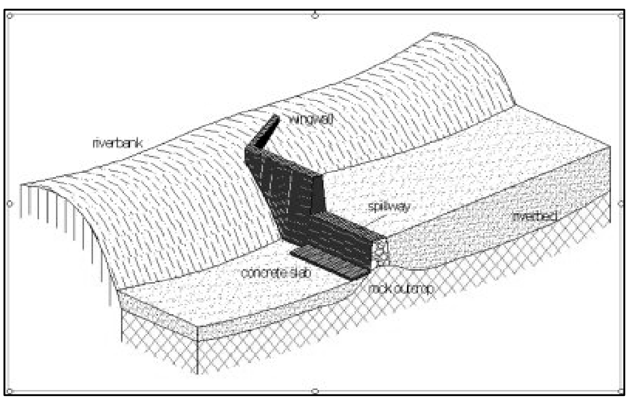
Rainwater Harvesting
Implementation Network

A practical guide to sand dam implementation

Water supply through local structures as adaptation to climate change



An updated guideline initially based on the Swiss Re 2007 award winning pilot project "Water harvesting to improve livelihoods in southern Ethiopia: from pilots to mainstream" and large-scale implementation of sand dams in Kenya and Ethiopia.

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This sand dam manual is based on a previous version 'Sand dam implementation guidelines' prepared as documentation material for training purposes. This publication is made possible by a financial contribution of the Rain Foundation and input from Acacia Water. Other contributions are from the University of Amsterdam and Ethiopian NGO's, AFD, ERHA, HCS, who have extensive experience in the matter.

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PREFACE

This manual is prepared for NGO's involved in water management and water harvesting, and more specifically working on sand dams. Experiences from Kenya and Ethiopia show that the implementation of a sand dam is much more than just implementing a structure. The most critical steps of the whole process from planning and construction to operation, maintenance and monitoring are dealt with in this manual.

The manual starts from a river-basin and sub-catchment scale and zooms in for implementation at the local level. By showing clear boxes and illustrations the process of data collection and field surveys is briefly described. Next to explaining the technical aspects it also focuses on the involvement of the community and understanding the context. Critical success factors such as proper siting and good operation and maintenance are discussed more in detail.

It is recommended to follow an on the job training dealing with the topics described in this manual to have a better understanding of sand dams. The information and examples provided are gathered from experiences but not necessarily applicable to your specific situation. Therefore it is very important - in case of uncertainty - to ask for input from an expert in the matter. If you have any questions or if you want to organize or participate in a training and or workshops please contact the Rain Foundation.

To keep this manual practical, attachments have been added in which further information is given like checklists, design (including water storage) and calculation tools . Also a CD-ROM has been provided with more information and tools.

TABLE OF CONTENT

List of Annexes

MODULE I - WHY THIS MANUAL?

1.1 Introduction: Waterbuffer on 3R

Managing the water buffer is the concept to assess the water storage needs and opportunities on the (sub)basin level with the objective to provide cost effective means to assure water availability throughout the year for rural livelihoods. It deals with building infrastructure and/or modifying the landscape to intentionally Recharge water for storage in tanks, in the ground or in ponds and Retain it there for Re-use during periods of deficit. These three R's (recharge, retention and reuse) are the pillars for management of the water buffer at scale with the purpose to make it available when needed. 3R can be applied in dry or humid areas with long periods of low (erratic) rainfall and create a perennial source of water for drinking (WASH), domestic use, subsistence agriculture and rural industry. The 3R concept (Box 1) is described in the booklet Managing the Water Buffer for Development and Climate Change Adaptation (ed. Van Steenbergen and Tuinhof, 2009) - 3R website (www.bebuffered.com).

Box 1: Managing the water buffer
Managing the water buffer at scale is an initiative to upscale local (rain)water harvesting and groundwater storage solutions through a systematic integration of the water buffer function in (sub) basin water management. The philosophy is to manage this buffer function through three subsequent steps – Recharge, Retention and Reuse. There are a large number of possible (technical) solutions to achieve this of which managed aquifer recharge (MAR) is an important component. 3R covers the broader process planning to retain and intercept the rainfall and runoff, store it underground or in tanks at appropriate places and plan for its re-use during the dry periods. 3R follows the IWRM principle but adds an implementation and financing dimension to it: 3R puts IWRM into practice and responds to needs expressed by the South to assure access to water a reality throughout the year.

The 3R concept is a systematic way to assess the water buffer needs, identify the technical (recharge, retention and reuse) options, select the most appropriate and cost effective solution and plan for its construction, operation and maintenance. It brings recharge, storage of water reuse into a broader framework of planning and management and to promote its application on a larger scale as an integrated part of the water management in watersheds and river basins (Figure 1).

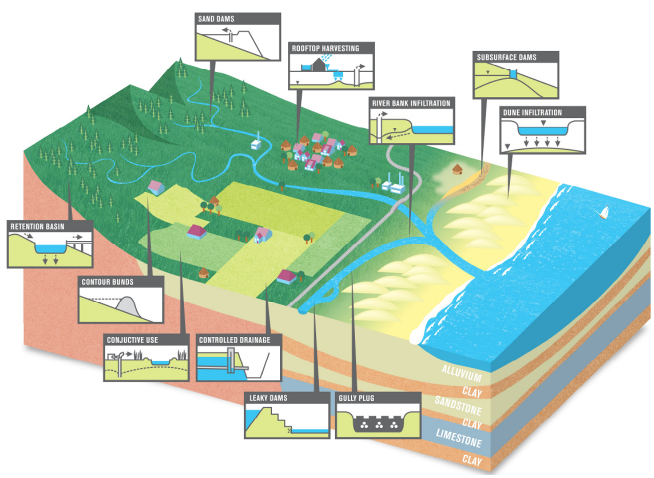


Figure 1: Info-graphic 3R concept

3R leads to the selection of technically and hydrological appropriate interventions to recharge store and re-use excess water for use during dry periods. Recharge and storage facilities may include rainwater harvesting, groundwater based storage (also known as Managed Aquifer Recharge) and surface water storage in ponds and reservoirs (see Figure 2). The 3R approach leads to investment in measures which often concerns known (proven local)technologies and solutions which are up scaled to provide a permanent source of water on the river (sub)basin scale (Steenbergen ea., 2009), but may also include new technologies and innovations which are proven in other regions, hence encouraging South-South cooperation. 3R measures may range from household interventions (such as roof top rainwater harvesting) to larger units which serve a number of households or a community (e.g. sand dams, surface water reservoirs).

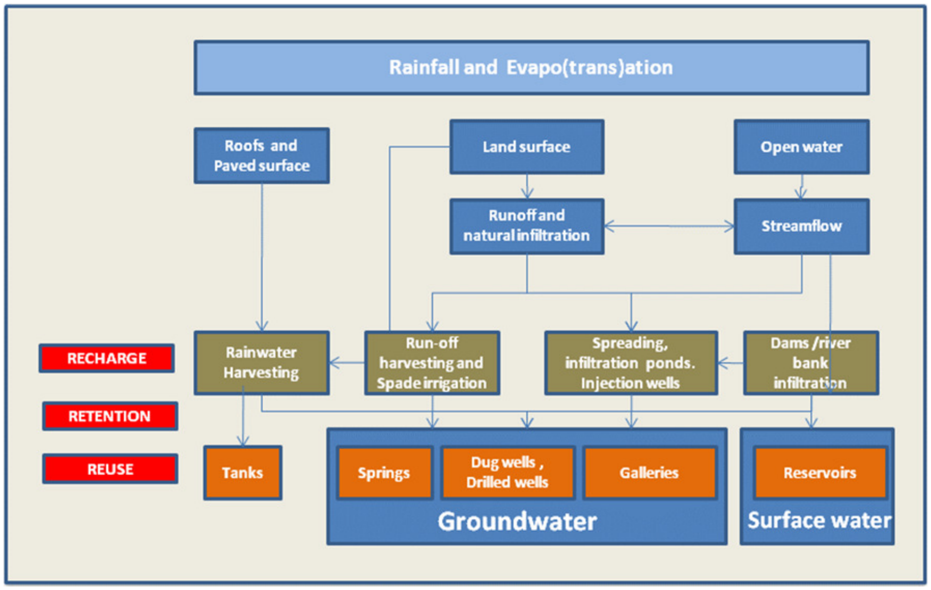


Figure 2: Overview of 3R options

1.2 Sand dams management broad overview

Sand dams in the 3R context

Sand dams are an important 3R technology in the water buffer management approach. The concept of sand storage dams is already known for decennia and there numerous examples of sand dams construct in many countries such as India, Zimbabwe, Burkina Faso, Ethiopia and Kenya. These are mostly isolated initiatives under which only a few dams were constructed in a village by a local NGO or by a group of farmers to enhance their water supply. Being focused on solving local problems, although very useful has generally not been an incentive to share the experience and knowledge for purposes of scaling up..

In the last 10 years there has been a growing recognition of the added value of sand dams as a low cost and robust means to enhance water availability also in areas that are affected by the negative effects of climate change. Initiatives have been taken to upscale the application of sand dams construction and to introduce them in areas where the physical environment is suitable for this construction. Two good examples are the case studies in Kenya and Ethiopia in **Appendix 1**.

The Rain Foundation (with support of Acacia Water) has taken the initiative to introduce the up scaling of sand dams in their program and has trained their partner organizations in the countries. The case study in **Appendix 1** concerning Ethiopia is one of the outcomes of that initiative. This training course brings together the collective knowledge and experience in the sand dam siting, design and construction that has been developed over the last years by several partners in different countries .

Sand dams: basic principles

A sand storage dam (or sand dam) is a small dam which is build on and into the riverbed of a seasonal sand river[1]. The functioning of a sand dam is based on the sedimentation process of coarse sand which is stored behind the structure. In this way the natural storage capacity of the riverbed aquifer is enlarged. The aquifer fills with water during the wet season, resulting from surface runoff and groundwater within the catchment. The riverbed is also recharged through the groundwater flow which is obstructed by the sand storage dam, creating additional groundwater storage for the community.

[1] Dry and sandy riverbeds are seasonal water courses that transport runoff-water from catchment areas into rivers or swamps once or a few times in a year. Dry riverbeds are also called ephemeral streambeds, seasonal water courses or sand rivers. Most of the rainwater being transported downstream in riverbeds appears as high flood events that can be up to several metres high. Sand rivers are only suitable for sand dams when coarse sands are available and also the river must be underlain by impervious bedrock (or clays like black cotton soil).

Photo 1**:** Typical sand storage dam during the dry season (Borst & de Haas, 2006)

During the dry season, water levels will drop due to abstraction of water, evaporation and possibly by leakage through the dam or vertical percolation into the bedrock. At the same time recharge of the riverbed aquifer takes place though subsurface flow (base flow) from the riverbanks towards the riverbed and through the riverbed itself. Mainly because of the large storage volume and the retention of water in sand, the sand dam can provide water throughout the dry season (when built under appropriate conditions), whereas otherwise the riverbed would have dried up. This allows the community to have access to water throughout the dry season.

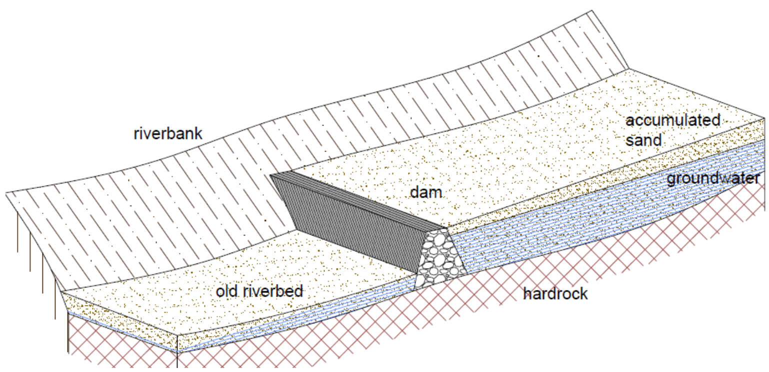


Figure 3: Schematic cross section of a typical sand storage dam (Borst & de Haas, 2006)

The volume of water available for abstraction is considerably larger than just the volume present in the riverbed sands. This is because a large quantity of the water is additionally stored in the riverbanks, recharging the sand dam reservoir in the dry season (Borst & de Haas, 2006; Hoogmoed, 2007).

Sand dams effectively increase the volume of groundwater for extraction as well as prolonging the period in which groundwater is available. Also other methods are available, Box 2 compares the sand dam with a surface water dam.

Box 2: Advantages of a sand dam compared to surface water dams.

Sand storage dams have several important advantages over surface water dams, resulting in a higher water quality and improved environmental conditions.

- Less evaporation (water storage in sand)
- Less contamination with sand (not direct contact of water with livestock and other animals)
- Better infiltration (water flowing through the riverbed of sand, disinfection or filtration)
- No more breeding of mosquitoes (unsuitable for malaria and other insects)
- Low cost structures (build by community)
- Proper maintenance (using local materials which can be maintained by community)
- Longterm sustainability (High community involvement and commitment)

1.3 Functions of a sand dam and types of sand dams

The primary function of a sand dam is increasing the water availability by storing water in the riverbed and -banks. Sand dams obstruct the groundwater flow through the riverbed, resulting in a (continuous replenishment of the) enlarged groundwater reservoir upstream of the dam. Depending on the porosity of the sand water is stored in the spaces (voids), which can hold up to 35 percent of the volume of sand. Besides this, sand dams can have other functions and positive side effects such as:

Recharge of regional groundwater: A cascade of sand dams along a river course will increase groundwater levels in a larger area. This positively effects the environment (vegetation) in the surrounding of the dam.

Rehabilitating of gullies and sand harvesting: Sand dams can rehabilitate eroded gullies. If a sand storage dam is built for this purpose, the dam doesn't have to be impermeable. The sand behind the dam can be harvested for sale. Usage of plastic bags filled with soil is more profitable for this purpose (Nissen-Petersen, 2006).

Photo 2: Sand dam in Kituï (Gijsbertsen, 2006).

Sand storage dams can be classified according to their construction material as indicated in Box 3 (Negassi et al., 2002):

Box 3: Classification Sand Dams:

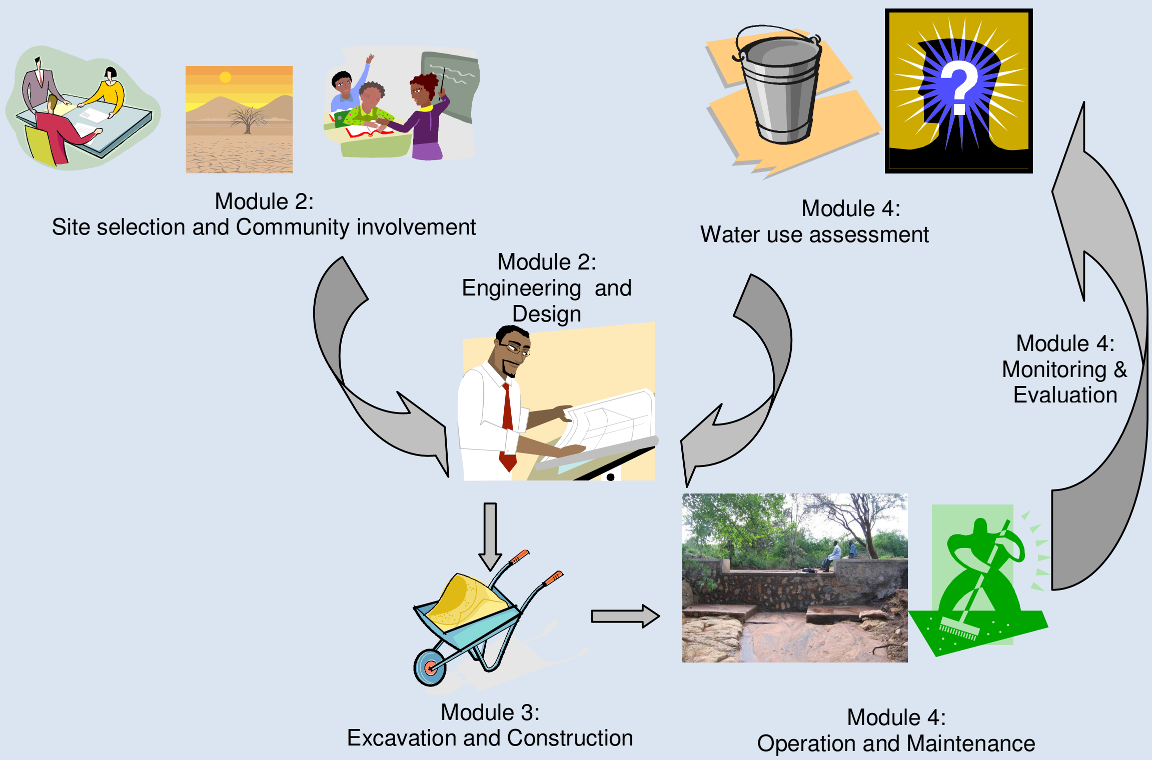
- **Stone-masonry dam:** A dam built with concrete blocks or stones. This type of dam can be constructed by local artisan. This type of dam is relatively expensive to construct and it requires special skill for its design and construction. A stone-masonry dam is durable and suitable for higher dams.
- **Reinforced concrete dam:** A dam consisting of a thin wall made of reinforced concrete. It is a durable structure, relatively expensive but suitable for any dam height.
- **Earth dam:** A dam consisting of impermeable soil material (mostly clay or clayey soils, or black soils). Although earth dams are most cost-effective, they cannot store large quantities of water which makes them less suitable. An earth dam can easily be damaged and even destroyed by underground flow. Earth dams are not popular and are seldom used (only for minor works).

1.4 Road map for sand dam implementation

After understanding the purpose and functioning of the sand dam, we continue with a step-wise approach in how to implement a sand dam. In the following chapters these will be discussed separately. The following steps (see Box 4) for implementation are identified;

- Site selection and community involvement;
- Engineering and Design;
- Water use assessment;
- Excavation and construction;
- Operation and maintenance (establishment of water management)
  (Water committee, care takers and provision of trainings)
- Monitoring and Evaluation

Box 4: Stepping stones in sand dam construction



This manual focuses on masonry dams with or without a reinforced foundation and a u-shaped spillway. After many years of practical experience and research on sand dam design by SASOL, this design has proven to be most effective, durable and easiest to construct by local beneficiaries. Although earth dams are most cost-effective, they cannot store large quantities of water which makes them less suitable.

MODULE II – HOW TO DESIGN A SAND DAM?

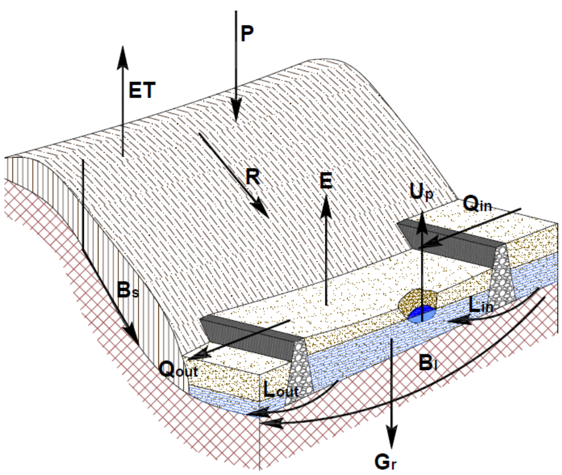
2.1 Hydrological principles of a sand dam

Functioning of a sand storage dam

In many semi arid regions, most of the peak river discharges are lost downstream and the storage and retention of water after rainfall events is limited. This is mainly due to the geomorphology of the upstream catchment with (steep) slopes and silty and clayey soils. Instead of infiltration in the soil and recharge of the groundwater, most of the rainfall leaves the catchment as surface runoff, runoff coefficients up to 70% are known.

The main function of the sand dam is to store and retain water. For this purpose it obstructs the groundwater flow through the impermeable riverbed. After one or two heavy rainfall events the aquifer can be completely filled with water. Because of the higher water table in the dam, also water flows towards the riverbanks. The recharge from the river or groundwater flow continues the replenishment of the created reservoir. The storage capacity of the dam is limited, if this recharge is interrupted. After the dam is depleted water can be extracted from the riverbanks. Water will be available in the sand dam as long as the groundwater flow from the riverbanks continues (Figure 4).

From a catchment perspective it can be very beneficial to take soil- and water conservation measures in the upstream areas. This increases infiltration of rain water and increases the groundwater flow. The raised water table in the riverbanks results in a groundwater flow from the riverbanks towards the river bed. Downstream of the dam the groundwater flow continues its natural course.



Water balance components

- ET Evapo(transpi)ration from slopes
- E Evaporation from riverbed
- P Precipitation
- R Surface runoff from slopes to river
- B_s Groundwater baseflow from slopes to river
- B_f Shallow and deep longitudinal baseflow
- Q_{out} River discharge outflow over downstream dam
- L_{out} Leakage underneath and around downstream dam
- Q_{in} River discharge inflow over upstream dam
- U_p Use of water (abstraction)
- G_r Loss of water into the ‘impermeable ground

Figure 4: Water balance components (Borst & de Haas, 2006).

Filling the sand dam aquifer

Before water can be stored in the sand dam it needs to be filled up with sediment. After heavy rainfall events, high river discharge transport large quantities of sediments. The grain sizes of the transported sediments are dependent on the river flow velocity and the material comprising the riverbanks. High silt and sand loads occur at the start of the rainy season, when most of the land is bare and soils are poorly protected against soil erosion.

The sedimentation process behind the dam occurs when the flow velocity of the river is decreased at some distance upstream of the structure. Coarse sediments can no longer be transported due to the lower flow velocities and are deposited. The materials found in the river bed prior to construction are a good indication of the type of sediment that will be stored by the sand dam through sedimentation. The sediments form a ridge, comparable to the formation of a delta.

Upstream of the ‘delta’, flow velocity is higher and coarse sediments are transported. Where the ‘delta’ stops, a sudden drop in flow velocity occurs causing coarse sediments to settle, building the ‘delta’ further towards the sand dam (see figure 3). Continuous repetition of this process causes the ridge of sand to move towards the dam, eventually filling the total volume behind the dam.

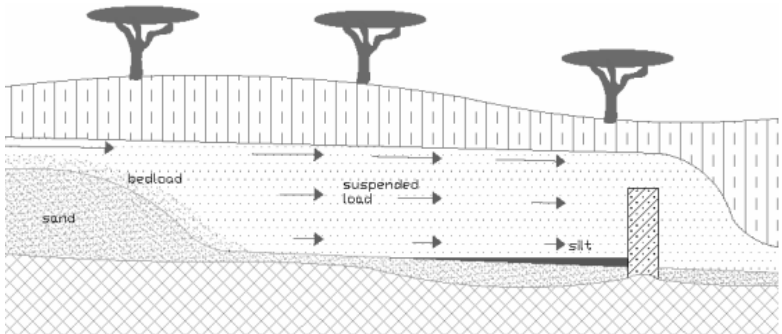


Figure 5: Schematic representation of the sedimentation process (Gijsbertsen, 2007)

The river also transports finer materials, like silt and clay which are mostly transported over the dam. Finer materials have a lower settling velocity compared to sand and will largely stay in suspension. Without the coarse material, the base flow water has excess energy leading to erosion of the river bed. Fine sediments will be (re)taken into suspension and transported, leaving the coarser grained material in the riverbed. But also fine sediments can settle resulting in a silt layer directly upstream of the sand dam which can affect the water storage negatively.

After the heavy rainfalls, the peak discharge in the river will decrease until the base flow. If the river runs dry completely, residual silt layers on top will dry and crack. Animals and people walking on the riverbed will pulverize this dry silt layer, making it susceptible for wind erosion (Borst & de Haas, 2006). These processes limit the accumulation of silt and clayey material behind the sand dam.

Sedimentation will continue until the ‘delta’ reaches the height (crest) of the sand storage dam. The sand storage dam is then matured and completely filled with coarse sand. Granite hard rock will produce coarse sand while shales will produces fine (clay or silty) material. It can take several wet seasons to fill the dam, depending on the availability of coarse sediments, height of the sand dam, river discharge, catchment slope and rainfall intensity.

It is recommended that sand dams are built in stages in upstream parts of a catchment, since the availability of coarse material is generally limited and base flow is small or absent. The optimum height of one stage is site specific. The first stage is typically 50 cm. It is recommended to consult an expert on this matter.

2.2 Site selection

Importance of site selection

The most important step for successful implementation of a sand dam is to select the proper site and location for construction. Accuracy in site selection will determine the final success of the dam. A construction site should therefore be appropriate to meet the physical requirements to establish a proper dam. Next to this community involvement (see chapter 4.2.) is essential to select a site, construct the dam and to take care of proper operation and maintenance (see chapter 4.2) to assure sustainability. This chapter will guide you through site selection for sand dams in 3 steps in relation to different scales (see Figure 6);

- River basin or catchment scale - Selecting potential sub catchments from a probability map based on a desk study (Box 4)
- Sub-catchment scale - Selecting potential riverbeds based on field data regarding the physical and sociological aspects (Box 6).
- Riverbed - Selecting of sand dam location(s) (Box 7 - 10)

Selecting potential catchments for sand dams

In case an entire catchment has to be assessed for selection of suitable sand dam sites, a quick scan is needed to assess the sub catchment areas where (i) water buffering is needed because there is no natural water buffer or surface water and (ii) to assess the sub catchment areas where the physical conditions are suitable for sand dam construction and (iii) where there is demand for water buffering.

A quick scan is a GIS bases analyses to map potential areas for building of sand dams. This will narrow down the focus, which will make site selection more specific and thus efficient. The quick scan is based on satellite information, internet data bases, available digital maps (or digitized maps supplemented with manual information). This GIS based analysis will provide a set of maps showing the potential areas where more detailed field data can be collected.

The type of maps and data used for a quick scan are typically: (see Box 5). Furthermore available information resources are provided in the reference section of this manual.

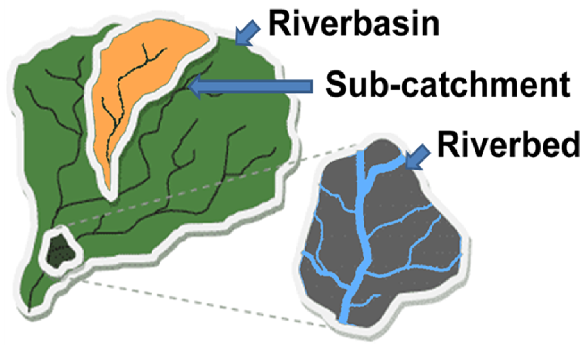


Figure 6: Identifying appropriate scales

Box 5: Quick scan

1. Topographical Map:
A topography map gives general information about the catchment, showing locations of rivers and the extent and general characteristics of the catchment. Furthermore in most cases information is given about the socio-economic infrastructure such as locations of villages and roads.

2. Digital Elevation Model:
A Digital Elevation Model (DEM) contains information on the morphology of an area (elevation and slopes). Furthermore, information on the slopes within a catchment can be derived from a DEM. A local drainage direction map can be calculated, which will give the drainage pattern (rivers) of the catchment.

3. Geological map and soil data:
The morphology and geology of the catchment informs us about the rock formation and soils in the upper catchment and the riverbed itself. This assessment could indicate weather the riverbed is hard rock, and thus impermeable. The catchment geology, with discharge characteristics and the slope, together, determine the grain sizes which can be actually stored in the sand dam. A geological map can indicate whether a catchment has the potential to produce (coarse) sand.

4. Aerial photographs and satellite images:
Aerial photographs and satellite images can support locating sandy riverbeds based on the morphology. Aster satellite images can also be used to indicate sandy riverbeds and different types of geology through the remote sensing techniques as used by Gijsbertsen (2007).

5. Precipitation and evaporation data:
When locating suitable regions for building sand dams, it is essential to know the climatic conditions of an area. Precipitation will be important because it influences discharge characteristics (base flow) and thus also the availability of coarse grained material in the riverbeds. Also an indication of the climate conditions can distinguish intermittent or ephemeral rivers.

6. Flood data:
Flood data is required to determine the maximum flood level and thus the minimal height of the riverbanks. It also provides information on discharge characteristics of a catchment during a rainfall event.

The analysis of these maps and data usually requires the input of specialized experts who have GIS experience and access to shape files (Box 5) and will result in a potential map for the whole catchment. In some cases, this quick scan will not be available and the NGO will start the site selection process within the sub-catchment where they are working. In that case the site selection will start with the next step.

Selecting potential riverbeds and river bed sections

The result of the desk study described in Box 5 shows the areas (or sub catchments) are suitable for constructing sand dams. In these sub catchments a more detailed assessment is carried out to select suitable rivers and river sections. Main criteria to select riverbeds and river bed sections within a sub catchment are given in **Appendix 2** and include priority criteria:

- The presence of communities (nomads or permanently – dry period)
- The slope of the river beds: the most suitable locations have a slope between 2 to 4 percent.).
- Average width of the river, which should not exceed 25-50 meter
- The rivers should be underlain by bedrock

Based on these criteria, a small number of river bed sections (2-3) are selected for field visits to promising river bed sections, which is needed to collect information and to consult the communities. Starting a sand dam project begins with establishing the community's awareness on the project by undertaking regular visits to the project area and facilitating meetings with the representatives and members of community. (Also see paragraph 4.2 and **Appendix 4**)

Box 6: Checklist for river section inspection and ranking

1. Location and types of water-indicating vegetation.
A good indicator for the presence for groundwater is current vegetation. Depending on the species, the groundwater depth and storage of water can be estimated

2. Location of waterholes, their depth to the water table and quality of the water.
The presence of waterholes is an indication that the riverbed contains deep water storage. The water quality in the waterhole is an indication of the quality of water which can be harvested.

3. Location and types of rocks and boulders.
If large boulders are present in the riverbed, special care should be taken in choosing the location. Preferably the sand dam is build on (and its wings attached) hard rock or compacted and strong soil.

4. Grain size of the sand (coarseness), particles in the riverbed.
The grain sizes which are present in the riverbed are a good indication of the material which will fill up the sand dam reservoir after construction. Coarse sand is preferred, since it has a higher infiltration capacity and water can be abstracted more easily. (Existence of gullies, might feed silt)

5. Shape and dimension of the riverbanks.
Suitable riverbeds for sand dam consist out of high riverbanks. During flood events the river should not flow over the riverbanks, because this can cause erosion of the riverbanks, flooding of downstream located villages and it might cause the river to change its course.

6. A (preferred) maximum width of 25 meter.
Preferably, riverbed width should not exceed 25 meters. The reinforcement required to construct such kind of long dam walls is too expensive; hence the sand dam will not be cost-effective.

7. An impermeable (bedrock) layer.
To ensure storage within the sand dam aquifer, losses to deeper groundwater should be minimized. Therefore, the dam should be built on solid bedrock or an impermeable layer.

8. Type, suitability and availability of construction material.
The construction materials which are locally available (such as sand, rock outcrops, bricks, etc.) can help to determine the most cost-effective type of sand dam for construction .

9. Presence of riverbed crossings and roads.
Rural roads often cross riverbeds. Preferably a sand dam is located near these crossings and can be easily reached through existing roads (also for transportation of materials).

10. Names of houses, schools and shops near the riverbed.
The local people benefit from the sand dam, may it be direct or indirectly. By measuring these positive social impacts before and after implementation, the actual social impact can be determined. .

11. Land rights.
Agreements based on rules and regulations (or bylaws) are needed to assure fair use and access to water for collective and individual usage. To avoid conflicts, special care should be taken in areas where the dam site is owned or used by two or more villages or several individuals.

The checklist in Box 6 is based on expert knowledge of Nissen-Petersen (2006) and includes to make a sketch of the selected river bed sections followed by the rapid appraisal (field visits) with information gathered from the social leaders and the community (paragraph 4.2). This is combined and integrated into a map, resulting in a ranking of the riverbed sections

A detailed description of these checkpoints is given in **Appendix 3** and will results in the selection of 2-3 selected approximate locations.

Selecting sand dam location(s)

The final step is to carry out a detailed survey in the 2-3 locations that are selected as potential dam sites. These specific sections will be visited together with the community representatives, to collect data based on which building location(s) are chosen, based on a number of detailed criteria that are checked in the field (see Box 7 up to 10). Measurements to be taken at these locations are (see also **Appendix 5**):

- The depth and coarseness of the sand at different levels (Box 7)
- Depth and type of basement and depth of groundwater (Box 8)
- Gradient of the river bed (Box 9)
- Width of the riverbed and height of the riverbanks (Box 10)

Box 7: Storage capacity and extraction percentage of sand

Most water can be retained and stored in riverbeds containing coarse sand. The porosity and the water holding capacity of sand can be determined using the following method. A 20 litre container with a plug in the bottom is filled with sand from the riverbed. The sand is slowly saturated with a measured volume of water. Then the plug is removed from the bottom of the container. The volume of water which has drained out of the sand within one hour is taken as a measure for the extractability. Table 3 gives values of extractability of water in different soils. This shows that coarse sand has the highest extractability making it also preferred for storage in the aquifer.

	Silt	***Fine Sand***	***Medium Sand***	***Coarse Sand***
Size (mm)	< 0.5	0.5 – 1.0	1.0 – 1.5	1.5 – 5.0
Saturation	38%	40%	41%	45%
Water Extraction	5%	19%	25%	35%

Box 8: Depth and type of basement and depth of groundwater (location of sand dam!)

