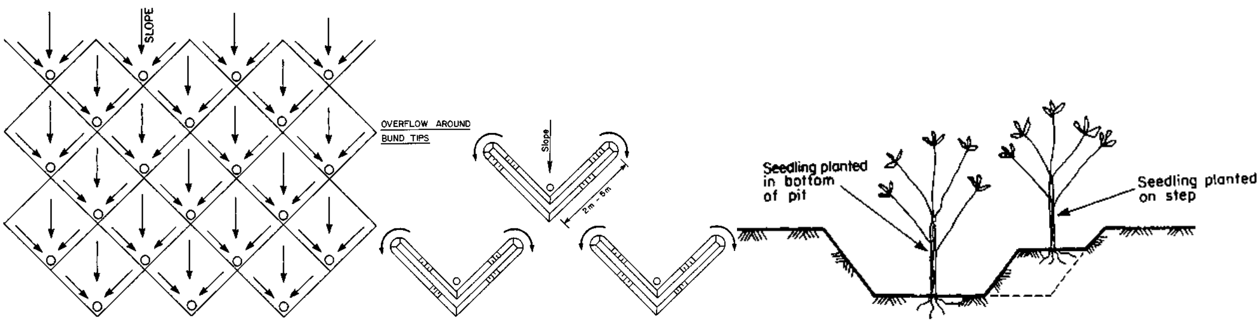
Operation and maintenance:

As with all earthen structures, the most critical period for semi-circular bunds is when rainstorms occur just after construction, since at this time the bunds are not yet fully consolidated. Any breakages must be repaired immediately. If damage occurs, it is

	recommended that a diversion ditch is provided if not already constructed. Semi-circular bunds which are used for fodder production normally need repairs of initial breaches only. This is because in the course of time, a dense network of the perennial grasses will protect the bunds against erosion and damage. The situation is different if animals have access to the bunded area and are allowed to graze. In this case, regular inspections and maintenance (repair) of bund damages will be necessary. Controlled grazing is also essential to maintain good quality rangeland, and the bunded area must be rested periodically for it to regenerate, so that natural reseeding can take place.
Enabling Environment: Motivation, demonstration and maybe initial support for example as food/cash for work.	**Level of beneficiary involvement:** Water harvesting for range improvement and for fodder production will mainly be applied in areas where the majority of the inhabitants are agro-pastoralists - at least in the Sub-Saharan Africa context. In these areas, the concept of improving communally used rangeland is usually alien. Therefore, it may be difficult to motivate the population to invest voluntarily, in the time and effort required for implementing and maintaining such a water harvesting system. Even when this is possible it is equally important to introduce an appropriate and acceptable range management programme to avoid over-grazing and subsequent degradation of the range.
Environment benefits: The technology results in increased vegetation. To make a sustainable result a rotation scheme with cutting and resting is necessary.	**Cultural acceptability:** The semi-circular bunds have been most successful where there was a high population density. It has been least successful when applied by pastoralists.
Advantages: • Some dramatic improvements in vegetation within the semi-circular bunds have been reported. • It is simple and easy to construct the bunds • It is cheap to implement this technology if manual labour is available.	**Disadvantages:** • The technology has not been spontaneously taken up by the people - possibly because of a reluctance to invest much time in improving grazing lands. • The structures are vulnerable to breakages when subjected to high volumes of runoff, but this is generally a function of the diversion ditches rather than the technology itself. When breakages due to overloading by runoff occur, the catchment to cultivation ratio need to be reduced. • This technology is not suitable for use with mechanisation. • Simi-circular bunds are primarily used for fodder production but grazing most be controlled or the fodder harvested for the animals to avoid trampling of the bunds.

10. Negarims

Micro Catchment Technique



Layout of diamond-shaped Negarims, the common variation which is single, open-ended structures in "V", and planting of 2 seedlings which will experience different moisture conditions to make sure that one will survive (Critchley et al, 1991).

Technical Description:

Negarim micro catchments are diamond-shaped basins surrounded by small earth bunds. Each micro catchment consists of a catchment area and an infiltration pit (cultivated area). The shape of each unit is normally square, but the appearance from above is of a network of diamond shapes with infiltration pits in the lowest corners. Runoff is collected from within the basin and stored in the infiltration pit.

The area of each unit is either determined on the basis of a calculation of the plant (tree) water requirement or, more usually, an estimate of this. Size of micro catchments (per unit) normally range between 10 m2 and 100 m2 depending on the specie of tree to be planted but larger sizes are also feasible, particularly when more than one tree will be grown within one unit. Where the ground slope exceeds 2.0%, the bund height near the infiltration pit must be increased. The table below gives recommended figures for different sizes and ground slopes.

