Building sand dams: a practical guide

Simon Maddrell and Ian Neal

Excellent Development

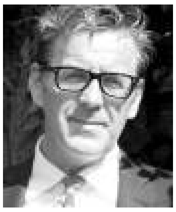
Excellent

Dedication

This guide is dedicated to the memory of Joshua Silu Mukusya (1949 - 2011), a true visionary and one of the original pioneers of sand dams. Joshua's knowledge of sand dams was unrivalled. For over 30 years he worked tirelessly to help hundreds of communities to work themselves out of poverty. He was the one of the original pioneer of sand dams in Kenya, but his work didn't stop with sand dams. His mission to find the best solutions to the many challenges faced by the people he served. This led him to trial and champion many different farming approaches such as fanya juu terracing, tree planting, community seed banks and farm demonstration plots to name a few. His work and passion for change touched the lives of thousands of people, a legacy that will be felt for generations to come. This guide is based on Joshua's experience and that of his son, Andrew Musila Silu. Without the generous sharing of this knowledge, this guide would not have been possible.

Photo 1: Joshua Silu Mukusya

About the authors



Simon Maddrell is the founder and Executive Director of Excellent Development. Simon has been involved with sand dams since 1985 when he first teamed up with Joshua Mukusya, leading an expedition of young volunteers from the UK to help build sand dams in Kenya. Simon was Chair of Excellent Development Kenya from 2005 to 2009. Simon has a BSc. in Development and Environmental Economics alongside 12 years of experience in the corporate sector.

Ian Neal has worked for Excellent since 2008. As Development and Technical Manager, he is responsible for Excellent's learning and research programme. Ian has a MSc. in Soil and Water Engineering from Cranfield University, a BA in Geography and over 20 years experience working in international development.

Acknowledgements

The authors are grateful to Andrew Musila Silu and the staff of ASDF, Jon Viducich and Sue Cavanna for reviewing this document. Musila is the co-founder and Development Director of ASDF and has sited and designed over 100 successful dams. From 2009-2012, Jon was a principal engineer for the Christian Council of Mozambique (CCM) and has helped construct over 35 dams in Tete and Manica provinces. Sue is director of Sahel Consulting with extensive experience of water and environmental development in drylands. The authors also grateful to the Andrews Charitable Trust, the Margaret Hayman Charitable Trust, the Tudor Trust and the Joffe Charitable Trust for their generous support without which this guide could not have been written.

Our strategic partnership

Excellent Development and ASDF have a strategic partnership based on shared values and philosophy. Together we are committed to community-led sustainable development and the global promotion of sand dam technology in drylands. It is our shared vision that sand dams will transform millions of lives.

Excellent | Pioneers of Sand Dams

Excellent Development is a UK registered international development NGO founded in 2002. The purpose of our work is to: (1) support rural communities in dryland areas to gain access to clean water and grow enough food to eat and sell; (2) promote sand dam technology as a means of enabling sustainable development and (3) support organisations to apply and implement sand dam technology. Since its inception, Excellent has supported the construction of over 350 dams and helped over 220,000 people improve their access to clean water.

Africa Sand Dam Foundation

The Africa Sand Dam Foundation (ASDF) is a registered Kenyan NGO founded in 2010. ASDF works in rural, dryland areas to empower marginalised communities to sustainably improve environments and livelihoods for poverty alleviation. They support communities to gain access to local, clean water for improved food production, health and income.

Disclaimer:

This guide reflects the authors' best effort to interpret a complex body of research and experience, and to translate this into a practical guide.

Citation:

This document should be cited as: Maddrell S and Neal I (2013), Building sand dams: a practical guide, Excellent Development, London.