The sand dam must be constructed at the location where the impermeable layer is closest to the riverbed surface. Preferably, also the basement upstream of this location is deeper, to get a larger sand dam aquifer. The depth of the sand in the riverbed can be surveyed by using an iron rod with a diameter of 16 mm (5/8"). Notches should be cut in the probing rods for every 25 cm, to collect sand samples when the rod is pulled up. A hammer is needed for hammering the rod into the riverbed, together with a tripod ladder used for hammering long probing rods. This survey is executed using the following procedure below:

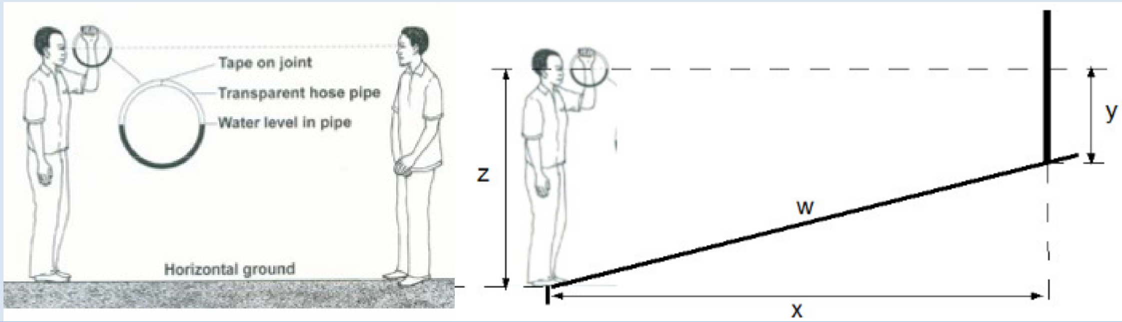
- *Hammer the probing rod straight down in the middle of the riverbed, until it hits the floor under the sand with a dull sound. Mark the level where the water is encountered and the depth of the bottom and pull the rod straight up without twisting.*

The procedure described in Box 8 is repeated at regular intervals, for example 5, 10 or 20 metres. The data gathered by this particular survey results in a map with profiles of the river section and cross sections at the locations. This map shows information about the river length with approximate dimensions and specific information (width, locations of cross-sectional, longitudinal profiles, water-indicating trees and waterholes). Based on this a more precise estimation of the water storage can be acquired and the location of the dam is decided. The data are also used to calculate the actual determination of the water storage, which can be calculated with the help of the SAND Dam Infiltration Tool (See paragraph 4.2).

Box 9: Gradient of the riverbed

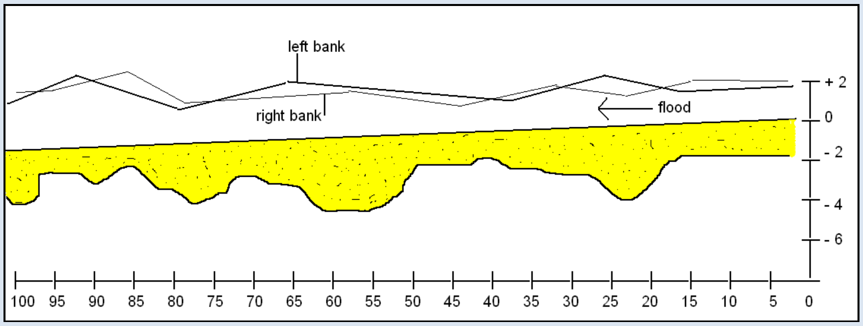
Measuring the gradient of the riverbed can be done by using a circular transparent hose, half-filled with water. One person should stand at the starting point, using the levelling tool. Another person should stand upstream of the person holding the levelling tool, with a long vertically pole. The person with the levelling tool makes sure that the water levels in the tube are in one line. The other person should indicate where this sight line crosses the pole. The height at which the line of sight crosses the pole is measured from the surface of the riverbed (parameter y [m]). Also the distance between point No. 1 and point No. 2 and the height of the eyes of the person holding the levelling tool is measured (parameter z [m]). With these figures the gradient (parameter w [m]) can be calculated using the following formula:

$$W = ((z - y)/x)*100 = \text{gradient [\%]}$$

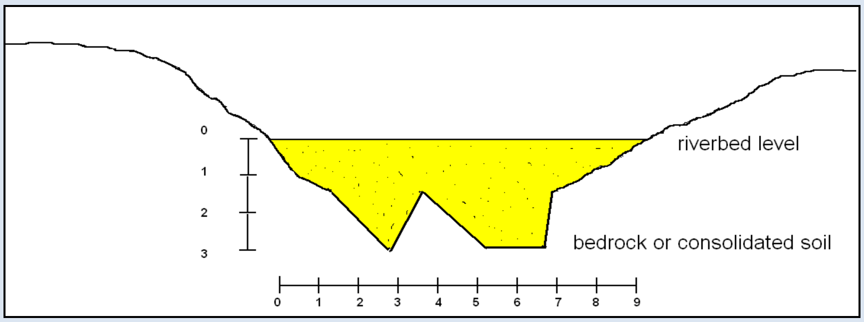


Box 10: Example of longitudinal profile and cross section

The figure below shows an example of a longitudinal profile. It shows the points at which the sand is deepest (here: 4.0 m deep between 55 and 60 metres) and where natural subsurface dykes (of solid bedrock or impermeable soil) are located (for example at 40, 70 and 85 metres). The locations with deep sand are the potential reservoir of a sand dam and the natural dykes are potential locations for a sand dam. The actual location of the dam can be determined after making a longitudinal profile of the selected riverbed section. The exact place is selected based on the deepest point with the largest storage reservoir. In the graph this is at 60 metres.



By knowing the longitudinal and cross-sectional profile, a calculation of the reservoir capacity can be made. The figure below gives an example of the deepest cross-section . It is important to take measurements every 1 or 2 metre across the riverbed to determine the riverbed morphology. If the cross-section is combined together with the longitudinal profile, the storage volume can be calculated accurately.



2.3 Preparing the Dam Design

The sand dam can be designed after the finalization of the water assessment. The outcome of this water assessment indicates the required sand storage, based on the assumed discrepancy in water storage, between the estimation of the water supply and the actual water demand over time. In addition to this calculation, the dam is designed according to the specific morphology of the riverbanks and the riverbed. There are different approaches in designing a sand dam, but this manual will focus on the designing approach of SASOL, combined with AFD. A sand dam can be defined in four main parts:

- The dam wall;
- Spillway;
- Wing walls;
- Stilling basin
- Abstraction well (see paragraph 3.4 and **Appendix 9**)

Dam height

For the determination of the height of the dam crest and the spillway at a specific location, it is very important that the water level and the maximum flood level will remain below the riverbanks, also after the construction of the dam. If the flood comes higher than the riverbanks (Bh), the river can damage the structure, or change its course. For this reason the dam crest and spill way height are determined by the maximum discharge and maximum flood height (see figure 9).

The most practical way of calculating the maximum discharge, is by getting information from the community (through interviews), or through a field survey (observations from the field, like flood marks).

The maximum discharge can be calculated in 3 different ways:

- Calculating the maximum discharge by the highest flood level (known by flood marks on the banks or information from the local community's);
- Calculating the discharge at the selected location using a certain return period (for example a rain event with a return period of 50 years) or otherwise, using a rainfall-runoff model or a mathematical formula for rainfall runoff.
- Area Slope Method.

Figure 7 shows in the top picture, a proper designed sand dam where the maximum flood level will remain lower than the riverbanks. In the picture below is shown a sand dam, by which the maximum flood level will exceed the riverbanks. In this scenario flooding and thus severe erosion of riverbanks (eventually causing dam failure) can or will occur.

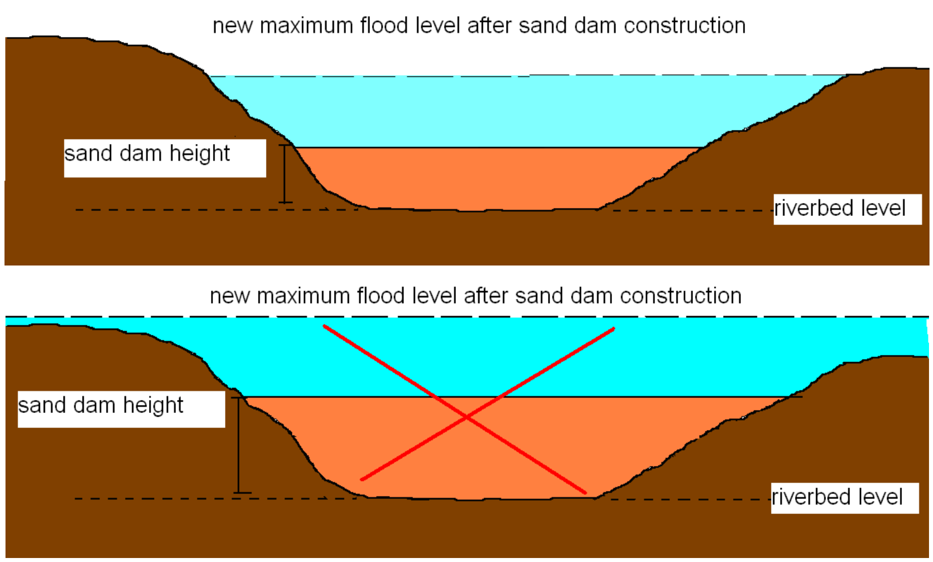


Figure 7**:** Examples of sand dam heights: do's and don'ts.

In Figure 8 you see a cross-section at a dam location, with the different parameters that have to be measured to calculate the maximum discharge.

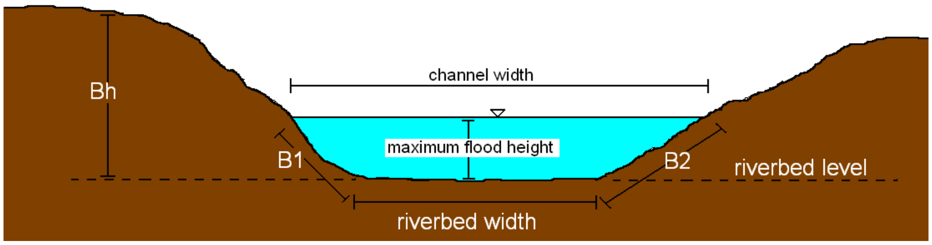


Figure 8: Cross section with maximum flood height

Box 11: Maximum discharge in riverbed section:

$Q = 1/n * A * R^{2/3} * S^{1/2}$

Q = maximum discharge in riverbed section (m^3/s)
n = Manning roughness of riverbed
A = wetted cross-sectional area (m^2), by: ½*(channel width + riverbed width)* flood height
P = wetted perimeter (m), by: B1 + riverbed width + B2
R = hydraulic radius (m), by: A/P
S = slope of riverbed (m/m)

Spillway, wing walls and stilling basin dimensions

The maximum discharge (See Box 11) is used to determine the spillway dimensions, for which the formula is given in the box below.

Box 12: Using maximum discharge to calculate spillway dimensions

$Q = c * L_s * H^{3/2}$

Q = maximum discharge in riverbed section (m^3/s)
c = 1,9 (constant depending on spillway shape, here: broad crested weir)
L_s = length of spillway (m)
H = height of spillway (m)

Cross-sectional width dimension of a sand dam

G_f = gross freeboard (m)
H_f = height freeboard (m)
H_d = total height of dam (m)
H_s = total height of spillway (m)
L_w = length wing wall (m)
L_{we} = length wing wall extension (m)
L_s = length spillway (m)

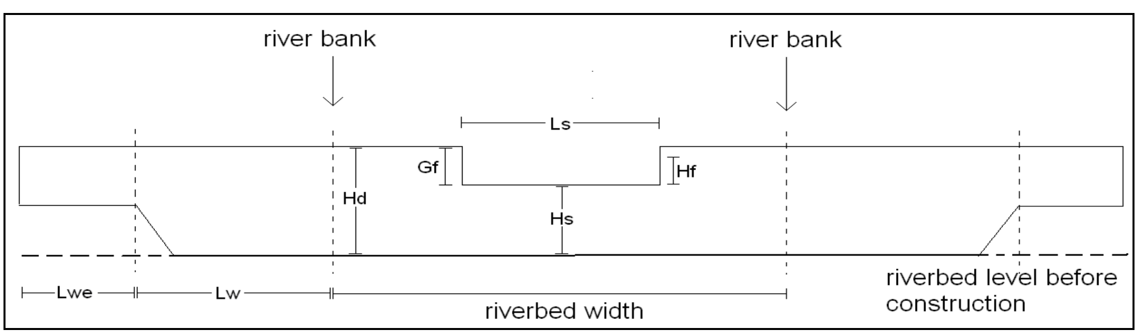


Figure 9: Cross section of a sand dam body and its dimensions.

For determining the excavation (depth) of the wing walls, which need to go into the riverbanks, the following characteristics of the bank have to be taken in account (Munyao et al, 2004):

- In loose riverbanks: approximately 10 metres into the riverbanks;
- In hard (consolidated) soils: approximately 7 metres into the riverbanks;
- In hard and impermeable soil: approximately 0 – 3 metre into riverbanks;
- In rock formation: no need of constructing in riverbanks.
- If there is risk of channel shifting, 15 meter wing walls are needed for precaution.

The length of the wing wall (Lw) should be approximately 2 metres into the riverbanks. The length of the wing wall extension (Lwe) should be approximately 5 metres. This is an example of wing wall dimensions in loose riverbanks

Box 13: Stilling basin dimensions

$S_L = c * L^{1/3} * H_2^{1/2}$

S_L = length of stilling basin (m) c = 0,96 (constant)
H_2 = height of freefall (m): height of water level upstream –height of water level downstream

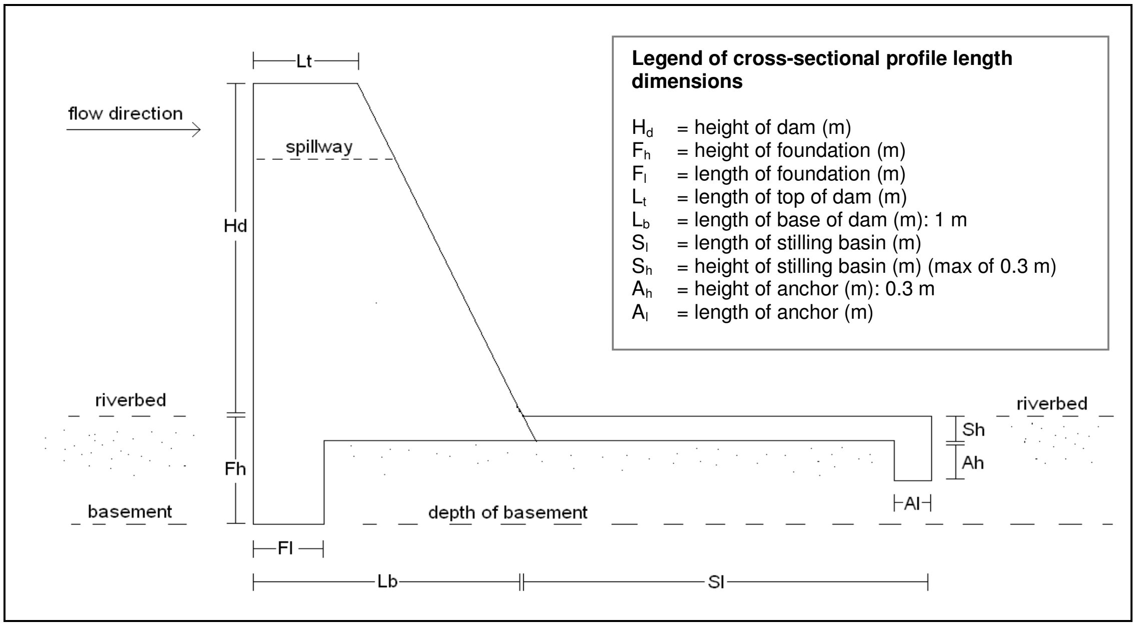


Figure 10: Cross sectional profile of a sand dam body and its dimensions.

The thickness of the stilling basin (S_h) should not be fixed to be max of 0.3m. It actually depends on the uplift pressure and impact load. If the material underneath is lose formation, the thickness can be even higher than 0.3m to prevent piping and collapse of the structure. Sometimes there will be a need to use reinforced concrete if the impact load is high and flood water brings rolling stones and wood planks. To determine the thickness either *Bligh's* or *Khosla's* Formulae of exit gradient and determination of thickness of apron can be used.

2.4 Finalizing the Dam Design

The dam design as described in the previous paragraph is according to site specific conditions as part of the sub-catchment within a riverbasin. The selection of opportunities for sand dams in a riverbasin and sub-catchment and the actual selection of the site location require for both scales specific selection criteria. The link between the different scales is the riverflow which determines the actual water storage when the sand dam is operational. For the sand dam design the strength and dimensions need to based on calculated or estimated river discharges. Another important aspect to consider in the design is the use of locally available materials and skills for construction. The local people should be able to maintain and repair the dam. Also it is important to consider the actual usage and construction of water tapping points which is discussed more in detail in the next chapter.

MODULE III - HOW TO CONSTRUCT A SAND DAM?

3.1 Materials and Labor

Materials

For the construction community involvement is essential. The local people need to able to work with the materials which are needed to construct the sand dam, depended on the type of dam that is suitable at the selected location. Furthermore this depends on physical properties of the catchment and on the materials available on the market and within the local area. If materials like stones and sand are locally available, this will reduce costs of materials and transport. In this paragraph we will focus on the bill of quantity for stone-masonry dams. There are some rules of thumbs for the construction of the stilling basin, dam and the foundation which are given in Box 14.

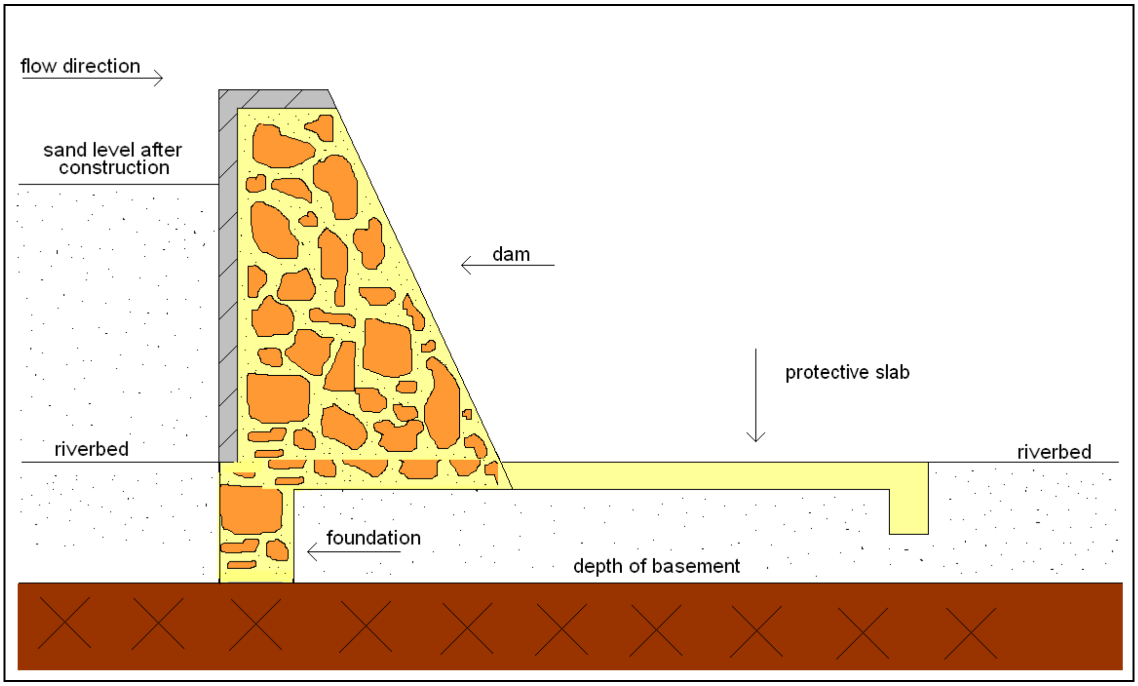


Figure 11: Cross sectional profile of a sand dam body.

Box 14: Construction materials masonry sand dam

Stilling basin:

- 1:3 mortar
- Large boulders

Dam:

- 1:4 mortar with well interlocked stones, ratio cement: sand: hardcore = 1:4:9-12
- Upstream wall and top of dam plastered with 1:3 mortar (30 mm)

Foundation:

- 1:3 mortar foundation (100 mm)
- 1:4 mortar with well interlocked stones, ratio cement: sand: hardcore = 1:4:9-12
- (reinforcement bars of barbed wire (400 mm spacing)

All required materials should be summarized in bill of quantities as shown in table 1.

Table 1: Example of a bill of quantity for materials and transportation costs in ETB (2007).

Description	Unit	Unit cost (ETB)	Total quantity for a sand dam	Costs per Volume of work (ETB per m^3)	Total cost (ETB)
Cement	50 kg bag	130	241.8	3.10	**31,434**
Reinforcement bars ½ Dia' (12m)	pieces	0	0.0	0.18	**0**
Reinforcement bars ¼ Dia' (12m)	pieces	0	0.0	0.18	**0**
Barbed wire	20 kg roll	68	6.0	0.08	**411**
Timber 2"x 2"	m^2	12	52.0	0.67	**624**
Polythene paper g 1000	metre	15	104.0	1.33	**1,560**
Reinforcement bars Dia' (10m)	pieces	140	3.1	0.04	**437**
Reinforcement bars Dia' (6mm)	kg	14	51.5	0.66	**721**
Black wire	kg	14	3.9	0.05	**55**
C.I.S. Nails	kg	18	2.3	0.03	**42**
Stone hard core2	m3	31.25	233.2	2.99	**7,288**
Sand13	m3	19	66.3	0.85	**1,260**
Water	m3	140	37.4	0.48	**5,242**
Other construction equipment (V.tools, Hand pump, Mould for well concrete rig)	unit	7,500	1.0	1.00	**7,500**
Camping site for skilled labourers	unit	6,500	1.00	1.00	**6,500**
Total					***63,073**

*Prices and quantities are highly variable: these depend very much on the site location and local markets.

In Table 1 is an example given of the cost for construction, more detailed information is given in **Appendix 7** with the guidelines to calculate the quantity of the materials derived from the dimensions of the dam.

Labour

In Table 2 an example is given of the bill of quantity for labour costs: the contribution of community workers will reduce the costs. The number of masons needed and days required to construct the sand dam depend largely on the size and location of the dam.

Table 2: Example of a bill of quantity for labour costs in ETB (2007).

Description	Unit (days p.p.)	Unit cost (ETB)	Total days	Cost per Volume of work (ETB per m^3)	Total cost (ETB)
4 masons	45,8	50	183.3	2.35	**9,165**
10 mason assistant	31	15	312.0	4.00	**4,680**
15 community workers	50	0	750	0	**0**
Total					**13,845**

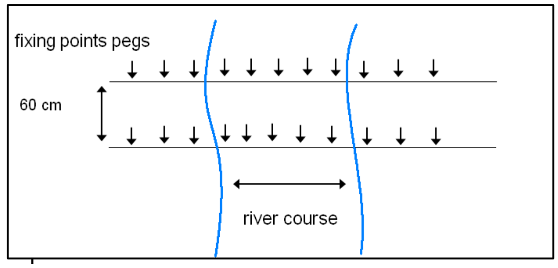
3.2 Excavation

The dam will be fixed on top of the impermeable river bed or placed on compacted soil. To make this possible the riverbed needs to be excavated until it reaches the hard rock. Also for the installation of the wingwalls into the riverbanks, excavation is needed. The total excavation works or "setting the trenche" requires marking the position and the size of the dam, taking in to account the size of the wing walls and required working space during construction.

To estimate the size of the trench, the following should be taken into account:

[2] Refers to collection, preparation and transport of stones and sand that is expected to be covered by community participation. The cost planned is for renting a truck for transportation.

- Measure the appropriate distance from one of the river banks depending on bank characteristics and fix a peg.
- Fix another peg across the river, perpendicular to the river course at the appropriate distance.
- Use a plumb bob and line mark several points from the building line and fix pegs.



igure 12: Setting a trench with pegs.

The marked trench is excavated (often using the hand dug) and guided by the building line (see below photo). The depth of the trench is determined by the depth of impermeable layer in the ground which will obstruct seepage below the sand storage dam. The removed soil should be placed downstream of the building location to avoid filling the aquifer. If the dam is build into bedrock material, a trench should be cut into the rock to ensure secure jointing of the rock and mortar. Care should be taken to make sure no fractures or weathering zones are present in the basement rock. If suspected, this can be tested by pouring water on the suspected weathered zones. If the water leaks away, the rock surface should be cleaned from the weathered rock or fractured rock. If clay forms the impermeable layer, the trench should be dug in for about 0.5 m to avoid seepage. After these conditions are met, the trench is ready for dam setting and construction (Munyao et al, 2004).

Photo 3: People excavating a trench (RAIN, 2007).

3.3 Dam Construction

Construction starts with placing the reinforcement columns vertically in the trench, followed by the construction of the foundation blinding slab. Reinforcement is only required if a very large or high dam is constructed. After this, the second horizontal reinforcement layer is placed, followed by the second foundation blinding slab and finally the actual masonry structure (of hard core and mortar) (Munyao et al, 2004. The construction steps are listed below and described in more detail in **Appendix 8** Construction of the dam follows a number of subsequent steps:

Step 1: Placing reinforcements

Step 2: Making the foundation blinding slab

Step 3: Constructing the first horizontal reinforcement layer

Step 4: Constructing the second foundation blinding slab

Step 5: Masonry comprising hardcore and mortar substructure

Step 6: Installation of templates above the sand level

Step 7: Constructing Masonry hardcore and mortar substructure within two templates

Step 8: Preparation and construction of the stilling basin structure along with the dam body

Step 9: Stilling basin construction with the stone pavement for flood protection

Step 10: Construction for the dam wall

Step 11: Plastering and pointing works

Intensive technical supervision and monitoring the progress are the major activity that should be attained during the construction process of a sand dam.

3.4 Installing Water points + protection

Traditional scoop holes

The most old fashioned and common way to abstract water from riverbeds is by means of a hand dug scoop hole. Water is collected by digging holes in the riverbed and through fetching water "using buckets or alike". The scoop wholes can provide significant amounts of water because recharge occurs through the aquifer. Even though recharge occurs, this method remains very susceptible for pollution, especially in combination with water for livestock. Therefore livestock and humans must have different tapping points. A common practice is the location for human scoop holes, close to the sand dam on the upstream side. The livestock should be given water at the downstream side of the sand storage dam. The distance between the waterholes for domestic use and livestock should be as much as possible.

Photo 4: Women using a scoop hole, Kituï, Kenya (Acacia Water, 2007).

Well with hand- or rope pump

Preferably a well is installed connected to the sand dam with a infiltration gallery. This will protect the water quality because animals and river water cannot contaminate the source. Many different types of wells exist. Most often wells are covered (to prevent contamination, resulting in higher water quality) and a hand pump is used for extraction of water. A maximum of 3 wells should be located on the upstream side and close to the dam embankment: approximately within 3 to 10 metres, since the sand reservoir will be deepest just upstream of the dam (depending on the longitudinal profile as described in paragraph 2.2). Before a well is located in the riverbank, a test drill is needed to check the profile in relation to the permeable layers. Recharge of the well can be established through an infiltration gallery.

Photo 5: Fetching water in Kituï (Acacia Water, 2007).

Box 15 provides practical guidelines to identify potential well locations. Water can be extracted from a well using a motor pump or hand pump. SASOL has been using rope pumps, washer pumps and hand pumps. However, the sustainability of the rope and washer pump might be unrealistic as long as people are not trained in proper operation and maintenance. Hand pumps are therefore recommended.

Box 15: Practical guidelines for locating wells.

The well should be located next to, or close to the dam at locations where the bedrock or impermeable layer is deepest. Experiences in Kenya and Ethiopia show that practical site specific information can be used to locate potential well locations. This includes:

- **Identifying locations of existing scoop holes:** Scoop holes are the best spots for communities' long-term experience to collect water from the river. Based on the locations of scoop holes, wells for a sand dam can be located nearby at either side of the river embankment.
- **Identifying locations near the sand dam where the riverbed material is deep**:A deeper riverbed means more storage. Therefore the best location for a well is up stream of the dam at either sides of the river embankment, at the location with the deepest riverbed for more water storage.

Pipe with tap

An outlet can be installed as a perforated pipe at the bottom of the dam just above the impermeable layer. The pipe should be covered with filter material and a geo-membrane to prevent entry of sand and silt. The main disadvantages of an outlet is that it can weaken the dam structure, making the maintenance complicated and also an expensive option according to some experiences (Understanding the Hydrology of (Kituï) sand dams: Short mission report, November 2005).

Construction of wells

A well for a sand dam is constructed similarly as a shallow hand dug well and usually constructed for exploration of shallow ground water. It is important that the well abstracts the water from the deepest parts of the aquifer which will produce the most safe water (bacteriological - long retention time).The lining of the well should preferably have no openings at shallow depths. It could even be considered just to have an open well-floor, covered by gravel.

If a well is constructed at the centre of a river, it is extremely important to protect it from high floods. The well has to be a 'hydrodynamic' type to withstand the forces of a flood and must be protected from siltation by keeping its height about 0.5 – 1 meter above the surface of the riverbed. The top must be covered with a concrete slab (facing downstream to prevent entry of floodwater) to prevent contamination and mosquito breeding. The detailed construction process for a well and wellhead is given in **Appendix 9**.

To protect the intake from high flood damages, alternatives can be considered. The intake can be constructed in, or close to the riverbank or by an outlet pipe through the dam.

Multiple Use

Another way of looking at water supply is, taking the community's diverse water needs as the starting point for providing services. This is called Multiple-use water services (MUS), which describe a participatory, integrated, and poverty-reduction focused approach. Multiple-use water services move beyond the conventional sectoral barriers of the domestic and productive sectors and provide for all water needs in a community (Mikhail and Yoder, 2008). One of the new challenges is to develop a water source for multiple uses, providing greater accessibility to domestic water and multiplying the benefits of micro irrigation and marketing efforts. In this way sand dams are a more interesting source for generating income. In the next chapter the cost and benefits of sand dams are discussed in detail.

MODULE IV - HOW TO MANAGE AND MONITOR THE DAM?

4.1 Lessons learned

Although every sand dam project has a unique location and context there are common aspects making a project successful. Learning from past experiences can improve and assure better project implementation in the future. In this way implementers will not make the same mistakes and are able to overcome common failures. There are several examples which can be taken into account from the beginning, during and after implementation. Besides examples what went wrong, it is much more interesting to know how these issues were resolved and or prevented. As a result we can actually learn from our mistakes and take corrective actions. The lessons learned can be divided into different steps within the project as indicated in paragraph 1.4. (from site selection up to monitoring and evaluation).

In general it is concluded that for any sand dam project the site selection is the most important critical aspect, which takes place in the preparation phase. As indicated in this manual (paragraph 2.2) it appears important to acquire proper field data and cross sections with longitudinal profiles. Here extra attention (by hiring external experts) is strongly advised to investigate sections of the riverbed. This prevents leakage, meandering and or malfunctioning of the structure in a later stage. It is important to invest in proper siting and to investigate the local area concerning the presence of scoop holes, types of sand in the river bed, boulders, gullies, riverbank characteristics, availability of materials and occurring flood levels. More details about specific lessons learned in detail to improve the siting are given in **Appendix 12.**

For the design several experiences have given insight in the failures, but often the same mistakes are reoccurring as a result of inappropriate adaptation of the design, to the site specific situation. Most attention should be given to the robustness of the structure to peak river discharges and occurrence of erosion damaging the structure. There are several adjustments and improvements for the dam design, which should be taken into account. Also there are guidelines for the optimum location of the wells (see chapter 3.4). In chapter 2.3 the design is already discussed in detail, more lessons learned from site specific experiences are given in **Appendix 12.**

Throughout the steps of the project, the organisation, communication and financial setup, (project-management) turned out to be very important for the efficiency of the overall implementation. Also the support of local authorities is a necessity. It is suggested to provide some of the community leaders appropriate trainings to acquire skills in project management (see paragraph 4.4). Improper management leads to Inefficient progress, disrupting of the implementation and conflicts between the stakeholders. During the construction a common mistake is caused by accidental flood occurrence, disrupting the construction process dramatically. For this reason proper planning and progress monitoring are needed to complete the construction before the rainy season. Another conflict is related to the responsibility of the functioning of the dam, it is suggested to select one party making the design and construction.

Several issues are related to the water quality and water treatment. Problems can be related to the contamination of the actual source (water reservoir) and the water tapping points for human and livestock. Furthermore the monitoring and usage of water acquires proper adequate facilities, management and rules for regulation. It remains vital for the hygiene to separate the water tapping points (see paragraph 3.4). One of the main preventive actions is to prevent infection through avoiding direct contact (contamination by human and or livestock) at the top of the dam. In addition also the surrounding riverbank (runoff which infiltrates in the dam) should be protected. This can be achieved by fencing (and local enforcement using a bylaw), to avoid entrance of the potential polluters to the infiltration area and avoid contaminated runoff from the surrounding area.

After the finalization of the project it remains important to document all relevant information and data. This information can be still useful and remains very important for monitoring and evaluation. A proper technical survey and documentation of the field data and benchmarks should be set to enable future evaluation.

4.2 Operation and Management principles

Community involvement

For the design, construction and implementation and sustainability of sand dam structures, community involvement is essential. The socio-economic inventory directly raises the communities' awareness on the project. Together with the physical en geographical preconditions, also socio-economic aspects such as; existing institutions, rules and habits of the communities, need to be assessed. The beneficiaries need to contribute to the development of sand dams and in return can significantly improve their livelihood and quality of life. For successful implementation the community needs to be involved from the beginning of implementation, to understand the concept and principles of a sand dam and to make it their own. Using the existing social structures and organisational setup can help to mobilise the community. Many types of community organizations mostly already exist within a community depending on their current needs. The community must be involved intensively to establish ownership which has proven to be one of the critical key factors for successful construction and maintenance of sand dams. The benefits of a sand dam are mostly collective but can also remunerate individual needs such as irrigation of specific land plots, watering livestock, brick making etc.. An organization which can meet the interest of the community as well as individuals and who can mobilise the required support from all stakeholders is required to carry out a successful sand dam project.

Photo 6: Beneficiary involvement in Borana, Ethiopia (Acacia Water, 2007).

Management of a sand dam and forming a Water Committee

After productive interaction with the social leaders, a community meeting is initiated together with the project staff, to discuss the possible environmental and social impact of the development of sand dams within the area. The following aspects need to be discussed in the community meeting.

1. Assessment of water problems,
2. Assessment of development issues within the project area,
3. Informing and educating on the various types of water harvesting technologies, in particular the sand dam technology,
4. First and indicative assessment of possible sand dam locations with the community.