A common variation is to build micro catchments as single, open-ended structures in "V" or semi-circular shape. The advantage is that surplus water can flow around the tips of the bunds, however, the storage capacity is less than that of a closed system. These types of bunds are particularly useful on broken terrain, and for small numbers of trees around homesteads.

Manure or compost should be applied to the planting pit to improve fertility and water-holding capacity. If grasses and herbs are allowed to develop in the catchment area, the runoff will be reduced to some extent, however, the fodder obtained gives a rapid return to the investment in construction. Regular weeding is necessary in the vicinity of the planting pit.

Tree seedlings of at least 30 cm height should be planted immediately after the first rain of the season. It is recommended that two seedlings are planted in each micro catchment - one in the bottom of the pit (which would survive even in a dry year) and one on a step at the back of the pit. If both plants survive, the weaker can be removed after the beginning of the second season. For some species, seeds can be planted directly. This eliminates the cost of a nursery.

Primary use:

Negarim micro catchments are mainly used for growing fruit or nut trees and bushes for fodder. This technique is appropriate for small-scale tree planting in any area which has a moisture deficit.

Useful design guidelines:

BUND HEIGHTS (cm) ON HIGHER GROUND SLOPES

Size Unit Micro catchment	Ground slope			
(m^2)	2%	3%	4%	5%
3x3	even bund height			
4x4	of 25 cm			30
5X5			30	35
6X6			35	45
8X8		35	45	55
10X12	30	45	55	
12X12	35	50	not recommended	
15 X 15	45			

The top of the bund should be at least 25 cm wide and side slopes should be at least in the range of 1:1 in order to reduce soil erosion during rainstorms. Whenever possible, the bunds should be provided with a grass cover since this is the best protection against erosion.

Useful in:

Negarim micro catchments are mainly useful for growing trees in arid and semi-arid areas.

Rainfall: can be as low as 150 mm per annum.
Soils: should be at least 1.5 m but preferably 2 m deep in order to ensure adequate root development and storage of the water harvested.
Slopes: from flat up to 5.0%.
Topography: need not be even - if uneven a block of micro catchments should be subdivided.
Negarim micro catchments are appropriate both in village afforestation blocks, or around homesteads where a few open-ended "V" shaped micro catchments provide shade or support amenity trees.

Limitation:

Not easily mechanised therefore limited in scale. Once the trees are planted, it is not possible to operate and cultivate with machines between the tree lines. Not suitable for crops.

Geographical extent of use:

Although the first reports of such micro catchments are from southern Tunisia the technique has been developed in the Negev desert of Israel. The word "Negarim" is derived from the Hebrew word for runoff - "Neger". Negarim micro catchments are the most well known form of all water harvesting systems.
Israel has the most widespread and best developed Negarim micro catchments, mostly located on research farms in the Negev Desert, where rainfall is as low as 100-150 mm per annum. However the technique, and variations of it, is widely used in other semi-arid and arid areas, especially in North and Sub-Saharan Africa and India. Because it is a well-proven technique, it is often one of the first to be tested by new projects.

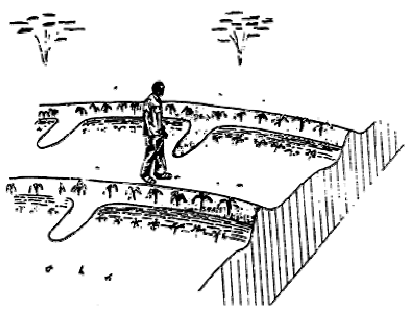
Effectiveness:

Have proved to increase fruit yield considerably in Israel and India. The negarims makes cultivation of trees and fodder grasses possible and thus re-vegetation of areas to dry for most vegetation.

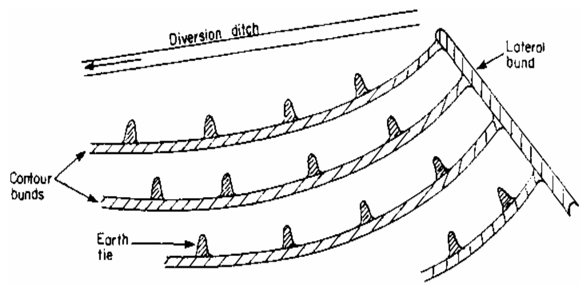
Cost: Negarim micro catchments have been developed in Israel for the production of fruit trees, but even there the returns on investment are not always positive. It is not a cheap technique, bearing in mind that one person-day is required to build (on average) two units, and costs per unit rise considerably as the micro catchment size increases. It is essential that the costs are balanced against the potential benefits. In the case of multipurpose trees in arid/semi-arid areas, for several years the main benefit will be the soil conservation effect and grass for fodder until the trees become productive.	**Operation and maintenance:** Maintenance will be required for repair of damages to bunds, which may occur if storms are heavy soon after construction when the bunds are not yet fully consolidated. The site should be inspected after each significant rainfall as breakages can have a "domino" effect if left unrepaired.
Enabling Environment: Motivation, demonstration, assistance with designing and maybe initial support for example as food/cash for work.	**Level of beneficiary involvement:** As much as possible to ensure ownership and thus maintenance
Environment benefits: Soil conservation, vegetation of arid areas	**Cultural acceptability:** One of the oldest techniques and already accepted in most places.
Advantages: • Enables some output from arid areas • Minimises erosion • Culturally acceptable technique	**Disadvantages:** • Labour intensive

