



World Food
Programme



Water Management for Building Resilient Livelihoods in the Arid Zones

FIELD PRACTITIONERS GUIDE NO.1



WFP Rural Resilience Programme

August 2018

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Foreword

Kenya's agricultural sector is evolving each day, driven by among others; the gathering momentum of the devolved system of Government, the need to transform agriculture from subsistence to agri-business, a growing population with increasingly complex consumer demands, as well as innovations emerging from farmer trials, the information superhighway, innovations, research and technology.

At the same time, Kenya's agriculture responds to and is affected by international protocols, among these, the Sustainable Development Goals (SDG) whose clarion call is "*Leaving no-one behind*". This motto, when applied in the Kenyan context literally calls for special attention to be accorded to the arid and semi-arid lands (ASALs), which constitute 83 percent of Kenya's land area. It is in the ASALs where agriculture faces special challenges associated with aridity, erratic weather, lack of water, and rudimentary technologies in how water is managed. In essence, the *ASALs should not be left behind!*

The Government of Kenya (GoK) is committed to implementing development initiatives that lead to food and nutrition security, national wealth creation and wellbeing, while also contributing to the achievement of the SDGs. In particular, the Ministry of Agriculture, Livestock, Fisheries and Irrigation (MoALF&I) is implementing programmes, projects and activities at national and county levels, which ultimately contribute to achieving the SDG-2: End Hunger, achieve food security and improved nutrition, and promote sustainable agriculture, whilst simultaneously contributing to a number of other SDGs (especially SDGs 1, 5, 6, 12, 13 and15). This will be achieved by infusing science, innovation and technology in smallholder agriculture, especially in the ASALs, where the knowledge gaps are greatest.

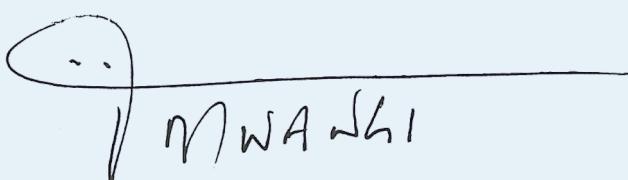
Aware of the complex nature and challenges that face agricultural development in the ASALs, the Ministry has been working with various development partners, among them the World Food Programme (WFP) towards supporting livelihoods in the ASALs. In particular, the WFP has in the past contributed to food relief efforts. However, as we implement the Agriculture Sector Transformation and Growth Strategy (ASTGS) and the BIG 4 on food and nutrition security, focus is now changing to support the most food-insecure communities (Flagship 6 of ASTGS) in the arid and semi-arid lands to become resilient and

adapt to shocks such as drought and climate change, by becoming food producers rather than recipients of food aid.

This focus sees ASALs as having resources which include the human, natural, social and financial capitals. Resilience building therefore takes cognizance of the inherent potential and through complementary efforts with partners, implements activities on the ground. This relies heavily on support and collaboration with County Governments, the private sector, development partners, non-state actors and all stakeholders. These partnerships are necessary to facilitate infrastructure development, community mobilization, implementation of income generating activities; skills development among land users and decision makers and to enhance best practice in resource management and agricultural production.

In our continued efforts to build knowledge, reach the decision makers, extension workers and farmers on solutions and interventions that upgrade agriculture in the ASALs, these set of Technical Manuals and Field Guides developed by WFP in collaboration with MoALF&I brings on board innovations, technologies and best practices that will help upscale agricultural productivity and improve rural livelihoods. I expect the materials to be shared widely and utilized so that the knowledge in them is turned into action, thereby benefitting farmers, communities and the country.

Lastly, I wish to reaffirm the commitment of the Ministry in supporting good practices and innovations that improve rural resilience and upgrade agricultural production in the ASALs, and indeed in all parts of the country where sustainable agriculture is practiced, as we continue the journey of making Kenya food and nutrition secure.

A handwritten signature in black ink, appearing to read "Mwangi". The signature is fluid and cursive, with a stylized "M" and "w". Above the signature, there is a small, roughly drawn oval shape with two short horizontal lines extending from its top edge, resembling a stylized eye or a mark.

Hon. Mwangi Kiunjuri, MGH, EGH

**Cabinet Secretary, Ministry of
Agriculture, Livestock, Fisheries
and Irrigation**

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1. Water Harvesting for Rangeland Rehabilitation

1.1 The Case for Water Harvesting for Pastures in the Arid Zones

1.1.1 Rainfall as the principle source of water for pastures

Arid lands by their very nature, have low and erratic rainfall, ranging 150 – 500 mm per annum, which is further split into two rainy seasons, further aggravating the moisture stress suffered by vegetation. The rains also fall in heavy **torrential storms** distributed in a few rain days in a year. This paradox means that arid lands suffer the duo challenges of prolonged droughts and flood destruction.

At another level, the arid zones have natural vegetation adapted to the soils, and climate, most of which are palatable to livestock and wildlife (Figure 1.1).



(a) Arid lands are adapted to small stock



(b) Arid lands support large ruminants

Figure 1.1 Arid lands have natural vegetation adapted to support livestock grazing

Pastures are dwindling due to increasingly sedentary pastoral livelihoods which have resulted in overgrazing, and land denudation. Left on their own, arid pasture lands are unlikely to recover without some interventions to enhance rainfall retention in the soil profile. Among others, water harvesting offers a plausible entry point to rehabilitate arid lands and improve their productivity.

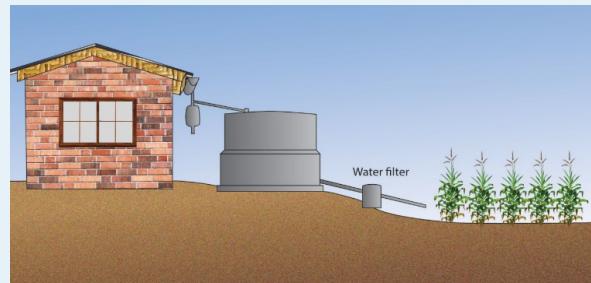
But what is water harvesting?

1.1.2 What is water harvesting

In the context of rangeland management, the term Water harvesting (WH) encompasses **rainwater harvesting and/or floodwater harvesting**, as well as **in-situ water conservation**, respectively defined as shown below:

(a) Rainwater harvesting (RWH):

The collection, conveyance, conservation and storage of rainwater for various purposes (drinking water, livestock watering or for irrigation).



(b) Flood water harvesting:

The diversion and storage of surface runoff into the soil profile/ crop root zone, including water storage in reservoirs (dams, weirs, sand dams, tanks, ponds or pans).



(c) In-situ water harvesting and conservation

The collection and conservation of rainfall where it falls, e.g. through soil and water conservation structures such as terraces and retention ditches, stone bunds and vegetative barriers.



1.1.3 Benefits of water harvesting

Water harvesting is an ingenious way of improving the productivity

of rangelands in dry areas where conventional sources of water are lacking or unreliable. The major advantages include:

- Stores excess rainfall, converting it from a destroyer into an asset
- Restoring the productivity of land which suffers from inadequate rainfall.
- Increasing vegetation on denuded rangelands,
- Offers resilience in food security through irrigation during the dry season
- Minimizing the effects of drought and prolonged dry spells
- Combating desertification by establishment of grasses, shrubs and trees in rangelands
- Providing water for domestic use and livestock consumption, thus reducing distance travelled in search of water
- Climate change adaptation and resilience by re-greening rangeland ecosystems.

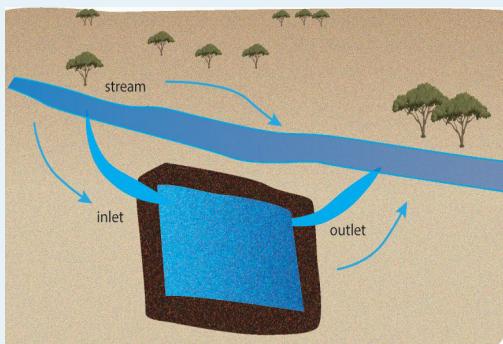
1.1.4 Precautions for water harvesting in arid zones

Arid zones have precarious climates, soils prone to salinity and sodicity, high temperatures that cause withering of vegetation, and generally high propensity for land degradation. Thus, in selecting water harvesting interventions, a number of precautions are observed as shown in Table 1.1

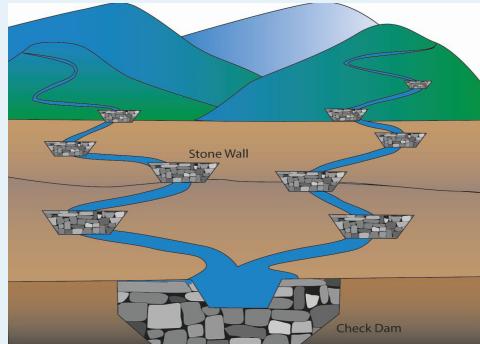
Table 1.1 The Do's and Don'ts of water harvesting in arid zones

| The Dos | The Don'ts |
|--|---|
| • Use technologies and practices that slow down surface runoff | • Do not attempt to block runoff completely. Such structures usually fail during extreme events |
| • Use porous buffers e.g. stone bunds, brushwood, grass, or vegetative barriers | • Do not use impermeable barriers such as stone masonry check-dams or brick walls |
| • Use of stone bunding wherever possible. Stones offer a strong porous barrier which does not decay or get eaten up by termites. | • Do not build high stone barriers as they block runoff. Rather, build short stone structures with a spillway for releasing flood flows |
| • If digging WH systems, always scratch the surface e.g. infiltration strips. This will allow ponding of smaller quantities of runoff which the fragile soils can handle | • Avoid digging deep trenches that cut into the sub-soil. Many soils in the arid zones have saline or sodic sub-soils prone to gullying, piping or collapse |

| The Dos | The Don'ts |
|--|---|
| <ul style="list-style-type: none"> When dealing with runoff harvesting and storages from dry riverbeds and other watercourses, it is best to store harvested water off-stream structures e.g. pans, and to provide overflow arrangements. | <ul style="list-style-type: none"> Avoid within-valley storage structures (with the exception of sand and sub-surface dams), as excessive flooding in arid zones can wash away water retaining structures. |
| <ul style="list-style-type: none"> Use scientific methods for site characterization, determining expected runoff flows and selection of best water harvesting technologies and design | <ul style="list-style-type: none"> Do not use the rule of thumb, baseless assumptions or "cut-and-paste" ideas seen elsewhere. Each water harvesting site is unique and must be assessed before treatment |
| <ul style="list-style-type: none"> Use local indicators and indigenous knowledge identifying where to place WH structures, as many sites for water harvesting lack baseline data | <ul style="list-style-type: none"> Do not ignore local knowledge in advising on risks and best options for water harvesting |
| <ul style="list-style-type: none"> Be sensitive to community socio-cultural issues in the choice of WH technology/ practice. | <ul style="list-style-type: none"> Do not ignore community ideas and sensitivities, even if scientific knowledge may be right. Weigh both. |
| <ul style="list-style-type: none"> Involve the community in planning, decision making, implementation and future management | <ul style="list-style-type: none"> Do not implement a top-down project. It will not be sustainable. |