In general the community elects a committee from their midst. This so-called water committee consists of a representative group of the community and will take part in several trainings. Hence awareness and involvement in the project processes will be ensured. The water committee will have the following objectives (Munyao et al, 2004):

- Performing a baseline survey on water use within the community,
- Participating in surveys concerning the riverbed resulting in selection of the building location,
- Organising the mobilization of the community for required participation works during the construction process,
- Supervising the implementation, operation and maintenance procedures.

Since the water committee and care takers have been trained and have coordinated community mobilization during implementation, the responsibility of the sand dam will be fully assigned to the water committee and care takers. The water committee will be responsible for the management of the sand dam as well as the payment scheme and the caretakers will be responsible for the daily monitoring, operation and maintenance of the sand dam, wells and surrounding area. The water committee, with support and assistance of the concerned local government departments and the implementing partner, will monitor all activities to ensure sustainability of the project.

The steps in community involvement and its objectives are discussed more in detail in **Appendix 3 .**

Maintenance

The approach on maintenance activities is based on the Kenyan experiences of SASOL. If a sand dam is properly constructed, it only requires limited maintenance. Proper maintenance of a sand dam can be only be assured if the community has acquired ownership and commitment to address issues properly. The following aspect will contribute to establish proper operation and maintenance;

- Good workmanship during the construction of the sand dam.
- Full involvement of the community to ensure operation, management and maintenance after completion of the project.
- Presence of a trained mason near to the sand dam project to ensure adequate repairs if there should be any serious damage to the structure, which is beyond the capacity of the trained caretakers.
- Proper linkage between the local community, local administration and governmental sector to ensure technical and advisory assistances for the community.

If these issues have been addressed maintenance can be kept at a minimum. In **Appendix 8** some guidelines are described for small technical maintenance issues.

4.3 Monitoring & Evaluation

Impact assessment - Water use assessment

A water use assessment is essential to estimate the actual water demand for a community over time. To understand the water demand of a community, the water need for each and every activity has to be investigated. This implicates the amount of water used by people for domestic purposes such as drinking, cooking and cleaning, as well as for agricultural production (using irrigation) or livestock keeping. Apart from the demand there is the actual water supply, (coming from the river) which determines the water availability or shortage over time. This directly reveals one of the main limitations of the sand dam, the total storage volume. Knowing the actual water demand and the water supply provides very important insights, concerning the water availability and expected water needs and or water quality requirements.

A water use assessment has to be executed by the implementing organisation before selecting the locations of the sand dam, to determine whether the sand dam can be used to meet the actual demands. The information which needs to be gathered for this survey includes:

- Number of households within a community;
- Number of adults (males/females) and children (males/females);
- Current water needs for each water requiring activity;
- Future expectation of the water demand

A proper water use assessment needs to reflect the water demand of the whole community. Therefore when executing a water use assessment, the water committee has to elect people from each group of the community (men, women, elder, youth etc) to contribute. This can be a member of the water committee itself as well as other members from the community. Water needs from each group of the community have to be included in the water use assessment.

An example of a water use assessment with a practical questionnaire is given in **Appendix 6** The questionnaire will provide a guideline to determine the water needs of a community. After finalization of the sand dam project (when the sand dam is mature and in full use), a second water use assessment should be carried out. The results of the water use assessment before and after the project can be compared, showing the actual contribution of the sand dam.

Performance monitoring - Water yield

Determining the volume of storage water is not that simple in the case of a sand dam. The total amount of water is not just the water which can be stored in the riverbed. Hoogmoed (2007) and Borst & de Haas (2006) have indicated that the riverbanks play a crucial role in the functioning of a sand storage dam, because of the continuous groundwater flow from the riverbanks to the riverbed. This additional storage capacity also partly compensates the loss of water through leakage, evaporation and abstraction. Therefore, the riverbanks must be included in the calculation of the water yield. A proper estimation can be acquired by using the SAND Dam Infiltration Tool[3] for calculating the volume of water which can be abstracted from the riverbed. A more detailed description of the calculation model and usage is given in the next paragraph**.**

The storage capacity can be only estimated! Sand dams depend largely on local factors, which are difficult to include in any model. Also factors like, irregularities or fractures in the basement, geomorphology of the catchment, rainfall events etc. can have a big influence on the success and yield of a sand storage dam. More information can be found on **www.sanddam.org**

The SAND Dam Infiltration Tool

Sand dams have demonstrated to store river water effectively during river flows and supply water to the local community during dry periods. It is important to be able to quantify the amount of water that a sand dam can supply to a local community to ensure proper site selection, planning and for funding purposes. The storage depends on both sand dam dimensions and many hydrological processes, including water exchange with adjacent river banks. This is complicated by the fact that river banks adjacent to a sand dam often contribute to the retention of superfluous water during the rainy season and consequently supply a sand dam with water during the dry season, providing additional storage. For this reason, designing sand dams is not straightforward, requiring at least some basic insight in their hydrology. To obtain this insight, the 3R Sand Dam Infiltration Tool (SAND-IT) is developed and can be employed for performing some basic hydrological calculations on sand dams. The complete instruction manual for SAND-IT is available on the provided CD-ROM.

SAND-IT utilizes user input and input from publicly-available information and programs to construct a simple hydrogeological model representation of one single sand dam, including adjacent river banks. The model employs Darcy's Equation and standard hydrogeological modeling procedures and assumptions to estimate the amount of water that can be provided by a sand dam, while taking into account specific environmental factors such as evaporation, leakage, and the duration of the rainy season and river flow. The model is constructed in Excel which provides a well-known and easy-to-use interface for the user with a need for basic information and options for more profound data input. Output is displayed in graphs that show the rise and recession of water levels over time and water balance terms of both the sand dam and river banks.

SAND-IT utilizes an array of mathematical equations that together describe the retention of river water by one single dam system, i.e., the rise of water levels during wet periods and the subsequent recession of water levels due to water use, evapotranspiration and leakage. Here, leakage is defined as the loss of stored water by subsurface flow underneath or around the sand dam. The sand dam is modelled as one single bar-shaped reservoir with a user defined length, width and depth. It may include one or two river banks that contribute to the retention of flood water (see Figure 13). Each river bank, the left one and the right one, consists of 5 reservoirs, which are modelled as parallel strips of equal length to, and increasing lateral distance from, the sand dam. Each river bank also has a user-defined depth. The width of each river bank reservoir is auto-calculated by the model, but can be constrained by a user defined width. Each river bank reservoir can exchange water with adjacent river bank reservoirs or the sand dam reservoir through groundwater flow. The two river banks situated at the periphery of the sand dam system (i.e., the 15th left most and right most river bank reservoirs) contain no-flow boundaries, implying that exchange of water with the outside world does not prevail. It is assumed that groundwater levels in the sand dam system are topographically controlled (i.e., groundwater levels are permanently below ground surface level) by surface runoff of access water.

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[3] The SAND Dam Infiltration Tool (SAND-IT) is developed by Acacia Water and KWR in order to make better and more accurate water storage estimations for siting. This tool requires simple input data from the field.

The model is based on several assumptions to simplify the complexity:

- The 3R sand dam infiltration tool calculates the volume of retention water over time by solving mass balance equations in tendem with Darcy's equation for groundwater flow.
- All reservoirs are assumed to be bar shaped, implying that the volume of water stored in a reservoir relates linearly with the water level.
- It is assumed that the sand dam system exclusively receives water by infiltrating river water during periods of river flow, and not by precipitation.
- Leakage is modeled as a permanent fraction of the total volume of water stored in a sand dam reservoir or river bank reservoir.
- The 3R tool assumes potential evapotranspiration across both river banks and a full reduction of evapotranspiration for groundwater levels lower than 1 meter below ground surface.

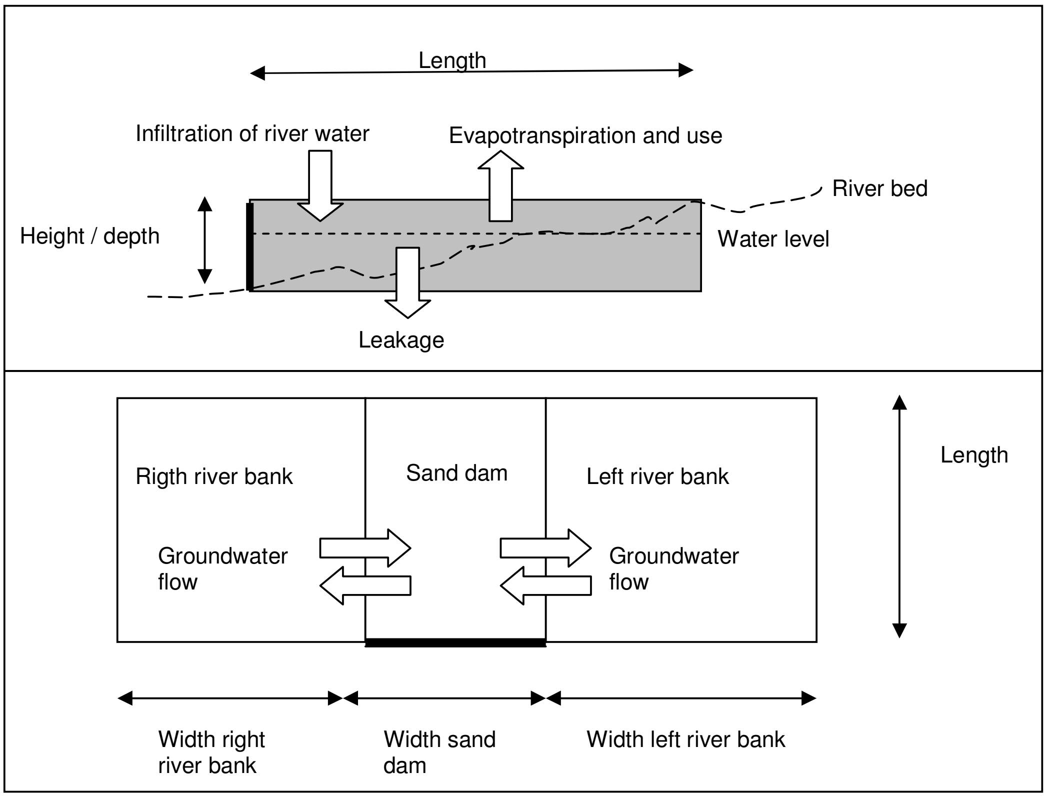

Figure 13: Model schematisation of a sand dam and adjacent river banks. a) Longitudal cross section through a sand dam. b) Cross section through a sand dam and adjacent river banks. (2011,Loon et al)

SAND-IT allows performing some explorative calculations using sand dam dimensions, the type of sediments in the sand dam and river banks and the average duration of river discharge as input variables. By providing more input data to the model, more advanced and reliable hydrological calculations are obtained. Providing permeabilities should preferably be established through slug tests and otherwise by grain size analysis. Hand-on methods for obtaining this information from the field are not included in this manual, but can be provided upon request.

The Excel spreadsheet model is arranged in progressive worksheets that should be consulted by the user in sequence. The first sheets contain a title page and brief introduction before proceeding to numerous pages that contain prompts for various dimensional, parameter or environmental inputs. Following this, a summary sheet of inputs and outputs is provided as well as several worksheets detailing relevant hydrogeological parameters over time such as water demand, gains, losses, storage and hydraulic heads. The model utilizes several large calculation worksheets to automatically perform the necessary model computations on given information and to calculate outputs. Many simplifying assumptions are made to make the model accessible to a broader audience and to cover the lack of high-quality data in remote and ungauged regions (See **Appendix 10**).

Water quality monitoring

Water stored in sand dam is of safe quality when it is protected against pollution. To confirm the reference water quality, the Water Committee should take a water sample from an observation well 50 meter upstream of the dam in the center of the river bed. A first sample has to be taken upon completion of the dam and sampling should be repeated on a yearly basis. The sample should be sent to a nearby laboratory for analysis on major ions (Cl, HCO3, SO4, NO3, K, Na, Fe) and physical parameters : EC and PH. If any changes are observed the water committee should call in the advice of water quality expert.

The main sources of pollution are the excreta from animals which dwell in the river during the dry season or dumping of other material which may cause pollution of the water during run-off and infiltration. The Water Community should take protection measures to avoid pollution of the riverbed:

- Livestock will be kept away from the river bed (100-200 m upstream of the dam
- No other garbage is dumped in the river bed especially during the dry period
- Organize a cleaning action just before the expected onset of the rains

Monitoring the impacts of the dam

One of the important issues in construction of sand dams is the question of its economic valuation. Is the dam cost effective? And is the cost of the dam generating enough benefits to justify the investment?

The cost effectiveness of the dams related to the proper siting, an appropriate design (no-over dimensioning,) and proper construction and supervision to avoid failures and delays.

The second question is important for funding agencies, to know that that their investment in the dams has a positive return through the benefits it provides. A widely used methodology to answer this question is the Cost Benefit Analyses (CBA). A CBA is an economic tool for evaluating the costs and benefits of an investment, thereby taking into account the total impact of a project on society as a whole and is also widely applied in the water sector. The CBA is considered a sound financial and economic analysis and can also be applied for sand dams. This has been done recently by Acacia (Acacia Water, 2010) and can be used as reference for CBA analysis of future dams. The CBA report is available on the provided CD-Rom.

Cost of dam

This is the easiest part of the equation. The cost elements of a dam are well known and proper documentation of the estimated cost and the real cost (after construction completion) should be an integrated part of the construction process. Table 3 gives a full list of the cost components as a checklist for calculating the cost of the dam.

Table 3: Generic list of 3R cost

Item	Item	Note
Capital expenditure	Preparation/quick scan	Consultant cost
	Siting and design	Consultant cost
	Construction	Degree of community participation
	Overhead profit	
Additional cost	Land acquisition	If needed these items may represent substantial cost
	Power supply	
	Legal cost	Fees
Social and environmental cost	EIA/SEA x)	Consultant cost
	Mitigation	Mitigation cost
Operating expenditures	Energy	Annual cost (US$/yr)
	Monitoring	
Maintenance	Maintenance of the structure	Annual cost (US$/yr)
Others		May include indirect cost

x) EIA: Environmental Impacts Assessment; SEA: Social Impacts Assessment

Benefits

The benefits are more diverse and include both direct and non-direct benefits (Table 4). Direct benefits are mainly the increased productivity, resulting in an increase of the family income. Indirect benefits such as improved health also contribute to the increase of income, but may also have other impacts (such as family cohesion and community well fare) that are more difficult to valuate.

Table 4: Generic list of benefits

Benefit	Item	Valuation
Reduced cost of water	Applicable if the cost of water before the 3R intervention was higher (e.g. tank car supply, bottled water)	Can be expressed in US$/yr
Increased household productivity	Economic benefits due to long term availability of more and better quality water which is used for crop growing, livestock watering or household industries	Benefits can be measured by increased production etc but will also be expressed in the increase in the (average) family income
Household/human well fare	Improved health, improved education, less time needed for water fetching, improved social cohesion and security	These benefits will partly be included in the increased family income and partly be indirect or long term benefits
Community, Government and Water shed benefits	Improved biodiversity Vegetation Drought resilience Reduction of subsidies Economic development	Indirect benefits for the **community** (economic development) or for the (regional) **government** (reduction of subsidies, drought resilience) and for the **water shed** (vegetation, biodiversity, reduced fertilizer use))

The benefits in table 5 refer to these benefits that are attributed to the construction of the dam. In terms of data collection this requires:

- A set of data prior to the construction of the dam
- A set of data of a location where no dam is constructed.

Annex gives checklist for the type of data that have to be collected by the Water Committee to allow for an economic evaluation of the dam after completion (yearly till 5 years after construction). The table below shows an example of the measured benefits of a sand dam in measured in Kitui, Kenya

Table 5: Summary of measured benefits (Lasage et all, 2008)

Indicator		Kindu (dam)		Koma (no dam)	
		1995	2005	1995	2005
Access to drinking water wet season	Km	1	1	1	1
Access to drinking water dry season	Km	3	1	4	4
Domestic water use	l/day	61	91	136	117
People exposed to drought	Nos	420	0	600	600
Health		0	+	0	0
Households with irrigated crops	%	37	68	38	38
Agricultural water cons.	l/day	220	440	160	110
Brick and basket production	Ksh/yr	1,500	4,500	0	0
Household incomes	Khs/yr	15,000	24,000	15,000	15,000
Vegetation density /biodiversity		O	+	O	O/-

1000 Khs = 14 USD; O: unchanged, +: slightly improved, - : slightly deteriorated

For a CBA, the cost and benefits have to be quantified. This is difficult for existing dams. New dams give the opportunity to incorporate a number of activities in the design and construction phase and after the completion of the dam. The economic evaluation itself can be carried out by a person who has experience in CBA application.

4.4 Sand dam management training

Training of local community

Based on the experiences of successful sand dam projects, the following aspects need to be addressed to carry out a community based sand dam project successfully. This included community trainings on implementation, operation, management and maintenance with the following objectives:

- Full participation in the process of the project planning and implementation;
- Enhanced awareness on project management;
- Ensured technical and management skills after project completion;
- Enhanced awareness on management of the water quality and risks involved.

This can be divided into three categories (based on the pilot sand dam project in Ethiopia):

- Sessions on the project planning, implementation and management of activities.
- Educational sessions on natural resources management, sanitation and hygiene;
- Technical trainings on operation, management and maintenance for the water committee.

During the training several educational sessions and workshops are given based on carefully selected questions to initiate group discussions. To make the training a successful contribution, at least each community elects five to seven members from the water committee and at least two other community members (future caretakers) for participating.

Sessions on the project planning, implementation and management activities

The lessons learned clearly indicate that in several cases a lack of proper project management led to several constrains during project implementation. One solution would be to focus on contingency planning with all relevant stakeholders for preparing project documents and programs in order to take care of possible cost escalations and implementation timeframes.

The following aspect should be addressed within this project management training;

- Proper planning of the construction – sufficient time available between the construction period and the anticipated starting period of the rainy season in the local area. (taking into account workers availability – migration)
- Acquiring skills with estimating and managing the project budget including a risk assessment
- Project monitoring and evaluation
- Giving importance to networking (to maintain contact with decision makers)

Educational sessions on natural resources management, sanitation and hygiene

These educational sessions will be facilitated by a qualified person from the implementing organisation, preferably in cooperation with a representative from the concerning local government department. During these sessions, representatives of the water committee are educated on several subjects to ensure awareness and understanding of natural resources management, sanitation and hygiene. Natural resources management will mainly focus on the proper and efficient management and usage of the sand dam. These sessions will take 5 days in total and are organised within the community (Munyao et al, 2004).

Box 16: Natural Resource Management training
This training aims to facilitate ways and means of management of natural resources. With the help of a questionnaire, the community gathers the necessary information about their available natural resources and explores ways and means of utilizing their natural resources to improve their livelihoods. By the end of the training, each community has developed a comprehensive list of the natural resources found in their villages. They compile the potential ways and means of using these resources in an action plan.

In the absence of hygienic water practices, attempts to ensure high water quality will be futile. Safe rainwater can be easily contaminated after extraction from the system, for example by the use of contaminated jerry cans or by contamination present on the hands of users. Therefore, hygiene education and monitoring of the operation and maintenance of the system, along with sanitary practices, are essential. Creating awareness on personal and system hygiene issues related to water is crucial. Local health organizations play an important role in educating consumers on water treatment methods, managing water supplies and giving specific guidance in managing, operating and maintaining RWH systems. Water supplies, sanitation facilities and hygiene behaviour work together as an integrated package: the quality of the approach in all components determines the outcome (Hygiene Promotion, Thematic Overview Paper 1, 2005).

Box 17: Hygiene training
This training focuses on creating awareness within the community on contamination risks of their water sources and giving guidelines for hygienic and practical guidelines on water usage. This training is based on the RAIN Water Quality Policy and on national and regional policies and programmes. At least one third of the local community is expected to participate, especially women since they are mainly responsible for collecting water, cleaning, washing and cooking: activities which have high risks of contamination.

Technical training on operation, maintenance and management

The water committee is responsible for proper operation, management and maintenance of the sand dam, which includes:

- Regular monitoring of the functioning and utilization of the sand dam; Workshop SAND Dam Infiltration Toolbox (SAND-IT), Appendix 10.
- Effective management of the water reservoir as far as possible.
- Establishing a demand driven payment scheme;

Two persons from the water committee or two community members will be trained on construction of the sand dam and wells by participating during construction. Technical knowledge and skills to execute maintenance and repair works is hereby ensured. These trained community members can become potential artisans for the construction of future sand dams within the area. They will become the caretakers of the sand dam, the wells and the surrounding area.

Box 18: Management training
The first step in the project management training workshop involves: the examination of the community experiences in their projects over the last five-year period, covering; Succesfull and unsuccessful projects and the reasons for success or failure. At the end of this analysis, the participants can draw lessons from experiences obtained in finalized projects, understanding the needs of the community and defining solutions themselves. This training will take several days and are organised within the community.

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Available Data Sources: for Quick scan
Digital elevation data of the Shuttle Radar Topography Mission (SRTM) can be freely downloaded from the internet, The data has a low resolution; 90 meter horizontal.
http://www.cgiar-csi.org/data/elevation/item/45-srtm-90m-digital-elevation-database-v41

Aster satellite images can be downloaded from http://asterweb.jpl.nasa.gov

Tropical Rainfall Measuring Mission (TRMM) satellite images, contain rainfall data with a spatial resolution of 4.3 km (In the region between 35°N and 35°S). Data is available on the internet on monthly basis http://neo.sci.gsfc.nasa.gov/Search.html

The geology of Kenya and Ethiopia is available from USGS. This map is part of the open file report 97-470A, version 2.0 2002, scale of 1:5,000,000. The dataset is an interim product of the U.S. Geological Survey's World Energy Project (WEP) and can be freely downloaded from the internet.

The New_LocClim program from the United Nations Food and Agriculture Organization (FAO) can be utilized in order to assist with the rainfall-runoff calculations, data on precipitation, evaporation and Runoff. New_LocClim is a freely available and easy-to-use spatial interpolator for agro-climatic data. It uses the FAO's Agromet database which contains climatic data from over 30000 stations all across the world. The New_LocClim program accesses this dataset and can provide the required information on average precipitation, evaporation, and runoff. The download set (which allows access to the Agromet database) can be downloaded http://www.fao.org/NR/climpag/pub/en3_051002_en.asp
LocClim also provides rainfall data (Freely available) http://www.fao.org/sd/2002/EN1203a_en.html

Appendix 1 Case studies from Ethiopia and Kenya

Sand storage dams to improve rural livelihoods in Kituï District, Kenya

The SASOL (Sahelian Solutions) Foundation started constructing sand storage dams in the Kituï District of Kenya in 1995. Since this period, over 500 sand storage dams have been constructed. The dams vary in size and dimensions because of differences in the geomorphology and the river flow. On average the Kituï dams are between 2-4 metres in height and around 20 metres in length.

The main advantage of the Kituï dams is that they use simple low cost technology and can be constructed by local communities using locally-available materials. The cost of an average sand storage dam, with a minimum life span of 50 years and storage of at least 2.000 m^3, is about US$ 7.500. About 40% of overall construction cost is provided by the community. They are involved in the construction of sand storage dams by provision of labour and collection of raw materials, by so called sand dam management groups. After construction, these groups have ownership and take care of the maintenance of the dams and protection of the water quality, which ensures sustainability.

Box 19: Quick facts Kituï region:

Area:	20.400 km^2
Population density:	25 persons / km^2
Climate:	semi arid (precipitation: 250-750 mm/year falling in two wet seasons, open water evaporation 2000 mm / year)
Geology:	Metamorphic and igneous basement covered with weathered rock
Soils:	Silty and clayey sediments, low fertility. In the western part black cotton soils.

Sand dams are build to improve the local water availability throughout the year, but next to this, there are several significant social and economic impacts as shown in Table 1. The main objective of a sand dam is securing drinking water for local communities and for domestic use, also it can provide water for development of rural commercial activities; such as small scale irrigation (cash crops and tree nurseries), and industrial activities (brick making). Besides improving the water availability it can save time, since less time is needed to fetch water (see table 1). In this way school attendance increases significantly and more time can be spent on other income generating activities, like household industries (basket weaving, sewing). Often sand dams are built in sequence, in this way the water table increases over a larger area. This can contribute to ecological regeneration throughout the catchment.

Table 6**:** Measured social and economic impacts of sand dams in the Kituï region, Kenya (after Thomas, 1999).

Vulnerability Categories	*Vulnerability indicators*	*Before dam construction*	*After dam construction*
Agriculture	# of cash crops	1.5	3
	% irrigated crops	37	68
Special aspects	Water collection Domestic (minutes)	140	90
	Water collection Life Stock (minutes)	110	50
Gender	Average walking distance women to water (km)	3	1
Economic	Income (US$./year)	230	350
Health	% households suffering from malnutrition	32	0

There are several examples of subsurface dams in Kituï that are already operating for 25 years or more, and which are still fully operational. Sand dams require little maintenance which is the responsibility of the dam committee. The committee should be trained to perform evaluations and report this to SASOL.

The catchment approach: an example project of combining water harvesting techniques in the Borana Region, southern Ethiopia

The Borana Zone is located in southern Ethiopia, it is a semi-arid area in which rural communities depend mostly on livestock farming (mostly pastoralists) and small-scale agriculture. Both activities are highly constrained by severe water shortage due to erratic rainfall and droughts. The spatial en temporal water scarcity remains, since the ephemeral rivers follow the precipitation and the water is not stored or retained.

The communities in the Borana zone live in very remote areas, with poor or without access to water, electricity and or sanitation facilities. Children in this region have the lowest school enrolment rate in the country, also because substantial amounts of time is spend in collecting water.

Water harvesting technology establishes a decentralised water source in areas, whereas other means of water supply have little potential. Here the sand dam technology provides a solution for the people of Borana. Rooftop water harvesting is not effective, because of the thatched roofs and limited storage (only provide sufficient water for the dry period) and the lack of good quality water.

Photo 7: Sand dam site after first flood event in Borana, Ethiopia (ERHA, 2008).

Photo 8**:** Woman fetching water from a surface runoff tank in Borana, Ethiopia (RAIN, 2007).

Communities are already known with the phenomenon of collecting water from ephemeral river beds. However the sand dam technology itself is not very common in Ethiopia. The combination of infrastructure to recharge groundwater and to harvest surface runoff water is innovative.

In 2007, RAIN, ERHA, AFD, Acacia and SASOL started an award winning pilot project of training 10 NGOs throughout the country along with implementation of 6 sand dams and 7 surface runoff tanks in Borana. It provided drinking water and water for irrigation and or industrial use in the short- and long-term for communities, living both adjacent to an ephemeral watershed (by sand dams) and those further away (by rainwater harvesting tanks) (see figure1). The project increased access to a reliable source of water for at least 10 communities and gave incentives for further up-scaling in other parts of the country.

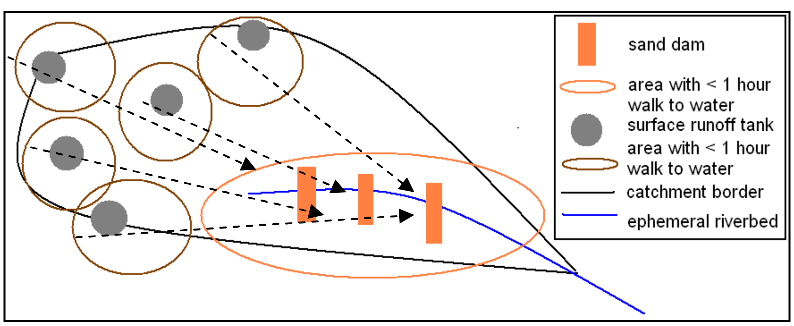


Figure 14**:** Hypothetical example of catchment approach in rainwater harvesting: combining sand dams and rainwater harvesting tanks in one (sub)catchment.

Appendix 2: Checklist for first and detailed technical site selection

Criteria for first site selection:	***compulsory***	***optional***
A stony catchment area (source of sand) and sandy riverbeds	x	
A sandy riverbed	x	
Two high and strong riverbanks	x	
A maximum width of 25 metre	x	
No fractured rocks or large boulders	x	
No salty rocks	x	
Presence of water-indicating vegetation		x
Presence of waterhole		x
Presence of riverbed crossings		x
Type of community structures within in the area, possible conflicts etc.	x	
Type, suitability and availability of construction material	x	

Steps for detailed site selection:	***compulsory***
Measuring the water extraction rate of potential riverbed(s) section(s)	x
Making a plan of the potential riverbed(s) section(s) with information on the river length and width, locations of cross-sectional and longitudinal profiles, water-indicating trees and waterholes	x
Making a longitudinal profile of the potential riverbed(s) section(s) by probing (see attachment 2)	x
Making cross-sectional profiles of the potential riverbed(s) section(s) by probing (see attachment 2)	x
Selecting different points in the riverbed section in which the sand is the deepest (potential reservoirs) and in which the natural underground dykes are most shallow (potential sand dams locations)	x
Selecting the point where the sand is the deepest and therefore the largest reservoir can be selected	x
Selecting the point where the underground dyke is most shallow and therefore the location of the sand dam	x
Making a cross-sectional profile of the potential sand dam location	x

Generally, sites feasible for sand dam construction have the following features;

- Having scoop wells with good quality of water
- Having no big boulders on the bed of the river
- Slope of the river bed not more than 5%
- Having an impermeable or bed rock layer at shallow depth
- Coarse sand on the bed with less silt content
- Stable and high enough river banks
- Maximum flood level below top of banks
- Straight reach with narrow width (<25m)
- Un-weathered bank and bed formations free from downstream directed stratification
- Local construction materials available at nearby areas
- Free from sources of contamination and salinity
- Accessible and close to majority of the beneficiaries
- Sites free from conflicts related to land rights and water usage

Appendix 3: Checklist for river section inspection and ranking

1. Location and types of water-indicating vegetation.

A good indicator for the presence for groundwater is current vegetation. Depending on the species, the groundwater depth and storage of water can be estimated. In the table below some names of trees are given which indicate water at a given depth below the surface.

Botanical name	Kiswahili and Kikamba names	GW-Level
Cyperus Rotundus	Kiindiu	3 – 7
Vangueria Tomentosa	Muiru Kikomoa	5 – 10
Delonix Elata	Mwangi	5 – 10
Grewia	Itiliku Itiliku	7 – 10
Markhamia hildebranditi	Muu Chyoo	8 – 15
Hyphaene Thebacia	Kikoko Ilala	9 – 15
Borassus Flabellierfer	Mvumo Kyatha	9 – 15
Ficus Walkefieldii	Mombu	9 – 15
Ficus natalensis	Muumo Muumo	9 – 15
Ficus malatocapra (Vista)	Mkuyu Mukuyu	9 – 20
Gelia aethiopica	Mvungunya Muatini	9 – 20
Piptadenia hildebranditi	Mganga Mukami	9 – 20
Acacia seyal	Mgunga Munini	9 – 20

Figure 15: Water-indicating vegetation with root depth.

2. Location of waterholes, their depth to the water table and quality of the water.

The presence of waterholes (especially after the rainy season) is an indication that the riverbed contains deep water storage and it does not leak to deeper groundwater rapidly. Especially attention is needed to those waterholes, which provide water over a long time, during the dry season. Here it is important to specify the depth of the water table in relation to the riverbed surface.

The water quality in the waterhole is an indication of the quality of water which can be harvested after building a sand dam. However, the water quality can improve significantly by taking protective measures against animals. (Improvements can be achieved, see: RAIN water quality guidelines).

3. Location and types of rocks and boulders.

If large boulders are present in the riverbed, special care should be taken in choosing the sand dam location. Preferably the sand dam is build on (and its wings attached or projected into hard rock or a consolidated and strong soil. If a large boulder is confused with massive rock, water can leak from the sand dam reservoir, leading to unnecessary loss and potential undermining of the sand dam. Check whether hard rock is present in the riverbanks and – bed by looking for rock outcrops (conducting probing test at different points using metal rods and hammer).

Pay special attention to the presence of halite near the riverbed, which is a salty whitish substance, that turns water saline. If salty rocks (white and pink mineral rocks) are situated in the riverbanks upstream of a dam, then the water may be saline and therefore only useful for livestock. Local communities often know if there are any salty rocks, because livestock consumes these rocks for the salt content.

Photo 9: Examples of salty rocks

Seepage under the dam may occur, if the riverbed itself contains large stones and boulders. When large boulders are observed downstream of the potential dam site,(as the chance of apron damage, even the spill way could be higher from the rolling builders by flood), special care should be taken, since this could damage the structure (rather look for alternative sites or consider a subsurface dam). Soil data can provide information on the location of sandy areas within a catchment (see next point 4).

4. Grain size of the sand (coarseness), particles in the riverbed.

The grain sizes which are present in the riverbed are a good indication of the material which will fill up the sand dam reservoir after construction. Coarse sand is preferred, since it has a higher infiltration capacity and water can be abstracted more easily.

5. **Shape and dimension of the riverbanks.**

Suitable riverbeds for sand dam consist out of high riverbanks. During flood events the river should not flow over the riverbanks, because this can cause erosion of the riverbanks, flooding of downstream located villages and it might cause the river to change its course. By using flood data and information from local water departments and local knowledge of the community, the maximum water height during a flood event can be estimated and determined. The minimal height of the riverbanks should be: *Minimum height riverbanks = Height of dam + Flood height + max. 10% (safety height)*

6. **A (preferred) maximum width of 25 meter.**

Preferably, riverbed width should not exceed 25 metres. The reinforcement required to construct such kind of long dam walls is too expensive; hence the sand dam will not be cost-effective. The choice for technology is also depending on the peak floods and the width of the river (over a maximum width of 25 metres subsurface dams seem more appropriate, (Nissen Peterson, 2006)) Other alternatives, such as subsurface dams, should be considered instead.

7. **An impermeable (bedrock)layer.**

To ensure storage of water within the sand dam aquifer, losses through leakage to deeper groundwater should be minimised. Therefore, the dam should be built on solid bedrock or an impermeable layer. This will also protect the sand dam from undermining through groundwater flow underneath the sand dam. This can be checked by using the geological map and outcrops in the area. Also, holes can be dug in the riverbed to find the depth of a consolidated layer or bedrock layer.