11. Tied Contour Ridges (furrows or bunds)

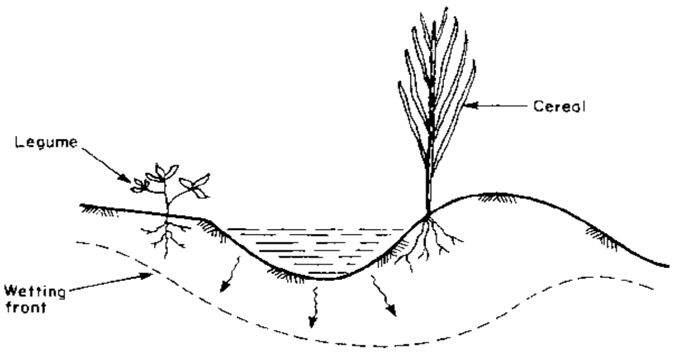
Micro Catchment Technique



Contour ridges as used in Kenya (Critchley *et al*., 1992).



Field layout for contour ridging which varies according to the catchment to harvest area ratio (Critchley *et al*., 1991).



Planting configuration (Critchley *et al*., 1991).

Technical Description:

Contour ridges is a micro catchment technique, sometimes called contour furrows or micro watersheds. Ridges follow the contour at a spacing of usually 1 to 2 metres. Runoff is collected from the uncultivated strip between ridges and stored in a furrow just above the ridges. Crops are planted on both sides of the furrow. The system is simple to construct - by hand or by machine - and can be even less labour intensive than the conventional tilling of a plot. The yield of runoff from the very short catchment lengths is extremely efficient and when designed and constructed correctly there should be no loss of runoff out of the system.

The main crop (usually a cereal) is seeded into the upslope side of the ridge between the top of the ridge and the furrow. At this point, the plants have a greater depth of top soil. An intercrop, usually a legume, can be planted in front of the furrow. It is recommended that the plant population of the cereal crop be reduced to approximately 65% of the standard for conventional rain fed cultivation. The reduced number of plants thus have more moisture available in years of low rainfall. Contour bunds with larger spacing (5-10 m) are useful growing trees.

Primary use:

The tied contour ridging system is used for crop production (crops are planted on the ridges as well as in the furrows) and tree planting (with a wider distance between ridges).

Useful design guidelines:

The overall layout consists of parallel, or almost parallel, earth ridges approximately on the contour at a spacing of between one and two metres. Soil is excavated and placed down slope to form a ridge, and the excavated furrow above the ridge collects runoff from the catchment strip between ridges. Small earth ties in the furrow are provided every few metres to ensure an even storage of runoff. A diversion ditch may be necessary to protect the system against runoff from outside. The cultivated area is not easy to define. It is a common practice to assume a 50 cm strip with the furrow at its centre. Crops are planted within this zone, and use the runoff concentrated in the furrow. Thus for a typical distance of 1.5 m between ridges, the C:CA ratio is 2:1; that is a catchment strip of one metre and a cultivated strip of half a metre. A distance of 2 metres between ridges would give a 3:1 ratio. The C:CA ratio can be adjusted by increasing or decreasing the distance between the ridges. In practice a spacing of 1.5 - 2.0 metres between ridges (C:CA ratios of 2:1 and 3:1 respectively) is generally recommended for annual crops in semi-arid areas.

Ridges need only be as high as necessary to prevent overtopping by runoff. As the runoff is harvested only from a small strip between the ridges, a height of 15 -20 cm is sufficient. If bunds are spaced at more than 2 metres, the ridge height must be increased.

Useful in:

Contour ridges for crop production can be used under the following conditions:

Rainfall: 350 - 750 mm. (and down to 200 mm for trees)
Soils: all soils which are suitable for agriculture. Heavy and compacted soils may be a constraint to construction of ridges by hand.
Slopes: from flat up to 5.0%.

Topography: must be even - areas with rills or undulations should be avoided.