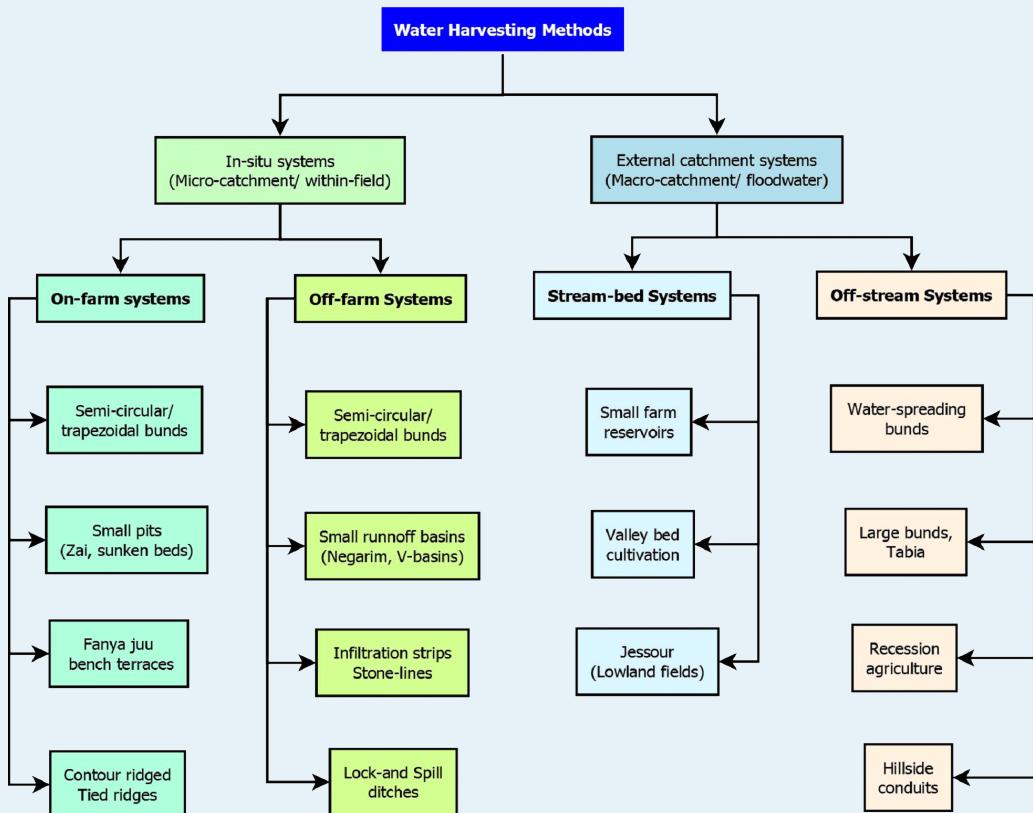
(a) Do—Preferably store flood flows off-stream



(b) Don't—Avoid storing flood flows in air-tight structures within valleys

Figure 1.2 Illustration of recommended water harvesting practices in arid zones

1.2 Decision Tree for identifying water harvesting methods for arid zones



1.2.1 Preparatory data gathering and planning

It is important to first gather data of the proposed project area and assessment:

- (i) Acquire maps and satellite imagery for the areas
- (ii) Also seek cadastral maps and study the area
- (iii) Do a reconnaissance visit, conduct transect walk,
- (iv) Conduct a participatory rural appraisal (PRA) of the community
- (v) Gather information on the history of the area, previous interventions, WH and other infrastructure in the area
- (vi) Take note of socio-cultural issues including gender, youth, labor, poverty
- (vii) Develop land suitability maps for different WH interventions
- (viii) Using this information, select sites and prioritize implementation.

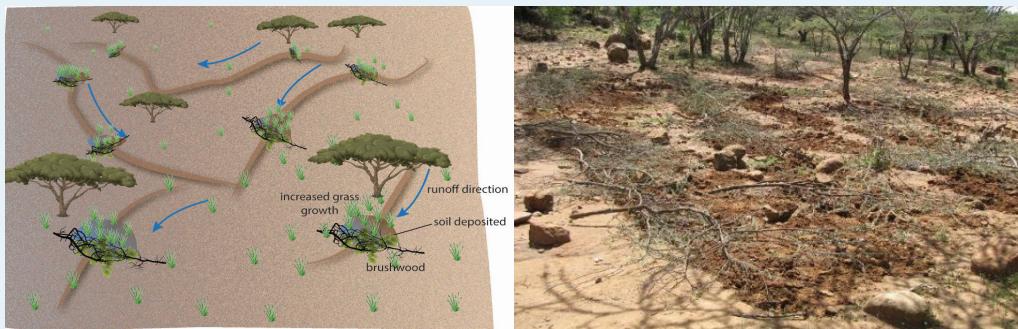
1.2.2 Community Mobilization

- Use suitability maps and cadastral maps, to identify best sites for interventions (biophysical considerations)
- Conduct stakeholder mapping to determine willingness to support the initiative
- Hold a meeting between with the community, giving priority to sites that have a community presence
- the willingness of local communities for implementing of WH technologies as relates to the land suitability maps, the possibilities of implementing WH based on biophysical conditions
- This iterative process is an efficient and practical tool planning a successful WH scheme. The approach integrated biophysical and socioeconomic aspects in a dynamic way that benefits the whole process.

1.3 Water harvesting technologies for rangeland rehabilitation

1.3.1 Brushwood barriers

- **Brushwood barriers** are made by cutting tree or bush branches and twigs, then strategically placing them on the ground in the path of surface runoff (Figure 1.3). This reduces raindrop impact, traps runoff (and grass seeds), improves infiltration, conserving the soil and thus facilitating revegetation.
- Certain trees and shrubs are of little value as forage in a rangeland ecology. Such trees and/or their branches can be cut as brushwood.
- The brushwood barriers work better when combined with grass re-seeding.



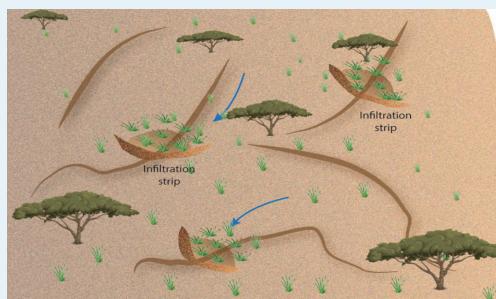
(a) Sketch of brushwood barriers to control runoff on rangelands

(Source: USAID, 2013, policy Brief 1)
 (b) Grazing land rehabilitated using brushwood barriers

Figure 1.3: Brushwood barriers to control runoff on rangeland

1.3.2 Infiltration strips by scratch plowing of rangelands

- **Infiltration strips** are created by scratch ploughing the soil surface.
- It involves the use of a tractor or animal-drawn implements to create furrows at a spacing of 1-2 m, preferably tined implements.
- It helps break the surface crust and improves rainwater infiltration into compacted and/or denuded rangelands
- The ditches also trap grass seeds which boost the regeneration of vegetation.
- The system works best when combined with range closures.
- It is recommended to do strip-seeding, rather than seeding the entire field, as this saves on costs of seeds and labor.



(a) Illustration of scratch plowed infiltration strips on rangeland



(photo: USAID 2013, policy Brief 1)
 (b) Scratch ploughed infiltration strips on grazing land

Figure 1.4: Scratch plowed infiltration strips for rehabilitation of grazing land

1.3.3 Mechanized contour ridges (Vallerani micro-catchment system)

(a) Design

- The Vallerani micro-catchment System (VS) is the mechanization of traditional water harvesting to create shallow scratched basins on denuded areas at a large scale
- Vallerani trenches are micro-catchments 4 m long and 0.5 m wide. They are made using a tractor-pulled plough specifically designed for this purpose.
- The soils are tilled with the special plough (the Nardi plough) which cuts a furrow perpendicular to the slope, throwing up a ridge on the downhill side and thereby creating a barrier on that side of the furrow. (Figure 1.7).
- The number of trenches varies according to the gradient of the terrain and the type of soil: the recommended number of micro-catchments for flat or gently sloping terrain is between 250 and 400 per hectare,
- The rows are spaced 5 to 7 m apart; and for steeper slopes, the rows should be spaced 3 to 4 m apart, with a density of up to 600 micro-catchments per hectare.
- In each Vallerani micro-catchment, two or three trees are planted or sown by direct seeding and then separated when they come up. Perennial grasses are sown a year later to allow the trees to become established first.



(Source: <http://teca.fao.org>)

(a) Constructing
Vallerani micro-
catchments with
machinery

(b) Freshly dug
Vallerani micro-
catchment strips

(c) Grass
establishment after
the rains

Figure 1.5 Vallerani micro-catchments ridges- construction and water retention

1.3.4 Semi-circular earth bunds for rangeland rehabilitation

Semi-circular bunds involve making earth bunds in the shape of a semi-circle with the tip of the bunds on the contour. They are suitable for arid and semi-arid areas where annual rainfall ranges about 200 - 750 mm. The slope steepness should be less than 2%, but with modified bund designs up to 5% slopes are allowable. Semi-circular bunds can be constructed in a variety of sizes, with a range of both radii and bund dimensions (Figure 1.6).

(a) Types of Semi-circular bunds for rangelands

For grasslands and range rehabilitation in arid zones, semi-circular bunds are made larger. Two types of semi-circular bunds can further be distinguished by shape as eye-brow and demi-lune or half-moon (figure 1.6).



(a) The “Eye-brow” (Crescent-shaped) design of semi-circular bunds for within-field water harvesting in which has a small channel



(b) Demi-Lune (Half-moon) design are large semi-circular bunds with a basin utilizing an external catchment or point sources runoff, such as from road drains, foot paths, steep hillsides and extensive open areas.

Figure 1.6 Semi-circular bunds in rangelands (a) Eye-brow and (b) demi-lune

(b) Design features

- The semi-circular bunds for rangeland rehabilitation are wider, with diameter of at least 5 m and up to 20 m to accumulate more water.

- They are constructed on the gentle slopes of 1 – 2 % in areas with
- Are adapted to areas receiving 200 to 700 mm annual rainfall
- The size of the ponded area (runon area) is enclosed by raised bunds, whose height depends on the amount of rainfall.
- Thus, generally, the catchment: cultivated area ratio is about 4:1 to 5: 1.
- Runoff water is collected from the area above the bund and ponded in the basin created by the bund.
- The depth of water is determined by the height of the bund and the position of the tips. Excess runoff discharges through the space between the tips of adjacent bunds.
- The bunds are staggered, so that excess runoff from one row is intercepted by the row behind it. For rangeland They are used for grass establishment, to recover badly eroded lands.

(c) Procedure for laying out semi-circular bunds

- (i) Mark the points along the contours and get smooth curved lines across the slope 8 m – 50 m apart depending on slope starting at the top of the field.
- (ii) Mark 6 m - 20 m radius and make a semi-circular bund down the slope and form a bund to bund measures 3 m - 10 m along the lines while from the bund line to another line ranges 3 m - 30 m.
- (iii) Lay out the lines of the semi-circular bunds in staggered rows
- (iv) At the inner part of the semi-circular demarcation, dig a trench of 20 cm – 30 cm throwing soil downward and create a semi-circular embankment.
- (v) Form the ridge downhill in a semi-circle to increase water retention
- (vi) In the trench or mid/ends of the bund fill with loose stones and plant some trees or shrubs on the ridges and inside bunds plant fodder trees to
- (vii) Plant grass on the ridges or pack stones o the embankment (Figure 1.7).
- (viii) Fence the area and involve local community to protect the treated area.



(a) Sketch of semi-circular bunds stabilized with stones

(b) semi-circular bunds stabilized with stones (Source Oweis et al, 2001)

Figure 1.7 semi-circular bunds stabilized with stones

Maintenance

Semi-circular earthen bunds require more regular maintenance than those made of stone, as the bunds are easily flattened by the effects of rainfall. 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.

1.3.5 Stone Bunding

Where stones are available, they can be used to construct bunds which facilitate water harvesting, for both micro-catchment and macro-catchment systems. Normally a line of stones (stone bund) is laid along a contour at intervals commensurate with the crop being grown and the catchment areas to generate the requisite runoff.