8. **Type, suitability and availability of construction material.**

The construction materials which are locally available (such as sand (water), rock outcrops, bricks, etc.) can help to determine the most cost-effective type of sand dam for construction. For example, a masonry dam is not a good choice when stones are not locally available in the area (Transporting the stones from other areas is very expensive).

9. **Presence of riverbed crossings and roads.**

Rural roads often cross riverbeds. Preferably a sand dam is located near these crossings and can be easily reached through existing roads (also for transportation and supply of materials).

10. **Names of houses, schools and shops near the riverbed.**

The local people benefit from the sand dam, direct or indirectly. By measuring these positive social impacts before and after implementation, the actual social impact can be determined. An assessment of the actual water use (before and after implementation can show how the community is benefiting from increased water availability, (indicate positive economic development or spin off).

11. **Land rights.**

Agreements based on rules and regulations (or bylaws) are needed to assure fair use and access to water for collective and individual usage. How to share and distribute the water are important issues to arrange properly, in order to realise fair access and usage. The allocation of water has to be arranged within the communities together with the farmers and pastoralist. To avoid conflicts, special care should be taken in areas where the dam site is owned or used by two or more villages or several individuals.

Appendix 4: Steps for community involvement during site selection.

Step 1: Creating awareness and sensitizing the community.

Starting a sand dam project in a catchment potentially suitable for implementation begins with sensitizing the community's awareness on the project, by undertaking regular visits to the project area and facilitating meetings with the representatives and members of community. All communication shall be carried out with respect to the existing institutions, rules and habits of the community.

Step 2: Community assessment and performing a water use assessment.

The best-suited sites identified during step 1 are visited and a dialogue with the community is held. During this meeting, the project staff and community discuss the possible environmental and social impact of the development of sand dam within the area. The following information needs to be gathered.

- Assessing the water problems of the targeted communities. During a plenary discussion problems and possible solution should be discussed by the community. Ownership, number of beneficiaries and their participation and involvement, timing of construction are discussed.
- Organising meetings or group dialoguing concerning the development issues within the project area. Project staff, community members including influential persons, local administrators, politicians, elders (both men and women), youth leaders and any other development agencies within the area should participate in these meetings.
- Informing and educating the community members on the various types of water harvesting technologies, in particular the sand dam technology. Advantages, disadvantages, feasibility, site selection criteria, the construction process and the level of community participation will be discussed.
- Assessing possible sand dam locations with the community. The community will be involved in site selection based on their local knowledge of the area. The selected sites should be discussed with local authorities.

Step 3: Establishing a water committee.

The water committee will need to be established, and its responsibilities will need to be defined in a binding document like a Memorandum of Understanding (MoU) between the water committee and the implementing partner. Each sand dam will have a water committee containing a maximum of nine members. At least 50 % of the committee members are selected from women representatives. Two members from the committee selected as care taker and will be responsible for operation and maintenance of the sand dam. Its duties are to mobilize resources, plan the site works, record progress, supervise and monitor the implementation process amongst else. The committee must on weekly basis monitor and evaluate the progress. On the part of the implementing partner, the MoU states:

- to supply all construction materials if not locally available;
- to supply in skilled labour;
- to provide technical supervision

Furthermore, the water committee and implementing partner will have to draw a Community Action Plan (CAP), containing an implementation schedule until completion. This is documented in a tabular format defining all the activities and responsibilities. It clearly defines the roles of each partner within the project i.e. the community and implementing organization.
The action plan will contain the following issues:

- Bill of Quantities for the material and labour in which the community will supply during the project.
- A work plan in which a clear and realistic time frame is given.
- Security of storage of materials and supervision on site.

On the part of the implementing partner, the MoU states:

- to supply all construction materials if not locally available;
- to supply in skilled labour;
- to provide technical supervision

Step 4: Organising community mobilization for required participation works during the construction process.

At the start of the construction process, the following activities are should be undertaken:

- The actual movement of resources like transportation of equipment and tools to the site,
- Involvement of skilled and unskilled labour. Elderly at the head of community committee are in charge of mobilizing community members because of their respected position and accepted authority in the community.
- The implementing partner will provide a representative at the grassroots' level; he/she will coordinate all activities. He/she advises elderly on community mobilization and participation.

Appendix 5: Data collection for the selected river section

The tools required for simple surveys as follows (Nissen-Petersen, E. 2006):

- Measuring rods made of 16 mm (5/8") iron rods for measuring depths of sand. Notches should be cut in the probing rods for every 25 cm to collect sand samples when the rods are pulled up.
- A circular levelling tool made of a transparent hosepipe for measuring the gradients of riverbeds.
- Two long tape measures, one hanging down vertically from the horizontal one, to measure width and depth of riverbeds.
- A tripod ladder for hammering long probing rods into the sand.
- A mason hammer.
- A 20 litres jerry can with water.
- Half a dozen of transparent plastic bottles with water.
- A knife and writing materials,
- A Data Sheet as shown below.

Example of a Data Sheet:

Measurement nr.	*Distance between measurements (m)*	*Width of riverbed (m)*	*Depth to water (m from surface)*	*Depth of the sand (m from surface)*	*Type of sand*	*Type of bedrock or soil under the sand*	*Height of the riverbank (m)*		*Items seen on the riverbanks*
							Left	Right	
1	0	20.8	-	0.5	Medium	Clay	1.5	1.9	Acacia tree
2	20	24.2	-	0.6	Fine	Clay	1.0	1.6	
3	20	28.2	-	0.7	Medium	Clay	1.4	1.84	Waterhole
4	20	25.5	0.30	1.25	Medium	Rock	1.3	1.7	
5	20	19.5	-	0.8	Coarse	Rock	1.4	1.65	Fig tree
6	20	21.3	-	0.7	Coarse	Clay	1.4	1.7	
7	20	18.6	0.8	1	Medium	Clay	1.97	1.55	
8	20	17	1.2	1.3	Coarse	Clay	1.3	1.64	Rock

Appendix 6: Questionnaire water use assessment

GENERAL						INTERVIEWER / NGO				INTERVIEWEE					
Date	Country	District	Village	GPS Longitude	GPS Latitude	Name Interviewer	Email and telephone nr.	NGO	Name employee NGO	Name	Gender	Age	Marital status	Main income generating activity	Other income generating activity

HOUSEHOLD (number of people living)					COMMUNITY					PERSON(S) FETCHING WATER in HOUSEHOLD				
Girls (0 - 15)	Boys (0- 15)	Men (>15)	Women (>15)	Total	Girls (0 - 15)	Boys (0- 15)	Men (>15)	Women (>15)	Total	Girls (0 - 15)	Boys (0- 15)	Men (>15)	Women (>15)	Total

DRY SEASON									
Main water source	Distance (km)	Time one way (hours)	Use for drinking?	Treatment method	**Other water source**	Distance (km)	Time one way (hours)	Use for drinking?	Treatment method

RAINY SEASON									
Main water source	Distance (km)	Time one way (hours)	Use for drinking?	Treament method	**Other water source**	Distance (km)	Time one way (hours)	Use for drinking?	Treatment method

WATER USE DRY SEASON (average litres per person per day)									WATER USE RAINY SEASON (average litres per person per day)								
No. of months	drinking	cooking	shower	washing	livestock	agriculture	other	Total	**No. of months**	drinking	cooking	shower	washing	livestock	agriculture	other	Total

Appendix 7: Calculating the quantities of materials

I. Concrete

Mix Ratio – 1 : a : b

Where: 1 = cement proportion : a = sand proportion : b = coarse aggregate proportion

If the amount of concrete needed is C, then:

Cement Quantity (kg) = 1 * C * 1400 * 1.3 * 1.05/(1+a+b)

Sand Quantity (m3) = a * C* 1.3 * 1.15/(1+a+b)

Gravel Quantity (m3) = b * C * 1.3 * 1.15/(1+a+b)

II. Stone Masonry

For water tight structures usually 65% of masonry body is proposed to be stone and 35% cement mortar. So, if the volume of stone masonry work is S, then

Volume of Stone (m^3) = 0.65 * S * 1.3

Volume of Mortar, M (m^3) = 0.35 * S

If mix ratio of mortar is 1: C,

Cement Quantity (kg) = 1 * M * 1400 * 1.2 * 1.05/(1+C)

Sand Quantity (m3) = C * M * 1.2 * 1.15/(1+C)

III. Plastering

Follow the same formula used for mortar ingredients of stone masonry.

IV. Pointing

Pointing area is taken as 1/3 of plastering area and then follows the same way used for plastering.

V. Water

Water required for mixing, curing, washing dirty construction faces, workers construction and food preparation is roughly calculated from the total cement requirement of the site.

If Z Quintals of cement is required to complete the construction work,

Total volume of water = 280 * Z

Appendix 8: Guideline for sand dam construction & maintenance

Step 1: Placing reinforcements
These are placed vertically across the entire length of the dam at an interval of 2.5m. They are round bars with a diameter of 12.5 mm and the length depending on the complete height of the dam. The amount necessary can be determined as follows:

No of columns = $\frac{Ld}{2} - 1$
With L_d : length of the dam in metres.

For example: iIf L_d =10, Then No of columns = $\frac{10}{2} - 1 = 4$

Mark the positions of the columns along the building line, then measure the vertical depths to the bottom of the trench and record them as follows.

No 1 =2.53m, No 2=2.27m, No 3 = 3.05m, No 4 = 1.97m

The round bars of the columns are firmly grouted into holes on 5cm deep that have been cut into the foundation at the requested depth (depending on the bedrock material or soil type).

Step 2: Making the foundation blinding slab
A layer of cement mortar (1:3) is prepared on the foundation to the depth of 5cm. When there is no foundation rock the vertical iron bars are placed in the mortar layer.

Step 3: Constructing the first horizontal reinforcement layer
After the mortar layer 12 strands of barbed wire are evenly divided over the building slab along the dam.

Step 4: Constructing the second foundation blinding slab
The barbed wire is covered by 5cm of foundation blinding slab.

Step 5: Masonry comprising hardcore and mortar substructure
After the foundation blinding slab sets and holds the columns firmly, the foundation trench is filled with masonry comprising clean hardcore and mortar (1:4). Mortar for filling should have more water. The joints between the rocks are filled 25mm of this mortar. The rocks should be tapped well to settle completely into all voids. When the filling reaches the level of the back flow, the construction of the backflow should be done along side that of the wall as shown. Masonry comprising is extended to the wind wells.

Step 6: Installation of templates above the sand level
The two templates made of timber are erected at the ends of the spillway for giving the outline of the dam wall, spillway and wing wall. Nylon strings have to be drawn tightly from the inner corners of the templates to pegs hammered into the soil next to the upper end of the wing walls. In this way, the position of the outer sides of the masonry wall can be determined.

Step 7: Constructing Masonry hardcore and mortar substructure within two templates
Flat stones have to set in cement mortar 1:4 along the inner lines of the strings. The next day, the space between the flat stones has to be filled with mortar, 1:4, into which round rubble stones were compacted. After that the flat stones were mortared onto the wing walls so that they could be filled with mortar and stones the following day.

Step 8: Preparation and construction of the stilling basin structure along with the dam body
The base of the dam wall, the spill-over apron and the spillway,(the latter being situated between the two templates), were only raised to 30 cm above the original sand level in the riverbed. A small flooding deposited a 20 cm layer of coarse sand that reached the first stage of the spillway. The

spillway was therefore raised another 100 cm above the sand level, for the next stage of the spillway. The wing walls construction is executed at a time while extending each stage of the dam height construction.

Step 9: Stilling basin construction with the stone pavement for flood protection at the bank of the river

Large boulders were concreted into the spill-over apron, to reduce the velocity (speed) and speed of surplus water falling over the spillway and wing walls. Stone pavement were placed as a unit part of the stilling basin and extended at either side of the riverbank to downstream of the flood flow.

Step 10: Construction for the dam wall

The next flooding deposited coarse sand up to the level of the spillway. The spillway was raised another 30 cm above the new sand level. The process of raising a spillway in stages of 30 cm height, may be completed in one rainy season provided the required number flooding occurs and builders are ready for their work without delay.

Step 11: Plastering and pointing works

Exposed dam section at the upstream side, top surface of the entire dam and wing wall section are plastered with cement mortar of ration 1:3. The upstream section of the dam well plastered to be watertight. Downstream-exposed section of the dam wall and the stone pavements extended from the stilling basin were pointed with cement mortar mix ratio of 1:3.

Guideline for sand dam maintenance

Repairing cracks and weak points in the dam

Sand dams require careful maintenance, and immediate repair, as flooding causes hundreds of tons of water to fall over the dam wall and onto the spill-over apron. Flood water may also spill over and erode the wing walls and, perhaps, even over the riverbanks during heavy rains. Extreme changes in temperature can cause the structure crack. If any cracks or weak points are observed in the sand dam, a technical engineer and mason should inspect the whole dam structure and execute repair works before the following rainy season.

Cleaning the well

The well should be covered and closed at all times. Regular checking of the water content is not recommended, since debris or human faeces could fall in the well and contaminate the water. If an animal, chemicals or other health-risk related substances have polluted the well, using the water for drinking purposes is strictly prohibited. The well should be inspected by an expert on water quality and a action plan should be made. If contamination is suspected which can be removed by simple and local water quality measures, then these should always be applied before use of the water.

Cleaning of the outlet

It is very important that the outlet isn't blocked with silt of other fine textured material. It is therefore important to have a good access to the outlet construction. Blocking of the outlet can be prevented by the designing criteria . Regular cleaning of the riverbed just upstream of the sand dam after a flood can prevent silt from percolating downwards into the riverbed and blocking the outlet. If contamination of the water is suspected which can be removed by simple and local water quality measures, then these should always be applied before use of the water.

Removing silt from the top of riverbed of the reservoir

The riverbed (especially just upstream of the sand dam) and the surrounding area of a sand dam have to be kept as clean as possible: rocks, branches, leaves, dead animals, animal dropping and fine textured material should be removed since they can lead to contamination of the water, reduce the capacity of the dam, lead to blocking of the reservoir and outlet or cause damage to the dam structure. Debris like rocks, branches, leaves and sediment are usually deposited after a flood event, so the time of inspecting is well known. But dead animals, animal dropping and other debris can be deposited any time. It is wise to have a strict schedule for inspection of the dam and its surroundings.

Appendix 9: Guideline for well construction

Based on (Nissen-Petersen E, 2006)

Step 1: Excavation.

- Select the site and clear the area for excavation
- Mark out a circle of 1-metre radius.
- Dig the well using skilled man power as the well should be excavated straight for the diameter of 2 metres.
- Excavation of well continues until a depth at which sufficient water from the lowest water level of the sand storage can be extracted. Well digging is normally carried out in the dry season when the water table is lowest.
- While the digging process is ongoing, local construction materials such as sand, stones and preparation of crashed stone will be executed simultaneously.

Step 2: Construction of concrete ring and blocks.

Preparation of concrete ring. This ring will have an outside radius of 75 cm and inside radius of 55 cm. The width of the ring is 20 cm and the thickness is 25 cm. The ring is made in a circular trench carefully dug to the correct dimensions. A concrete of mix of cement, sand and crashed stone (1:3:4) is used and six round of 3 mm galvanized wire are used to provide reinforcement of the ring. Additionally, 16 vertical pieces of wire 60cm long are attached to the reinforcing for fixing rope when lowering the ring in to the shaft. The ring is kept wet for seven days to cure the concrete.
The concrete blocks are made in specially fabricated mould with curved sides. The block is 15cm high, 10cm wide and 50 cm long. The concrete mix is the same as for the ring. The blocks are placed on a plastic sheet and kept wet for seven days for curing.

Step 3: Construction of the well cover.

The well's cover is made with a diameter of 150 cm and thickness of 10 cm; it has a hole of 60 cm in diameter in the middle. This will be used for drawing water. An additional smaller hole, 10cm in diameter, is made to one side as outlet hole to allow an exchange of fresh air. The cover is cast in an excavation in the ground. The same concrete mix is used as before together with 8 rounds wire connected by 31 shorter pieces of reinforcement.
The well lid to cover the centre hole is made in a similar manner with barbed wire reinforcement of 50 mm thickness. Two handles of round bars should be made for lifting.

Step 4: Construction of the well shaft.

The well ring is lowered using ropes if sufficient depth of the well has been reached.
The con is lowered using ropes with the help of at least 15 men because of the weight. The concrete blocks are lowered one by one in a bucket. A cement and sand mortar mix (1-3) is used for the vertical joints and between the ring and the first course.

In the horizontal joints between the first and second course and the second and third course, no matter is used so that water can gain entry. One round 3-mm galvanized wire is used with mortar between the third and fourth course and a step made from a round iron bar is installed. The same sequence continues until there are six horizontal joints without mortar through which water can enter. All subsequent joints are mortared. Steps are installed every three courses. After every six courses, the surrounding space in the well shaft is filled with coarse sand to act as a filter.

The shaft is built till 60 cm above ground level to prevent surface runoff from entering the well. Barbed wire is left sticking out to joint with the reinforcement in the apron that will be constructed around the well shaft to keep the area clean and prevent contamination.

The apron extends around the well shaft and slopes outward to a distance of 1.2 metres. This area is first excavated and then back-filled with hardcore to a depth of 30cm, to which is added a 5-cm layer of ballast. A 5-cm layer of concrete (1:3:4, cement:sand:ballast) is laid on the surface, and barbed wire is placed concentrically and radially for reinforcing. A further 5 cm of concrete covers the reinforcing.

The apron is surrounded by al low wall with a gap to allow spilt water to drain away. Building two steps complete the work, each 30 cm high, to the well cover, plastering as necessary and placing the lid in position. Before the well can be used, the community must remove all the water and clean the bottom.

Appendix 10: Working with SAND Dam Infiltration Tool: Water storage

The worksheets have color-coded tabs according to purpose; sheets requiring input are with green tabs, sheets where output is presented are with blue tabs and one sheet where large amounts of calculations are performed with a dark grey tab. The user should give input data only in the green tabbed input sheets at the given prompts. Instructions for data input are provided in the next section. The Basic Input and Results sheet displays two boxes: the "Main Input Variables"-box and the "Preliminary Results"-box. In the "Main Input Variables"-box, some elementary input for the sand dam and the river banks needs to be entered.

Main Input Variables box:
This box consists of five boxes that are reserved for input for successively (1) the sand dam, (2) the right river bank, (3) the left river bank, (4) some environmental variables and (5) output control. Below, the input fields of each of these boxes are briefly described.

In the sand dam box, the dimensions of the sand dam need to be specified (*height, length, width and area*), as well as the *sediment type* and *leakage factor*. The most appropriate sediment type should be selected from the drop-down list. The selected sediment type is used to auto-calculate the permeability and main extractable porosity of the sand dam's sediments using Table 2. If available, an empirically established extractable porosity can also be entered in this box. This will override the auto-calculated porosity.

Leakage factors, defined as the percentage loss in the reservoir over a day, represent losses through the dam and through the material underlying the reservoir. The leakage factor strongly influences the available water from the dam system, but is particularly difficult to establish by field surveys. Leakage factors are therefore often used as calibration parameters. Note that a leakage factor of 0 % will be used if not specified differently.

The right river bank and left river bank boxes provide the opportunity to specify the geohydrological features of either river banks. Firstly, *sediment types* need to be selected from drop down lists for each river bank. The *permeability* can be overridden in the "Additional river bank data input"-sheet (see below). Optionally, values for *the depth of the impermeable substrate* (m below dam crest), the *maximum width of the river bank*, and a leakage factor can be entered. If not specified, depths and

leakage factors are set equal to that specified for the sand dam and the maximum width of the river bank is auto-calculated. It is advised to enter a maximum river bank width, because auto-calculated river bank widths can become unrealistically large. (If river banks are not expected to contribute to the retention of river water, a very small width of e.g. 0.001 m should be entered.)

In the "Environmental variables"-box, values for the expected duration of *river discharge (days)*, *evapotranspiration (mm/d)* and *water demand (m3/d)* need to be specified. The expected duration of river discharge is used to (1) auto-calculate the width of each river bank based on a tidal attenuation equation, and (2) calculate recharge of the sand bank by river water, assuming that the sand bank is completely flooded during periods of river flow. The characteristics of both river discharge and water demand can be further specified in one of the following sheets. The evaporation input is considered to be the total potential evaporation and estimates can be obtained from FAO's New_LocClim program. No evaporation is assumed to occur if the water table is below an extinction depth of 1m below the surface.

Finally, the user is provided the option to set the *length of time steps* in the "Output control"-box. By choosing a relatively large time step, calculation time can be substantially reduced.

The Preliminary Results box
The right hand side of the Basic Input and Results Sheet (columns G-M) provides some of the results of the calculations performed by the 3R tool. These results include an estimation of the Volume-water level relation, the rise and recession of groundwater levels in the sand dam in response to river water infiltration, and water balances over a one year period, including the error in the calculated water balance.

Optional Sand Dam Data Input

This sheet provides the opportunity to provide the 3R-tool with additional data collected from the field, once the sand dam is operational, i.e., the sand dam is filled with sediments. The sheet contains input fields for three types of data, namely (1) experimentally established permeabilities of the sediments in the sand dam, (2) porosities of the sediments in the sand dam, and (3) depths throughout the sand dam.

Permeability

In the "Override kdam"-box, one can specify the *permeability of the sediments* in the sand dam. Preferably, the permeability is established by performing multiple slug tests. If no slug test data is available, one may enter permeabilities derived from grain size determinations. Instructions about both methods can be found in the 3R documentation A maximum number of 5 experimentally established permeabilities can be entered. If more than 5 values are available, one may enter an average value.

Porosity

In the "Sedimentology"-box, one can specify *main-extractable porosities* of the sediments in the sand dam for up to three zones. These zones represent horizontal layers composed of distinctly different sediments. In the absence of multiple layers, one may leave the lower input fields empty.

Depths

In the "sand dam depths"-box, one can *specify observed depths* of the sand dam. These depths are used to calculate the V-h relation more accurately, but they are not used as input of the equations that describe the water level rise and recessions over time. The user should specify whether depths have been gathered randomly throughout the sand dam, or by means of a transect study.

Infiltration input to dam

This sheet allows the user to enter times when *infiltration* into the sand dam system is occurring. Infiltration into the sand dam is the only system input considered by the model, no surface runoff from the banks or direct rainfall is assumed to occur. To govern infiltration into the sand dam, a constant value of infiltration over a surface area is used whenever surface water ponding or flow is observed. The user can define multiple times when this occurs and also, the amount of total dam surface area undergoing infiltration can be input. The constant rate of infiltration is considered to be $0.25*k_{dam}$ of the sediments in the dam as recommended as a general rule by Bouwer (1978). The flexibility in infiltration duration and intensity can be used to reflect longer and shorter wet seasons of varying intensity.

Water use

SAND-IT assumes that water is only abstracted from the sand dam, and not from the river plains. The *volume of water demand* needs to be specified in the Water Demand Sheet. The user may either specify a permanent water demand or a temporally varying water demand. In the latter case, both abstraction rates and their timing need to be specified.

Optional river bank data input

In the Optional River Bank Data Input Sheet, more detailed information about the sedimentology of both river banks can be entered. The user may prompt up to 5 *permeabilities and porosities*, which are used to override the values auto-calculated by the model using the specified sediment type in the "Basic input and preliminary results sheet". If more than five empirically established values are available, the user may enter average values. Note that permeabilities should preferably be established through slug tests and otherwise by grain size analysis.

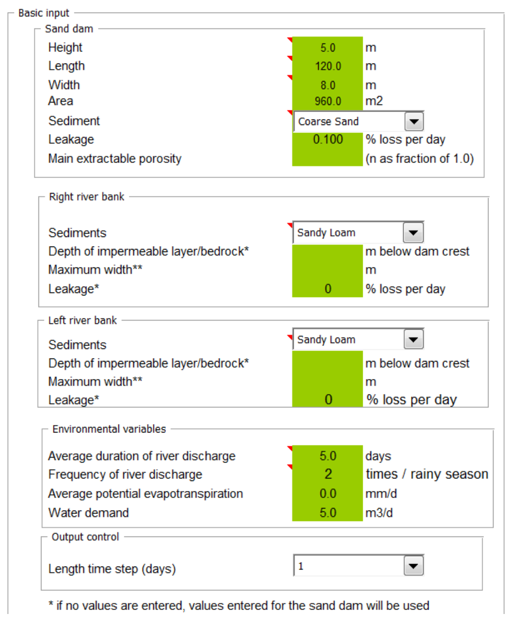
The complete instruction manual for SAND-IT is available on the provided CD-ROM.

Appendix 11: Case Study using SAND-IT

The Model SAND-IT allow users to simulate the hydrological process of a sand dam at a specific site location using simple local input. The actual water storage over time can be calculation according to the local situation. In this way the functioning of the sand dam is better understood and improvements of the design can be initiated. To have an idea how the model works a sand dam “Ougele” in the Borena Region in South Ethopia is used as a case study. Information (input from the field) which was not available is estimated. The model run is calculated for one year.

Input: In the field the following data has been collected and or estimated;

- Dimensions of the dam;
- Sediments are Based on Soil profile/Slug test of the dam (Coarse sand) and the riverbanks (Sandy-loam)
- Estimations of the riverflow (days and infiltration covering area)
- Wateruse > roughly estimated

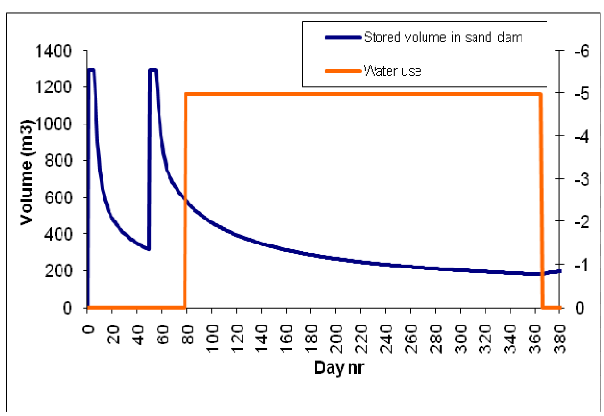


In the simulation we have assumed to have little losses in the dam and no losses in the riverbank. Furthermore we have assumed to have two rainfall events of 5 days with 100% infiltration with and interval of 50 days. The waterdemand is estimated at 5 m^3 per day from day 80 up to 365.

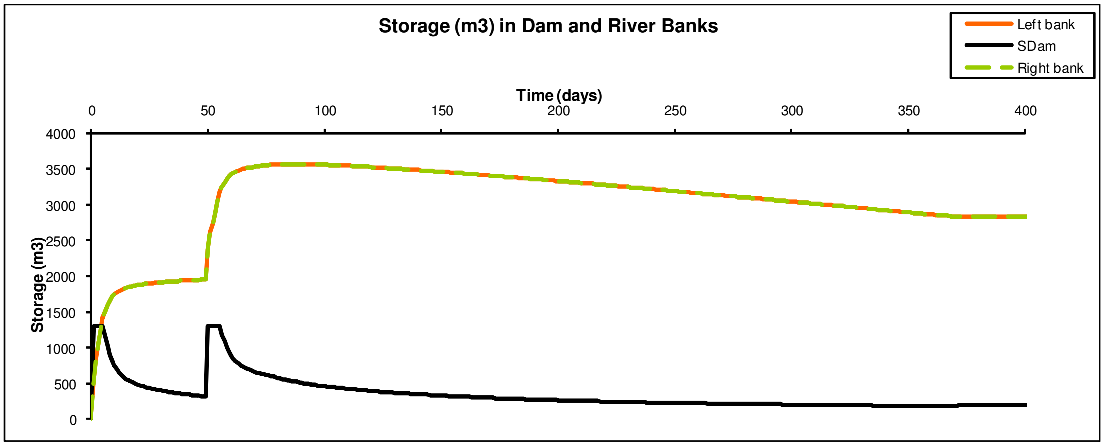
Water balance of sand bank (m3)		
Gains	Recharge	7014
	From right bank	647
	From left bank	647
Losses	Use	-1430
	Leakage	-211
	Right bank	-3037
	Left bank	-3037
	ET	0
Volume	Start	0
	End	215
Balance error (%)		2

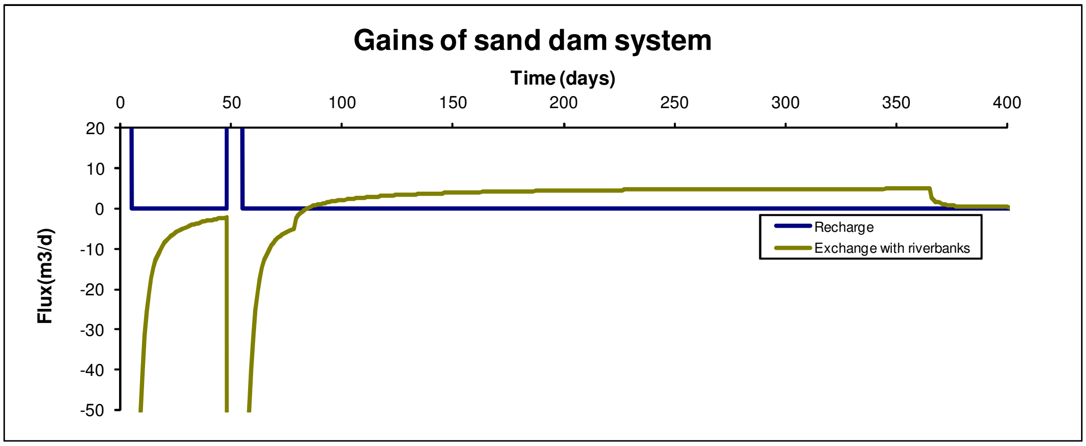
Output: The model provides simple output and more sophisticated output. The model is finished after the calculation on the right side of the preliminary results gives fixed figures. These figures show the complete water balance of the dam and the riverbanks with the leakage, evapotranspiration and the water use. We can see that in total more than 7000m3 water is stored in the total system and 1300m^3 are gained from the riverbanks! More than 3000m^3 is stored in the riverbanks but also water has been supplied through the riverbanks *doubling* the water storage of the sand dam capacity! Futhermore almost 1500 m3 are used by the local people and only 215m^3 is lossed. Evapotranspiration is not considered since the water is stored mostly deeper than 1 m (also in the riverbanks).

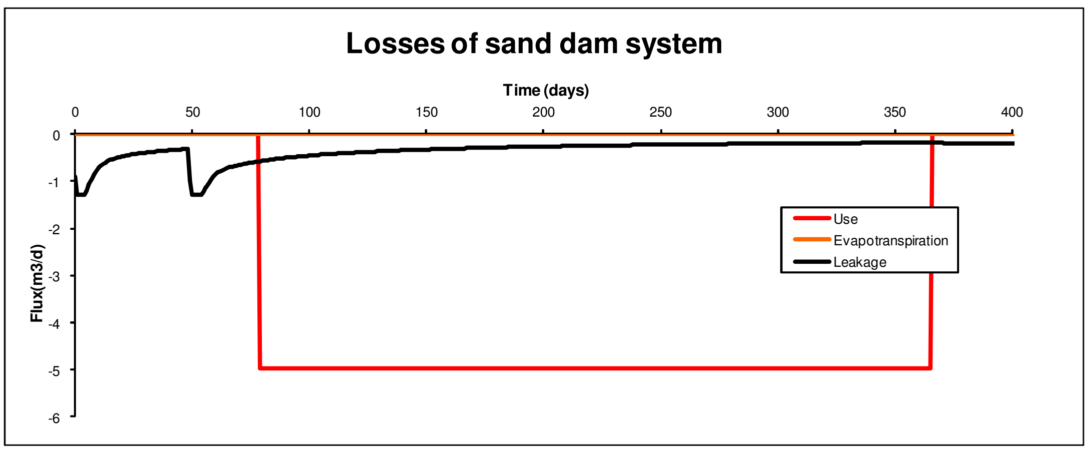
The graph shows that recharge is taking place and when water is exchanged to the riverbanks decreasing the storage in the dam. After the second rainfall event, the dam is again completely filled and provides again water to the riverbanks. When the wateruse starts the amount of water storage decreases. At the end we see that the water storage is increasing, through water supply from the riverbanks. If the waterlevel in the dam is lower (due to either wateruse or leakage) more water is supplied from the riverbanks! On the next page you can see more sophisticated results, try to explain yourself!



This sheet displays three graphs of output for the entire sand dam system: (1) Storage in sand dam and River Banks, (2) Gains of the entire sand dam system, and (3) losses of the entire sand dam system







Changing the values of the variables gives insight in the actual hydrological processes and shows the sensitivity of the total sand dam system. The model clearly shows the benefits of the riverbanks and the effects of leakages and or evapotranspiration. Also the model gives the possibility to use more detailed information providing more accurate results. Until now it does not use any rainfall data apart from including the riverflow events in amount of days. Only for a catchment analysis (estimating riverdischarges and water availability) actual rainfall information in the catchment is considered important. Therefore in this model the infiltration with additional rainfall on top of the sand dam and riverbank is not included. Also it doesn't neglect evapotranspiration below 1 m depth in the riverbanks, because trees and vegetation will use significant amounts of water.

Appendix 12: Specific Lessons learned

General recommendations

- Site selection when building sand dams is of critical importance
- It is very important to involve the community during the whole process.
- Find or collect information on rainfall amount in the areas where dams are to be built in order to estimate the peak runoff for safe design of the sand dams, spillway and stilling basin.
- Maturity of dams can be measured in different ways: dam full of sand, ground water table stabilized. Choose the most appropriate and have the relevant documentation available so that it can be used to judge the preconditions for evaluation and monitoring.
- Every sand dam design should be specific to catchment and channel hydraulic considerations and not replicated to another site without pretesting on the same.
- A proper technical survey and documentation of the field data and benchmarks should be set to enable future evaluation.

Siting

- Areas where scoop wells are found are good indications for constructing productive sand dams.The presence of scoop holes is an indication that people are accustomed to use the water from the riverbed.
- Conduct proper investigation on the soil characteristics in channels to establish the right length of the wing walls. Test pits in the river bed be dug prior to trenching to establish the depth and type of the basement. Grouting with cement slurry may deem necessary at the foundation to make it water tight.
- Gullies can be an important source of silt. If gullies are present upstream of the dam, check dams should be constructed or flow should be diverted to limit silt supply during the sedimentation stage of the dam.
- Boulders. Look for large boulders being present so that the sand dam is indeed build onto rock instead of boulder. Also, it is an indication whether a gabion might be needed to protect the sand dam.