The technology is being used in a variety of climatic and soil conditions and can be adapted to rainfall by adjusting the distance between contours and also the area of cropping. Water harvesting potential is reduced or lost if the catchment area is planted. At Baringo, Kenya, where there is a mean annual rainfall of 655 mm, the project area has a catchment to cultivated area ratio of 2:1.

Limitation:

Contour ridges are limited to areas with relatively high rainfall, as the amount of harvested runoff is comparatively small due to the small catchment area.

Geographical extent of use:

Contour ridges for crops are not a widespread technique in Africa, but have been adopted in Kenya, Niger, Zimbabwe, amongst others. It does not seem to be taken up spontaneously, however, and is mainly promoted through projects and government policy. Nevertheless, tied ridges are widely used in commercial farming situations in southern Africa also as a mean of controlling soil erosion.

Effectiveness:

Data from Kenya suggest that there are considerable yield advantages in using the contour system. When used in combination with appropriate crops, it also has a demonstrated ability to reduce the risk of crop failure due to drought by concentrating the runoff. This technology has been used with millet, cowpeas and sorghum.

The application and effectiveness of the technology is believed to be greatest in those areas where soils have been degraded to the extent that the people cannot reverse the trend using their own resources. An external input of mechanical equipment can have a large impact in these situations.

Cost:

With human labour, an estimated 32 person days/ha (approximately $1.5/day) is required. Using machinery, the time requirement is reduced, but the costs are increased to an estimated $100/ha.

Operation and maintenance:

If contour ridges are correctly laid out and built, it is unlikely that there will be any overtopping and breaching. Nevertheless if breaches do occur, the ridges or ties must be repaired immediately. The uncultivated catchment area between the ridges should be kept free of vegetation to ensure that the

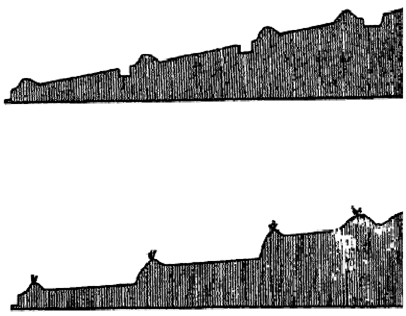
	optimum amount of runoff flows into the furrows. At the end of each season the ridges need to be rebuilt to their original height. After two or three seasons, depending on the fertility status of the soils, it may be necessary to move the ridges down slope by approximately a metre or more, which will result in a fresh supply of nutrients to the plants.
Enabling Environment: Globally, this is a well-documented and widely-practised technology which can be adapted to a variety of conditions. However, in Africa, it requires effective extension and promotion before it is widely adopted	**Level of beneficiary involvement:** While possible to prepare with hand implements, most projects have used mechanised equipment to construct the contour ridges. Farming practices thereafter are left in the hands of the community. The siting of contours can be done by the community after training.
Environment benefits: Benefits of land rehabilitation and reduced soil erosion are normal results when this technology is used.	**Cultural acceptability:** The contour ridge technique is one of the simplest and cheapest methods of water harvesting, but as it implies a new tillage and planting method compared with conventional cultivation, farmers may be initially reluctant to accept this technique. Demonstration and motivation are therefore very important. It can be implemented by the farmer using a hoe, at no or little extra cost. Alternatively it can be mechanized and a variety of implements can be used. When used by a farmer on his own land, the system does not create any conflicts of interest between the implementer and the beneficiary. It has been reported that farmers were reluctant to repair bunds after they were washed away in Baringo, Kenya.
Advantages: • This low cost technology has the potential to increase food security in below normal rainfall years. • The system can be implemented using either a mechanised or manual labour approach. • As with other water harvesting methods, it is more likely to be successful in areas which experience severe dry spells and/or highly variable rainfalls. • The technology reduces soil erosion and increases soil moisture content. • Even crop growth due to the fact that each plant has approximately the same contributing catchment area.	**Disadvantages:** • The unusual cropping system of planting on ridges and next to furrows, but leaving the catchment unplanted may be a disincentive for adopting this technology. • The relatively low planting density discourages farmers, especially in a good year • The system may appear more labour-intensive than it actually is. • The technique does not work well on steep slopes.

Key references:

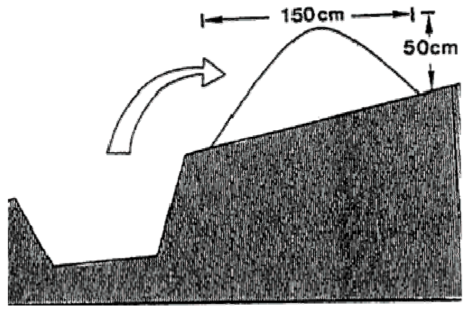
Critchley, W., Siegert, K., and contributions from: Chapman, C.	1991	A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production	FAO	Book and On-line publication
DTIE	1998	Sourcebook of Alternative technologies for Freshwater Augmentation in Africa	UNEP	Newsletter and technical publications
Ministry of Agriculture and Rural Development, Ethiopia, RELMA; World Agroforestry Centre	2005	Managing Land –A practical guidebook for development agents in Ethiopia	RELMA	Technical Handbook No. 36

12. Fanya-juu Terracing

Micro Catchment Technique



Initial profile and later development of fanya juu terraces (Critchley et al., 1991).