Benefits of stone bunding

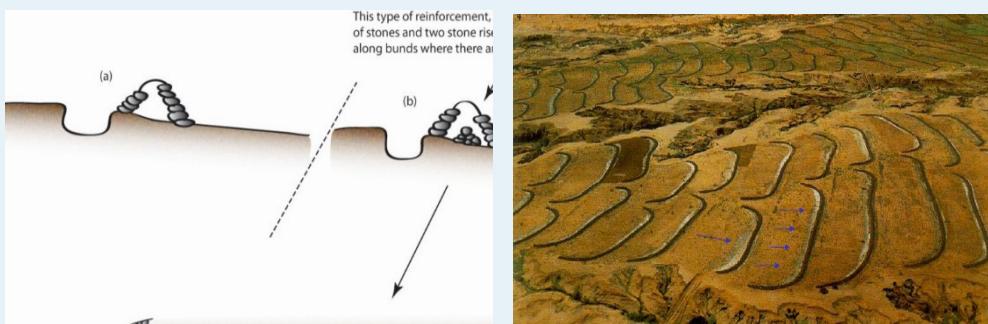
- It is simple to implement at the local level. It facilitates soil moisture conservation for crop production and reduces soil erosion.
- Stone bunds do not readily wash away and, therefore, the technique is not vulnerable to unusual and variable intensity rainfall events.
- The structure tends to be stronger and long lasting.
- Stone bunds are especially safer to use since they form a porous barrier, which slows down runoff, and is unlikely to fail in case of extreme flooding.
- Stone bunding is particularly suited to areas where stones are plentiful.

(a) Contour stone bunds

Contour stone bunds are buffer strips created by arranging stones in across the slope on the contour to form a barrier. However, the crop is grown just ahead of the stone bund, leaving the upper end of the terrace free to make a catchment (Figure 1.8). Contour stone bunds do not concentrate runoff but keep it spread. They also reduce the rate of runoff allowing infiltration, and any excess water passes through the bund but at low non-erosive velocities.

Design features

- The stones are packed across the slope on the contour to form a barrier.
- The crop or pasture is grown just ahead of the stone bund, leaving the upper end of the terrace free to make a catchment (figure 1.8).
- The structures should be at least 25 cm high, base width of 35 to 40 cm. and length from 25 to 100 m, bottom width 1.5-2 m and top width 30-50cm. The bund has wings about 5-15 meters to retain runoff.
- The bunds are set in a trench of 5 to 10 cm depth which increases stability.
- The spacing between bunds varies but is usually between 15 to 30 m.



(source: www.slideshare.net/water.in.africa/nico-van-leeuwen-ppt)

(a) Contour stone bunds for overland flow

(b) View of large-scale stone bunding

Figure 1.8 Contour stone bunds for overland flow

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2. Sustainable Irrigation Technologies for the Arid Zones

2.1 Why Irrigate the Arid Lands?

2.1.1 What is irrigation?

Irrigation is the *“controlled application of water for agricultural purposes, particularly crops, pastures and other plants, to supply water requirements not satisfied by rainfall”*. It is an intervention that seeks to artificially increase water made available to the crop root zone.

There are many types of irrigation systems. Irrigation water can come from rivers, boreholes, shallow wells, lakes, ponds, springs, or water harvested ponds and pans. The application methods are also diverse, ranging from surface method to sprinkler and to drip irrigation (Figure 2.1).



(a) Irrigation of vegetables using sprinkler



(b) Using drip irrigation saves water

Figure 2.1 Irrigation in arid zones – a necessity for sustainable food production

2.1.2 Benefits of Irrigation

Irrigation has many advantages, some of the main ones include:

- **Increased agricultural productivity** – as irrigation makes it possible to grow crops in areas otherwise too dry for agriculture, open up idle land and improve productivity of rainfed agriculture
- **Increased yields** - When irrigated, yields of conventional crops, (crops grown on both dryland and irrigated land,) are commonly increased two to three-fold or more in the drier regions

- **Improved incomes**- Irrigation enables market targeting and production of niche crops thus improving farm incomes
- **Improved quality of produce** – Irrigation enables the farmer to apply water when required and in commensurate amounts to improved quality of produce
- **Crop diversification**- Irrigation makes possible the production of a broader range of crops, many of which are considered specialty crops, (crops that are generally not viable under dryland agriculture). These are typically higher value crops,
- **Labor productivity**- Irrigation creating employment and adding value to forage crop production.
- **Stability**- Irrigated crop yields are more stable and reliable, resulting in greater income stability, reduced crop failure rates, and greater assurance in meeting production targets and marketing contracts.
- **Environmental conservation** – Irrigation enables the growing of trees, grasses and generally “greening up” of environments, thereby reducing hazards such as wind erosion, desert creep and denudation of vegetation.
- **Climate change mitigation** -Irrigation avails water for crop production regardless of rainfall patterns and is a climate change preparedness, adaptation and mitigation intervention

2.1.3 Limitations of Irrigation

Irrigation development is also faced with various limitations, such as:

- **High installation costs** – Irrigation development can be expensive, requiring heavy investment in installations and paying for specialists
- **Pollution** -Irrigation may lead to pollution of water resources due to increased use of fertilizers, pesticides and other chemicals
- **Drainage water management** – The management drainage/waste water poses problems especially in low-lying areas and floodplains.
- **Depletion of ground water** - In case of irrigation using ground water, there can be depletion of underground aquifers, sometimes this can cause ground subsidence
- **Salinity build up** - Under-irrigation or irrigation giving only just enough water for the plant (e.g. in drip line irrigation) gives poor

soil salinity control which leads to increased soil salinity with consequent build up of toxic salts on soil surface in areas with high evaporation.

- **Raising water tables** - Deep percolation from over-irrigation may result in rising water tables which in some instances can lead to problems of waterlogging in other areas
- **Water conflicts** - Irrigation takes water from its natural state to divert elsewhere. This can cause conflicts over water between various users
- **Socio-cultural constraints** – In the arid zones, irrigation is quite often introduced to farmers whose cultural background was pastoralism or agro-pastoralism. This lack of know-how can pose challenges that must be overcome through capacity building and selection of technologies amenable to local cultural norms.

2.1.4 Factors considered in identifying irrigation systems for arid zones

In selecting irrigation methods for arid zones, the factors considered include:

- **Source of water for irrigation** - Arid lands are by their very nature water scarce. They have few perennial rivers, hence water for irrigation is limited to groundwater and rainwater harvesting, itself also a scarce resource.
- **Water-efficient methods** -irrigation systems that use less water, e.g. micro-irrigation. Hence, avoid surface irrigation methods (except spate irrigation)
- **Uniform water distribution** in the crop root zone,
- **Avoid salinity build up** in the soil -that is why basin and furrow irrigation are not recommended for arid areas
- **Reduces water conveyance losses** – Thus utilizing piped conveyance rather than canals, or lining canals with concrete
- **Occupy minimum land**, especially land taken over by field ditches and bunds, -the reason for using micro-irrigation
- **Adaptable crops** that optimize yields, use less water and are quick maturing
- **Economically justifiable** -Inexpensive, easy to operate, low running costs
- **Sustainability - Socio-cultural, health and environmental** resilience e.g. avoiding water-borne diseases, or where irrigation water is used for drinking

2.1.5 Irrigation methods suited to arid zones

Based on the above considerations, some three water application methods hold most promise for adoption in the arid zones. They include:

- (i) Solar powered irrigation
- (ii) Drip Irrigation
- (iii) Sub-surface Irrigation
- (iv) Spate Irrigation
- (v) Water efficient practices for irrigated agriculture

These are further described here as follows:

2.2 Solar-powered irrigation for the arid zones

2.2.1 Why solar powered irrigation?

Solar energy, with an average of 325 days of bright sunlight every year, remains one of Africa's most abundant but scarcely used resources. It provides an inexhaustible source of clean, renewable energy. Solar-powered irrigation is reliable, cost-effective and environmentally sustainable energy for decentralized irrigation and successful models exist.



(a) Solar power provides free, clean energy in the arid lands- harnessed for irrigation



(b) Using drip irrigation to save water and produce more food in arid lands

Figure 2.2 Solar powered pumps lifting borehole water for irrigation

2.2.2 Portable solar pump

It is also possible to purchase a low-cost portable solar-powered pump. It is durable, light weight and has no battery, hence has low maintenance requirements



(photos by B. Mati)

(a) Portable solar panel and pump

(b) Portable solar pump carried in transport

Figure 2.3: Portable solar pumping kit (a) at work and (b) carried in transport

2.2.3 Benefits of solar power for irrigation

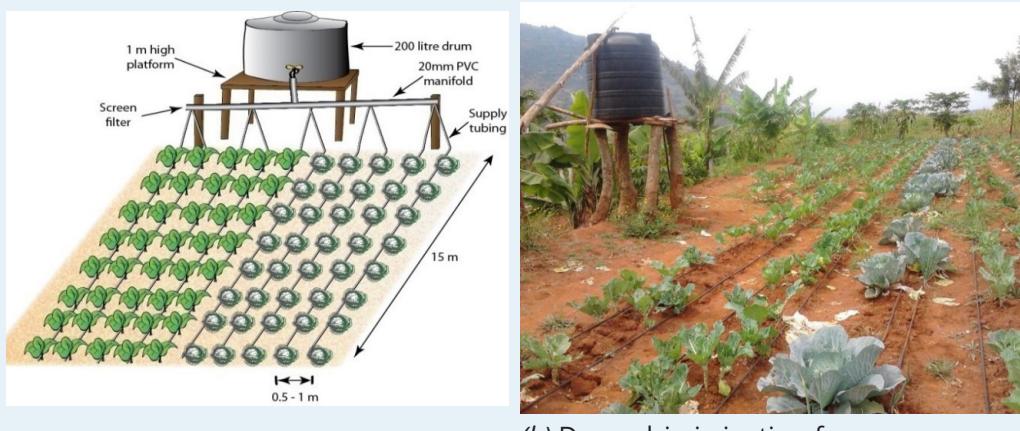
Solar energy enables electricity to be generated in any part of world as it is a renewable resource. The cost of solar PV has come down as cost of diesel has been regularly increasing. At present the cost of solar PV is much less to diesel, solar PV cost shall be half of diesel within three to four years, since approaching towards grid parity. Advantages of off-grid solar PV include:

- Solar resource is abundantly and locally available.
- It is distributed form of electricity, need no transmission lines.
- It is clean and renewable, no emission.
- Free from fluctuating fuel prices and provides energy security.
- The capacity can be added since the system is flexible and scalable.
- It involves minimum maintenance since no moving parts.

2.3. Drip Irrigation

2.3.1 What is drip irrigation?

Drip irrigation (or trickle irrigation), is an irrigation system in which water is slowly applied at or near the root of the plant, drop by drop (Figure 2.4). The system is based on the fundamental concept of irrigating only the root zone of the crop, which would maintain excellent soil-water-plant relationship. Only the crop root zone is wetted thus reducing water wastage, weeds and other pests.



(a) Sketch of a drum drip kit

(b) Drum drip irrigation for vegetables

Figure 2.4: Illustration of a drip irrigation system for smallholder farm

(a) Benefits of drip irrigation

- Drip irrigation is the most efficient method of irrigating. While sprinkler systems are around 75-85% efficient, drip systems typically are 90% or higher. If managed properly, evaporation and runoff are minimized.
- Higher crop yields due to uniform water application as drip irrigation takes place on a frequent basis and soil moisture remains at optimal level.
- Improved crop quality due to targeting water at the root zone compared to other irrigation methods.
- Reduced pests and diseases, including reduced weeds, as the land between the plants remains dry.
- Reduced labor costs especially since agronomic practices such as weeding are reduced. A drip irrigation system can be automated such that water is automatically switched on and off for pre-set depths of irrigation.
- Low energy requirement compared to conventional pressurized

- system because of the lower operational water pressure required for drip systems.
- Reduced salinity hazard since drip irrigation does not substantially raise the water table.

(b) Limitations of drip irrigation

- High cost** – Fully equipped drip irrigation systems have high initial costs
- Technical limitations - A higher level of design, management and maintenance is required with drip irrigation than other methods.
- Drip irrigation **emitters may get clogged**. Emitters have very small nozzle ranging 0.2-2.0 mm in diameter which becomes blocked easily.
- Drip irrigation **requires clean water** free of sediments, e.g. it is not recommended for water from sandy formations and water pans
- Poorly developed crop root zone, as plant root activity is limited to the zone wetted by the drip emitters.
- Restricted movement of machinery and farm operations since drip lines are spread around the cropped land.