Design and construction

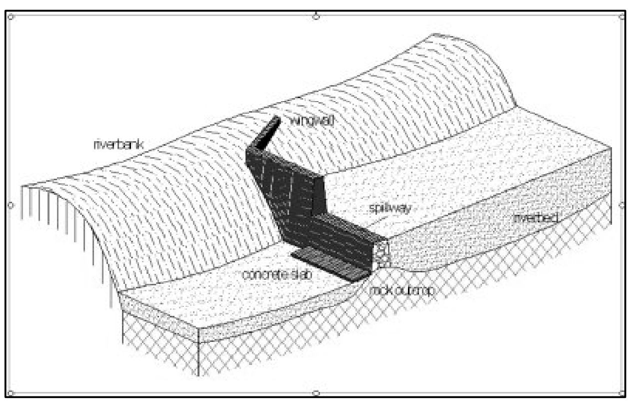
- Implementing organisations build structures according to own design and the implementing organisations should be responsible for repair if the structures are damaged directly after finishing construction.
- The appearance of so called piping (conduction underneath the dam exceeding a certain critical value of the soil) is re-mediated by founding the dam on an impervious floor to increase the path of percolation hence reducing the exit gradient.The appearance of so called rupture of floor due to uplift, occurs if the weight of the floor is insufficient to resist the uplift pressure, the floor may burst and the effective length of the impervious layer reduced. The remedy is the construction of a back slab (protective slab) of appropriate thickness at various points. This should be evident in the design where the thickness of the dam wall is not uniform.
- The quality and length of the wing walls determine the lifespan of the sand dam. Do not save money by shortening the length of the wing walls!
- The well should be located between 0.5 and 3 meter upstream of the dam. An infiltration gallery can be constructed to maximize water flow from the riverbed to the well. The well should be located where its save from erosion.
- The well should not be deeper than the basement layer of the dam.
- The functioning of the well should be checked after construction and the community should be trained to repair. The NGO should check regularly whether the pump still functions. A chain and lock should be put to prevent the pump from misuse.

RAIN

Rainwater Harvesting
Implementation Network

A practical guide to sand dam implementation

Water supply through local structures as adaptation to climate change



An updated guideline initially based on the Swiss Re 2007 award winning pilot project "Water harvesting to improve livelihoods in southern Ethiopia: from pilots to mainstream" and large-scale implementation of sand dams in Kenya and Ethiopia.

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This sand dam manual is based on a previous version 'Sand dam implementation guidelines' prepared as documentation material for training purposes. This publication is made possible by a financial contribution of the Rain Foundation and input from Acacia Water. Other contributions are from the University of Amsterdam and Ethiopian NGO's, AFD, ERHA, HCS, who have extensive experience in the matter.

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PREFACE

This manual is prepared for NGO's involved in water management and water harvesting, and more specifically working on sand dams. Experiences from Kenya and Ethiopia show that the implementation of a sand dam is much more than just implementing a structure. The most critical steps of the whole process from planning and construction to operation, maintenance and monitoring are dealt with in this manual.

The manual starts from a river-basin and sub-catchment scale and zooms in for implementation at the local level. By showing clear boxes and illustrations the process of data collection and field surveys is briefly described. Next to explaining the technical aspects it also focuses on the involvement of the community and understanding the context. Critical success factors such as proper siting and good operation and maintenance are discussed more in detail.

It is recommended to follow an on the job training dealing with the topics described in this manual to have a better understanding of sand dams. The information and examples provided are gathered from experiences but not necessarily applicable to your specific situation. Therefore it is very important - in case of uncertainty - to ask for input from an expert in the matter. If you have any questions or if you want to organize or participate in a training and or workshops please contact the Rain Foundation.

To keep this manual practical, attachments have been added in which further information is given like checklists, design (including water storage) and calculation tools . Also a CD-ROM has been provided with more information and tools.

TABLE OF CONTENT

List of Annexes

MODULE I - WHY THIS MANUAL?

1.1 Introduction: Waterbuffer on 3R

Managing the water buffer is the concept to assess the water storage needs and opportunities on the (sub)basin level with the objective to provide cost effective means to assure water availability throughout the year for rural livelihoods. It deals with building infrastructure and/or modifying the landscape to intentionally Recharge water for storage in tanks, in the ground or in ponds and Retain it there for Re-use during periods of deficit. These three R's (recharge, retention and reuse) are the pillars for management of the water buffer at scale with the purpose to make it available when needed. 3R can be applied in dry or humid areas with long periods of low (erratic) rainfall and create a perennial source of water for drinking (WASH), domestic use, subsistence agriculture and rural industry. The 3R concept (Box 1) is described in the booklet Managing the Water Buffer for Development and Climate Change Adaptation (ed. Van Steenbergen and Tuinhof, 2009) - 3R website (www.bebuffered.com).

Box 1: Managing the water buffer
Managing the water buffer at scale is an initiative to upscale local (rain)water harvesting and groundwater storage solutions through a systematic integration of the water buffer function in (sub) basin water management. The philosophy is to manage this buffer function through three subsequent steps – Recharge, Retention and Reuse. There are a large number of possible (technical) solutions to achieve this of which managed aquifer recharge (MAR) is an important component. 3R covers the broader process planning to retain and intercept the rainfall and runoff, store it underground or in tanks at appropriate places and plan for its re-use during the dry periods. 3R follows the IWRM principle but adds an implementation and financing dimension to it: 3R puts IWRM into practice and responds to needs expressed by the South to assure access to water a reality throughout the year.

The 3R concept is a systematic way to assess the water buffer needs, identify the technical (recharge, retention and reuse) options, select the most appropriate and cost effective solution and plan for its construction, operation and maintenance. It brings recharge, storage of water reuse into a broader framework of planning and management and to promote its application on a larger scale as an integrated part of the water management in watersheds and river basins (Figure 1).

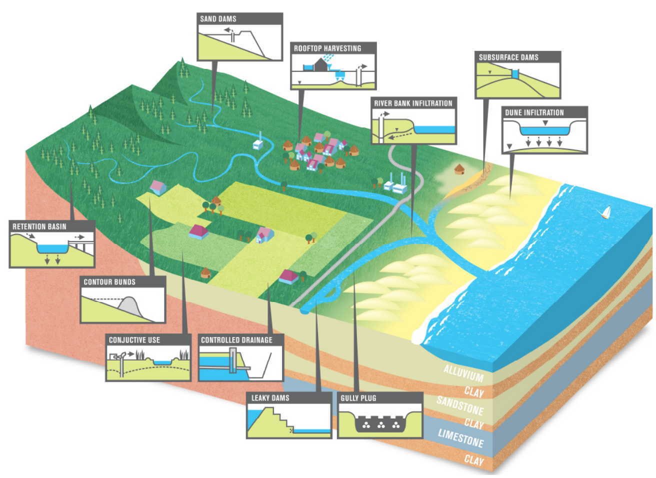


Figure 1: Info-graphic 3R concept

3R leads to the selection of technically and hydrological appropriate interventions to recharge store and re-use excess water for use during dry periods. Recharge and storage facilities may include rainwater harvesting, groundwater based storage (also known as Managed Aquifer Recharge) and surface water storage in ponds and reservoirs (see Figure 2). The 3R approach leads to investment in measures which often concerns known (proven local)technologies and solutions which are up scaled to provide a permanent source of water on the river (sub)basin scale (Steenbergen ea., 2009), but may also include new technologies and innovations which are proven in other regions, hence encouraging South-South cooperation. 3R measures may range from household interventions (such as roof top rainwater harvesting) to larger units which serve a number of households or a community (e.g. sand dams, surface water reservoirs).

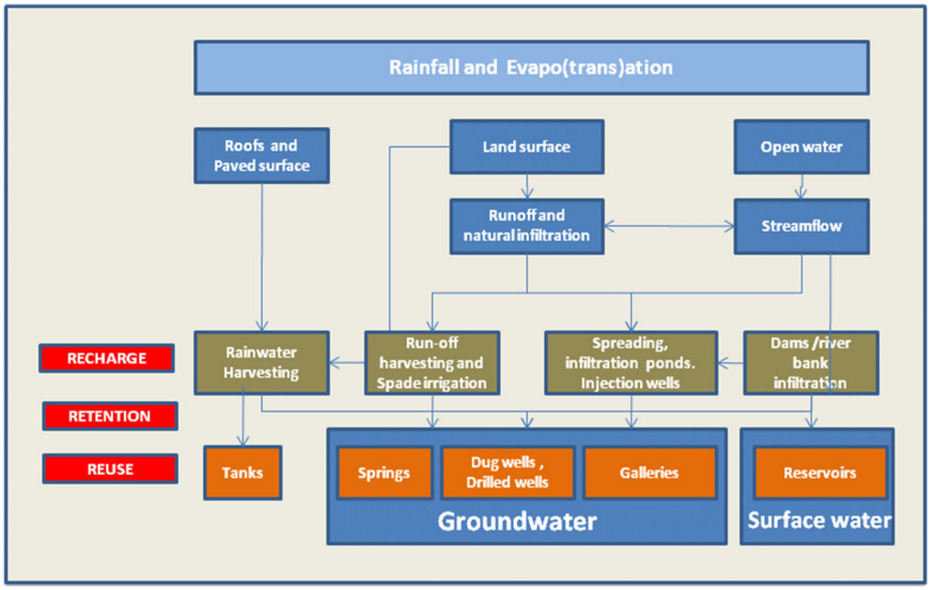


Figure 2: Overview of 3R options

1.2 Sand dams management broad overview

Sand dams in the 3R context

Sand dams are an important 3R technology in the water buffer management approach. The concept of sand storage dams is already known for decennia and there numerous examples of sand dams construct in many countries such as India, Zimbabwe, Burkina Faso, Ethiopia and Kenya. These are mostly isolated initiatives under which only a few dams were constructed in a village by a local NGO or by a group of farmers to enhance their water supply. Being focused on solving local problems, although very useful has generally not been an incentive to share the experience and knowledge for purposes of scaling up..

In the last 10 years there has been a growing recognition of the added value of sand dams as a low cost and robust means to enhance water availability also in areas that are affected by the negative effects of climate change. Initiatives have been taken to upscale the application of sand dams construction and to introduce them in areas where the physical environment is suitable for this construction. Two good examples are the case studies in Kenya and Ethiopia in **Appendix 1**.

The Rain Foundation (with support of Acacia Water) has taken the initiative to introduce the up scaling of sand dams in their program and has trained their partner organizations in the countries. The case study in **Appendix 1** concerning Ethiopia is one of the outcomes of that initiative. This training course brings together the collective knowledge and experience in the sand dam siting, design and construction that has been developed over the last years by several partners in different countries .

Sand dams: basic principles

A sand storage dam (or sand dam) is a small dam which is build on and into the riverbed of a seasonal sand river[1]. The functioning of a sand dam is based on the sedimentation process of coarse sand which is stored behind the structure. In this way the natural storage capacity of the riverbed aquifer is enlarged. The aquifer fills with water during the wet season, resulting from surface runoff and groundwater within the catchment. The riverbed is also recharged through the groundwater flow which is obstructed by the sand storage dam, creating additional groundwater storage for the community.

[1] Dry and sandy riverbeds are seasonal water courses that transport runoff-water from catchment areas into rivers or swamps once or a few times in a year. Dry riverbeds are also called ephemeral streambeds, seasonal water courses or sand rivers. Most of the rainwater being transported downstream in riverbeds appears as high flood events that can be up to several metres high. Sand rivers are only suitable for sand dams when coarse sands are available and also the river must be underlain by impervious bedrock (or clays like black cotton soil).

Photo 1**:** Typical sand storage dam during the dry season (Borst & de Haas, 2006)

During the dry season, water levels will drop due to abstraction of water, evaporation and possibly by leakage through the dam or vertical percolation into the bedrock. At the same time recharge of the riverbed aquifer takes place though subsurface flow (base flow) from the riverbanks towards the riverbed and through the riverbed itself. Mainly because of the large storage volume and the retention of water in sand, the sand dam can provide water throughout the dry season (when built under appropriate conditions), whereas otherwise the riverbed would have dried up. This allows the community to have access to water throughout the dry season.

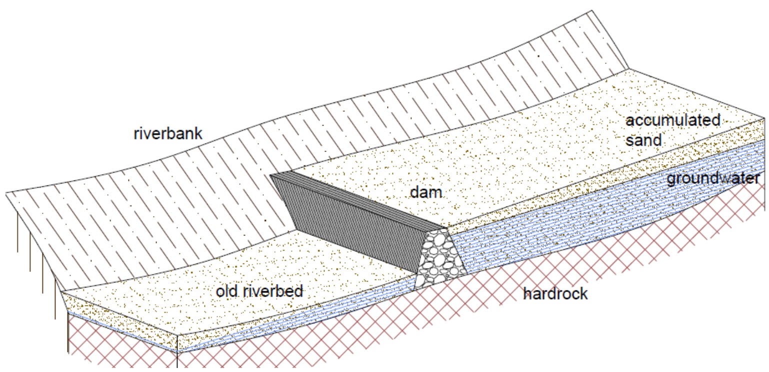


Figure 3: Schematic cross section of a typical sand storage dam (Borst & de Haas, 2006)

The volume of water available for abstraction is considerably larger than just the volume present in the riverbed sands. This is because a large quantity of the water is additionally stored in the riverbanks, recharging the sand dam reservoir in the dry season (Borst & de Haas, 2006; Hoogmoed, 2007).

Sand dams effectively increase the volume of groundwater for extraction as well as prolonging the period in which groundwater is available. Also other methods are available, Box 2 compares the sand dam with a surface water dam.

Box 2: Advantages of a sand dam compared to surface water dams.

Sand storage dams have several important advantages over surface water dams, resulting in a higher water quality and improved environmental conditions.

- Less evaporation (water storage in sand)
- Less contamination with sand (not direct contact of water with livestock and other animals)
- Better infiltration (water flowing through the riverbed of sand, disinfection or filtration)
- No more breeding of mosquitoes (unsuitable for malaria and other insects)
- Low cost structures (build by community)
- Proper maintenance (using local materials which can be maintained by community)
- Longterm sustainability (High community involvement and commitment)

1.3 Functions of a sand dam and types of sand dams

The primary function of a sand dam is increasing the water availability by storing water in the riverbed and -banks. Sand dams obstruct the groundwater flow through the riverbed, resulting in a (continuous replenishment of the) enlarged groundwater reservoir upstream of the dam. Depending on the porosity of the sand water is stored in the spaces (voids), which can hold up to 35 percent of the volume of sand. Besides this, sand dams can have other functions and positive side effects such as:

Recharge of regional groundwater: A cascade of sand dams along a river course will increase groundwater levels in a larger area. This positively effects the environment (vegetation) in the surrounding of the dam.

Rehabilitating of gullies and sand harvesting: Sand dams can rehabilitate eroded gullies. If a sand storage dam is built for this purpose, the dam doesn't have to be impermeable. The sand behind the dam can be harvested for sale. Usage of plastic bags filled with soil is more profitable for this purpose (Nissen-Petersen, 2006).

Photo 2: Sand dam in Kituï (Gijsbertsen, 2006).

Sand storage dams can be classified according to their construction material as indicated in Box 3 (Negassi et al., 2002):

Box 3: Classification Sand Dams:

- **Stone-masonry dam:** A dam built with concrete blocks or stones. This type of dam can be constructed by local artisan. This type of dam is relatively expensive to construct and it requires special skill for its design and construction. A stone-masonry dam is durable and suitable for higher dams.
- **Reinforced concrete dam:** A dam consisting of a thin wall made of reinforced concrete. It is a durable structure, relatively expensive but suitable for any dam height.
- **Earth dam:** A dam consisting of impermeable soil material (mostly clay or clayey soils, or black soils). Although earth dams are most cost-effective, they cannot store large quantities of water which makes them less suitable. An earth dam can easily be damaged and even destroyed by underground flow. Earth dams are not popular and are seldom used (only for minor works).

1.4 Road map for sand dam implementation

After understanding the purpose and functioning of the sand dam, we continue with a step-wise approach in how to implement a sand dam. In the following chapters these will be discussed separately. The following steps (see Box 4) for implementation are identified;

- Site selection and community involvement;
- Engineering and Design;
- Water use assessment;
- Excavation and construction;
- Operation and maintenance (establishment of water management)
  (Water committee, care takers and provision of trainings)
- Monitoring and Evaluation

Box 4: Stepping stones in sand dam construction

This manual focuses on masonry dams with or without a reinforced foundation and a u-shaped spillway. After many years of practical experience and research on sand dam design by SASOL, this design has proven to be most effective, durable and easiest to construct by local beneficiaries. Although earth dams are most cost-effective, they cannot store large quantities of water which makes them less suitable.

MODULE II – HOW TO DESIGN A SAND DAM?

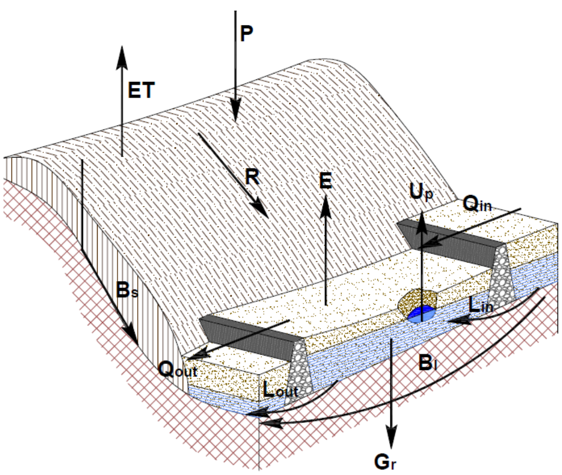
2.1 Hydrological principles of a sand dam

Functioning of a sand storage dam

In many semi arid regions, most of the peak river discharges are lost downstream and the storage and retention of water after rainfall events is limited. This is mainly due to the geomorphology of the upstream catchment with (steep) slopes and silty and clayey soils. Instead of infiltration in the soil and recharge of the groundwater, most of the rainfall leaves the catchment as surface runoff, runoff coefficients up to 70% are known.

The main function of the sand dam is to store and retain water. For this purpose it obstructs the groundwater flow through the impermeable riverbed. After one or two heavy rainfall events the aquifer can be completely filled with water. Because of the higher water table in the dam, also water flows towards the riverbanks. The recharge from the river or groundwater flow continues the replenishment of the created reservoir. The storage capacity of the dam is limited, if this recharge is interrupted. After the dam is depleted water can be extracted from the riverbanks. Water will be available in the sand dam as long as the groundwater flow from the riverbanks continues (Figure 4).

From a catchment perspective it can be very beneficial to take soil- and water conservation measures in the upstream areas. This increases infiltration of rain water and increases the groundwater flow. The raised water table in the riverbanks results in a groundwater flow from the riverbanks towards the river bed. Downstream of the dam the groundwater flow continues its natural course.



Water balance components

- ET Evapo(transpi)ration from slopes
- E Evaporation from riverbed
- P Precipitation
- R Surface runoff from slopes to river
- B_s Groundwater baseflow from slopes to river
- B_f Shallow and deep longitudinal baseflow
- Q_{out} River discharge outflow over downstream dam
- L_{out} Leakage underneath and around downstream dam
- Q_{in} River discharge inflow over upstream dam
- U_p Use of water (abstraction)
- G_r Loss of water into the ‘impermeable ground

Figure 4: Water balance components (Borst & de Haas, 2006).

Filling the sand dam aquifer

Before water can be stored in the sand dam it needs to be filled up with sediment. After heavy rainfall events, high river discharge transport large quantities of sediments. The grain sizes of the transported sediments are dependent on the river flow velocity and the material comprising the riverbanks. High silt and sand loads occur at the start of the rainy season, when most of the land is bare and soils are poorly protected against soil erosion.

The sedimentation process behind the dam occurs when the flow velocity of the river is decreased at some distance upstream of the structure. Coarse sediments can no longer be transported due to the lower flow velocities and are deposited. The materials found in the river bed prior to construction are a good indication of the type of sediment that will be stored by the sand dam through sedimentation. The sediments form a ridge, comparable to the formation of a delta.

Upstream of the 'delta', flow velocity is higher and coarse sediments are transported. Where the 'delta' stops, a sudden drop in flow velocity occurs causing coarse sediments to settle, building the 'delta' further towards the sand dam (see figure 3). Continuous repetition of this process causes the ridge of sand to move towards the dam, eventually filling the total volume behind the dam.

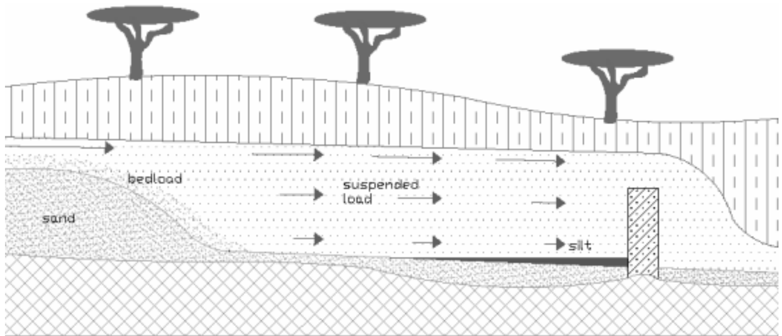


Figure 5: Schematic representation of the sedimentation process (Gijsbertsen, 2007)

The river also transports finer materials, like silt and clay which are mostly transported over the dam. Finer materials have a lower settling velocity compared to sand and will largely stay in suspension. Without the coarse material, the base flow water has excess energy leading to erosion of the river bed. Fine sediments will be (re)taken into suspension and transported, leaving the coarser grained material in the riverbed. But also fine sediments can settle resulting in a silt layer directly upstream of the sand dam which can affect the water storage negatively.

After the heavy rainfalls, the peak discharge in the river will decrease until the base flow. If the river runs dry completely, residual silt layers on top will dry and crack. Animals and people walking on the riverbed will pulverize this dry silt layer, making it susceptible for wind erosion (Borst & de Haas, 2006). These processes limit the accumulation of silt and clayey material behind the sand dam.

Sedimentation will continue until the 'delta' reaches the height (crest) of the sand storage dam. The sand storage dam is then matured and completely filled with coarse sand. Granite hard rock will produce coarse sand while shales will produces fine (clay or silty) material. It can take several wet seasons to fill the dam, depending on the availability of coarse sediments, height of the sand dam, river discharge, catchment slope and rainfall intensity.

It is recommended that sand dams are built in stages in upstream parts of a catchment, since the availability of coarse material is generally limited and base flow is small or absent. The optimum height of one stage is site specific. The first stage is typically 50 cm. It is recommended to consult an expert on this matter.

2.2 Site selection

Importance of site selection

The most important step for successful implementation of a sand dam is to select the proper site and location for construction. Accuracy in site selection will determine the final success of the dam. A construction site should therefore be appropriate to meet the physical requirements to establish a proper dam. Next to this community involvement (see chapter 4.2.) is essential to select a site, construct the dam and to take care of proper operation and maintenance (see chapter 4.2) to assure sustainability. This chapter will guide you through site selection for sand dams in 3 steps in relation to different scales (see Figure 6);

- River basin or catchment scale - Selecting potential sub catchments from a probability map based on a desk study (Box 4)
- Sub-catchment scale - Selecting potential riverbeds based on field data regarding the physical and sociological aspects (Box 6).
- Riverbed - Selecting of sand dam location(s) (Box 7 - 10)

Selecting potential catchments for sand dams

In case an entire catchment has to be assessed for selection of suitable sand dam sites, a quick scan is needed to assess the sub catchment areas where (i) water buffering is needed because there is no natural water buffer or surface water and (ii) to assess the sub catchment areas where the physical conditions are suitable for sand dam construction and (iii) where there is demand for water buffering.

A quick scan is a GIS bases analyses to map potential areas for building of sand dams. This will narrow down the focus, which will make site selection more specific and thus efficient. The quick scan is based on satellite information, internet data bases, available digital maps (or digitized maps supplemented with manual information). This GIS based analysis will provide a set of maps showing the potential areas where more detailed field data can be collected.

The type of maps and data used for a quick scan are typically: (see Box 5). Furthermore available information resources are provided in the reference section of this manual.

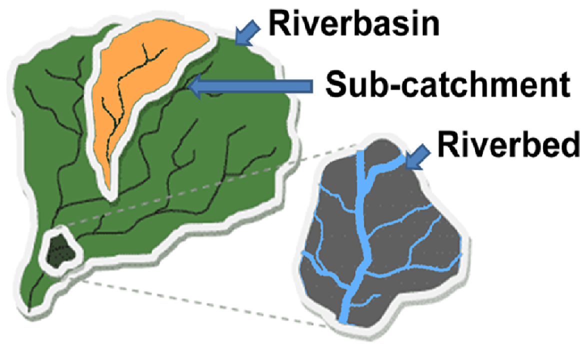


Figure 6: Identifying appropriate scales

Box 5: Quick scan

1. Topographical Map:
A topography map gives general information about the catchment, showing locations of rivers and the extent and general characteristics of the catchment. Furthermore in most cases information is given about the socio-economic infrastructure such as locations of villages and roads.

2. Digital Elevation Model:
A Digital Elevation Model (DEM) contains information on the morphology of an area (elevation and slopes). Furthermore, information on the slopes within a catchment can be derived from a DEM. A local drainage direction map can be calculated, which will give the drainage pattern (rivers) of the catchment.

3. Geological map and soil data:
The morphology and geology of the catchment informs us about the rock formation and soils in the upper catchment and the riverbed itself. This assessment could indicate weather the riverbed is hard rock, and thus impermeable. The catchment geology, with discharge characteristics and the slope, together, determine the grain sizes which can be actually stored in the sand dam. A geological map can indicate whether a catchment has the potential to produce (coarse) sand.

4. Aerial photographs and satellite images:
Aerial photographs and satellite images can support locating sandy riverbeds based on the morphology. Aster satellite images can also be used to indicate sandy riverbeds and different types of geology through the remote sensing techniques as used by Gijsbertsen (2007).

5. Precipitation and evaporation data:
When locating suitable regions for building sand dams, it is essential to know the climatic conditions of an area. Precipitation will be important because it influences discharge characteristics (base flow) and thus also the availability of coarse grained material in the riverbeds. Also an indication of the climate conditions can distinguish intermittent or ephemeral rivers.

6. Flood data:
Flood data is required to determine the maximum flood level and thus the minimal height of the riverbanks. It also provides information on discharge characteristics of a catchment during a rainfall event.

The analysis of these maps and data usually requires the input of specialized experts who have GIS experience and access to shape files (Box 5) and will result in a potential map for the whole catchment. In some cases, this quick scan will not be available and the NGO will start the site selection process within the sub-catchment where they are working. In that case the site selection will start with the next step.

Selecting potential riverbeds and river bed sections

The result of the desk study described in Box 5 shows the areas (or sub catchments) are suitable for constructing sand dams. In these sub catchments a more detailed assessment is carried out to select suitable rivers and river sections. Main criteria to select riverbeds and river bed sections within a sub catchment are given in **Appendix 2** and include priority criteria:

- The presence of communities (nomads or permanently – dry period)
- The slope of the river beds: the most suitable locations have a slope between 2 to 4 percent.).
- Average width of the river, which should not exceed 25-50 meter
- The rivers should be underlain by bedrock

Based on these criteria, a small number of river bed sections (2-3) are selected for field visits to promising river bed sections, which is needed to collect information and to consult the communities. Starting a sand dam project begins with establishing the community's awareness on the project by undertaking regular visits to the project area and facilitating meetings with the representatives and members of community. (Also see paragraph 4.2 and **Appendix 4**)

Box 6: Checklist for river section inspection and ranking

1. Location and types of water-indicating vegetation.
A good indicator for the presence for groundwater is current vegetation. Depending on the species, the groundwater depth and storage of water can be estimated

2. Location of waterholes, their depth to the water table and quality of the water.
The presence of waterholes is an indication that the riverbed contains deep water storage. The water quality in the waterhole is an indication of the quality of water which can be harvested.

3. Location and types of rocks and boulders.
If large boulders are present in the riverbed, special care should be taken in choosing the location. Preferably the sand dam is build on (and its wings attached) hard rock or compacted and strong soil.

4. Grain size of the sand (coarseness), particles in the riverbed.
The grain sizes which are present in the riverbed are a good indication of the material which will fill up the sand dam reservoir after construction. Coarse sand is preferred, since it has a higher infiltration capacity and water can be abstracted more easily. (Existence of gullies, might feed silt)

5. Shape and dimension of the riverbanks.
Suitable riverbeds for sand dam consist out of high riverbanks. During flood events the river should not flow over the riverbanks, because this can cause erosion of the riverbanks, flooding of downstream located villages and it might cause the river to change its course.

6. A (preferred) maximum width of 25 meter.
Preferably, riverbed width should not exceed 25 meters. The reinforcement required to construct such kind of long dam walls is too expensive; hence the sand dam will not be cost-effective.

7. An impermeable (bedrock) layer.
To ensure storage within the sand dam aquifer, losses to deeper groundwater should be minimized. Therefore, the dam should be built on solid bedrock or an impermeable layer.

8. Type, suitability and availability of construction material.
The construction materials which are locally available (such as sand, rock outcrops, bricks, etc.) can help to determine the most cost-effective type of sand dam for construction .

9. Presence of riverbed crossings and roads.
Rural roads often cross riverbeds. Preferably a sand dam is located near these crossings and can be easily reached through existing roads (also for transportation of materials).

10. Names of houses, schools and shops near the riverbed.
The local people benefit from the sand dam, may it be direct or indirectly. By measuring these positive social impacts before and after implementation, the actual social impact can be determined. .

11. Land rights.
Agreements based on rules and regulations (or bylaws) are needed to assure fair use and access to water for collective and individual usage. To avoid conflicts, special care should be taken in areas where the dam site is owned or used by two or more villages or several individuals.

The checklist in Box 6 is based on expert knowledge of Nissen-Petersen (2006) and includes to make a sketch of the selected river bed sections followed by the rapid appraisal (field visits) with information gathered from the social leaders and the community (paragraph 4.2). This is combined and integrated into a map, resulting in a ranking of the riverbed sections

A detailed description of these checkpoints is given in **Appendix 3** and will results in the selection of 2-3 selected approximate locations.

Selecting sand dam location(s)

The final step is to carry out a detailed survey in the 2-3 locations that are selected as potential dam sites. These specific sections will be visited together with the community representatives, to collect data based on which building location(s) are chosen, based on a number of detailed criteria that are checked in the field (see Box 7 up to 10). Measurements to be taken at these locations are (see also **Appendix 5**):

- The depth and coarseness of the sand at different levels (Box 7)
- Depth and type of basement and depth of groundwater (Box 8)
- Gradient of the river bed (Box 9)
- Width of the riverbed and height of the riverbanks (Box 10)

Box 7: Storage capacity and extraction percentage of sand

Most water can be retained and stored in riverbeds containing coarse sand. The porosity and the water holding capacity of sand can be determined using the following method. A 20 litre container with a plug in the bottom is filled with sand from the riverbed. The sand is slowly saturated with a measured volume of water. Then the plug is removed from the bottom of the container. The volume of water which has drained out of the sand within one hour is taken as a measure for the extractability. Table 3 gives values of extractability of water in different soils. This shows that coarse sand has the highest extractability making it also preferred for storage in the aquifer.

	Silt	***Fine Sand***	***Medium Sand***	***Coarse Sand***
Size (mm)	< 0.5	0.5 – 1.0	1.0 – 1.5	1.5 – 5.0
Saturation	38%	40%	41%	45%
Water Extraction	5%	19%	25%	35%

Box 8: Depth and type of basement and depth of groundwater (location of sand dam!)

The sand dam must be constructed at the location where the impermeable layer is closest to the riverbed surface. Preferably, also the basement upstream of this location is deeper, to get a larger sand dam aquifer. The depth of the sand in the riverbed can be surveyed by using an iron rod with a diameter of 16 mm (5/8"). Notches should be cut in the probing rods for every 25 cm, to collect sand samples when the rod is pulled up. A hammer is needed for hammering the rod into the riverbed, together with a tripod ladder used for hammering long probing rods. This survey is executed using the following procedure below:

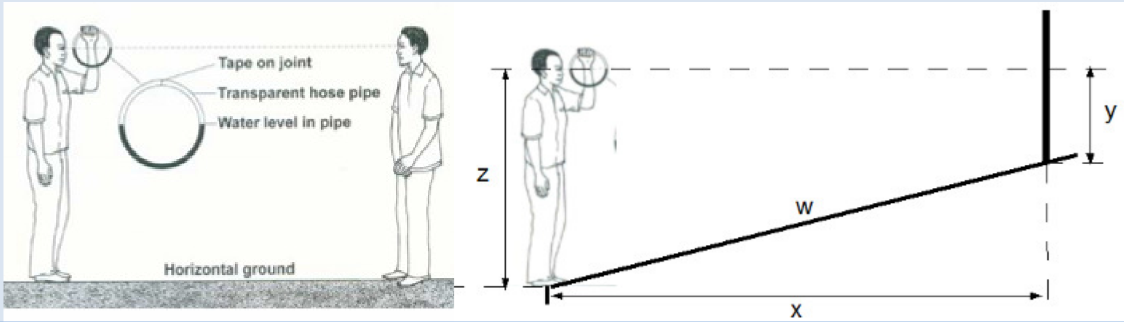
- *Hammer the probing rod straight down in the middle of the riverbed, until it hits the floor under the sand with a dull sound. Mark the level where the water is encountered and the depth of the bottom and pull the rod straight up without twisting.*

The procedure described in Box 8 is repeated at regular intervals, for example 5, 10 or 20 metres. The data gathered by this particular survey results in a map with profiles of the river section and cross sections at the locations. This map shows information about the river length with approximate dimensions and specific information (width, locations of cross-sectional, longitudinal profiles, water-indicating trees and waterholes). Based on this a more precise estimation of the water storage can be acquired and the location of the dam is decided. The data are also used to calculate the actual determination of the water storage, which can be calculated with the help of the SAND Dam Infiltration Tool (See paragraph 4.2).