Table of contents

List of photos, figures and tables

Glossary and abbreviations

50-year (or lifetime) flood	The flood level expected to be equalled or exceeded every 50 years on average
Abstraction	Withdrawal and collection of water from the watertable or a water deposit
Annual flood	The flood level expected to be equalled or exceeded once a year on average
Aquifer	A layer of permeable water-bearing rock or unconsolidated sediments
Apron	Concrete platform at the base of the dam that prevents undercutting
Auger	A tool to drill holes in the ground
ASDF	African Sand Dam Foundation
Bank-full flow	Discharge when the main river channel is flowing full
Base-flow	Subsurface flows through riverbed sediments
Catchment or watershed	The area drained by a river
Cost-effectiveness	A dam's yield relative to its cost
Crest	The highest point of the sand dam
Cross profile	X-section of the river showing the gradient of the banks and valley sides
Curing or hydration	The chemical process that causes cement to harden
Drainable porosity	The volume of water that drains from sediment under gravity
Earth dam	A dam constructed of compacted clay soil that impounds surface run-off
Freeboard	The depth of the maximum flow over the spillway or spillways
Gorge	A point where the river has cut a narrow valley
Graded or sorted	A well graded or sorted sediment has little variance in grain size
Gulley	A deep ditch or channel cut by running water
Haffir	A shallow clay-soil pond that collects and stores surface run-off
Infiltration gallery	A network of perforated pipes that collects water from the river sediment
PESTLE analysis	Political, Economic, Social, Technical, Legal and Environmental analysis
Porosity	The pore spaces in soil or rock
Sand river	A seasonal river predominantly filled with sandy sediment
Siting	Deciding the exact point at which an individual sand-dam will be built
Spillway	The (central) channel of a dam that carries excess water over the dam
Throw-back	The distance that sediment and water collects behind a dam
Valley head	The highest point of a catchment
Wadi	Another name for a seasonal, sandy river
Watertable	The level where the aquifer is saturated
Wing-walls	The side walls of the sand dam

NGO	Non-government organisation	um	Micrometre, 1,000 um = 1 mm
USV	Upstream View	mm	Millimetre, 1,000 mm = 1 metre
g	Gramme	cm	Centimetre, 100 cm = 1 metre
kg	Kilogramme, 1000 grammes	m	Metre, 1,000 m = 1 kilometre
l	Litre, 1 litre of water weighs 1 kg	m^3	Cubic metre, 1,000 litres = 1 m^3

Foreword:

I am delighted to provide the foreword for the Excellent Development Sand Dam Manual. Sand dams are one of the technologies that help to address the issues I have been fighting during my six years as Executive Secretary of the UN Convention to Combat Desertification.

Desertification, land degradation and drought have far-reaching impacts: from extreme poverty to food and water insecurity & hunger, deforestation, loss of biodiversity and vulnerability to climatic shocks, instability, crises and environmentally-induced migrations.

Sand dams are an interesting technology in that they are only suitable for dryland areas suffering from land degradation. Water that runs down seasonal rivers carrying soil separates and fills the dam with sand - but also millions of litres of water. Apart from storing such water all year round it is protected from evaporation and doesn't allow waterborne diseases or a water vector for mosquitoes to breed. More critically, the time subsistence farmers save in water collection enables them to focus on reversing land degradation through soil and water conservation and improved agriculture. Excellent has supported the building of 369 dams with 111 communities in Kenya, who as a result have shown significant improvements in diets, health and incomes.

I need to say, however, there is no 'silver bullet' to address land degradation. It is site specific and it is eco-specific. There are many other inspiring success stories that could be scaled up and disseminated with huge potential benefits for all. For example, in projects in Malawi, under a canopy of evergreen Faidherbia trees, agricultural yields increased by 280 percent. Farmer-managed natural regeneration and agro-forestry techniques, have already contributed to improving millions of hectares across Africa particularly in places like Niger. Sand dams are one of the technologies that enable people to invest in such activities through reducing the time to collect water by three to five hours per day. Such sustainable land management techniques, avoided degradation and rehabilitated natural capital will deliver new opportunities for real, sustainable, poverty reduction around the world.