2.3.2 Drip Irrigation design and installation

(a) Components of a drip irrigation system

There are different kinds of drip irrigation systems. However, the basic components (Figure 2.5) of a typical drip irrigation system has the following:

- Water source—to provide the amount of water required at the necessary pressure to distribute and push water out of the drip emitters;
- Main and sub-main lines - carry and distribute water to the drip laterals;
- Drip laterals—to carry the water and distribute it to the drip emitters;
- Filter - removes sediments from the irrigation water;
- Emitters—to control the flow of water from the laterals into the soil;
- Accessories and control valves.

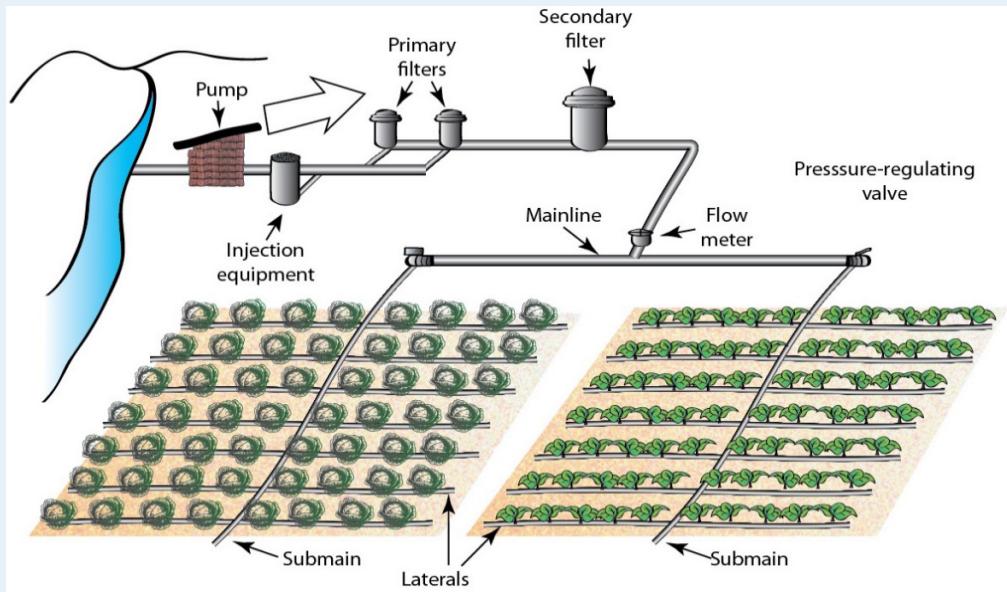


Figure 2.5: Components of a drip irrigation systems

(b) Installation of the drip irrigation system

Proper installation is crucial to the effectiveness and long-term operation of any inline drip system. Observe the following guidelines:

- Keep all pipes and fittings clear of dirt and debris, protect exposed ends by taping or plugging while assembling other components,
- Flush the system thoroughly prior to installing the last connections,
- Install all inline drippers at an even depth,
- Use loop-type galvanized fabric staples or pins to keep tubing in place,
- Verify the location of each air/vacuum relief valve in field, ensuring one is installed at each localized high point, and
- During and after installation, keep off the already installed inline drip tubing and be careful when working around the system to avoid damage.

2.3.3 Design and installation of home-made drippers

(a) Why home-made drippers?

Drip irrigation kits are factory-made and thus expensive. Farmers can make certain components of the drip system themselves, thus cutting

costs. Home-made drippers are easy to maintain and unclog, making drip irrigation amenable to use of water contains sediments. Also, the method permits the farmer to punch drippers that correspond to the crop spacing. Two methods are discussed here.

- (i) Tied pipe dripper, and
- (ii) Threaded pipe dripper.

2.3.4 Preparing a tied pipe dripper

This comprises a perforated pipe drip emitter with plastic covering. In construction, a narrow plastic pipe is punctured to create a small hole. The hole is then tied with using a small polythene paper to reduce water out-flow from a jet into drops. This is illustrated here below:

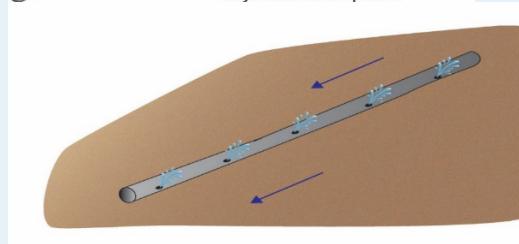
1. Purchase a roll of $\frac{1}{2}$ inch PVC pipe.



2. Lay the PVC pipe along the crop rows (e.g. papaya)

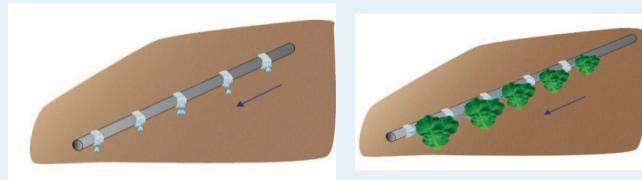


3. Using a safety pin, punch a tiny hole adjacent each plant



4. This small hole releases a small jet. That is not drip irrigation

5. Cover each hole by tying a plastic strip around the pipe



6. The finished perforated pipe drip emitter with plastic sheet covering



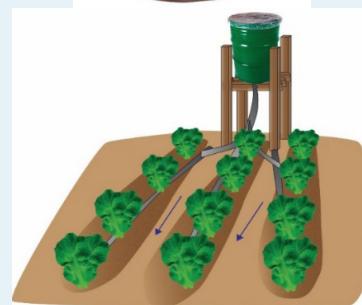
2.3.5 Preparing a threaded pipe dripper

This comprises a perforated pipe drip emitter with threaded string. In this systems, two holes are punctured directly across the pipe, and then a small thread passed through both holes to reduce water outflow from a jet into drops. The thread is knotted on both ends so as to retain it in place. The thread can also be used to unclog the emitter in case it gets clogged, by simply twisting it.

1. Purchase a roll of $\frac{1}{2}$ inch PVC pipe.



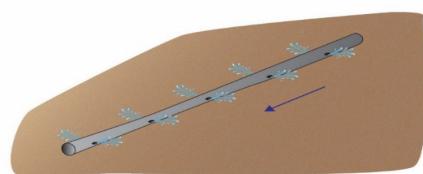
2. Lay the PVC pipe along the crop rows (e.g. banana).



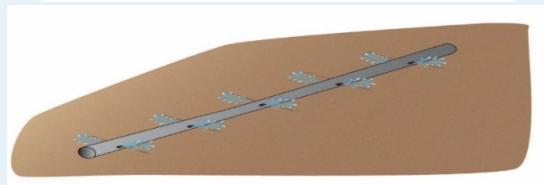
3. Using a big sewing needle, thread it with a nylon string. Pass the needle through the pipe so that you have 2 hole



4. The two small holes releases water jets in two directions. That is not drip irrigation.



5. Cut the string and thread knots on both sides.



6. The finished perforated pipe drip emitter with threaded string.



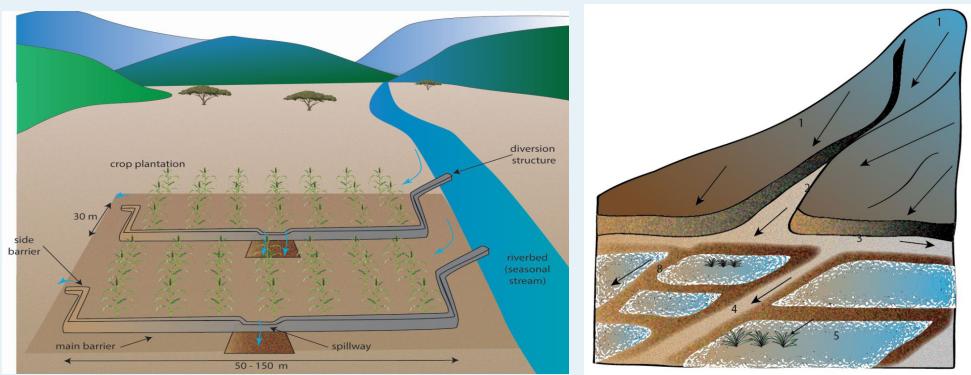
2.3.6 Operations and maintenance of drip irrigation systems

- (i) Review the installation and make sure the specified components have been installed. Check markings on the inline drip tubing to ensure products have been used. Verify row spacing (emitter spacing per specified product).
- (ii) Verify that the water source, control valves, filter unit, tubing and connections are installed and operating well,
- (iii) Run the system for an extended period and observe the wetted pattern (if possible). Verify consistent wetting pattern is evident on the surface.
- (iv) Measure the pressure at the control valve and at each flush valve. Record the pressure and note for reference to aid future troubleshooting.
- (v) Note the current controller schedule per valve, including run time, days per week, and flow (if available).

2.4 Spate Irrigation

2.4.1 What is spate irrigation?

Spate irrigation (or spateflow irrigation) is a unique method of irrigation which utilizes flood water, harvested from ephemeral watercourses during and immediately after a rainfall event. It utilizes large quantities of flood flow from valleys (Figure 2.6a) or from the highlands to the lowlands (figure 2.6b). In spate irrigation, flood water is physically diverted from stream channels using canals to bunded fields that may be located at some distance from the source of runoff. Spate irrigation is carried out on a large scale, requiring engineering design and oversight during construction.



(a) Illustration of spate irrigation using flood flows from a valley

(b) Illustration of spate irrigation using flood flows from a hillside

Figure 2.6 Illustration of spate irrigation using flood flows

2.4.2 Conditions that favour spate irrigation

Spate irrigation schemes contain unique features and considerations must be made to ensure the following features are attainable.

- (i) **Ingenious diversion systems**, built to capture short floods but also designed to keep out the larger and most destructive water flows;
- (ii) **Crops**: drought resistant crops, such as sorghum, pulses and trees e.g. mango, crops that withstand waterlogging e.g. sugarcane and grasses.
- (iii) **Soils**: The cropped area should have deep alluvial soils with

relatively good infiltration rates and which can hold moisture for long duration.

- (iv) **Sediment management**, as the flood water has high sediment loads that would otherwise fill reservoirs and clog intake structures and distribution canals. Canals should be regularly de-silted.
- (v) **Social organization** is necessary to manage the sometimes complex system, ensure timely maintenance of the structures and channels and oversee the fair distribution of the flood.

2.4.3 Operation and maintenance of spate irrigation system

In operation, temporary diversion embankments are constructed across a valley or dry riverbed where floods occur. The canals divert spate flows to adjacent arable areas. These embankments are made of riverbed sand, stones and brush wood with no provision for gates or spillways (figure 2.7). The spate-flow is let into a field, or series of fields, until they are flooded to a depth of at least 20 cm or more. It is recommended to divide flows into proportions which farmers can manage. Earthen structures are relatively cost effective to build but require maintenance and repairs during the irrigation season to remain functional.



(photos courtesy of M. Tesfai)

(a) Spateflow diversion canals before it rains



(b) Sorghum grown with spate irrigation

Figure 2.7: Spateflow diversion structures and crop grown with spate irrigation

2.5 Efficient Irrigation Water Management

There are several water and land management techniques that facilitate the reduction of amount of water used in irrigation, yet achieve optimum crop yields for almost any crop type. These encompass both infrastructural changes as well as water management and conservation practices to include the following:

2.5.1 Reducing water wastage in conveyance and application

Reducing water losses in irrigation systems, can be achieved by:

- Reducing seepage losses by lining canals or using piped conveyance
- Removal of weeds to reduced unproductive evapotranspiration
- Efficient water application methods; e.g. converting from basin to furrow, furrow to sprinkler, sprinkler to drip irrigation,
- Reducing wasteful evaporation losses e.g. adopt drip irrigation, shade nets, or adopt sub-surface irrigation
- Reducing runoff and percolation losses due to over-irrigation.
- Adoption of good irrigation practices such as system of crop intensification (SCI) or deficit irrigation, which save irrigation water.