Construction of the bund (Critchley et al., 1991).

Technical Description:

The structure is called Fanya juu (juu is Swahili word for 'up') because during construction, the soil is thrown up-slope to make an embankment which forms a runoff barrier leaving a trench (canal) which is used for retaining or collecting runoff. *Fanya-juu* terraces are constructed by throwing soil up slope from a ditch to form a bund along a contour. The trench is 60 cm wide by 60 cm deep, and the bund 50 cm high by 150 cm across at the base. Enlarged fanya juus are about 1.5 m deep and one metre wide.

Through gradual erosion and redistribution of soils within the enclosed fields, the terraced lands level off, forming the terraces. Soil and rainwater are conserved within the bunds, and the bunds are usually stabilised with planted fodder grasses. Cutoff drains may be installed in order to protect the terraces from surplus runoff. If stones are available, stone terrace walls are appropriate as they allows surplus water to pass between the stones and overtop the walls. Distance between bunds depends upon the slope (5 m on steeply sloping lands to 20 m on more gently sloping lands)

Often, runoff from external catchments (roads, homestead compounds or grazing land) is led into the canals which act as retention ditches allowing water more time to infiltrate the soil.

Primary use:
Crops such as bananas, pawpaws, citrus and guava are grown in the ditches. Fodder grasses or scrubs are planted on the bunds.

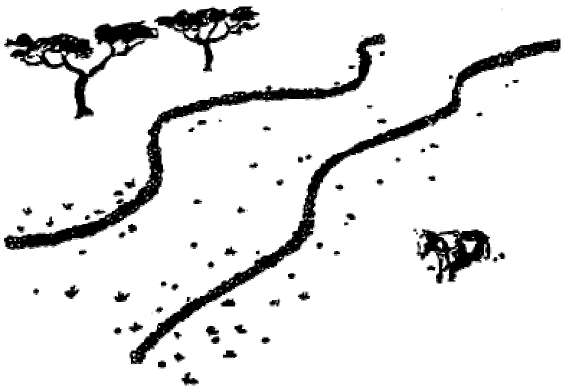
Useful in:	**Limitation:**
This technology is suitable for regions with about 700 mm annual rainfall or above. Soils should be deep. The technique is suitable both on gentle slopes and has proven effective in water harvesting on slopes greater than 5% where other water harvesting techniques are not recommended.	Labour intensive.
Geographical extent of use:	**Effectiveness:**
The technology is known from the Machakos and Kitui Districts of Kenya, which is hilly and subject to widespread erosion. 70% of the cultivated land in the Machakos District is reported to have been terraced. Similar terracing systems are found in many countries where	In Machakos, crop yields have increased by 50% (or by 400 kg/ha) through the use of fanya-juu terraces.

the stones from rocky slopes are used to build the bunds or terrace walls, often on very steep slopes. Contour ridges may be combined with this system.	
Cost: The labour required for construction is estimated at 150 to 350 person days/ha for terraces and cutoff drains	**Operation and maintenance:** Regular maintenance of the embankment is required.
Enabling Environment: Motivation, demonstration, assistance with designing and maybe initial support for example as food/cash for work. As there is a history of forced terracing in East Africa, motivation and strong local involvement is very important.	**Level of beneficiary involvement:** In Kenya, the implementation of this technology is normally undertaken by self-help groups who work collectively on each others lands. Some richer members of the community employ others to prepare the terraces since family labour on its own is generally not adequate for constructing these features
Environment benefits: Fanya Juu teases are effectively controlling soil erosion if well maintained. Where a whole catchment has been terraced there is an improvement in stream flows with consequent benefits for a village water supply.	**Cultural acceptability:** In Kenya, the technology has fitted well into culture of the self-help groups present in the areas of application to date, and reinforces their emphasis on full involvement of the community in freshwater augmentation efforts. The technology has already been established in the area and, therefore, there was no cultural resistance to it.