Box 9: Gradient of the riverbed

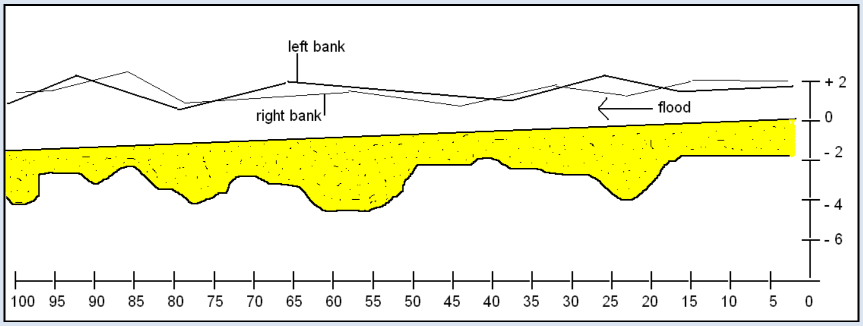
Measuring the gradient of the riverbed can be done by using a circular transparent hose, half-filled with water. One person should stand at the starting point, using the levelling tool. Another person should stand upstream of the person holding the levelling tool, with a long vertically pole. The person with the levelling tool makes sure that the water levels in the tube are in one line. The other person should indicate where this sight line crosses the pole. The height at which the line of sight crosses the pole is measured from the surface of the riverbed (parameter y [m]). Also the distance between point No. 1 and point No. 2 and the height of the eyes of the person holding the levelling tool is measured (parameter z [m]). With these figures the gradient (parameter w [m]) can be calculated using the following formula:

$$W = ((z - y)/x)*100 = \text{gradient } [\%]$$

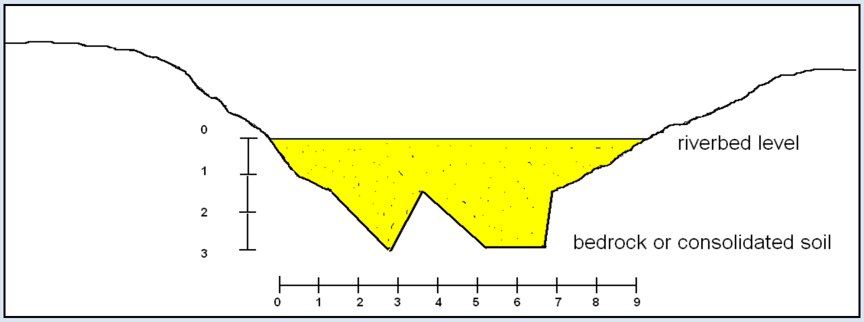


Box 10: Example of longitudinal profile and cross section

The figure below shows an example of a longitudinal profile. It shows the points at which the sand is deepest (here: 4.0 m deep between 55 and 60 metres) and where natural subsurface dykes (of solid bedrock or impermeable soil) are located (for example at 40, 70 and 85 metres). The locations with deep sand are the potential reservoir of a sand dam and the natural dykes are potential locations for a sand dam. The actual location of the dam can be determined after making a longitudinal profile of the selected riverbed section. The exact place is selected based on the deepest point with the largest storage reservoir. In the graph this is at 60 metres.



By knowing the longitudinal and cross-sectional profile, a calculation of the reservoir capacity can be made. The figure below gives an example of the deepest cross-section . It is important to take measurements every 1 or 2 metre across the riverbed to determine the riverbed morphology. If the cross-section is combined together with the longitudinal profile, the storage volume can be calculated accurately.



2.3 Preparing the Dam Design

The sand dam can be designed after the finalization of the water assessment. The outcome of this water assessment indicates the required sand storage, based on the assumed discrepancy in water storage, between the estimation of the water supply and the actual water demand over time. In addition to this calculation, the dam is designed according to the specific morphology of the riverbanks and the riverbed. There are different approaches in designing a sand dam, but this manual will focus on the designing approach of SASOL, combined with AFD. A sand dam can be defined in four main parts:

- The dam wall;
- Spillway;
- Wing walls;
- Stilling basin
- Abstraction well (see paragraph 3.4 and **Appendix 9**)

Dam height

For the determination of the height of the dam crest and the spillway at a specific location, it is very important that the water level and the maximum flood level will remain below the riverbanks, also after the construction of the dam. If the flood comes higher than the riverbanks (Bh), the river can damage the structure, or change its course. For this reason the dam crest and spill way height are determined by the maximum discharge and maximum flood height (see figure 9).

The most practical way of calculating the maximum discharge, is by getting information from the community (through interviews), or through a field survey (observations from the field, like flood marks).

The maximum discharge can be calculated in 3 different ways:

- Calculating the maximum discharge by the highest flood level (known by flood marks on the banks or information from the local community's);
- Calculating the discharge at the selected location using a certain return period (for example a rain event with a return period of 50 years) or otherwise, using a rainfall-runoff model or a mathematical formula for rainfall runoff.
- Area Slope Method.

Figure 7 shows in the top picture, a proper designed sand dam where the maximum flood level will remain lower than the riverbanks. In the picture below is shown a sand dam, by which the maximum flood level will exceed the riverbanks. In this scenario flooding and thus severe erosion of riverbanks (eventually causing dam failure) can or will occur.

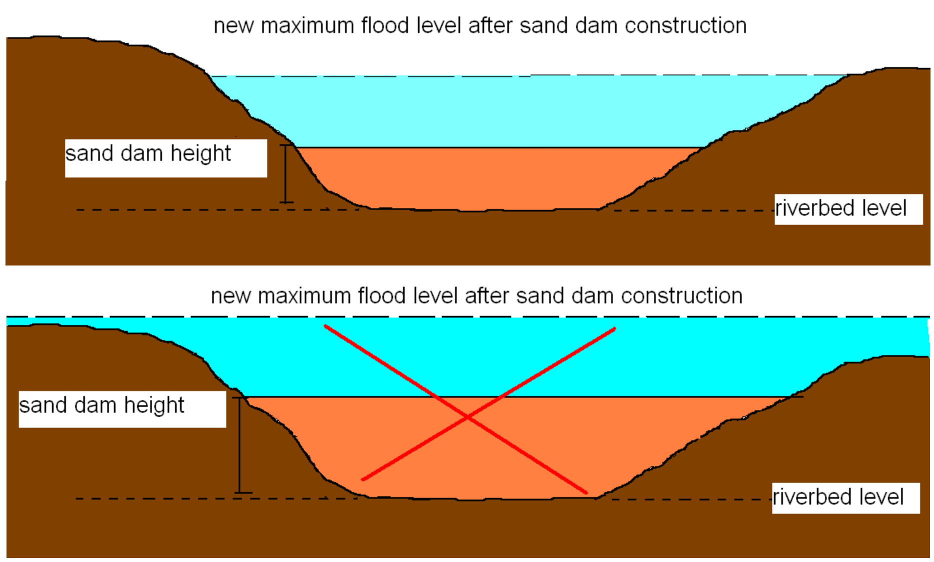


Figure 7**:** Examples of sand dam heights: do's and don'ts.

In Figure 8 you see a cross-section at a dam location, with the different parameters that have to be measured to calculate the maximum discharge.

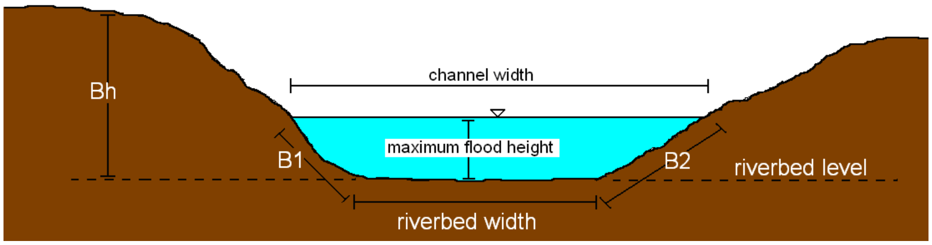


Figure 8: Cross section with maximum flood height

Box 11: Maximum discharge in riverbed section:

$Q = 1/n * A * R^{2/3} * S^{1/2}$

Q = maximum discharge in riverbed section (m^3/s)	
n = Manning roughness of riverbed	
A = wetted cross-sectional area (m^2), by:	½*(channel width + riverbed width)* flood height
P = wetted perimeter (m), by:	B1 + riverbed width + B2
R = hydraulic radius (m), by:	A/P
S = slope of riverbed (m/m)	

Spillway, wing walls and stilling basin dimensions

The maximum discharge (See Box 11) is used to determine the spillway dimensions, for which the formula is given in the box below.

Box 12: Using maximum discharge to calculate spillway dimensions

$Q = c * L_s * H^{3/2}$

Q = maximum discharge in riverbed section (m^3/s)
c = 1,9 (constant depending on spillway shape, here: broad crested weir)

L_s = length of spillway (m)
H = height of spillway (m)

Cross-sectional width dimension of a sand dam

G_f = gross freeboard (m)
H_f = height freeboard (m)
H_d = total height of dam (m)
H_s = total height of spillway (m)

L_w = length wing wall (m)
L_{we} = length wing wall extension (m)
L_s = length spillway (m)

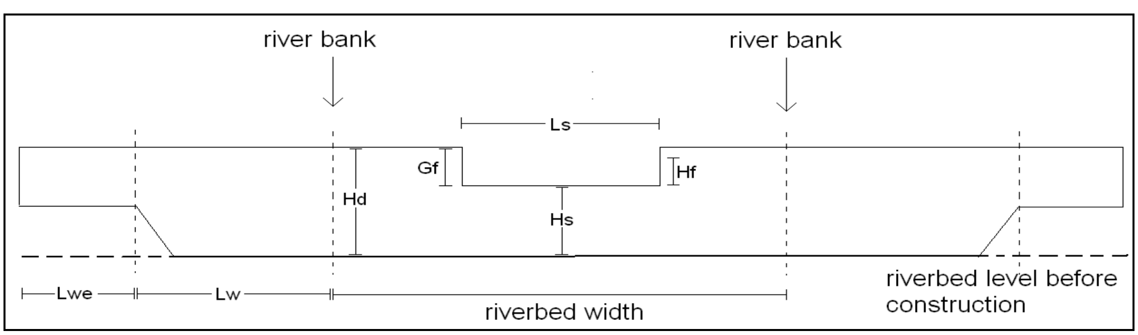


Figure 9: Cross section of a sand dam body and its dimensions.

For determining the excavation (depth) of the wing walls, which need to go into the riverbanks, the following characteristics of the bank have to be taken in account (Munyao et al, 2004):

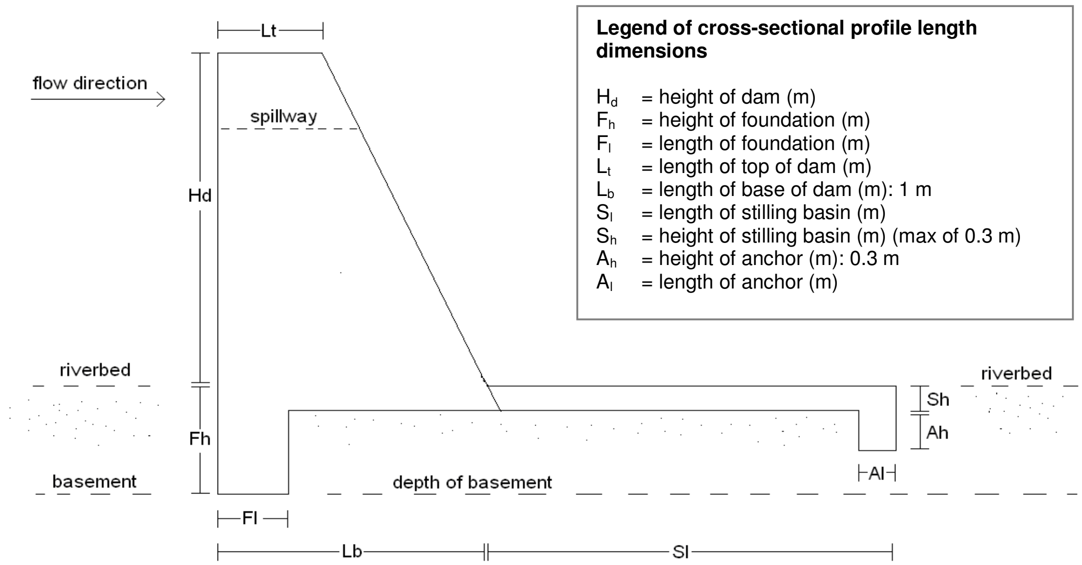
- In loose riverbanks: approximately 10 metres into the riverbanks;
- In hard (consolidated) soils: approximately 7 metres into the riverbanks;
- In hard and impermeable soil: approximately 0 – 3 metre into riverbanks;
- In rock formation: no need of constructing in riverbanks.
- If there is risk of channel shifting, 15 meter wing walls are needed for precaution.

The length of the wing wall (Lw) should be approximately 2 metres into the riverbanks. The length of the wing wall extension (Lwe) should be approximately 5 metres. This is an example of wing wall dimensions in loose riverbanks

Box 13: Stilling basin dimensions

$S_L = c * L^{1/3} * H_2^{1/2}$

S_L = length of stilling basin (m) c = 0,96 (constant)
H_2 = height of freefall (m): height of water level upstream –height of water level downstream



Legend of cross-sectional profile length dimensions

H_d = height of dam (m)
F_h = height of foundation (m)
F_l = length of foundation (m)
L_t = length of top of dam (m)
L_b = length of base of dam (m): 1 m
S_l = length of stilling basin (m)
S_h = height of stilling basin (m) (max of 0.3 m)
A_h = height of anchor (m): 0.3 m
A_l = length of anchor (m)

Figure 10: Cross sectional profile of a sand dam body and its dimensions.

The thickness of the stilling basin (S_h) should not be fixed to be max of 0.3m. It actually depends on the uplift pressure and impact load. If the material underneath is lose formation, the thickness can be even higher than 0.3m to prevent piping and collapse of the structure. Sometimes there will be a need to use reinforced concrete if the impact load is high and flood water brings rolling stones and wood planks. To determine the thickness either *Bligh's* or *Khosla's* Formulae of exit gradient and determination of thickness of apron can be used.

2.4 Finalizing the Dam Design

The dam design as described in the previous paragraph is according to site specific conditions as part of the sub-catchment within a riverbasin. The selection of opportunities for sand dams in a riverbasin and sub-catchment and the actual selection of the site location require for both scales specific selection criteria. The link between the different scales is the riverflow which determines the actual water storage when the sand dam is operational. For the sand dam design the strength and dimensions need to based on calculated or estimated river discharges. Another important aspect to consider in the design is the use of locally available materials and skills for construction. The local people should be able to maintain and repair the dam. Also it is important to consider the actual usage and construction of water tapping points which is discussed more in detail in the next chapter.

MODULE III - HOW TO CONSTRUCT A SAND DAM?

3.1 Materials and Labor

Materials

For the construction community involvement is essential. The local people need to able to work with the materials which are needed to construct the sand dam, depended on the type of dam that is suitable at the selected location. Furthermore this depends on physical properties of the catchment and on the materials available on the market and within the local area. If materials like stones and sand are locally available, this will reduce costs of materials and transport. In this paragraph we will focus on the bill of quantity for stone-masonry dams. There are some rules of thumbs for the construction of the stilling basin, dam and the foundation which are given in Box 14.

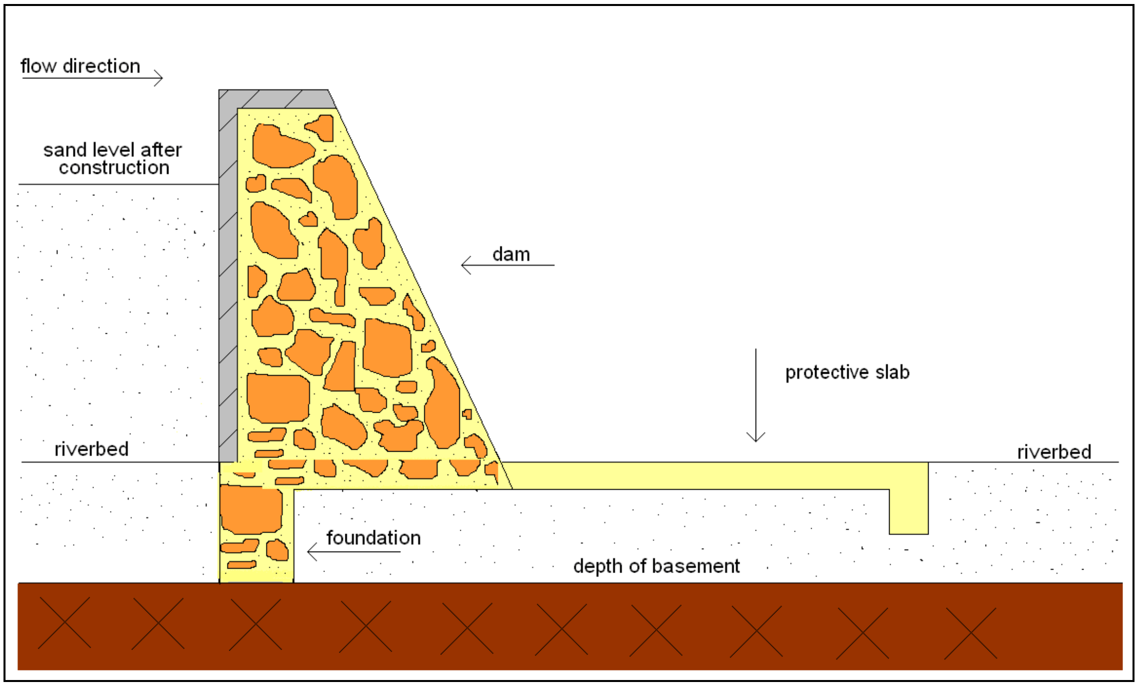


Figure 11: Cross sectional profile of a sand dam body.

Box 14: Construction materials masonry sand dam

Stilling basin:
- 1:3 mortar
- Large boulders

Dam:
- 1:4 mortar with well interlocked stones, ratio cement: sand: hardcore = 1:4:9-12
- Upstream wall and top of dam plastered with 1:3 mortar (30 mm)

Foundation:
- 1:3 mortar foundation (100 mm)
- 1:4 mortar with well interlocked stones, ratio cement: sand: hardcore = 1:4:9-12
- (reinforcement bars of barbed wire (400 mm spacing)

All required materials should be summarized in bill of quantities as shown in table 1.

Table 1: Example of a bill of quantity for materials and transportation costs in ETB (2007).

Description	Unit	Unit cost (ETB)	Total quantity for a sand dam	Costs per Volume of work (ETB per m^3)	Total cost (ETB)
Cement	50 kg bag	130	241.8	3.10	**31,434**
Reinforcement bars ½ Dia' (12m)	pieces	0	0.0	0.18	**0**
Reinforcement bars ¼ Dia' (12m)	pieces	0	0.0	0.18	**0**
Barbed wire	20 kg roll	68	6.0	0.08	**411**
Timber 2"x 2"	m^2	12	52.0	0.67	**624**
Polythene paper g 1000	metre	15	104.0	1.33	**1,560**
Reinforcement bars Dia' (10m)	pieces	140	3.1	0.04	**437**
Reinforcement bars Dia' (6mm)	kg	14	51.5	0.66	**721**
Black wire	kg	14	3.9	0.05	**55**
C.I.S. Nails	kg	18	2.3	0.03	**42**
Stone hard core2	m3	31.25	233.2	2.99	**7,288**
Sand13	m3	19	66.3	0.85	**1,260**
Water	m3	140	37.4	0.48	**5,242**
Other construction equipment (V.tools, Hand pump, Mould for well concrete rig)	unit	7,500	1.0	1.00	**7,500**
Camping site for skilled labourers	unit	6,500	1.00	1.00	**6,500**
Total					***63,073**

*Prices and quantities are highly variable: these depend very much on the site location and local markets.

In Table 1 is an example given of the cost for construction, more detailed information is given in **Appendix 7** with the guidelines to calculate the quantity of the materials derived from the dimensions of the dam.

Labour

In Table 2 an example is given of the bill of quantity for labour costs: the contribution of community workers will reduce the costs. The number of masons needed and days required to construct the sand dam depend largely on the size and location of the dam.

Table 2: Example of a bill of quantity for labour costs in ETB (2007).

Description	Unit (days p.p.)	Unit cost (ETB)	Total days	Cost per Volume of work (ETB per m^3)	Total cost (ETB)
4 masons	45,8	50	183.3	2.35	**9,165**
10 mason assistant	31	15	312.0	4.00	**4,680**
15 community workers	50	0	750	0	**0**
Total					**13,845**

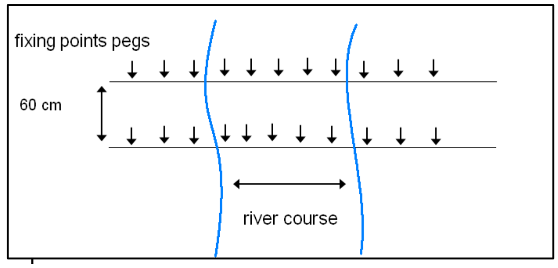
3.2 Excavation

The dam will be fixed on top of the impermeable river bed or placed on compacted soil. To make this possible the riverbed needs to be excavated until it reaches the hard rock. Also for the installation of the wingwalls into the riverbanks, excavation is needed. The total excavation works or "setting the trenche" requires marking the position and the size of the dam, taking in to account the size of the wing walls and required working space during construction.

To estimate the size of the trench, the following should be taken into account:

[2] Refers to collection, preparation and transport of stones and sand that is expected to be covered by community participation. The cost planned is for renting a truck for transportation.

- Measure the appropriate distance from one of the river banks depending on bank characteristics and fix a peg.
- Fix another peg across the river, perpendicular to the river course at the appropriate distance.
- Use a plumb bob and line mark several points from the building line and fix pegs.



igure 12: Setting a trench with pegs.

The marked trench is excavated (often using the hand dug) and guided by the building line (see below photo). The depth of the trench is determined by the depth of impermeable layer in the ground which will obstruct seepage below the sand storage dam. The removed soil should be placed downstream of the building location to avoid filling the aquifer. If the dam is build into bedrock material, a trench should be cut into the rock to ensure secure jointing of the rock and mortar. Care should be taken to make sure no fractures or weathering zones are present in the basement rock. If suspected, this can be tested by pouring water on the suspected weathered zones. If the water leaks away, the rock surface should be cleaned from the weathered rock or fractured rock. If clay forms the impermeable layer, the trench should be dug in for about 0.5 m to avoid seepage. After these conditions are met, the trench is ready for dam setting and construction (Munyao et al, 2004).

Photo 3: People excavating a trench (RAIN, 2007).

3.3 Dam Construction

Construction starts with placing the reinforcement columns vertically in the trench, followed by the construction of the foundation blinding slab. Reinforcement is only required if a very large or high dam is constructed. After this, the second horizontal reinforcement layer is placed, followed by the second foundation blinding slab and finally the actual masonry structure (of hard core and mortar) (Munyao et al, 2004. The construction steps are listed below and described in more detail in **Appendix 8** Construction of the dam follows a number of subsequent steps:

Step 1: Placing reinforcements

Step 2: Making the foundation blinding slab

Step 3: Constructing the first horizontal reinforcement layer

Step 4: Constructing the second foundation blinding slab

Step 5: Masonry comprising hardcore and mortar substructure

Step 6: Installation of templates above the sand level

Step 7: Constructing Masonry hardcore and mortar substructure within two templates

Step 8: Preparation and construction of the stilling basin structure along with the dam body

Step 9: Stilling basin construction with the stone pavement for flood protection

Step 10: Construction for the dam wall

Step 11: Plastering and pointing works

Intensive technical supervision and monitoring the progress are the major activity that should be attained during the construction process of a sand dam.

3.4 Installing Water points + protection

Traditional scoop holes

The most old fashioned and common way to abstract water from riverbeds is by means of a hand dug scoop hole. Water is collected by digging holes in the riverbed and through fetching water "using buckets or alike". The scoop wholes can provide significant amounts of water because recharge occurs through the aquifer. Even though recharge occurs, this method remains very susceptible for pollution, especially in combination with water for livestock. Therefore livestock and humans must have different tapping points. A common practice is the location for human scoop holes, close to the sand dam on the upstream side. The livestock should be given water at the downstream side of the sand storage dam. The distance between the waterholes for domestic use and livestock should be as much as possible.

Photo 4: Women using a scoop hole, Kituï, Kenya (Acacia Water, 2007).

Well with hand- or rope pump

Preferably a well is installed connected to the sand dam with a infiltration gallery. This will protect the water quality because animals and river water cannot contaminate the source. Many different types of wells exist. Most often wells are covered (to prevent contamination, resulting in higher water quality) and a hand pump is used for extraction of water. A maximum of 3 wells should be located on the upstream side and close to the dam embankment: approximately within 3 to 10 metres, since the sand reservoir will be deepest just upstream of the dam (depending on the longitudinal profile as described in paragraph 2.2). Before a well is located in the riverbank, a test drill is needed to check the profile in relation to the permeable layers. Recharge of the well can be established through an infiltration gallery.

Photo 5: Fetching water in Kituï (Acacia Water, 2007).

Box 15 provides practical guidelines to identify potential well locations. Water can be extracted from a well using a motor pump or hand pump. SASOL has been using rope pumps, washer pumps and hand pumps. However, the sustainability of the rope and washer pump might be unrealistic as long as people are not trained in proper operation and maintenance. Hand pumps are therefore recommended.

Box 15: Practical guidelines for locating wells.

The well should be located next to, or close to the dam at locations where the bedrock or impermeable layer is deepest. Experiences in Kenya and Ethiopia show that practical site specific information can be used to locate potential well locations. This includes:

- **Identifying locations of existing scoop holes:** Scoop holes are the best spots for communities' long-term experience to collect water from the river. Based on the locations of scoop holes, wells for a sand dam can be located nearby at either side of the river embankment.
- **Identifying locations near the sand dam where the riverbed material is deep**:A deeper riverbed means more storage. Therefore the best location for a well is up stream of the dam at either sides of the river embankment, at the location with the deepest riverbed for more water storage.

Pipe with tap

An outlet can be installed as a perforated pipe at the bottom of the dam just above the impermeable layer. The pipe should be covered with filter material and a geo-membrane to prevent entry of sand and silt. The main disadvantages of an outlet is that it can weaken the dam structure, making the maintenance complicated and also an expensive option according to some experiences (Understanding the Hydrology of (Kituï) sand dams: Short mission report, November 2005).

Construction of wells

A well for a sand dam is constructed similarly as a shallow hand dug well and usually constructed for exploration of shallow ground water. It is important that the well abstracts the water from the deepest parts of the aquifer which will produce the most safe water (bacteriological - long retention time).The lining of the well should preferably have no openings at shallow depths. It could even be considered just to have an open well-floor, covered by gravel.

If a well is constructed at the centre of a river, it is extremely important to protect it from high floods. The well has to be a 'hydrodynamic' type to withstand the forces of a flood and must be protected from siltation by keeping its height about 0.5 – 1 meter above the surface of the riverbed. The top must be covered with a concrete slab (facing downstream to prevent entry of floodwater) to prevent contamination and mosquito breeding. The detailed construction process for a well and wellhead is given in **Appendix 9**.

To protect the intake from high flood damages, alternatives can be considered. The intake can be constructed in, or close to the riverbank or by an outlet pipe through the dam.

Multiple Use

Another way of looking at water supply is, taking the community's diverse water needs as the starting point for providing services. This is called Multiple-use water services (MUS), which describe a participatory, integrated, and poverty-reduction focused approach. Multiple-use water services move beyond the conventional sectoral barriers of the domestic and productive sectors and provide for all water needs in a community (Mikhail and Yoder, 2008). One of the new challenges is to develop a water source for multiple uses, providing greater accessibility to domestic water and multiplying the benefits of micro irrigation and marketing efforts. In this way sand dams are a more interesting source for generating income. In the next chapter the cost and benefits of sand dams are discussed in detail.

MODULE IV - HOW TO MANAGE AND MONITOR THE DAM?

4.1 Lessons learned

Although every sand dam project has a unique location and context there are common aspects making a project successful. Learning from past experiences can improve and assure better project implementation in the future. In this way implementers will not make the same mistakes and are able to overcome common failures. There are several examples which can be taken into account from the beginning, during and after implementation. Besides examples what went wrong, it is much more interesting to know how these issues were resolved and or prevented. As a result we can actually learn from our mistakes and take corrective actions. The lessons learned can be divided into different steps within the project as indicated in paragraph 1.4. (from site selection up to monitoring and evaluation).

In general it is concluded that for any sand dam project the site selection is the most important critical aspect, which takes place in the preparation phase. As indicated in this manual (paragraph 2.2) it appears important to acquire proper field data and cross sections with longitudinal profiles. Here extra attention (by hiring external experts) is strongly advised to investigate sections of the riverbed. This prevents leakage, meandering and or malfunctioning of the structure in a later stage. It is important to invest in proper siting and to investigate the local area concerning the presence of scoop holes, types of sand in the river bed, boulders, gullies, riverbank characteristics, availability of materials and occurring flood levels. More details about specific lessons learned in detail to improve the siting are given in **Appendix 12.**

For the design several experiences have given insight in the failures, but often the same mistakes are reoccurring as a result of inappropriate adaptation of the design, to the site specific situation. Most attention should be given to the robustness of the structure to peak river discharges and occurrence of erosion damaging the structure. There are several adjustments and improvements for the dam design, which should be taken into account. Also there are guidelines for the optimum location of the wells (see chapter 3.4). In chapter 2.3 the design is already discussed in detail, more lessons learned from site specific experiences are given in **Appendix 12.**

Throughout the steps of the project, the organisation, communication and financial setup, (project-management) turned out to be very important for the efficiency of the overall implementation. Also the support of local authorities is a necessity. It is suggested to provide some of the community leaders appropriate trainings to acquire skills in project management (see paragraph 4.4). Improper management leads to Inefficient progress, disrupting of the implementation and conflicts between the stakeholders. During the construction a common mistake is caused by accidental flood occurrence, disrupting the construction process dramatically. For this reason proper planning and progress monitoring are needed to complete the construction before the rainy season. Another conflict is related to the responsibility of the functioning of the dam, it is suggested to select one party making the design and construction.

Several issues are related to the water quality and water treatment. Problems can be related to the contamination of the actual source (water reservoir) and the water tapping points for human and livestock. Furthermore the monitoring and usage of water acquires proper adequate facilities, management and rules for regulation. It remains vital for the hygiene to separate the water tapping points (see paragraph 3.4). One of the main preventive actions is to prevent infection through avoiding direct contact (contamination by human and or livestock) at the top of the dam. In addition also the surrounding riverbank (runoff which infiltrates in the dam) should be protected. This can be achieved by fencing (and local enforcement using a bylaw), to avoid entrance of the potential polluters to the infiltration area and avoid contaminated runoff from the surrounding area.

After the finalization of the project it remains important to document all relevant information and data. This information can be still useful and remains very important for monitoring and evaluation. A proper technical survey and documentation of the field data and benchmarks should be set to enable future evaluation.

4.2 Operation and Management principles

Community involvement

For the design, construction and implementation and sustainability of sand dam structures, community involvement is essential. The socio-economic inventory directly raises the communities' awareness on the project. Together with the physical en geographical preconditions, also socio-economic aspects such as; existing institutions, rules and habits of the communities, need to be assessed. The beneficiaries need to contribute to the development of sand dams and in return can significantly improve their livelihood and quality of life. For successful implementation the community needs to be involved from the beginning of implementation, to understand the concept and principles of a sand dam and to make it their own. Using the existing social structures and organisational setup can help to mobilise the community. Many types of community organizations mostly already exist within a community depending on their current needs. The community must be involved intensively to establish ownership which has proven to be one of the critical key factors for successful construction and maintenance of sand dams. The benefits of a sand dam are mostly collective but can also remunerate individual needs such as irrigation of specific land plots, watering livestock, brick making etc.. An organization which can meet the interest of the community as well as individuals and who can mobilise the required support from all stakeholders is required to carry out a successful sand dam project.

Photo 6: Beneficiary involvement in Borana, Ethiopia (Acacia Water, 2007).

Management of a sand dam and forming a Water Committee

After productive interaction with the social leaders, a community meeting is initiated together with the project staff, to discuss the possible environmental and social impact of the development of sand dams within the area. The following aspects need to be discussed in the community meeting.

1. Assessment of water problems,
2. Assessment of development issues within the project area,
3. Informing and educating on the various types of water harvesting technologies, in particular the sand dam technology,
4. First and indicative assessment of possible sand dam locations with the community.

In general the community elects a committee from their midst. This so-called water committee consists of a representative group of the community and will take part in several trainings. Hence awareness and involvement in the project processes will be ensured. The water committee will have the following objectives (Munyao et al, 2004):

- Performing a baseline survey on water use within the community,
- Participating in surveys concerning the riverbed resulting in selection of the building location,
- Organising the mobilization of the community for required participation works during the construction process,
- Supervising the implementation, operation and maintenance procedures.

Since the water committee and care takers have been trained and have coordinated community mobilization during implementation, the responsibility of the sand dam will be fully assigned to the water committee and care takers. The water committee will be responsible for the management of the sand dam as well as the payment scheme and the caretakers will be responsible for the daily monitoring, operation and maintenance of the sand dam, wells and surrounding area. The water committee, with support and assistance of the concerned local government departments and the implementing partner, will monitor all activities to ensure sustainability of the project.

The steps in community involvement and its objectives are discussed more in detail in **Appendix 3 .**

Maintenance

The approach on maintenance activities is based on the Kenyan experiences of SASOL. If a sand dam is properly constructed, it only requires limited maintenance. Proper maintenance of a sand dam can be only be assured if the community has acquired ownership and commitment to address issues properly. The following aspect will contribute to establish proper operation and maintenance;

- Good workmanship during the construction of the sand dam.
- Full involvement of the community to ensure operation, management and maintenance after completion of the project.
- Presence of a trained mason near to the sand dam project to ensure adequate repairs if there should be any serious damage to the structure, which is beyond the capacity of the trained caretakers.
- Proper linkage between the local community, local administration and governmental sector to ensure technical and advisory assistances for the community.