2.5.2 Shade nets

Shade nets are fine nets usually purchased from agro-dealers. Shade net covers reduce direct solar radiation on the soil as well as wind, thereby conserving water otherwise lost in unproductive evaporation. The main limitation is their high costs. Also, although they can protect the crop from large predators e.g. birds, they do not offer adequate protection from very small insects and diseases. Unlike greenhouses which overheat the cropped area and are expensive, shade nets provide a cooler environment for water conservation in the arid zones.



(a) Shade net used as shelter belt
(photos by B. Mati)



(b) Shelter belt of trees protecting irrigated crop

Figure 2.8 Types of shelterbelts (a) Shade net and (b) natural trees shelter belt

2.5.3 Supplemental irrigation

Supplemental irrigation (SI) is the application of limited amounts of irrigation water to a crop that also benefits from natural rainfall. The additional amount of water alone is inadequate for crop production. Hence, the essential characteristic of SI is the supplemental nature of rainfall and irrigation. SI is normally considered to be a rainfed method of irrigation, whereby the extra water to top up the rainfall deficit, is normally obtained from water harvesting.

2.5.4 Deficit irrigation

Deficit irrigation (regulated deficit irrigation or drought irrigation), is a method of irrigation in which the amount of water used is kept *below* the maximum level and the minor stress that develops has minimal effects on the yield. Generally, the crop is subjected to a certain level of water stress, either during a particular period in its growth stages or throughout the whole growing season, so as to save water. It is one way of maximizing water use efficiency/ water productivity. In times of water shortage or drought, deficit irrigation can bring about higher economic gains in comparison to maximizing yields per unit water for a crop. Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water.

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3. Water Pans for the Arid Zones

3.1 Basics about water pans

3.1.1 What is a water pan?

A water pan is a small reservoir, about 1 m to 3 m deep, usually dug off-stream with raised and compacted banks all around. They are constructed to collect and store runoff water from various surfaces including from hillsides, roads, rocky areas and open rangeland (figure 3.1). Water pans receive their water wholly from surface runoff. The capacity of pans can range from 500 to 1,000,000m³. Structures whose reservoir capacity is less than 500 m³ are called tanks or farm ponds, while those exceeding 5,000 m³ are called dams. The water collected can be used for drinking (after treatment), livestock watering and/or supplemental irrigation.



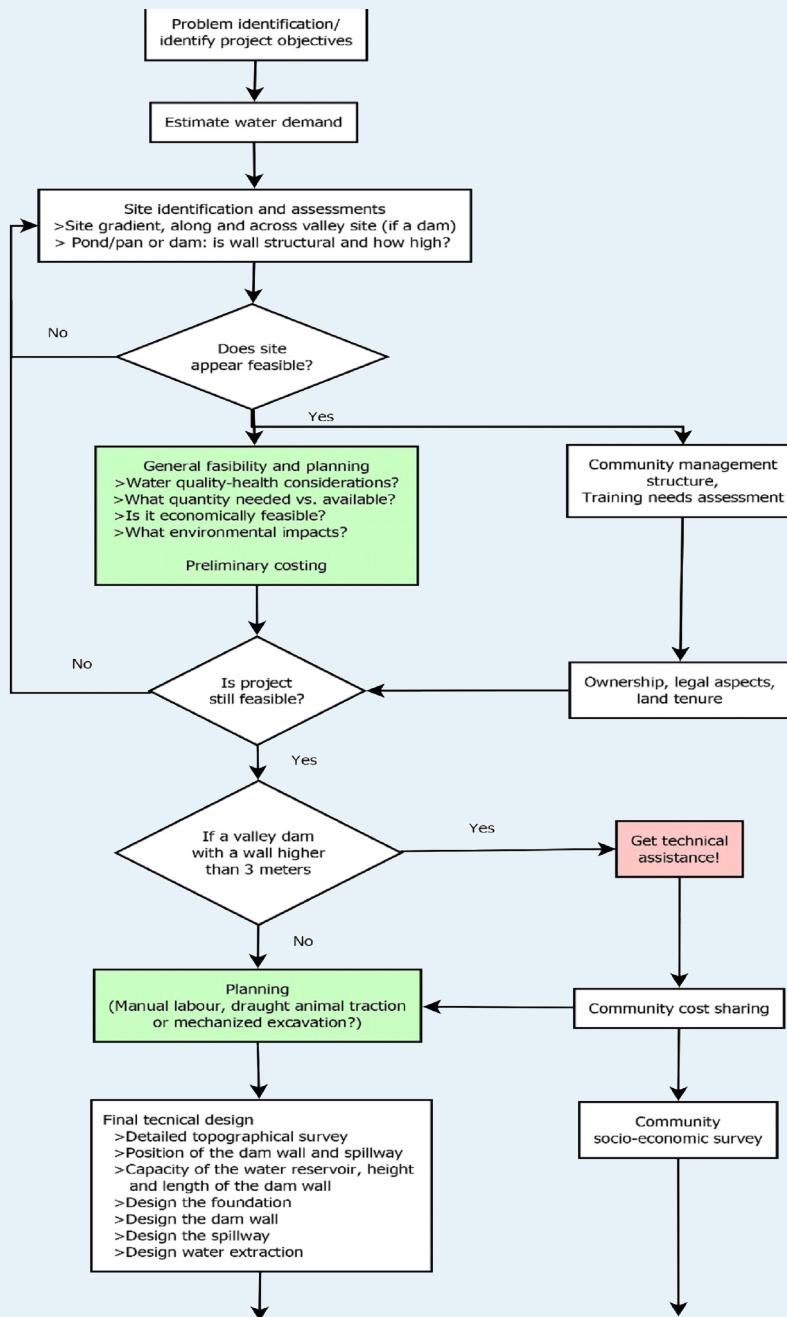
Figure 3.1 A water pan in a protected catchment collects clean water

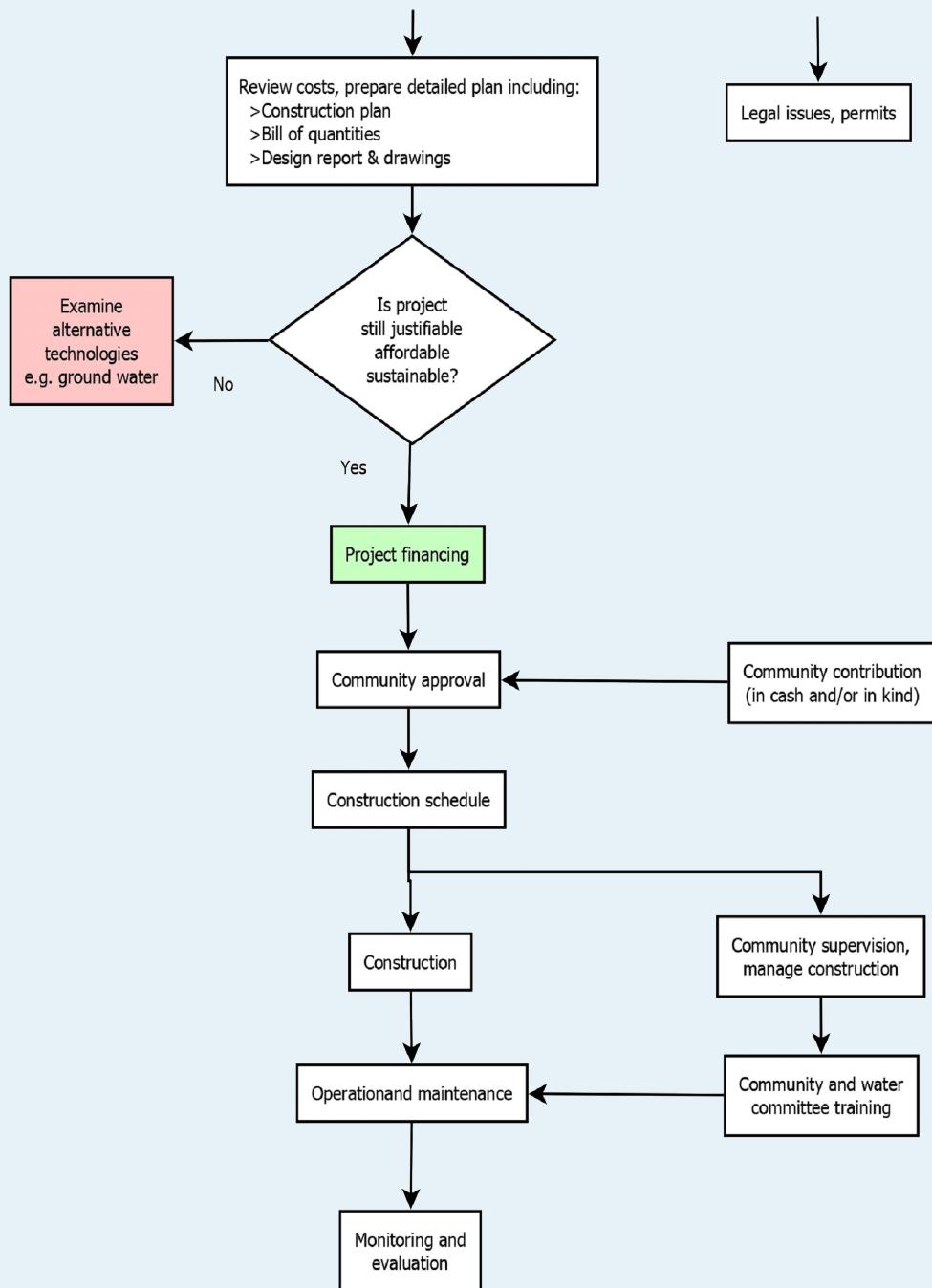
3.1.2 Why construct a water pan?

Water pans are constructed mainly in locations where the topography does not have a suitable site for a dam e.g. on flatter or rolling terrain and instead only a scooped out excavation may be feasible. A major advantage of pans is that relatively larger volumes of rainwater can be

stored when compared to tanks or farm ponds. The storage structure is easy to construct and use. Pans can be used to collect runoff from home compound, where houses are grass-thatched. Below is a decision tree for identifying suitability for a water pan.

3.1.3 Decision Tree for planning and design of a water pan





(Adapted from Nissen-Petersen, 2003)

3.2 Site Selection, Design, Layout and Construction of a Water Pan

3.2.1 Site selection

From an economic view point, the water pan should be located where maximum storage volume is obtained for minimum volume of excavation. They are generally built close to settlements, and on grazing lands rather than farmlands. Pans are excavated on gentle sloping lands; less than 2% or 1:50; this simplifies construction and minimizes erosion. The catchment land above must be gently sloping as well (Figure 3.2). Catchment should be grassed to help in trapping silt.

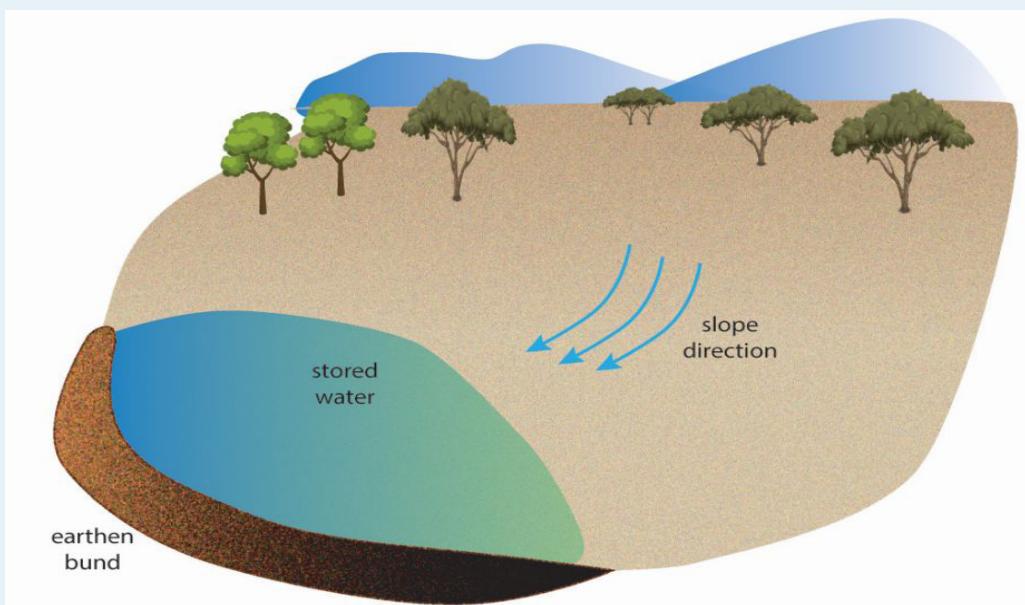


Figure 3.2 Illustration of a water pan for in an open area

(a) Characteristics of a Good Pond Site

A good pond site should have the following characteristics:

- (ii) Be at the lowest point where water collects naturally after the rains
- (iii) The pan should sit in an area that is known to hold water after the rains, or where local indicators, e.g. certain trees, intimate that the pan will hold water (not lose water by seepage or deep percolation).