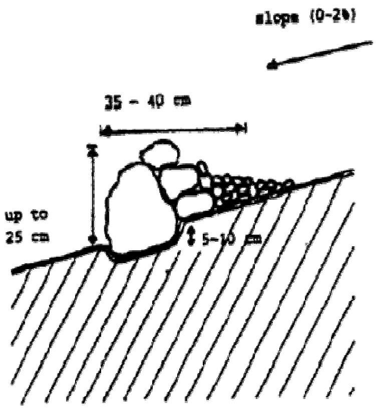
13. Contour Stone Bunds

Pictures:

Micro/External Catchment Technique



Artists impression, contour stone bunding (Critchley *et al.*, 1991).



Detail of stone bund (Critchley *et al.*, 1991.)

Technical Description:

Contour stone bunds are used to slow down and filter runoff, thereby increasing infiltration and capturing sediment. The water and sediment harvested lead directly to improved crop performance..

Making bunds - or merely lines - of stones is a traditional practice in parts of Sahelian West Africa, notably in Burkina Faso. Improved construction and alignment along the contour makes the technique considerably more effective. The great advantage of systems based on stone is that there is no need for spillways, where potentially damaging flows are concentrated. The filtering effect of the semi-permeable barrier along its full length gives a better spread of runoff than earth bunds are able to do. Furthermore, stone bunds require much less maintenance.

For rehabilitation of barren and crusted soils the farmers often use a combination of stone bunds and planting pits. The contour stone bunds do not concentrate runoff but keep it spread. They also reduce the rate of runoff allowing infiltration, which is further enhanced through the use of the planting pits. Farmers often start at the lower points of a field and work upslope rather than the conventional wisdom which would suggest starting at the higher points in the catchment and working down slope. Stone bunds, however, are not easily damaged or destroyed by runoff, and, by starting lower on the slope, farmers can be certain to harvest sufficient runoff for production of a crop in a year of below average or irregular rainfall.

Primary use:

For crop or tree production on gently sloping land

Useful design guidelines:

Stone bunds or a single line of stones following the contour, or the approximate contour, are laid across fields or grazing land. The resulting structures are up to 25 cm high with a base width of 35 to 40 cm. To increases stability they are set in a trench of 5 to 10 cm depth which. The spacing between bunds varies depending largely on the amount of stone and labour available. Bund spacing of 20 metres for slopes of less than 1%, and 15 metres for slopes of 1-2%, are recommended.

There is no need for diversion ditches or provision of spillways.

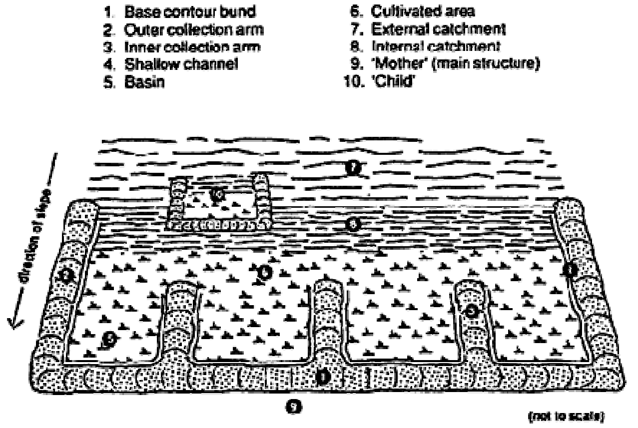
It is important to incorporate a mixture of large and small stones. A common error is to use only large stones, which

allow runoff to flow freely through the gaps in-between. The bund should be constructed according to the "reverse filter" principle - with smaller stones placed upstream of the larger ones to facilitate rapid siltation.	
Useful in: Stone bunds for crop production can be used under the following conditions: Rainfall: 200 mm - 750 mm; from arid to semi-arid areas. Soils: agricultural soils. Slopes: preferably below 2%. Topography: need not be completely even. Stone availability: must be good local supply of stone.	**Limitation:** Availability of stones
Geographical extent of use: **Stones have tradition**ally been used to mark fields where available. Stone bunds on the contour were pioneered in the 1980s in Burkina Faso as a simple and effective technique for conserving water and soil resources. Since that time, it has been spreading rapidly and is for example used in Mali, Sudan, Niger and Kenya.	**Effectiveness:** Farmers use stone bunds on fields currently under cultivation and to expand cultivation to new areas. Stone bunding is particularly attractive to farmers because of its ability to be implemented on fields already under cultivation. Yields in the first year have been increased by an estimated 40%. When barren fields are rehabilitated, yields of 1 200 kg/ha have been achieved in the first year. Application of fertilisers has only rarely been necessary, and the expected decline in fertility has not been observed although it is expected that, ultimately, there will be a need for a limited use of fertilisers.
Cost: Labour requirements are very sensitive to availability of stone and the productivity of the labours would decrease significantly if stone has to be transported over greater distances and/or is of too large a size and has to be broken. Labour can be estimated as $ 1.5/day	**Operation and maintenance:** There is limited, ongoing repair required as the stones are not vulnerable to erosion. However, silting behind the stone bunds requires that the stones to be re-laid from time to time or it has been suggested that the planting of perennial grass on the bunds will maintain their function of slowing and spreading water and help to retain deposited silt within the bund basins. Care must be taken that overtopping of the bunds does not lead to erosion on the downstream face, with subsequent gully formation and undercutting of the bund.
Enabling Environment: Demonstration in farmers field	**Level of beneficiary involvement:** In Burkina Faso , the technology has spread of its own accord after the initial, demonstration project. Thousands of hectares outside of the project area currently use this technology. It is entirely farmer managed.
Environment benefits: The technology has noticeable, positive environmental impacts, leading to the rehabilitation of degraded lands and reducing soil erosion.	**Cultural acceptability:** Stones have traditionally been used in soil and water conservation as well as for marking ones field. Farmers in the Yatenga Region of Burkina Faso have traditionally used stone lines on their fields. For this reason, the further development of the concept into installation of stone bunds has been readily accepted. Farmer-to-farmer extension has been shown to be an effective tool which is underrated in many projects.