If these issues have been addressed maintenance can be kept at a minimum. In **Appendix 8** some guidelines are described for small technical maintenance issues.

4.3 Monitoring & Evaluation

Impact assessment - Water use assessment

A water use assessment is essential to estimate the actual water demand for a community over time. To understand the water demand of a community, the water need for each and every activity has to be investigated. This implicates the amount of water used by people for domestic purposes such as drinking, cooking and cleaning, as well as for agricultural production (using irrigation) or livestock keeping. Apart from the demand there is the actual water supply, (coming from the river) which determines the water availability or shortage over time. This directly reveals one of the main limitations of the sand dam, the total storage volume. Knowing the actual water demand and the water supply provides very important insights, concerning the water availability and expected water needs and or water quality requirements.

A water use assessment has to be executed by the implementing organisation before selecting the locations of the sand dam, to determine whether the sand dam can be used to meet the actual demands. The information which needs to be gathered for this survey includes:

- Number of households within a community;
- Number of adults (males/females) and children (males/females);
- Current water needs for each water requiring activity;
- Future expectation of the water demand

A proper water use assessment needs to reflect the water demand of the whole community. Therefore when executing a water use assessment, the water committee has to elect people from each group of the community (men, women, elder, youth etc) to contribute. This can be a member of the water committee itself as well as other members from the community. Water needs from each group of the community have to be included in the water use assessment.

An example of a water use assessment with a practical questionnaire is given in **Appendix 6** The questionnaire will provide a guideline to determine the water needs of a community. After finalization of the sand dam project (when the sand dam is mature and in full use), a second water use assessment should be carried out. The results of the water use assessment before and after the project can be compared, showing the actual contribution of the sand dam.

Performance monitoring - Water yield

Determining the volume of storage water is not that simple in the case of a sand dam. The total amount of water is not just the water which can be stored in the riverbed. Hoogmoed (2007) and Borst & de Haas (2006) have indicated that the riverbanks play a crucial role in the functioning of a sand storage dam, because of the continuous groundwater flow from the riverbanks to the riverbed. This additional storage capacity also partly compensates the loss of water through leakage, evaporation and abstraction. Therefore, the riverbanks must be included in the calculation of the water yield. A proper estimation can be acquired by using the SAND Dam Infiltration Tool[3] for calculating the volume of water which can be abstracted from the riverbed. A more detailed description of the calculation model and usage is given in the next paragraph**.**

The storage capacity can be only estimated! Sand dams depend largely on local factors, which are difficult to include in any model. Also factors like, irregularities or fractures in the basement, geomorphology of the catchment, rainfall events etc. can have a big influence on the success and yield of a sand storage dam. More information can be found on **www.sanddam.org**

The SAND Dam Infiltration Tool

Sand dams have demonstrated to store river water effectively during river flows and supply water to the local community during dry periods. It is important to be able to quantify the amount of water that a sand dam can supply to a local community to ensure proper site selection, planning and for funding purposes. The storage depends on both sand dam dimensions and many hydrological processes, including water exchange with adjacent river banks. This is complicated by the fact that river banks adjacent to a sand dam often contribute to the retention of superfluous water during the rainy season and consequently supply a sand dam with water during the dry season, providing additional storage. For this reason, designing sand dams is not straightforward, requiring at least some basic insight in their hydrology. To obtain this insight, the 3R Sand Dam Infiltration Tool (SAND-IT) is developed and can be employed for performing some basic hydrological calculations on sand dams. The complete instruction manual for SAND-IT is available on the provided CD-ROM.

SAND-IT utilizes user input and input from publicly-available information and programs to construct a simple hydrogeological model representation of one single sand dam, including adjacent river banks. The model employs Darcy's Equation and standard hydrogeological modeling procedures and assumptions to estimate the amount of water that can be provided by a sand dam, while taking into account specific environmental factors such as evaporation, leakage, and the duration of the rainy season and river flow. The model is constructed in Excel which provides a well-known and easy-to-use interface for the user with a need for basic information and options for more profound data input. Output is displayed in graphs that show the rise and recession of water levels over time and water balance terms of both the sand dam and river banks.

SAND-IT utilizes an array of mathematical equations that together describe the retention of river water by one single dam system, i.e., the rise of water levels during wet periods and the subsequent recession of water levels due to water use, evapotranspiration and leakage. Here, leakage is defined as the loss of stored water by subsurface flow underneath or around the sand dam. The sand dam is modelled as one single bar-shaped reservoir with a user defined length, width and depth. It may include one or two river banks that contribute to the retention of flood water (see Figure 13). Each river bank, the left one and the right one, consists of 5 reservoirs, which are modelled as parallel strips of equal length to, and increasing lateral distance from, the sand dam. Each river bank also has a user-defined depth. The width of each river bank reservoir is auto-calculated by the model, but can be constrained by a user defined width. Each river bank reservoir can exchange water with adjacent river bank reservoirs or the sand dam reservoir through groundwater flow. The two river banks situated at the periphery of the sand dam system (i.e., the 15th left most and right most river bank reservoirs) contain no-flow boundaries, implying that exchange of water with the outside world does not prevail. It is assumed that groundwater levels in the sand dam system are topographically controlled (i.e., groundwater levels are permanently below ground surface level) by surface runoff of access water.

[3] The SAND Dam Infiltration Tool (SAND-IT) is developed by Acacia Water and KWR in order to make better and more accurate water storage estimations for siting. This tool requires simple input data from the field.

The model is based on several assumptions to simplify the complexity:

- The 3R sand dam infiltration tool calculates the volume of retention water over time by solving mass balance equations in tendem with Darcy's equation for groundwater flow.
- All reservoirs are assumed to be bar shaped, implying that the volume of water stored in a reservoir relates linearly with the water level.
- It is assumed that the sand dam system exclusively receives water by infiltrating river water during periods of river flow, and not by precipitation.
- Leakage is modeled as a permanent fraction of the total volume of water stored in a sand dam reservoir or river bank reservoir.
- The 3R tool assumes potential evapotranspiration across both river banks and a full reduction of evapotranspiration for groundwater levels lower than 1 meter below ground surface.

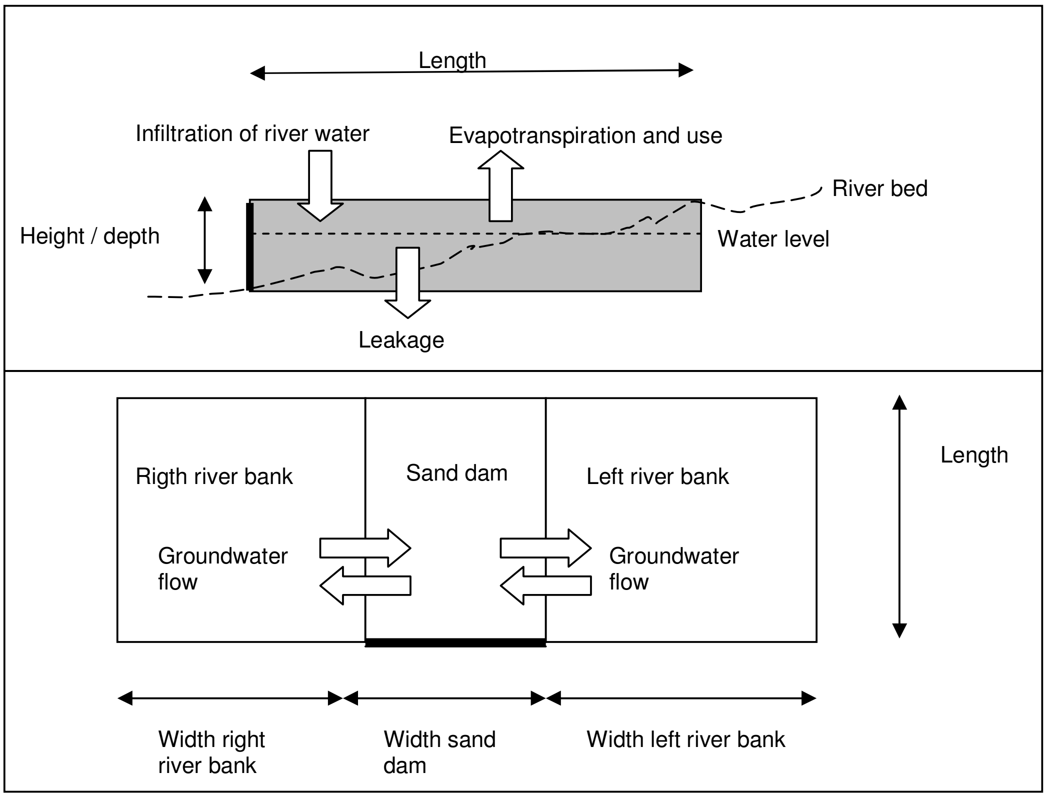


Figure 13: Model schematisation of a sand dam and adjacent river banks. a) Longitudal cross section through a sand dam. b) Cross section through a sand dam and adjacent river banks. (2011,Loon et al)

SAND-IT allows performing some explorative calculations using sand dam dimensions, the type of sediments in the sand dam and river banks and the average duration of river discharge as input variables. By providing more input data to the model, more advanced and reliable hydrological calculations are obtained. Providing permeabilities should preferably be established through slug tests and otherwise by grain size analysis. Hand-on methods for obtaining this information from the field are not included in this manual, but can be provided upon request.

The Excel spreadsheet model is arranged in progressive worksheets that should be consulted by the user in sequence. The first sheets contain a title page and brief introduction before proceeding to numerous pages that contain prompts for various dimensional, parameter or environmental inputs. Following this, a summary sheet of inputs and outputs is provided as well as several worksheets detailing relevant hydrogeological parameters over time such as water demand, gains, losses, storage and hydraulic heads. The model utilizes several large calculation worksheets to automatically perform the necessary model computations on given information and to calculate outputs. Many simplifying assumptions are made to make the model accessible to a broader audience and to cover the lack of high-quality data in remote and ungauged regions (See **Appendix 10**).

Water quality monitoring

Water stored in sand dam is of safe quality when it is protected against pollution. To confirm the reference water quality, the Water Committee should take a water sample from an observation well 50 meter upstream of the dam in the center of the river bed. A first sample has to be taken upon completion of the dam and sampling should be repeated on a yearly basis. The sample should be sent to a nearby laboratory for analysis on major ions (Cl, HCO3, SO4, NO3, K, Na, Fe) and physical parameters : EC and PH. If any changes are observed the water committee should call in the advice of water quality expert.

The main sources of pollution are the excreta from animals which dwell in the river during the dry season or dumping of other material which may cause pollution of the water during run-off and infiltration. The Water Community should take protection measures to avoid pollution of the riverbed:

- Livestock will be kept away from the river bed (100-200 m upstream of the dam
- No other garbage is dumped in the river bed especially during the dry period
- Organize a cleaning action just before the expected onset of the rains

Monitoring the impacts of the dam

One of the important issues in construction of sand dams is the question of its economic valuation. Is the dam cost effective? And is the cost of the dam generating enough benefits to justify the investment?

The cost effectiveness of the dams related to the proper siting, an appropriate design (no-over dimensioning,) and proper construction and supervision to avoid failures and delays.

The second question is important for funding agencies, to know that that their investment in the dams has a positive return through the benefits it provides. A widely used methodology to answer this question is the Cost Benefit Analyses (CBA). A CBA is an economic tool for evaluating the costs and benefits of an investment, thereby taking into account the total impact of a project on society as a whole and is also widely applied in the water sector. The CBA is considered a sound financial and economic analysis and can also be applied for sand dams. This has been done recently by Acacia (Acacia Water, 2010) and can be used as reference for CBA analysis of future dams. The CBA report is available on the provided CD-Rom.

Cost of dam

This is the easiest part of the equation. The cost elements of a dam are well known and proper documentation of the estimated cost and the real cost (after construction completion) should be an integrated part of the construction process. Table 3 gives a full list of the cost components as a checklist for calculating the cost of the dam.

Table 3: Generic list of 3R cost

Item	Item	Note
Capital expenditure	Preparation/quick scan	Consultant cost
	Siting and design	Consultant cost
	Construction	Degree of community participation
	Overhead profit	
Additional cost	Land acquisition	If needed these items may represent substantial cost
	Power supply	
	Legal cost	Fees
Social and environmental cost	EIA/SEA x)	Consultant cost
	Mitigation	Mitigation cost
Operating expenditures	Energy	Annual cost (US$/yr)
	Monitoring	
Maintenance	Maintenance of the structure	Annual cost (US$/yr)
Others		May include indirect cost

x) EIA: Environmental Impacts Assessment; SEA: Social Impacts Assessment

Benefits

The benefits are more diverse and include both direct and non-direct benefits (Table 4). Direct benefits are mainly the increased productivity, resulting in an increase of the family income. Indirect benefits such as improved health also contribute to the increase of income, but may also have other impacts (such as family cohesion and community well fare) that are more difficult to valuate.

Table 4: Generic list of benefits

Benefit	Item	Valuation
Reduced cost of water	Applicable if the cost of water before the 3R intervention was higher (e.g. tank car supply, bottled water)	Can be expressed in US$/yr
Increased household productivity	Economic benefits due to long term availability of more and better quality water which is used for crop growing, livestock watering or household industries	Benefits can be measured by increased production etc but will also be expressed in the increase in the (average) family income
Household/human well fare	Improved health, improved education, less time needed for water fetching, improved social cohesion and security	These benefits will partly be included in the increased family income and partly be indirect or long term benefits
Community, Government and Water shed benefits	Improved biodiversity Vegetation Drought resilience Reduction of subsidies Economic development	Indirect benefits for the **community** (economic development) or for the (regional) **government** (reduction of subsidies, drought resilience) and for the **water shed** (vegetation, biodiversity, reduced fertilizer use))

The benefits in table 5 refer to these benefits that are attributed to the construction of the dam. In terms of data collection this requires:

- A set of data prior to the construction of the dam
- A set of data of a location where no dam is constructed.

Annex gives checklist for the type of data that have to be collected by the Water Committee to allow for an economic evaluation of the dam after completion (yearly till 5 years after construction). The table below shows an example of the measured benefits of a sand dam in measured in Kitui, Kenya

Table 5: Summary of measured benefits (Lasage et all, 2008)

Indicator		Kindu (dam)		Koma (no dam)	
		1995	2005	1995	2005
Access to drinking water wet season	Km	1	1	1	1
Access to drinking water dry season	Km	3	1	4	4
Domestic water use	l/day	61	91	136	117
People exposed to drought	Nos	420	0	600	600
Health		0	+	0	0
Households with irrigated crops	%	37	68	38	38
Agricultural water cons.	l/day	220	440	160	110
Brick and basket production	Ksh/yr	1,500	4,500	0	0
Household incomes	Khs/yr	15,000	24,000	15,000	15,000
Vegetation density /biodiversity		O	+	O	O/-

1000 Khs = 14 USD; O: unchanged, +: slightly improved, - : slightly deteriorated

For a CBA, the cost and benefits have to be quantified. This is difficult for existing dams. New dams give the opportunity to incorporate a number of activities in the design and construction phase and after the completion of the dam. The economic evaluation itself can be carried out by a person who has experience in CBA application.

4.4 Sand dam management training

Training of local community

Based on the experiences of successful sand dam projects, the following aspects need to be addressed to carry out a community based sand dam project successfully. This included community trainings on implementation, operation, management and maintenance with the following objectives:

- Full participation in the process of the project planning and implementation;
- Enhanced awareness on project management;
- Ensured technical and management skills after project completion;
- Enhanced awareness on management of the water quality and risks involved.

This can be divided into three categories (based on the pilot sand dam project in Ethiopia):

- Sessions on the project planning, implementation and management of activities.
- Educational sessions on natural resources management, sanitation and hygiene;
- Technical trainings on operation, management and maintenance for the water committee.

During the training several educational sessions and workshops are given based on carefully selected questions to initiate group discussions. To make the training a successful contribution, at least each community elects five to seven members from the water committee and at least two other community members (future caretakers) for participating.

Sessions on the project planning, implementation and management activities

The lessons learned clearly indicate that in several cases a lack of proper project management led to several constrains during project implementation. One solution would be to focus on contingency planning with all relevant stakeholders for preparing project documents and programs in order to take care of possible cost escalations and implementation timeframes.

The following aspect should be addressed within this project management training;

- Proper planning of the construction – sufficient time available between the construction period and the anticipated starting period of the rainy season in the local area. (taking into account workers availability – migration)
- Acquiring skills with estimating and managing the project budget including a risk assessment
- Project monitoring and evaluation
- Giving importance to networking (to maintain contact with decision makers)

Educational sessions on natural resources management, sanitation and hygiene

These educational sessions will be facilitated by a qualified person from the implementing organisation, preferably in cooperation with a representative from the concerning local government department. During these sessions, representatives of the water committee are educated on several subjects to ensure awareness and understanding of natural resources management, sanitation and hygiene. Natural resources management will mainly focus on the proper and efficient management and usage of the sand dam. These sessions will take 5 days in total and are organised within the community (Munyao et al, 2004).

Box 16: Natural Resource Management training
This training aims to facilitate ways and means of management of natural resources. With the help of a questionnaire, the community gathers the necessary information about their available natural resources and explores ways and means of utilizing their natural resources to improve their livelihoods. By the end of the training, each community has developed a comprehensive list of the natural resources found in their villages. They compile the potential ways and means of using these resources in an action plan.

In the absence of hygienic water practices, attempts to ensure high water quality will be futile. Safe rainwater can be easily contaminated after extraction from the system, for example by the use of contaminated jerry cans or by contamination present on the hands of users. Therefore, hygiene education and monitoring of the operation and maintenance of the system, along with sanitary practices, are essential. Creating awareness on personal and system hygiene issues related to water is crucial. Local health organizations play an important role in educating consumers on water treatment methods, managing water supplies and giving specific guidance in managing, operating and maintaining RWH systems. Water supplies, sanitation facilities and hygiene behaviour work together as an integrated package: the quality of the approach in all components determines the outcome (Hygiene Promotion, Thematic Overview Paper 1, 2005).

Box 17: Hygiene training
This training focuses on creating awareness within the community on contamination risks of their water sources and giving guidelines for hygienic and practical guidelines on water usage. This training is based on the RAIN Water Quality Policy and on national and regional policies and programmes. At least one third of the local community is expected to participate, especially women since they are mainly responsible for collecting water, cleaning, washing and cooking: activities which have high risks of contamination.

Technical training on operation, maintenance and management

The water committee is responsible for proper operation, management and maintenance of the sand dam, which includes:

- Regular monitoring of the functioning and utilization of the sand dam; Workshop SAND Dam Infiltration Toolbox (SAND-IT), Appendix 10.
- Effective management of the water reservoir as far as possible.
- Establishing a demand driven payment scheme;

Two persons from the water committee or two community members will be trained on construction of the sand dam and wells by participating during construction. Technical knowledge and skills to execute maintenance and repair works is hereby ensured. These trained community members can become potential artisans for the construction of future sand dams within the area. They will become the caretakers of the sand dam, the wells and the surrounding area.

Box 18: Management training
The first step in the project management training workshop involves: the examination of the community experiences in their projects over the last five-year period, covering; Succesfull and unsuccessful projects and the reasons for success or failure. At the end of this analysis, the participants can draw lessons from experiences obtained in finalized projects, understanding the needs of the community and defining solutions themselves. This training will take several days and are organised within the community.

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Available Data Sources: for Quick scan

Digital elevation data of the Shuttle Radar Topography Mission (SRTM) can be freely downloaded from the internet, The data has a low resolution; 90 meter horizontal.
http://www.cgiar-csi.org/data/elevation/item/45-srtm-90m-digital-elevation-database-v41

Aster satellite images can be downloaded from http://asterweb.jpl.nasa.gov

Tropical Rainfall Measuring Mission (TRMM) satellite images, contain rainfall data with a spatial resolution of 4.3 km (In the region between 35°N and 35°S). Data is available on the internet on monthly basis http://neo.sci.gsfc.nasa.gov/Search.html

The geology of Kenya and Ethiopia is available from USGS. This map is part of the open file report 97-470A, version 2.0 2002, scale of 1:5,000,000. The dataset is an interim product of the U.S. Geological Survey's World Energy Project (WEP) and can be freely downloaded from the internet.

The New_LocClim program from the United Nations Food and Agriculture Organization (FAO) can be utilized in order to assist with the rainfall-runoff calculations, data on precipitation, evaporation and Runoff. New_LocClim is a freely available and easy-to-use spatial interpolator for agro-climatic data. It uses the FAO's Agromet database which contains climatic data from over 30000 stations all across the world. The New_LocClim program accesses this dataset and can provide the required information on average precipitation, evaporation, and runoff. The download set (which allows access to the Agromet database) can be downloaded http://www.fao.org/NR/climpag/pub/en3_051002_en.asp
LocClim also provides rainfall data (Freely available) http://www.fao.org/sd/2002/EN1203a_en.html

Appendix 1 Case studies from Ethiopia and Kenya

Sand storage dams to improve rural livelihoods in Kituï District, Kenya

The SASOL (Sahelian Solutions) Foundation started constructing sand storage dams in the Kituï District of Kenya in 1995. Since this period, over 500 sand storage dams have been constructed. The dams vary in size and dimensions because of differences in the geomorphology and the river flow. On average the Kituï dams are between 2-4 metres in height and around 20 metres in length.

The main advantage of the Kituï dams is that they use simple low cost technology and can be constructed by local communities using locally-available materials. The cost of an average sand storage dam, with a minimum life span of 50 years and storage of at least 2.000 m^3, is about US$ 7.500. About 40% of overall construction cost is provided by the community. They are involved in the construction of sand storage dams by provision of labour and collection of raw materials, by so called sand dam management groups. After construction, these groups have ownership and take care of the maintenance of the dams and protection of the water quality, which ensures sustainability.

Box 19: Quick facts Kituï region:

Area:	20.400 km^2
Population density:	25 persons / km^2
Climate:	semi arid (precipitation: 250-750 mm/year falling in two wet seasons, open water evaporation 2000 mm / year)
Geology:	Metamorphic and igneous basement covered with weathered rock
Soils:	Silty and clayey sediments, low fertility. In the western part black cotton soils.

Sand dams are build to improve the local water availability throughout the year, but next to this, there are several significant social and economic impacts as shown in Table 1. The main objective of a sand dam is securing drinking water for local communities and for domestic use, also it can provide water for development of rural commercial activities; such as small scale irrigation (cash crops and tree nurseries), and industrial activities (brick making). Besides improving the water availability it can save time, since less time is needed to fetch water (see table 1). In this way school attendance increases significantly and more time can be spent on other income generating activities, like household industries (basket weaving, sewing). Often sand dams are built in sequence, in this way the water table increases over a larger area. This can contribute to ecological regeneration throughout the catchment.

Table 6**:** Measured social and economic impacts of sand dams in the Kituï region, Kenya (after Thomas, 1999).

Vulnerability Categories	*Vulnerability indicators*	*Before dam construction*	*After dam construction*
Agriculture	# of cash crops	1.5	3
	% irrigated crops	37	68
Special aspects	Water collection Domestic (minutes)	140	90
	Water collection Life Stock (minutes)	110	50
Gender	Average walking distance women to water (km)	3	1
Economic	Income (US$./year)	230	350
Health	% households suffering from malnutrition	32	0

There are several examples of subsurface dams in Kituï that are already operating for 25 years or more, and which are still fully operational. Sand dams require little maintenance which is the responsibility of the dam committee. The committee should be trained to perform evaluations and report this to SASOL.

The catchment approach: an example project of combining water harvesting techniques in the Borana Region, southern Ethiopia

The Borana Zone is located in southern Ethiopia, it is a semi-arid area in which rural communities depend mostly on livestock farming (mostly pastoralists) and small-scale agriculture. Both activities are highly constrained by severe water shortage due to erratic rainfall and droughts. The spatial en temporal water scarcity remains, since the ephemeral rivers follow the precipitation and the water is not stored or retained.

The communities in the Borana zone live in very remote areas, with poor or without access to water, electricity and or sanitation facilities. Children in this region have the lowest school enrolment rate in the country, also because substantial amounts of time is spend in collecting water.

Water harvesting technology establishes a decentralised water source in areas, whereas other means of water supply have little potential. Here the sand dam technology provides a solution for the people of Borana. Rooftop water harvesting is not effective, because of the thatched roofs and limited storage (only provide sufficient water for the dry period) and the lack of good quality water.

Photo 7: Sand dam site after first flood event in Borana, Ethiopia (ERHA, 2008).

Photo 8**:** Woman fetching water from a surface runoff tank in Borana, Ethiopia (RAIN, 2007).

Communities are already known with the phenomenon of collecting water from ephemeral river beds. However the sand dam technology itself is not very common in Ethiopia. The combination of infrastructure to recharge groundwater and to harvest surface runoff water is innovative.

In 2007, RAIN, ERHA, AFD, Acacia and SASOL started an award winning pilot project of training 10 NGOs throughout the country along with implementation of 6 sand dams and 7 surface runoff tanks in Borana. It provided drinking water and water for irrigation and or industrial use in the short- and long-term for communities, living both adjacent to an ephemeral watershed (by sand dams) and those further away (by rainwater harvesting tanks) (see figure1). The project increased access to a reliable source of water for at least 10 communities and gave incentives for further up-scaling in other parts of the country.

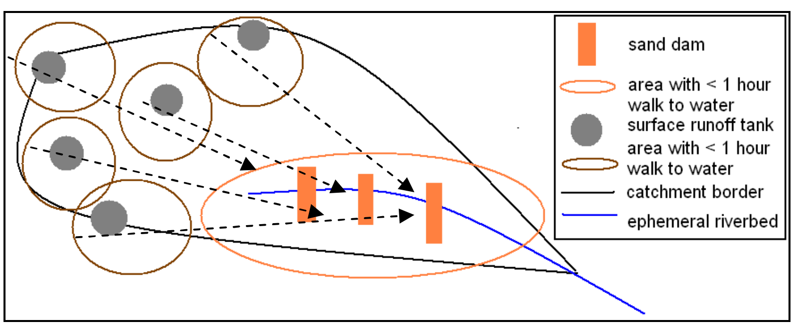


Figure 14**:** Hypothetical example of catchment approach in rainwater harvesting: combining sand dams and rainwater harvesting tanks in one (sub)catchment.

Appendix 2: Checklist for first and detailed technical site selection

Criteria for first site selection:	*compulsory*	*optional*
A stony catchment area (source of sand) and sandy riverbeds	x	
A sandy riverbed	x	
Two high and strong riverbanks	x	
A maximum width of 25 metre	x	
No fractured rocks or large boulders	x	
No salty rocks	x	
Presence of water-indicating vegetation		x
Presence of waterhole		x
Presence of riverbed crossings		x
Type of community structures within in the area, possible conflicts etc.	x	
Type, suitability and availability of construction material	x	

Steps for detailed site selection:	*compulsory*
Measuring the water extraction rate of potential riverbed(s) section(s)	x
Making a plan of the potential riverbed(s) section(s) with information on the river length and width, locations of cross-sectional and longitudinal profiles, water-indicating trees and waterholes	x
Making a longitudinal profile of the potential riverbed(s) section(s) by probing (see attachment 2)	x
Making cross-sectional profiles of the potential riverbed(s) section(s) by probing (see attachment 2)	x
Selecting different points in the riverbed section in which the sand is the deepest (potential reservoirs) and in which the natural underground dykes are most shallow (potential sand dams locations)	x
Selecting the point where the sand is the deepest and therefore the largest reservoir can be selected	x
Selecting the point where the underground dyke is most shallow and therefore the location of the sand dam	x
Making a cross-sectional profile of the potential sand dam location	x

Generally, sites feasible for sand dam construction have the following features;

- Having scoop wells with good quality of water
- Having no big boulders on the bed of the river
- Slope of the river bed not more than 5%
- Having an impermeable or bed rock layer at shallow depth
- Coarse sand on the bed with less silt content
- Stable and high enough river banks
- Maximum flood level below top of banks
- Straight reach with narrow width (<25m)
- Un-weathered bank and bed formations free from downstream directed stratification
- Local construction materials available at nearby areas
- Free from sources of contamination and salinity
- Accessible and close to majority of the beneficiaries
- Sites free from conflicts related to land rights and water usage

Appendix 3: Checklist for river section inspection and ranking

1. Location and types of water-indicating vegetation.

A good indicator for the presence for groundwater is current vegetation. Depending on the species, the groundwater depth and storage of water can be estimated. In the table below some names of trees are given which indicate water at a given depth below the surface.

Botanical name	Kiswahili and Kikamba names	GW-Level
Cyperus Rotundus	Kiindiu	3 – 7
Vangueria Tomentosa	Muiru Kikomoa	5 – 10
Delonix Elata	Mwangi	5 – 10
Grewia	Itiliku Itiliku	7 – 10
Markhamia hildebranditi	Muu Chyoo	8 – 15
Hyphaene Thebacia	Kikoko Ilala	9 – 15
Borassus Flabellierfer	Mvumo Kyatha	9 – 15
Ficus Walkefieldii	Mombu	9 – 15
Ficus natalensis	Muumo Muumo	9 – 15
Ficus malatocapra (Vista)	Mkuyu Mukuyu	9 – 20
Gelia aethiopica	Mvungunya Muatini	9 – 20
Piptadenia hildebranditi	Mganga Mukami	9 – 20
Acacia seyal	Mgunga Munini	9 – 20

Figure 15: Water-indicating vegetation with root depth.

2. Location of waterholes, their depth to the water table and quality of the water.

The presence of waterholes (especially after the rainy season) is an indication that the riverbed contains deep water storage and it does not leak to deeper groundwater rapidly. Especially attention is needed to those waterholes, which provide water over a long time, during the dry season. Here it is important to specify the depth of the water table in relation to the riverbed surface.

The water quality in the waterhole is an indication of the quality of water which can be harvested after building a sand dam. However, the water quality can improve significantly by taking protective measures against animals. (Improvements can be achieved, see: RAIN water quality guidelines).

3. Location and types of rocks and boulders.

If large boulders are present in the riverbed, special care should be taken in choosing the sand dam location. Preferably the sand dam is build on (and its wings attached or projected into hard rock or a consolidated and strong soil. If a large boulder is confused with massive rock, water can leak from the sand dam reservoir, leading to unnecessary loss and potential undermining of the sand dam. Check whether hard rock is present in the riverbanks and – bed by looking for rock outcrops (conducting probing test at different points using metal rods and hammer).

Pay special attention to the presence of halite near the riverbed, which is a salty whitish substance, that turns water saline. If salty rocks (white and pink mineral rocks) are situated in the riverbanks upstream of a dam, then the water may be saline and therefore only useful for livestock. Local communities often know if there are any salty rocks, because livestock consumes these rocks for the salt content.

Photo 9: Examples of salty rocks

Seepage under the dam may occur, if the riverbed itself contains large stones and boulders. When large boulders are observed downstream of the potential dam site,(as the chance of apron damage, even the spill way could be higher from the rolling builders by flood), special care should be taken, since this could damage the structure (rather look for alternative sites or consider a subsurface dam). Soil data can provide information on the location of sandy areas within a catchment (see next point 4).

4. Grain size of the sand (coarseness), particles in the riverbed.

The grain sizes which are present in the riverbed are a good indication of the material which will fill up the sand dam reservoir after construction. Coarse sand is preferred, since it has a higher infiltration capacity and water can be abstracted more easily.

5. **Shape and dimension of the riverbanks.**

Suitable riverbeds for sand dam consist out of high riverbanks. During flood events the river should not flow over the riverbanks, because this can cause erosion of the riverbanks, flooding of downstream located villages and it might cause the river to change its course. By using flood data and information from local water departments and local knowledge of the community, the maximum water height during a flood event can be estimated and determined. The minimal height of the riverbanks should be: *Minimum height riverbanks = Height of dam + Flood height + max. 10% (safety height)*

6. **A (preferred) maximum width of 25 meter.**

Preferably, riverbed width should not exceed 25 metres. The reinforcement required to construct such kind of long dam walls is too expensive; hence the sand dam will not be cost-effective. The choice for technology is also depending on the peak floods and the width of the river (over a maximum width of 25 metres subsurface dams seem more appropriate, (Nissen Peterson, 2006)) Other alternatives, such as subsurface dams, should be considered instead.

7. **An impermeable (bedrock)layer.**

To ensure storage of water within the sand dam aquifer, losses through leakage to deeper groundwater should be minimised. Therefore, the dam should be built on solid bedrock or an impermeable layer. This will also protect the sand dam from undermining through groundwater flow underneath the sand dam. This can be checked by using the geological map and outcrops in the area. Also, holes can be dug in the riverbed to find the depth of a consolidated layer or bedrock layer.

8. **Type, suitability and availability of construction material.**

The construction materials which are locally available (such as sand (water), rock outcrops, bricks, etc.) can help to determine the most cost-effective type of sand dam for construction. For example, a masonry dam is not a good choice when stones are not locally available in the area (Transporting the stones from other areas is very expensive).

9. **Presence of riverbed crossings and roads.**

Rural roads often cross riverbeds. Preferably a sand dam is located near these crossings and can be easily reached through existing roads (also for transportation and supply of materials).

10. **Names of houses, schools and shops near the riverbed.**

The local people benefit from the sand dam, direct or indirectly. By measuring these positive social impacts before and after implementation, the actual social impact can be determined. An assessment of the actual water use (before and after implementation can show how the community is benefiting from increased water availability, (indicate positive economic development or spin off).

11. **Land rights.**

Agreements based on rules and regulations (or bylaws) are needed to assure fair use and access to water for collective and individual usage. How to share and distribute the water are important issues to arrange properly, in order to realise fair access and usage. The allocation of water has to be arranged within the communities together with the farmers and pastoralist. To avoid conflicts, special care should be taken in areas where the dam site is owned or used by two or more villages or several individuals.

Appendix 4: Steps for community involvement during site selection.

Step 1: Creating awareness and sensitizing the community.

Starting a sand dam project in a catchment potentially suitable for implementation begins with sensitizing the community's awareness on the project, by undertaking regular visits to the project area and facilitating meetings with the representatives and members of community. All communication shall be carried out with respect to the existing institutions, rules and habits of the community.