- (iv) The capacity catchment area ratio should be such that the pan can fill up easily during the rainy season.
- (v) Pan storage should be able to be filled by 5% of mean annual precipitation in the catchment area.
- (vi) The capacity should not be too small to be choked up with sediments
- (vii) The pan should be located where it could serve a major purpose e.g. if for irrigation, it should be above the irrigated fields
- (viii) The catchment area should be put under conservation practices.

3.3.2 Design of pans and ponds

(a) Components of storage ponds

The components of a pan are quite similar to those of an underground tank or farm pond. Basically, a pan must have a catchment area, diversion channel, desilting basins, the reservoir and the water delivery system, mainly pipes and taps (Figure 3.3). A properly designed and constructed pan has an embankment which is covered with grass sod to prevent collapse or erosion of the banks.

- The inlet should be stone pitched to prevent soil erosion.
- A mesh should be provided at the inlet to prevent floating material from entering the pond. The slope of the sides shall depend on the soil condition.
- In order to prevent seepage losses through sides and bottom, these are lined with plastic sheeting. This should be embedded properly and the outlet stone-pitched to prevent soil erosion.
- A water extraction piping, pump or well is constructed at a suitable point of pond to facilitate withdrawal of water. The well has to be constructed by raising two masonry wing walls and one front wall. A suitable platform fitted with iron fixtures for simple pumps is necessary.
- A silt trap should be provided at the inlet point to prevent sediment load from entering the pond.

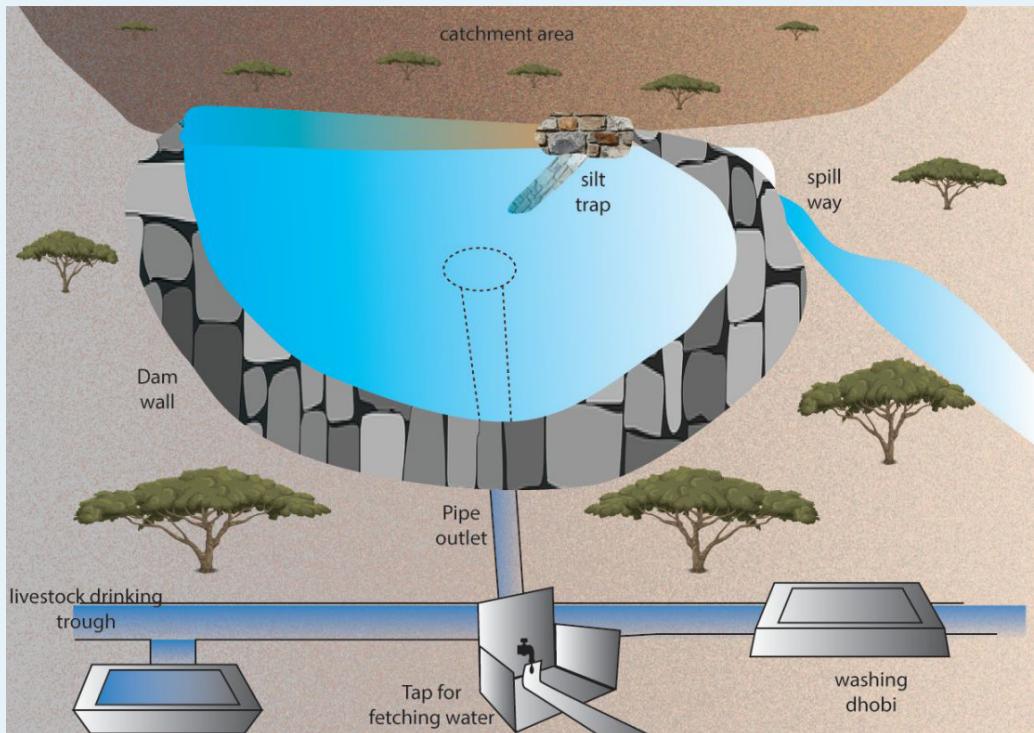


Figure 3.3. Major components of a water pan designed for integrated use

(b) Sizing the water pan based on water demand

Pans are usually designed for community use. Hence total water demand can be calculated as follows:

$$\text{Water Demand (m}^3\text{)} = \underline{(\text{No. of households}) \times (\text{water use per household})}$$

Efficiency factor

An **efficiency factor** (e.g. 0.5) can be used to take care of losses due to evaporation, spillages and unexpected use of the water.

(c) Water demand

Household water demand can be estimated as the total water used by individuals (people and livestock) in each household. In Kenya, water requirement for human consumption on average are estimated at human 20lts/ person/day, while for large stock, it is 30lts/head/day, and for small stock 5 lts/head/day. The size of a pond/pan for water harvesting is usually dictated by runoff availability and adequate catchment area, which also includes roads, footpaths, home compounds or open grasslands.

(d) Determining the storage volume

A detailed survey is usually required to estimate the size of the catchment area and the reservoir storage for different water levels. For calculating the reservoir storage volumes, simple field surveys are carried out using a GPS and local skills. The equation for computing storage volumes, for different pond levels is:

$$V = \frac{(SD^2)(B + nD)}{2}$$

Where,

V = total storage volume of pan in m³

B = channel width B (meters) at bund site

n = bank slopes e.g. n: 1 (fall of 1 metre in a length of n metres)

S = bed slope of channel – S:1 (fall of 1 metre in a length of S metres along the channel bed)

D = depth of water above the channel bed (metres).

The storage capacity should be at least double the total water requirement to take care of evaporation and seepage losses. As a rough guide, 10 per extra storage may be provided for sediment deposition.

(e) Determining spillway dimensions

Ponds located in low rainfall areas may have peak discharges during rainy season are too small to require evacuation through a concrete or masonry spillway. Instead a pipe spillway may be provided. Normally the pipe should be large enough to pass the peak discharge without moderation due to the reservoirs. However, where the reservoir is large with considerable storage capacity the moderation effect may be considered using the following formula:

$$Q_o = 1.25 - (1500V - 0.06)^{1/2}$$

$$Q_o \quad RA$$

Where,

Q_o = Rate of outflow when the pipe first flows full in m^3

Q = Peak rate of inflow in m^3

V = Available storage in ha.m

R = Runoff in mm, and

A = Drainage area in hectares (same as watershed area)

The above equation provides a rough guide to estimate of the size of the mechanical spillway pipe required for a pan.

(e) Design for integrated use

Since water for domestic use is scarce in the semi-arid areas, a water pan should be designed and constructed for integrated use. The water will anyway be used for multiple purposes, including drinking, laundry, livestock watering or irrigation.

3.3.3 Layout of the water pan

Site surveys should be conducted to determine the land slope and orientation. A typical pan design should include the following drawings:

- Site map (google, 1:50,000 or 1:100,000 contour map);
- Site layout (showing water flows);
- Inlet channel cross section and longitudinal profile;
- Outlet channel cross section and longitudinal profile;
- Cross section (pan and silt trap);
- Control/spillway/overflow sill details;
- Inlet/outlet details/ramp details.



(a) Surveying the site



(b) Bush clearing

Figure 3.4 Surveying and land preparation works

Soil characteristics - The site should have soils with good water retention characteristics. For instance black cotton soils with fine clay have poor percolation / seepage properties therefore good sites for pan locations.

Topography - The site should have gentle slopes of 1% and a maximum 5%. Use community knowledge and or choose natural depressions known to impound water during rainy season.

Avoiding pollution - The pan sites should be located upstream of any pollution sources.

3.4 Construction of the Water pan

(a) Stripping

Excavation of pans starts with “stripping” the proposed area of 0.20 m - 0.30 m of topsoil. This topsoil is then stockpiled for later use as a cover to the excavated material. The excavated soil is disposed off.

(b) Excavation

Pans may be excavated by hand or using machinery. A small pan can be constructed with the use of a bulldozer where the bulldozer simply excavates and pushes material. Push distances should be kept less than 60 m. Larger pans will also require a bulldozer as well as some sort of loader (wheeled or tracked) and several tippers. However, for efficiency and precision, it is recommended that the pan be excavated using machinery (Figure 3.5).



(Photo: Baringo WFP-AC project)

Figure 3.5 Mechanized excavation of water pan

Excavation works: Whether human labor or mechanization is used, the excavated material should be placed on leeward side and compacted so that it does not fall back into the reservoir. The pan bed is then compacted upon completion to reduce seepage (Figure 3.6a).

Side slopes: - During the excavation of the reservoir, it is important to provide side slopes of 1:3 to facilitate ease of access in to the pan and prevent accident for people and livestock.

Spillway: - - provide spillway channel for excess water to flow behind the silt trap and provide a masonry sill at the off-take point to prevent erosion.

Bed slope: - the pan bed should have a slope of 5% from inlet to the embankment to provide non eroding flow of water.

Inlet: The inlets should be well placed and linked to the catchment drainage system to able to bring the maximum available run-off into the pan.

Sedimentation basin: A sedimentation basin or silt trap is normally constructed to minimize siltation. The silt traps will reduce velocity of surface runoff allowing sediments to settle so that cleaner water enters the pan, preventing siltation.

Seepage control: - Provide a clay blanket (at least 300 mm thick) on the bed and sides of pan compacted in 150 mm layers. This seals cracks in the structure.

Fencing: – provide chain link fence or live hedge around the pan to avoid direct entry of people and/or livestock to the water. The fence also protects the catchment from degradation and resulting in clean water (Figure 3.6b).



(Photo credit: Baringo WFP-AC project)
(a) A newly excavated water pan



(Photo: B. Mati)
(b) Water pan fenced and in protected catchment

Figure 3.6 Water pan newly constructed and established in protected catchment

3.5 Water off-take infrastructure and safety

To avoid water contamination and siltation, pans should be designed and constructed in such a way that people and livestock do not go to the pan to collect water. Instead, the water should be delivered to community watering point and livestock watering bays through piping or a well connected to the reservoir.

Infiltration well: – Provide infiltration well by installing horizontal collectors buried in a gravel envelope; wells be at least 2m below the pan bed and fitted with hand pump with manhole cover. The horizontal collectors have provision for plugging to stop flow when the well is under maintenance. For drinking water supplies, the well may be disinfected with and water pumped out before use.

Water points for human use – Pipe the water away from the pan and provide stand pipes for domestic water supplies (Figure 3.7a).

Livestock drinking bays – Livestock should not directly access the pan. Provide livestock troughs on the downstream side of the water pan (Figure 3.7b).



(Photo: Baringo WFP-AC project)
(a) Water from pan piped to community tap



(Photo: Baringo WFP-AC project)
(b) Water supplied to livestock drinking trough

Figure 3.7 Water draw-off points from a piped to users

Health and hygiene: It is therefore imperative to provide a water pan that incorporates issues of safety, health, livestock, hygiene and sanitation. Whenever possible, amenities such as toilets, bathrooms and washing dhobi should also be provided, located downstream of the pan (Figure 3.8).