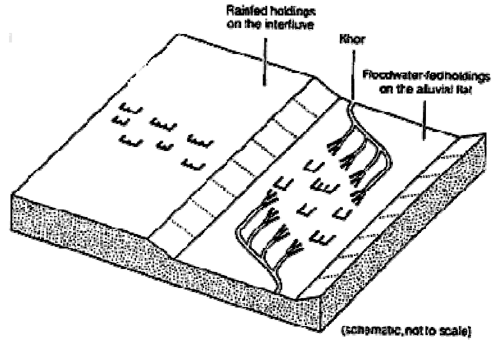
Advantages:	**Disadvantages:**
• Benefits to farmers have been evident • The technology is simple to implement at the local level. • Stone bunds do not readily wash away and, therefore, the technique is not vulnerable to unusual and variable intensity rainfall events.	• The popularity of the technique has resulted in shortages of stones and, therefore, a higher cost for latecomers.

14. Earth Bunds with external catchment (Teras)

External Catchment Technique



Typical element of the teras water harvesting structure



Overview of a teras water harvesting system

Technical Description:

Earthen bunds are essentially an external catchment, long slope technique of water harvesting. Typically a u-shaped structure of earthen bunds which farmers build on their cultivated lands to harvest runoff from adjacent upslope catchments, this technique usually collects rainwater and, sometimes, floodwaters.

The base bund approximately follows the contour line and impounds the runoff. Two outer arms fulfil the same function and also act as conveyance structures which direct water to the cultivated lands. Sometimes, shorter inner arms are added which divide the land into smaller basins and improve the spread of captured runoff. A shallow channel is left on the inside of the bund to support the conveyance and circulation of runoff.

Excess water is normally drained along the tips of the outer arms which are reinforced with materials such as stones, brushwood or old tyres. Bunds are usually 0.5 m high and 2 m deep at the base, but these dimensions can vary greatly depending on both the slope and the amount of runoff expected in the area. The base can be between 50 to 300 m long, while the arms are usually 20 to 100 m long. The size of the cultivated area serviced by such a structure is 0.2 to 3 ha.

Primary use:

Cultivation of crops

Useful in:

The technology is appropriate for arid areas with short duration intensive rainfall, for example aggravated by presence of mountains. Low infiltration further increases the generation of runoff from teras catchments. Catchments are normally 2 to 3 times the cultivated area in regions of 150 to 400 mm annual rainfall.

Limitation:
Availability of suitable external catchment.

Geographical extent of use:

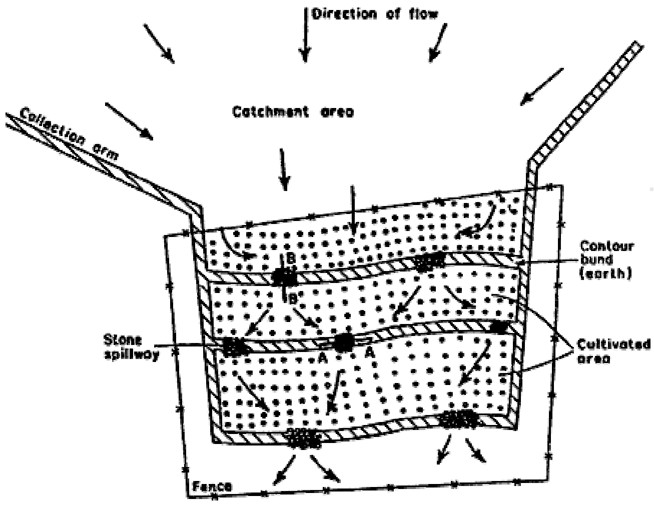
One of the few examples of traditional water harvesting technologies where the technique is applied over a wide area. The Teras system in Sudan dates back to the