Step 2: Community assessment and performing a water use assessment.

The best-suited sites identified during step 1 are visited and a dialogue with the community is held. During this meeting, the project staff and community discuss the possible environmental and social impact of the development of sand dam within the area. The following information needs to be gathered.

- Assessing the water problems of the targeted communities. During a plenary discussion problems and possible solution should be discussed by the community. Ownership, number of beneficiaries and their participation and involvement, timing of construction are discussed.
- Organising meetings or group dialoguing concerning the development issues within the project area. Project staff, community members including influential persons, local administrators, politicians, elders (both men and women), youth leaders and any other development agencies within the area should participate in these meetings.
- Informing and educating the community members on the various types of water harvesting technologies, in particular the sand dam technology. Advantages, disadvantages, feasibility, site selection criteria, the construction process and the level of community participation will be discussed.
- Assessing possible sand dam locations with the community. The community will be involved in site selection based on their local knowledge of the area. The selected sites should be discussed with local authorities.

Step 3: Establishing a water committee.

The water committee will need to be established, and its responsibilities will need to be defined in a binding document like a Memorandum of Understanding (MoU) between the water committee and the implementing partner. Each sand dam will have a water committee containing a maximum of nine members. At least 50 % of the committee members are selected from women representatives. Two members from the committee selected as care taker and will be responsible for operation and maintenance of the sand dam. Its duties are to mobilize resources, plan the site works, record progress, supervise and monitor the implementation process amongst else. The committee must on weekly basis monitor and evaluate the progress. On the part of the implementing partner, the MoU states:

- to supply all construction materials if not locally available;
- to supply in skilled labour;
- to provide technical supervision

Furthermore, the water committee and implementing partner will have to draw a Community Action Plan (CAP), containing an implementation schedule until completion. This is documented in a tabular format defining all the activities and responsibilities. It clearly defines the roles of each partner within the project i.e. the community and implementing organization.
The action plan will contain the following issues:

- Bill of Quantities for the material and labour in which the community will supply during the project.
- A work plan in which a clear and realistic time frame is given.
- Security of storage of materials and supervision on site.

On the part of the implementing partner, the MoU states:

- to supply all construction materials if not locally available;
- to supply in skilled labour;
- to provide technical supervision

Step 4: Organising community mobilization for required participation works during the construction process.

At the start of the construction process, the following activities are should be undertaken:

- The actual movement of resources like transportation of equipment and tools to the site,
- Involvement of skilled and unskilled labour. Elderly at the head of community committee are in charge of mobilizing community members because of their respected position and accepted authority in the community.
- The implementing partner will provide a representative at the grassroots' level; he/she will coordinate all activities. He/she advises elderly on community mobilization and participation.

Appendix 5: Data collection for the selected river section

The tools required for simple surveys as follows (Nissen-Petersen, E. 2006):

- Measuring rods made of 16 mm (5/8") iron rods for measuring depths of sand. Notches should be cut in the probing rods for every 25 cm to collect sand samples when the rods are pulled up.
- A circular levelling tool made of a transparent hosepipe for measuring the gradients of riverbeds.
- Two long tape measures, one hanging down vertically from the horizontal one, to measure width and depth of riverbeds.
- A tripod ladder for hammering long probing rods into the sand.
- A mason hammer.
- A 20 litres jerry can with water.
- Half a dozen of transparent plastic bottles with water.
- A knife and writing materials,
- A Data Sheet as shown below.

Example of a Data Sheet:

Measurement nr.	*Distance between measurements (m)*	*Width of riverbed (m)*	*Depth to water (m from surface)*	*Depth of the sand (m from surface)*	*Type of sand*	*Type of bedrock or soil under the sand*	*Height of the riverbank (m)*		*Items seen on the riverbanks*
							Left	Right	
1	0	20.8	-	0.5	Medium	Clay	1.5	1.9	Acacia tree
2	20	24.2	-	0.6	Fine	Clay	1.0	1.6	
3	20	28.2	-	0.7	Medium	Clay	1.4	1.84	Waterhole
4	20	25.5	0.30	1.25	Medium	Rock	1.3	1.7	
5	20	19.5	-	0.8	Coarse	Rock	1.4	1.65	Fig tree
6	20	21.3	-	0.7	Coarse	Clay	1.4	1.7	
7	20	18.6	0.8	1	Medium	Clay	1.97	1.55	
8	20	17	1.2	1.3	Coarse	Clay	1.3	1.64	Rock

Appendix 6: Questionnaire water use assessment

GENERAL						INTERVIEWER / NGO				INTERVIEWEE					
Date	Country	District	Village	GPS Longitude	GPS Latitude	Name Interviewer	Email and telephone nr.	NGO	Name employee NGO	Name	Gender	Age	Marital status	Main income generating activity	Other income generating activity

HOUSEHOLD (number of people living)					COMMUNITY					PERSON(S) FETCHING WATER in HOUSEHOLD				
Girls (0 - 15)	Boys (0- 15)	Men (>15)	Women (>15)	Total	Girls (0 - 15)	Boys (0- 15)	Men (>15)	Women (>15)	Total	Girls (0 - 15)	Boys (0- 15)	Men (>15)	Women (>15)	Total

DRY SEASON									
Main water source	Distance (km)	Time one way (hours)	Use for drinking?	Treatment method	**Other water source**	Distance (km)	Time one way (hours)	Use for drinking?	Treatment method

RAINY SEASON									
Main water source	Distance (km)	Time one way (hours)	Use for drinking?	Treament method	**Other water source**	Distance (km)	Time one way (hours)	Use for drinking?	Treatment method

WATER USE DRY SEASON (average litres per person per day)									WATER USE RAINY SEASON (average litres per person per day)								
No. of months	drinking	cooking	shower	washing	livestock	agriculture	other	Total	**No. of months**	drinking	cooking	shower	washing	livestock	agriculture	other	Total

Appendix 7: Calculating the quantities of materials

I. Concrete

Mix Ratio – 1 : a : b

Where: 1 = cement proportion : a = sand proportion : b = coarse aggregate proportion

If the amount of concrete needed is C, then:

Cement Quantity (kg) = 1 * C * 1400 * 1.3 * 1.05/(1+a+b)

Sand Quantity (m3) = a * C* 1.3 * 1.15/(1+a+b)

Gravel Quantity (m3) = b * C * 1.3 * 1.15/(1+a+b)

II. Stone Masonry

For water tight structures usually 65% of masonry body is proposed to be stone and 35% cement mortar. So, if the volume of stone masonry work is S, then

Volume of Stone (m^3) = 0.65 * S * 1.3

Volume of Mortar, M (m^3) = 0.35 * S

If mix ratio of mortar is 1: C,

Cement Quantity (kg) = 1 * M * 1400 * 1.2 * 1.05/(1+C)

Sand Quantity (m3) = C * M * 1.2 * 1.15/(1+C)

III. Plastering

Follow the same formula used for mortar ingredients of stone masonry.

IV. Pointing

Pointing area is taken as 1/3 of plastering area and then follows the same way used for plastering.

V. Water

Water required for mixing, curing, washing dirty construction faces, workers construction and food preparation is roughly calculated from the total cement requirement of the site.

If Z Quintals of cement is required to complete the construction work,

Total volume of water = 280 * Z

Appendix 8: Guideline for sand dam construction & maintenance

Step 1: Placing reinforcements
These are placed vertically across the entire length of the dam at an interval of 2.5m. They are round bars with a diameter of 12.5 mm and the length depending on the complete height of the dam. The amount necessary can be determined as follows:

No of columns = $\frac{Ld}{2} - 1$

With L_d : length of the dam in metres.

For example: iIf L_d =10, Then No of columns = $\frac{10}{2} - 1 = 4$

Mark the positions of the columns along the building line, then measure the vertical depths to the bottom of the trench and record them as follows.

No 1 =2.53m, No 2=2.27m, No 3 = 3.05m, No 4 = 1.97m

The round bars of the columns are firmly grouted into holes on 5cm deep that have been cut into the foundation at the requested depth (depending on the bedrock material or soil type).

Step 2: Making the foundation blinding slab
A layer of cement mortar (1:3) is prepared on the foundation to the depth of 5cm. When there is no foundation rock the vertical iron bars are placed in the mortar layer.

Step 3: Constructing the first horizontal reinforcement layer
After the mortar layer 12 strands of barbed wire are evenly divided over the building slab along the dam.

Step 4: Constructing the second foundation blinding slab
The barbed wire is covered by 5cm of foundation blinding slab.

Step 5: Masonry comprising hardcore and mortar substructure
After the foundation blinding slab sets and holds the columns firmly, the foundation trench is filled with masonry comprising clean hardcore and mortar (1:4). Mortar for filling should have more water. The joints between the rocks are filled 25mm of this mortar. The rocks should be tapped well to settle completely into all voids. When the filling reaches the level of the back flow, the construction of the backflow should be done along side that of the wall as shown. Masonry comprising is extended to the wind wells.

Step 6: Installation of templates above the sand level
The two templates made of timber are erected at the ends of the spillway for giving the outline of the dam wall, spillway and wing wall. Nylon strings have to be drawn tightly from the inner corners of the templates to pegs hammered into the soil next to the upper end of the wing walls. In this way, the position of the outer sides of the masonry wall can be determined.

Step 7: Constructing Masonry hardcore and mortar substructure within two templates
Flat stones have to set in cement mortar 1:4 along the inner lines of the strings. The next day, the space between the flat stones has to be filled with mortar, 1:4, into which round rubble stones were compacted. After that the flat stones were mortared onto the wing walls so that they could be filled with mortar and stones the following day.

Step 8: Preparation and construction of the stilling basin structure along with the dam body
The base of the dam wall, the spill-over apron and the spillway,(the latter being situated between the two templates), were only raised to 30 cm above the original sand level in the riverbed. A small flooding deposited a 20 cm layer of coarse sand that reached the first stage of the spillway. The

spillway was therefore raised another 100 cm above the sand level, for the next stage of the spillway. The wing walls construction is executed at a time while extending each stage of the dam height construction.

Step 9: Stilling basin construction with the stone pavement for flood protection at the bank of the river
Large boulders were concreted into the spill-over apron, to reduce the velocity (speed) and speed of surplus water falling over the spillway and wing walls. Stone pavement were placed as a unit part of the stilling basin and extended at either side of the riverbank to downstream of the flood flow.

Step 10: Construction for the dam wall
The next flooding deposited coarse sand up to the level of the spillway. The spillway was raised another 30 cm above the new sand level. The process of raising a spillway in stages of 30 cm height, may be completed in one rainy season provided the required number flooding occurs and builders are ready for their work without delay.

Step 11: Plastering and pointing works
Exposed dam section at the upstream side, top surface of the entire dam and wing wall section are plastered with cement mortar of ration 1:3. The upstream section of the dam well plastered to be watertight. Downstream-exposed section of the dam wall and the stone pavements extended from the stilling basin were pointed with cement mortar mix ratio of 1:3.

Guideline for sand dam maintenance

Repairing cracks and weak points in the dam
Sand dams require careful maintenance, and immediate repair, as flooding causes hundreds of tons of water to fall over the dam wall and onto the spill-over apron. Flood water may also spill over and erode the wing walls and, perhaps, even over the riverbanks during heavy rains. Extreme changes in temperature can cause the structure crack. If any cracks or weak points are observed in the sand dam, a technical engineer and mason should inspect the whole dam structure and execute repair works before the following rainy season.

Cleaning the well
The well should be covered and closed at all times. Regular checking of the water content is not recommended, since debris or human faeces could fall in the well and contaminate the water. If an animal, chemicals or other health-risk related substances have polluted the well, using the water for drinking purposes is strictly prohibited. The well should be inspected by an expert on water quality and a action plan should be made. If contamination is suspected which can be removed by simple and local water quality measures, then these should always be applied before use of the water.

Cleaning of the outlet
It is very important that the outlet isn't blocked with silt of other fine textured material. It is therefore important to have a good access to the outlet construction. Blocking of the outlet can be prevented by the designing criteria . Regular cleaning of the riverbed just upstream of the sand dam after a flood can prevent silt from percolating downwards into the riverbed and blocking the outlet. If contamination of the water is suspected which can be removed by simple and local water quality measures, then these should always be applied before use of the water.

Removing silt from the top of riverbed of the reservoir
The riverbed (especially just upstream of the sand dam) and the surrounding area of a sand dam have to be kept as clean as possible: rocks, branches, leaves, dead animals, animal dropping and fine textured material should be removed since they can lead to contamination of the water, reduce the capacity of the dam, lead to blocking of the reservoir and outlet or cause damage to the dam structure. Debris like rocks, branches, leaves and sediment are usually deposited after a flood event, so the time of inspecting is well known. But dead animals, animal dropping and other debris can be deposited any time. It is wise to have a strict schedule for inspection of the dam and its surroundings.

Appendix 9: Guideline for well construction

Based on (Nissen-Petersen E, 2006)

Step 1: Excavation.

- Select the site and clear the area for excavation
- Mark out a circle of 1-metre radius.
- Dig the well using skilled man power as the well should be excavated straight for the diameter of 2 metres.
- Excavation of well continues until a depth at which sufficient water from the lowest water level of the sand storage can be extracted. Well digging is normally carried out in the dry season when the water table is lowest.
- While the digging process is ongoing, local construction materials such as sand, stones and preparation of crashed stone will be executed simultaneously.

Step 2: Construction of concrete ring and blocks.

Preparation of concrete ring. This ring will have an outside radius of 75 cm and inside radius of 55 cm. The width of the ring is 20 cm and the thickness is 25 cm. The ring is made in a circular trench carefully dug to the correct dimensions. A concrete of mix of cement, sand and crashed stone (1:3:4) is used and six round of 3 mm galvanized wire are used to provide reinforcement of the ring. Additionally, 16 vertical pieces of wire 60cm long are attached to the reinforcing for fixing rope when lowering the ring in to the shaft. The ring is kept wet for seven days to cure the concrete.

The concrete blocks are made in specially fabricated mould with curved sides. The block is 15cm high, 10cm wide and 50 cm long. The concrete mix is the same as for the ring. The blocks are placed on a plastic sheet and kept wet for seven days for curing.

Step 3: Construction of the well cover.

The well's cover is made with a diameter of 150 cm and thickness of 10 cm; it has a hole of 60 cm in diameter in the middle. This will be used for drawing water. An additional smaller hole, 10cm in diameter, is made to one side as outlet hole to allow an exchange of fresh air. The cover is cast in an excavation in the ground. The same concrete mix is used as before together with 8 rounds wire connected by 31 shorter pieces of reinforcement.

The well lid to cover the centre hole is made in a similar manner with barbed wire reinforcement of 50 mm thickness. Two handles of round bars should be made for lifting.

Step 4: Construction of the well shaft.

The well ring is lowered using ropes if sufficient depth of the well has been reached.

The con is lowered using ropes with the help of at least 15 men because of the weight. The concrete blocks are lowered one by one in a bucket. A cement and sand mortar mix (1-3) is used for the vertical joints and between the ring and the first course.

In the horizontal joints between the first and second course and the second and third course, no matter is used so that water can gain entry. One round 3-mm galvanized wire is used with mortar between the third and fourth course and a step made from a round iron bar is installed. The same sequence continues until there are six horizontal joints without mortar through which water can enter. All subsequent joints are mortared. Steps are installed every three courses. After every six courses, the surrounding space in the well shaft is filled with coarse sand to act as a filter.

The shaft is built till 60 cm above ground level to prevent surface runoff from entering the well. Barbed wire is left sticking out to joint with the reinforcement in the apron that will be constructed around the well shaft to keep the area clean and prevent contamination.

The apron extends around the well shaft and slopes outward to a distance of 1.2 metres. This area is first excavated and then back-filled with hardcore to a depth of 30cm, to which is added a 5-cm layer of ballast. A 5-cm layer of concrete (1:3:4, cement:sand:ballast) is laid on the surface, and barbed wire is placed concentrically and radially for reinforcing. A further 5 cm of concrete covers the reinforcing.

The apron is surrounded by al low wall with a gap to allow spilt water to drain away. Building two steps complete the work, each 30 cm high, to the well cover, plastering as necessary and placing the lid in position. Before the well can be used, the community must remove all the water and clean the bottom.

Appendix 10: Working with SAND Dam Infiltration Tool: Water storage

The worksheets have color-coded tabs according to purpose; sheets requiring input are with green tabs, sheets where output is presented are with blue tabs and one sheet where large amounts of calculations are performed with a dark grey tab. The user should give input data only in the green tabbed input sheets at the given prompts. Instructions for data input are provided in the next section. The Basic Input and Results sheet displays two boxes: the “Main Input Variables”-box and the “Preliminary Results”-box. In the “Main Input Variables”-box, some elementary input for the sand dam and the river banks needs to be entered.

Main Input Variables box:
This box consists of five boxes that are reserved for input for successively (1) the sand dam, (2) the right river bank, (3) the left river bank, (4) some environmental variables and (5) output control. Below, the input fields of each of these boxes are briefly described.

In the sand dam box, the dimensions of the sand dam need to be specified (*height, length, width and area*), as well as the *sediment type* and *leakage factor*. The most appropriate sediment type should be selected from the drop-down list. The selected sediment type is used to auto-calculate the permeability and main extractable porosity of the sand dam’s sediments using Table 2. If available, an empirically established extractable porosity can also be entered in this box. This will override the auto-calculated porosity.

Leakage factors, defined as the percentage loss in the reservoir over a day, represent losses through the dam and through the material underlying the reservoir. The leakage factor strongly influences the available water from the dam system, but is particularly difficult to establish by field surveys. Leakage factors are therefore often used as calibration parameters. Note that a leakage factor of 0 % will be used if not specified differently.

The right river bank and left river bank boxes provide the opportunity to specify the geohydrological features of either river banks. Firstly, *sediment types* need to be selected from drop down lists for each river bank. The *permeability* can be overridden in the “Additional river bank data input”-sheet (see below). Optionally, values for *the depth of the impermeable substrate* (m below dam crest), the *maximum width of the river bank*, and a leakage factor can be entered. If not specified, depths and

leakage factors are set equal to that specified for the sand dam and the maximum width of the river bank is auto-calculated. It is advised to enter a maximum river bank width, because auto-calculated river bank widths can become unrealistically large. (If river banks are not expected to contribute to the retention of river water, a very small width of e.g. 0.001 m should be entered.)

In the “Environmental variables”-box, values for the expected duration of *river discharge (days)*, *evapotranspiration (mm/d)* and *water demand (m3/d)* need to be specified. The expected duration of river discharge is used to (1) auto-calculate the width of each river bank based on a tidal attenuation equation, and (2) calculate recharge of the sand bank by river water, assuming that the sand bank is completely flooded during periods of river flow. The characteristics of both river discharge and water demand can be further specified in one of the following sheets. The evaporation input is considered to be the total potential evaporation and estimates can be obtained from FAO’s New_LocClim program. No evaporation is assumed to occur if the water table is below an extinction depth of 1m below the surface.

Finally, the user is provided the option to set the *length of time steps* in the “Output control”-box. By choosing a relatively large time step, calculation time can be substantially reduced.

The Preliminary Results box
The right hand side of the Basic Input and Results Sheet (columns G-M) provides some of the results of the calculations performed by the 3R tool. These results include an estimation of the Volume-water level relation, the rise and recession of groundwater levels in the sand dam in response to river water infiltration, and water balances over a one year period, including the error in the calculated water balance.

Optional Sand Dam Data Input
This sheet provides the opportunity to provide the 3R-tool with additional data collected from the field, once the sand dam is operational, i.e., the sand dam is filled with sediments. The sheet contains input fields for three types of data, namely (1) experimentally established permeabilities of the sediments in the sand dam, (2) porosities of the sediments in the sand dam, and (3) depths throughout the sand dam.

Permeability
In the "Override kdam"-box, one can specify the *permeability of the sediments* in the sand dam. Preferably, the permeability is established by performing multiple slug tests. If no slug test data is available, one may enter permeabilities derived from grain size determinations. Instructions about both methods can be found in the 3R documentation A maximum number of 5 experimentally established permeabilities can be entered. If more than 5 values are available, one may enter an average value.

Porosity
In the "Sedimentology"-box, one can specify *main-extractable porosities* of the sediments in the sand dam for up to three zones. These zones represent horizontal layers composed of distinctly different sediments. In the absence of multiple layers, one may leave the lower input fields empty.

Depths
In the "sand dam depths"-box, one can *specify observed depths* of the sand dam. These depths are used to calculate the V-h relation more accurately, but they are not used as input of the equations that describe the water level rise and recessions over time. The user should specify whether depths have been gathered randomly throughout the sand dam, or by means of a transect study.

Infiltration input to dam
This sheet allows the user to enter times when *infiltration* into the sand dam system is occurring. Infiltration into the sand dam is the only system input considered by the model, no surface runoff from the banks or direct rainfall is assumed to occur. To govern infiltration into the sand dam, a constant value of infiltration over a surface area is used whenever surface water ponding or flow is observed. The user can define multiple times when this occurs and also, the amount of total dam surface area undergoing infiltration can be input. The constant rate of infiltration is considered to be $0.25*k_{dam}$ of the sediments in the dam as recommended as a general rule by Bouwer (1978). The flexibility in infiltration duration and intensity can be used to reflect longer and shorter wet seasons of varying intensity.

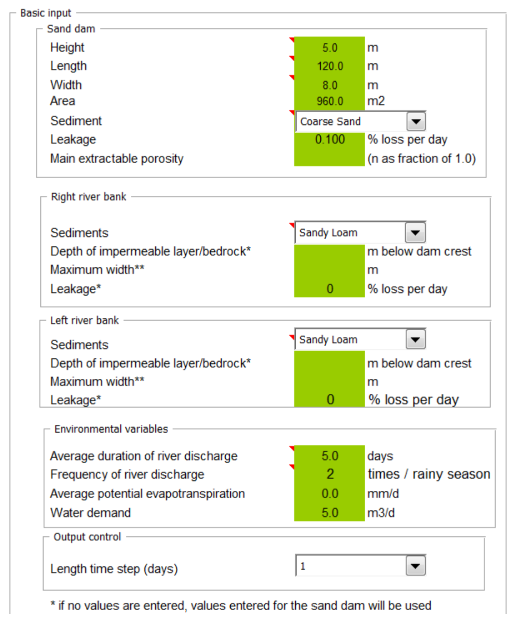
Water use
SAND-IT assumes that water is only abstracted from the sand dam, and not from the river plains. The *volume of water demand* needs to be specified in the Water Demand Sheet. The user may either specify a permanent water demand or a temporally varying water demand. In the latter case, both abstraction rates and their timing need to be specified.

Optional river bank data input
In the Optional River Bank Data Input Sheet, more detailed information about the sedimentology of both river banks can be entered. The user may prompt up to 5 *permeabilities and porosities*, which are used to override the values auto-calculated by the model using the specified sediment type in the "Basic input and preliminary results sheet". If more than five empirically established values are available, the user may enter average values. Note that permeabilities should preferably be established through slug tests and otherwise by grain size analysis.

The complete instruction manual for SAND-IT is available on the provided CD-ROM.

Appendix 11: Case Study using SAND-IT

The Model SAND-IT allow users to simulate the hydrological process of a sand dam at a specific site location using simple local input. The actual water storage over time can be calculation according to the local situation. In this way the functioning of the sand dam is better understood and improvements of the design can be initiated. To have an idea how the model works a sand dam “Ougele” in the Borena Region in South Ethopia is used as a case study. Information (input from the field) which was not available is estimated. The model run is calculated for one year.



Input: In the field the following data has been collected and or estimated;

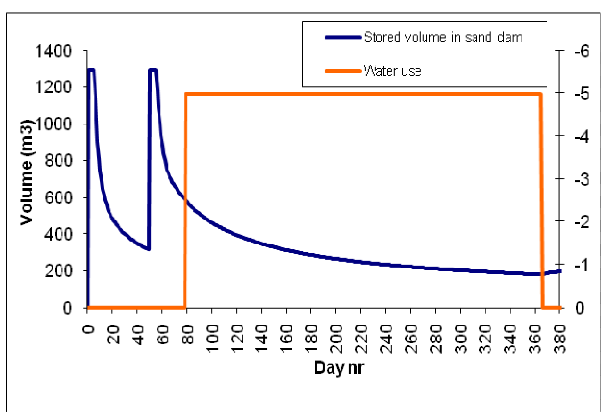
- Dimensions of the dam;
- Sediments are Based on Soil profile/Slug test of the dam (Coarse sand) and the riverbanks (Sandy-loam)
- Estimations of the riverflow (days and infiltration covering area)
- Wateruse > roughly estimated

In the simulation we have assumed to have little losses in the dam and no losses in the riverbank. Furthermore we have assumed to have two rainfall events of 5 days with 100% infiltration with and interval of 50 days. The waterdemand is estimated at 5 m^3 per day from day 80 up to 365.

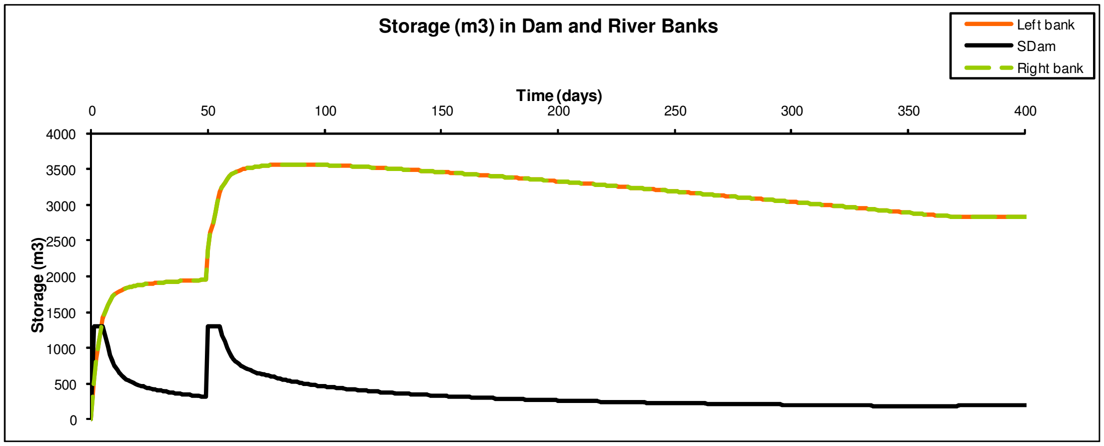
Water balance of sand bank (m3)		
Gains	Recharge	7014
	From right bank	647
	From left bank	647
Losses	Use	-1430
	Leakage	-211
	Right bank	-3037
	Left bank	-3037
	ET	0
Volume	Start	0
	End	215
Balance error (%)		2

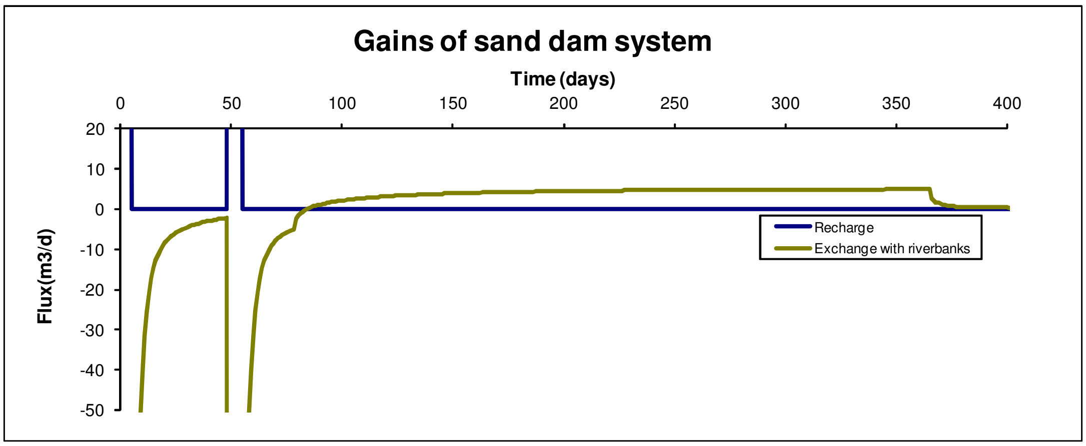
Output: The model provides simple output and more sophisticated output. The model is finished after the calculation on the right side of the preliminary results gives fixed figures. These figures show the complete water balance of the dam and the riverbanks with the leakage, evapotranspiration and the water use. We can see that in total more than 7000m3 water is stored in the total system and 1300m^3 are gained from the riverbanks! More than 3000m^3 is stored in the riverbanks but also water has been supplied through the riverbanks *doubling* the water storage of the sand dam capacity! Futhermore almost 1500 m3 are used by the local people and only 215m^3 is lossed. Evapotranspiration is not considered since the water is stored mostly deeper than 1 m (also in the riverbanks).

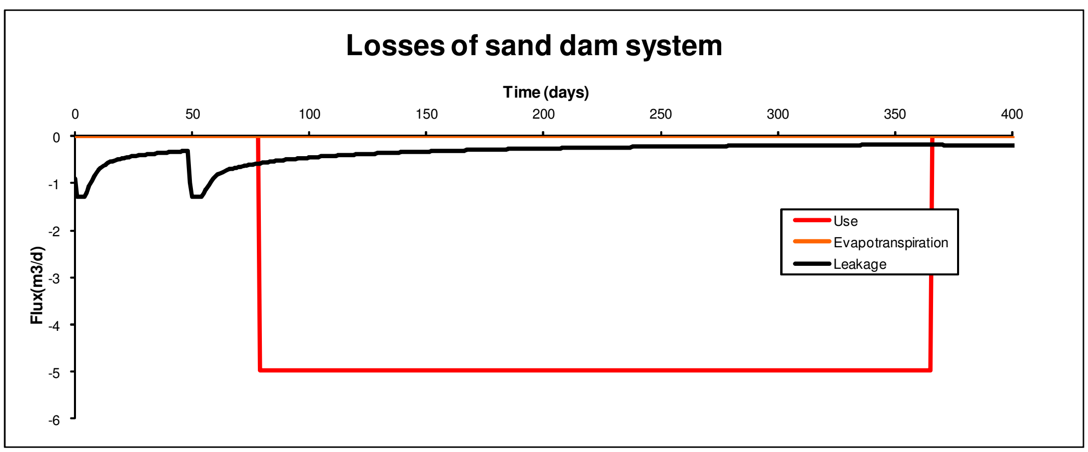
The graph shows that recharge is taking place and when water is exchanged to the riverbanks decreasing the storage in the dam. After the second rainfall event, the dam is again completely filled and provides again water to the riverbanks. When the wateruse starts the amount of water storage decreases. At the end we see that the water storage is increasing, through water supply from the riverbanks. If the waterlevel in the dam is lower (due to either wateruse or leakage) more water is supplied from the riverbanks! On the next page you can see more sophisticated results, try to explain yourself!



This sheet displays three graphs of output for the entire sand dam system: (1) Storage in sand dam and River Banks, (2) Gains of the entire sand dam system, and (3) losses of the entire sand dam system







Changing the values of the variables gives insight in the actual hydrological processes and shows the sensitivity of the total sand dam system. The model clearly shows the benefits of the riverbanks and the effects of leakages and or evapotranspiration. Also the model gives the possibility to use more detailed information providing more accurate results. Until now it does not use any rainfall data apart from including the riverflow events in amount of days. Only for a catchment analysis (estimating riverdischarges and water availability) actual rainfall information in the catchment is considered important. Therefore in this model the infiltration with additional rainfall on top of the sand dam and riverbank is not included. Also it doesn't neglect evapotranspiration below 1 m depth in the riverbanks, because trees and vegetation will use significant amounts of water.

Appendix 12: Specific Lessons learned

General recommendations

- Site selection when building sand dams is of critical importance
- It is very important to involve the community during the whole process.
- Find or collect information on rainfall amount in the areas where dams are to be built in order to estimate the peak runoff for safe design of the sand dams, spillway and stilling basin.
- Maturity of dams can be measured in different ways: dam full of sand, ground water table stabilized. Choose the most appropriate and have the relevant documentation available so that it can be used to judge the preconditions for evaluation and monitoring.
- Every sand dam design should be specific to catchment and channel hydraulic considerations and not replicated to another site without pretesting on the same.
- A proper technical survey and documentation of the field data and benchmarks should be set to enable future evaluation.

Siting

- Areas where scoop wells are found are good indications for constructing productive sand dams.The presence of scoop holes is an indication that people are accustomed to use the water from the riverbed.
- Conduct proper investigation on the soil characteristics in channels to establish the right length of the wing walls. Test pits in the river bed be dug prior to trenching to establish the depth and type of the basement. Grouting with cement slurry may deem necessary at the foundation to make it water tight.
- Gullies can be an important source of silt. If gullies are present upstream of the dam, check dams should be constructed or flow should be diverted to limit silt supply during the sedimentation stage of the dam.
- Boulders. Look for large boulders being present so that the sand dam is indeed build onto rock instead of boulder. Also, it is an indication whether a gabion might be needed to protect the sand dam.

Design and construction

- Implementing organisations build structures according to own design and the implementing organisations should be responsible for repair if the structures are damaged directly after finishing construction.
- The appearance of so called piping (conduction underneath the dam exceeding a certain critical value of the soil) is re-mediated by founding the dam on an impervious floor to increase the path of percolation hence reducing the exit gradient.The appearance of so called rupture of floor due to uplift, occurs if the weight of the floor is insufficient to resist the uplift pressure, the floor may burst and the effective length of the impervious layer reduced. The remedy is the construction of a back slab (protective slab) of appropriate thickness at various points. This should be evident in the design where the thickness of the dam wall is not uniform.
- The quality and length of the wing walls determine the lifespan of the sand dam. Do not save money by shortening the length of the wing walls!
- The well should be located between 0.5 and 3 meter upstream of the dam. An infiltration gallery can be constructed to maximize water flow from the riverbed to the well. The well should be located where its save from erosion.
- The well should not be deeper than the basement layer of the dam.
- The functioning of the well should be checked after construction and the community should be trained to repair. The NGO should check regularly whether the pump still functions. A chain and lock should be put to prevent the pump from misuse.