(Photos: B. Mati)

(a) Toilets and bathrooms downstream of pan



(b) Washing dhobi with water piped from pan

Figure 3.8 Sanitation amenities provided behind the pan

3.6 Operation and Maintenance of water pans

- Engage the community from the very inception of the project so that they have ownership
- Establish a water user committee for responsible oversight of the management of the water pan
- Ensure capacity building of local committee on their roles and responsibilities for prudent use of water and taking care of the pan
- Prepare a monitoring and evaluation system to track condition of the pan
- Establish a system that ensures routine operation and maintenance of the water system including fencing, hygienic handling of water, rotational guarding and any other agreed arrangements by the community.
- Leave in place a system for equitable sharing of water, gender mainstreaming, conflict management and environmental management as well as operation and maintenance of pumps and other accessories to enhance sustainability.
- Conduct faecal coliform & turbidity test and provide household level water treatment as appropriate
- Inlets should be cleaned regularly, be able to direct all the water from the catchments area while silt traps facilitate deposition of silt away from the pan during the rainy seasons.
- All potential problems must be repaired as soon as possible to safeguard the dam. side slopes should be cleared on a regular basis.

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4. Sand and Sub-Surface Dams for Water Storage in Arid Zones

4. 1 What is sand river water storage?

A **sand river** (locally known as lagga in northern Kenya), is an ephemeral river mostly found in the dry areas, whose profile comprises mostly of coarse sand, and which carries short lived but heavy flash floods, also laden with sand.

Sand river storage is water harvesting and storage in reservoirs designed to hold both water and coarse sand. The main structure is normally a dam constructed across a sand river.

Why water storage in sand river beds?

Water in sand rivers can be tapped when other sources have dried up. Sand rivers have been used as traditional water sources in arid regions where communities dig holes or shallow wells within the sand bed to obtain water during the dry season.

How do you improve water storage in sand river bed?

Water level in the sand falls and may dry up during the long dry seasons. Sand river storage is improved by construction of three types of dams;

- (i) Sand dam built of masonry,
- (ii) Subsurface dams built of stone masonry, and
- (iii) Subsurface dams built of clay.

What is a sand dam?

A sand dam is a reservoir created when a **short concrete embankment** is constructed across a sand river allowing the storage of both water and sand carried by the river flow into the dam.

What is a sub-surface dam?

A sub-surface dam is a reservoir created when a short embankment (made of concrete or compacted clay) is constructed **beneath the surface a sand river** allowing the storage of both water and sand carried by the river flow into the dam.

How do sand and sub-surface dams store water?

The dry river bed contains sand which has voids that can hold water. During the rains, these voids fill with water but it flows away. When a sand dam or subsurface dam is constructed, the water and sand accumulate in the dam till it is full up to spillway. The sand storage created can contain up to 35% water.

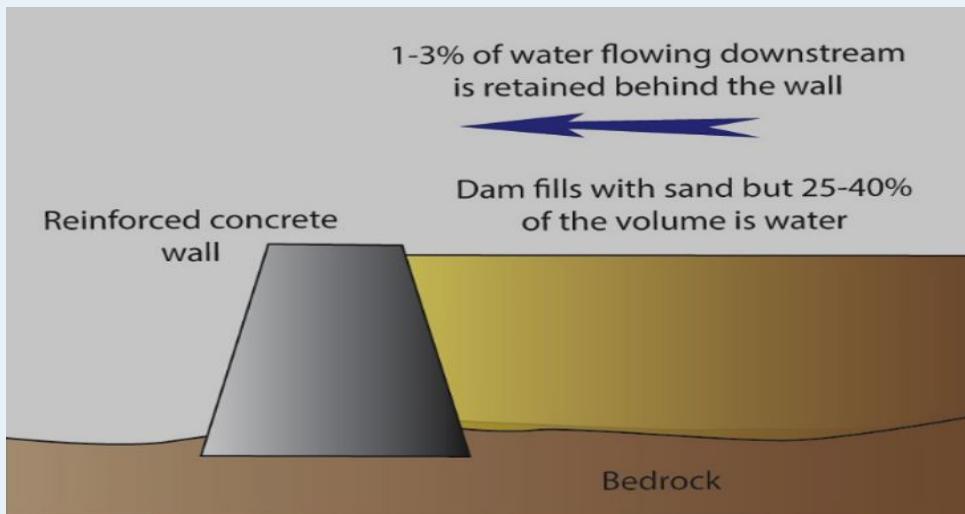


Figure 4.1 Illustration of sand dam water storage

Where are sand and sub-surface dams technically feasible?

There are 2 pre-conditions for a suitable sand dam site:

- Sand dams must be sited on a seasonal river with sufficient sandy sediment.
- Sand dams must be sited where there is accessible bedrock in the river bed.
- The catchment area should be stable (not eroded).

4.2 Benefits of sand and subsurface dams

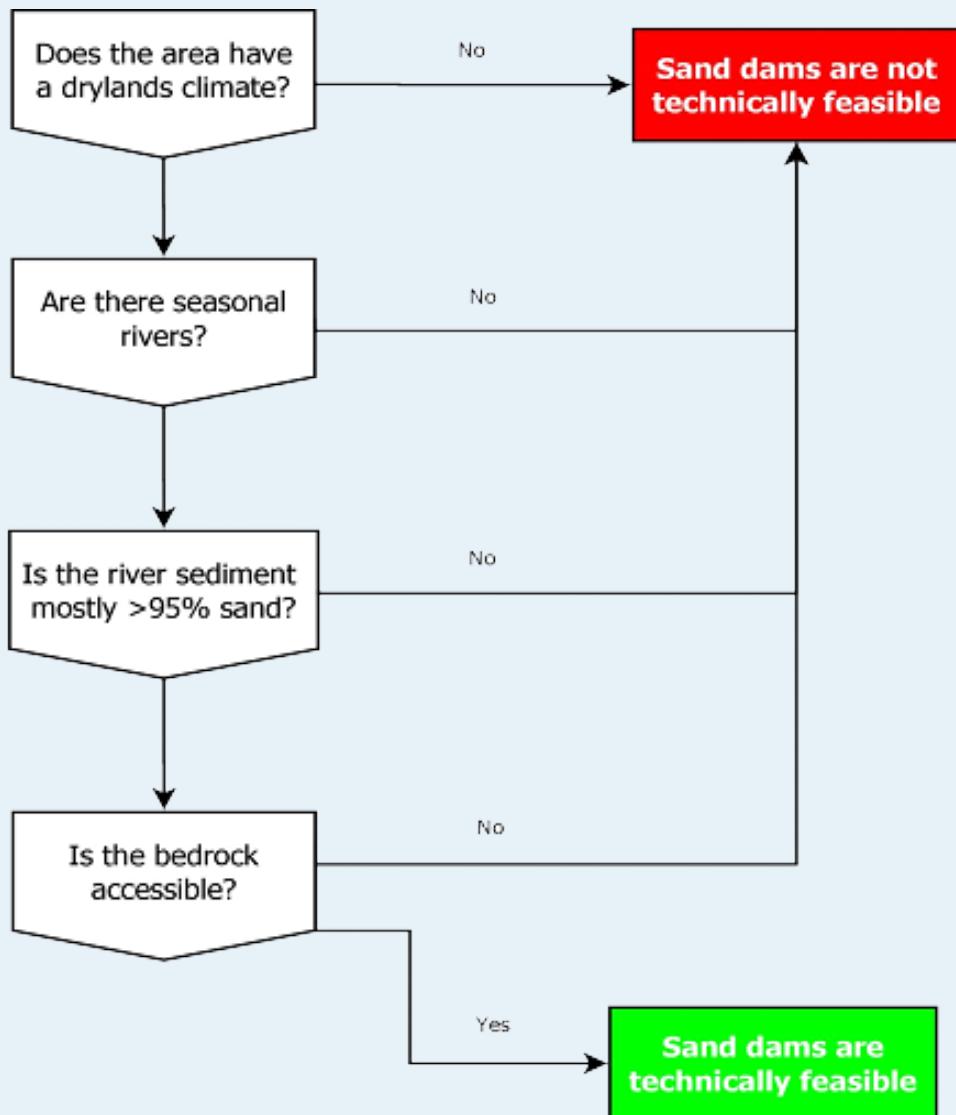
- Since the water is stored beneath the sand, it is not exposed to losses by evaporation are reduced. Evaporation can be zero when the water level is 60 cm or more below the sand surface.
- The water is good quality for drinking, as it has been filtered by the sand and is stored underground away from contamination.

- Mosquitoes, insects, frogs, snakes and organisms that carry water-borne diseases, cannot breed in underground water reservoirs.
- During high flows, floodwater can still pass over the dam to reach people living downstream.
- Once built, subsurface dams require little or no maintenance.
- Ground water dams can also be used to green up catchments by utilizing lateral seepage of subsurface storage.

4.3 Major limitations

- Subsurface dams store water below the ground, thus lifting devices or pumps are needed to extract the water for use.
- Finding natural dyke is difficult or the ideal site may be located in a remote area away from water users.
- Site selection requires intensive geological and hydrological investigation.
- Low effectiveness of water storage as water is stored in sand pores which is determined by effective porosity, about 20 to 35% of the reservoir volume.
- Interception of downstream groundwater flow a subsurface dam may prevent downstream groundwater flow, and exhausts groundwater in the downstream areas. It is also possible to design a dam with a structure that allows some of the reserved water to drain. Therefore, this problem can be avoided by appropriate site selection that considers groundwater flow.

4.4 Decision Tree for identification of sand and sub-surface dam



4.5 Site identification, Planning, Construction and Management

The following steps are following in site identification, planning, design and construction of sand and sub-surface dams.

1) Identify a suitable catchment

- Conduct a site survey

Good catchment

- A suitable catchment has stony or rocky hillsides
- Over 25% water may be extracted from coarse types of sand originating from stony hillsides
- A good catchment is rocky, gravelly, preferably covered by vegetation



Bad catchment

- Catchments with clay, silt or fine sand will produce runoff that clogs the sand/sub-surface dam.
- Less than 5% water can be extracted from fine textured sand originating from farmland
- A bad catchment – eroded lands and areas with silts, clays and fine sand



2) Identify a suitable riverbed

- Walk along the river profile

A good riverbed site for sand dam:

- Choose an ephemeral (seasonal) sand river (dry river bed) which is periodically flooded during a normal rainy season
- Stable riverbanks to avoid collapse
- A natural valley to contain the water reservoir upstream
- A natural underground dyke
- Alternatively, a rocky riverbed for good foundation for a sand dam.



A bad riverbed site for a sand dam

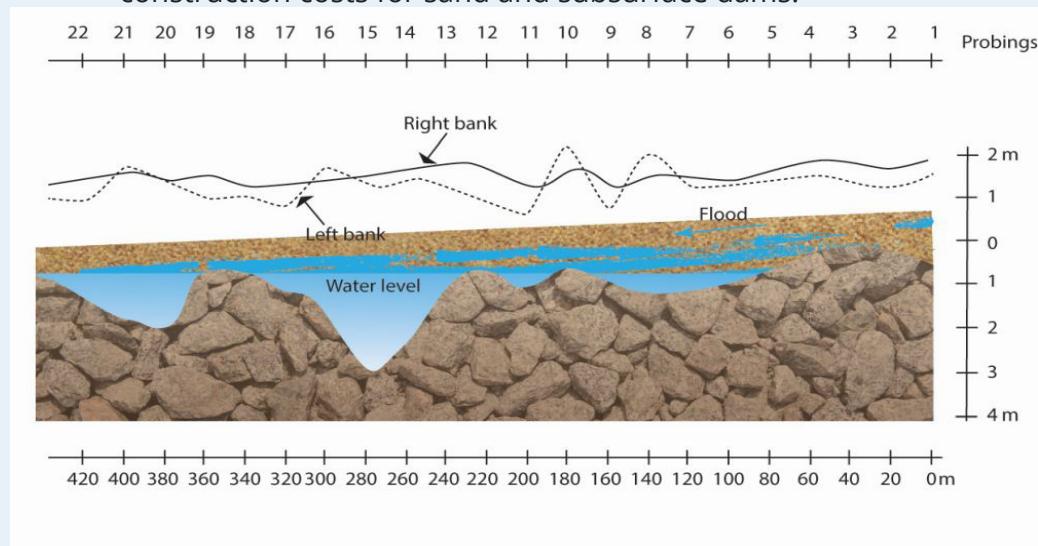
- River flows laden with silts and suspended sediments
- It could be actually a gully
- The banks are unstable and collapse easily
- The water is muddy during the rainy season



3) Locate a natural dyke

Why a natural dyke?