Effectiveness:

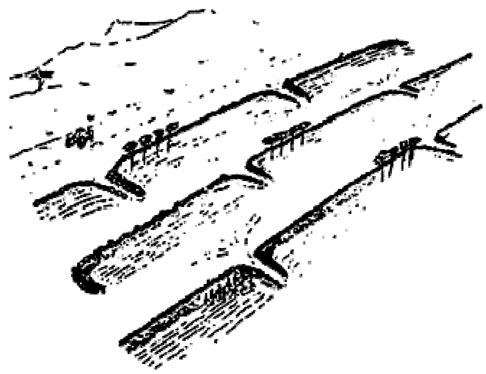
The technique allows the production of a crop of millet or sorghum. Based on data from the Sudan, yields may reach 750 kg/ha in a good year. Quick maturing millet should be

immigration of Arab tribes from the ninth century A.D who developed the method. In West Africa (Ghana, Burkina Faso and Mali) the system has been widely adopted in valley bottoms.	planted immediately after the water from a storm has subsided. This crop grows and matures in about 80 days.
Cost: The bunds can be constructed manually and mechanised There are no data available on costs.	**Operation and maintenance:** This system is regarded as labour- extensive. Nomadic tribes use the system and fit maintenance into the schedule. Generally, between 3 and 18 days/ha of work is required to ensure that the system runs efficiently. However, additional work is required for repair and adjusting of bunds in order for the system to work optimally.
Enabling Environment: In Sudan the system is entirely farmer initiated and managed. Extension and training is needed to spread the technique	**Level of beneficiary involvement:** Entirely traditional and farmer-managed, earthen bunds may be built by hand using simple tools, although the use of hired tractors is becoming more common.
Environment benefits: Use of this technology reduces land degradation.	**Cultural acceptability:** There are no cultural restrictions.
Advantages: • Makes it possible to grow crops in arid and semi-arid areas with short spell high intensive rainfall. • The technology is traditionally entirely farmer managed and, therefore, has no problems with ownership and is not subject to the organisational problems of other soil and water conservation techniques.	**Disadvantages:** • The lack of a spillway can result in breaking of bunds.

15. Contour Ridges with external catchments



External-catchment water harvesting system



Macro-catchment water harvesting in Niger

Technical Description:

A further variation of the contour ridging technique described in a previous fact sheet, this technology uses an external catchment (uncultivated area, rock surfaces or roads) and incorporates a stone spillway into the contour bund, providing for excess runoff to flow around the structure. Bunds are made of earth or, occasionally, stone, and, in Niger, they are usually covered with a layer of stone on the top and back slope.

The area impounded by the bund is planted. The usual catchment to cultivated area ratio is 2:1 but reaches 5:1 in Kenya where off contour bunds are used as collection systems to channel runoff to cultivated plots.

For full utilisation of the cropping area, the spillway height should be level with the base of the spillway on the next contour uphill. Levelling of the ground between contours assists in water spreading when runoff is collected. The spillway height determines the depth of water retained and is usually about 10 cm.

Primary use:

Cultivation of crops

Useful in:

This technology is suitable areas with low and unreliable rainfall, with an annual precipitation of 350 to 650 mm. It is also well-suited for use in the reclamation of degraded land.

Limitation:

Availability of a suitable catchment, runoff-generating catchment

Labour availability

Geographical extent of use:

A variety of bund systems are used widely all over the globe, but this particular system is introduced and practiced in Niger and Kenya.

Effectiveness:

In Kenya, the comparison with control plots has shown a significant increase in yields of sorghum and cow peas. No data is available.

Cost: In Niger, the estimated construction cost is about $500/ha for bunds, land preparation and fertiliser. In Kenya, 100 person days/ha are commonly devoted to construction.	**Operation and maintenance:** Maintenance is required to control erosion around spillways and bund wing walls. Achieving adequate compaction of bunds with manual construction methods is difficult and may result in breaches during the first year of operation. Grass planted on the bunds and spillways helps to protect these surfaces from erosion and reduces maintenance requirements, particularly since some resistance to the repair of breached bunds was reported in Kenya.
Enabling Environment: Information, demonstration on farmers' field and support for initial construction work.	**Level of beneficiary involvement:** In the Kenyan project introducing the system, all bund construction work was done manually, whereas, the bunds were constructed by machine and only the stone laid by hand in the Nigerian project. Construction work was largely done through food-for-work programmes and there is some concern about the level of true involvement of people. In at least one application, it was observed that there was little voluntary participation in the use of this technology by the community.