- Underground dyke gives free storage capacity and reduced construction costs for sand and subsurface dams.



Where to find natural dyke?

Easy to locate as where local people dig shallow wells in the riverbed during the dry season

Ask the local people.



How to locate a natural dyke

Alternative methods:

- Digging trial pits
- Probing with an iron rod hammered into the sand
- Dowsing with two rods made from a brazing rod cut in two halves



4) Assess the quality of sand for water release properties

- This assesses how easily the sand can release water.
- Sand should have a high porosity and extractable yield.
- Collect the sand samples from the river-bed
- The best soil type is coarse sand, which can yield up to 35% water by volume



Measure soil porosity

- Fill a container of known volume with a sample of dry river sediment,
- Saturate sample with water

Volume of water added = Porosity (%)

Volume of sediment,

Allow water to drain from the sample for 24 hours and measure the volume,

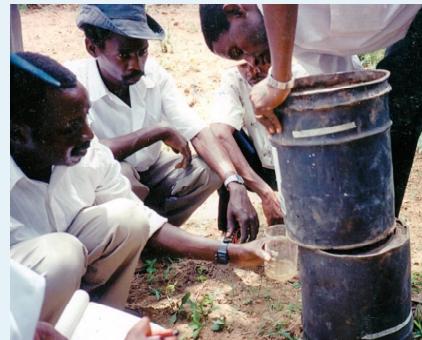
**Volume of water that freely drains =
Drainable Porosity (%)**



5) Measure the yield of water from sand samples

A simple field method to measure water extraction capacities of sand is to use a drum, whose base has a filter

Use drums to measure the water-release properties of the sand



6) For sub-surface dam, identify the best clay material for making the dam embankment



(photos: Nissen Peterssen, 2016)

The right clay could be on nearby river banks, or form another place



Measure the permeability of the clay
Clay should be impermeable

7) Estimate (calculate) the storage capacity and yield of extractable water

The extractable volume of water from a sand dam is estimated using the formula below multiplied by the extraction percentage

$$Q = L \times T \times D$$

6

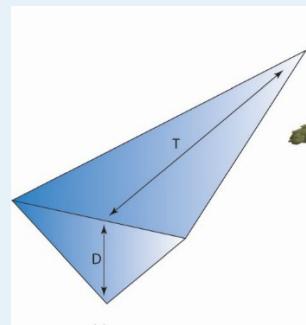
Where

Q is the storage capacity in cubic metres

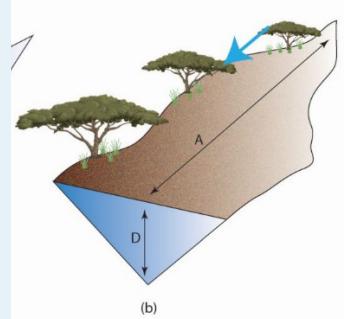
L is the length of dam wall at full supply

D is the maximum depth in metres, and

T is the throwback in metres



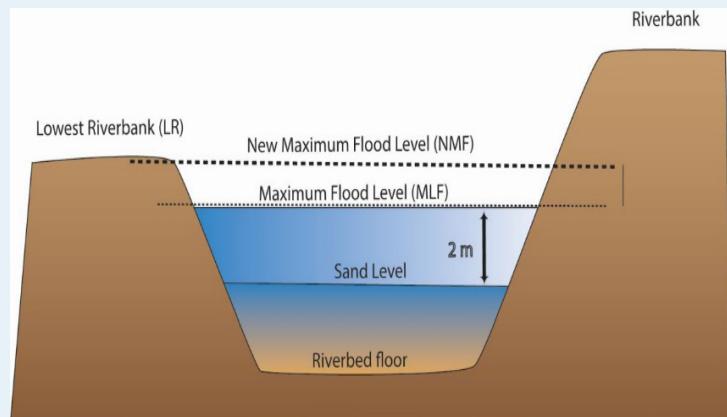
(a)



(b)

8) Determine maximum height of spillways

The maximum height of a spillway is found by deducting the maximum flood level (MFL) from the height of lowest riverbank (LR).



Note - Sub-surface dams:

Since sub-surface dams are constructed beneath the surface, spillway is not needed

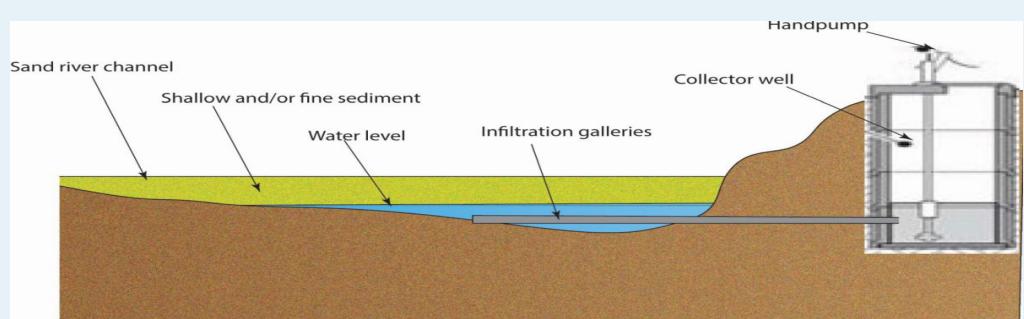
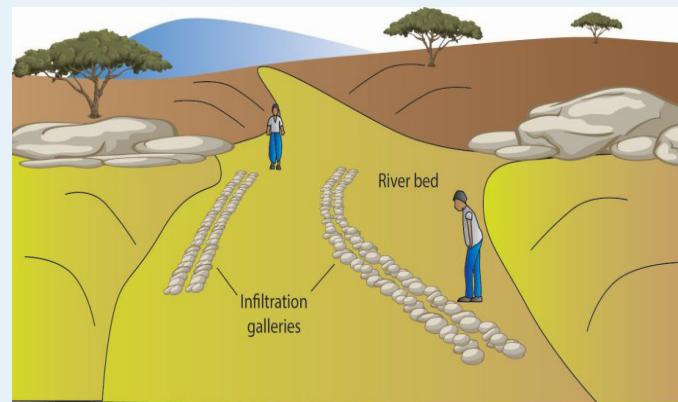
9) Prepare a good foundation

- Foundation should reach down to the impervious layer beneath the sand.
- Create a key trench, then foundation dug into a river bed floor
- Prevent seepage by building on clay or rock foundations



10) Install an Infiltration gallery

- An infiltration gallery is a horizontal pipe or network of pipes, usually plastic, with slots that is placed in the river bed
- Slotted pipes can be purchased pre-fabricated or fabricated at site.

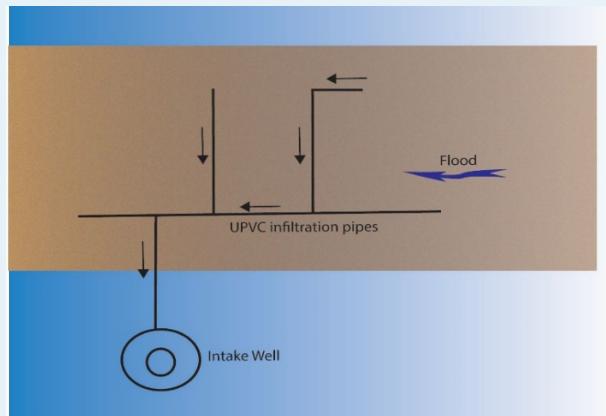


Longitudinal profile of the layout of infiltration galleries during construction

11) Auxiliary structures using an intake well.

These include:

- Draw-off pipes (or well)
- Taps and watering point for people
- Cattle drinking bays
- Catchment protection (grass & tree planting upstream of sand or sub-surface dam)
- Fencing the sand dam and catchment areas



12) Construction of the sand dam

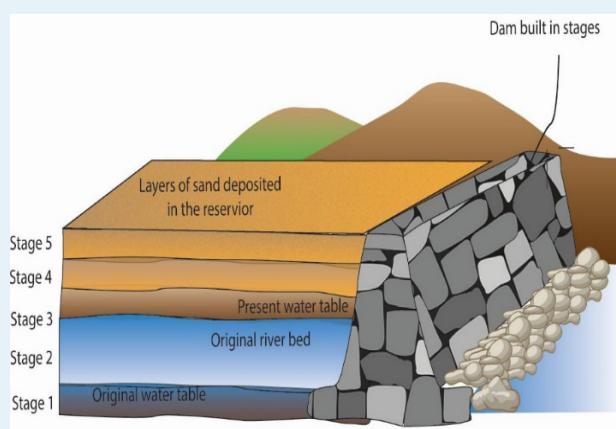
- Can use concrete or -stone masonry or rubble stones for the embankment
- But rubble stone masonry costs 30% less than concrete
- Reinforce the structure with iron bars
- Create a mould of two templates of timber for pouring in concrete.



13) Construct sand dam in stages

Correct way to construct sand dam

- Sand dams are “grown” since they are constructed over several years.
- Construct the structure in stages, preferably just 30 cm height per season



14) Construction of sub-surface dam

- Sub-surface dams are constructed beneath the surface
- They have a foundation
- The entire structure is beneath the surface
- Can be made using compacted clay



15) Intake well used for water draw-off point

- Domestic use (drinking, washing)
- Livestock watering
- Supplemental irrigation of crops
- Environmental conservation e.g. tree planting



16) Water draw-off using piped outlet

Where gravity allows, use piped draw-off to community water point

Provide livestock watering point



17) Hygiene and safety

- Ensure there is no open defecation in/ near the river bed or upstream
- Prevent bathing/ washing upstream of the dam
- Livestock should not drink water direct from the sand dam/ sub-surface dam
- There must be no pit-latrines on the bank upstream
- Do not dig unprotected wells in the sand storage river bed as these act as conduits of contamination



18) Protect the sand/sub-surface dam from pollution

- Provide fencing around the sand dam / sub-surface dam.
- Mobilize the community to take charge of the sand dam / sub-surface dam.

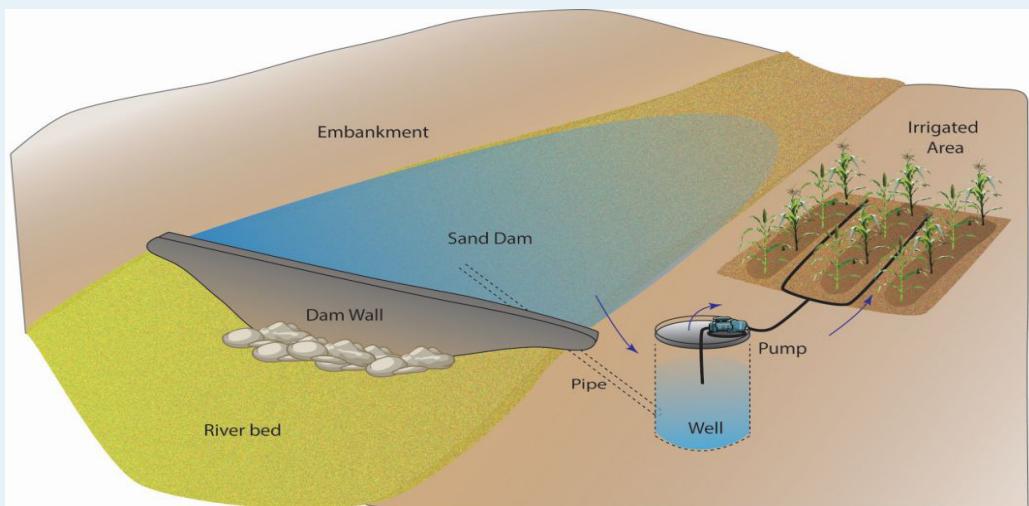


Figure 4.2 Illustration of a complete sand dam fitted with shallow well for irrigation

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