I like very much, not only the approach of sand dams, but I like the passion and the people behind them. I really wish that we could do more in taking this technology, this approach and this understanding to many others. We are not there yet, but I am convinced, sustainable land management is an idea whose time has come.

I wish Excellent Development well in their efforts to bring the importance of sustainable land management, and the role of sand dams in that, to the attention of all of us who care about the future of our planet.

I hope that this manual, which offers a practical guide accessible to non-technical people, inspires and empowers people in drylands to take action in tackling the scourge of land degradation.

L. Gnacadja

Luc Gnacadja,

Executive Secretary,

United Nations Convention to Combat Desertification

Chapter 1: An introduction to this guide

This guide describes the process of siting, designing, building and managing sand dams. It is aimed at technical and programme management staff working in arid and semi-arid lands who are interested in trying out sand dams in new areas. The guide draws upon the existing body of experience of building sand dams in Kenya where the majority of the world's sand dams are located. The primary purpose is to capture this experience in order to inspire and guide others. The manual may be used as both an everyday field guide and as an education or training tool.

Building sand dams is not for amateurs. However you do not need to be a qualified engineer or hydrologist to build a robust, effective sand dam. To reinforce this message, the guide avoids the use of technical or specialist terms wherever possible. What is required is: (1) a sound understanding of how seasonal rivers flow and the impact of sand dams on this, (2) a sound understanding of the principles of sand dam siting, design and construction and the causes of failure and (3) access to experienced artisans with knowledge of stone-masonry construction. Bite size nuggets and rules are highlighted in **green text**.

Beyond these technical considerations, the key to success lies in the approach of the implementing organisation and in particular, how it works with end-users and the host community to place them at the heart of decision-making and how it integrates sand dams within a wider programme. What works varies from place to place and from programme to programme. Success relies on good development practice and adapting the application of the technology to local conditions as well as getting the technical aspects right.

Chapter 2 introduces sand dams, their history and the benefits they bring. **Chapter 3** provides guidance on assessing where sand dams are technically feasible and have the greatest potential. **Chapter 4** discusses some of the factors that should be considered when planning to introduce sand dams in a new area. **Chapter 5** is a step-by-step guide to siting a sand dam. **Chapter 6** is a step by step guide to designing a sand dam. **Chapter 7** offers guidance on procurement of materials and other vital pre-construction activities. **Chapter 8** is a step by step guide to construction and **Chapter 9** describes how to monitor, repair and manage a sand dam to prevent it failing once it has been built. **Chapter 10** describes and compares alternative water technologies used in rural drylands and **chapter 11** is a conclusion. Finally in the annexes you will find useful information including the support Excellent and ASDF offer to organisations considering piloting sand dams and examples of legal forms.

Feedback: The authors recognise there remain significant gaps in current knowledge on sand dams. If you have built a sand dam in the past or if you are planning to do so in the future, we would love to hear from you and learn from your experience. We welcome readers' comments and suggestions for improving later editions of this guide. Please send feedback to projects@excellent.org.uk.

Chapter 2: An introduction to sand dams

2.1 What is a sand dam and how does it work?

People have always collected water from holes dug in seasonal sandy riverbeds. Over time people have learnt that sediment is deepest and water lasts longest when the hole is dug immediately upstream of a rock bar across the streambed. Sand dams effectively build upon this natural process.

A sand dam is a reinforced stone-masonry wall (or similarly robust and impermeable weir) built across a seasonal, sandy riverbed and is one of the world's lowest-cost rainwater harvesting solutions. Sand dams are a simple, robust, low maintenance, rainwater harvesting technology that provides a clean, year-round, local water supply for domestic and productive uses and are widely suited to the world's dryland regions. They act as a catalyst for wider development. Sand dams provide water for livestock, small irrigated horticulture and, for fish ponds, tree nurseries and fruit orchards. They recharge the aquifer and rejuvenate the riverine ecology enabling fodder crops to be grown along the banks.

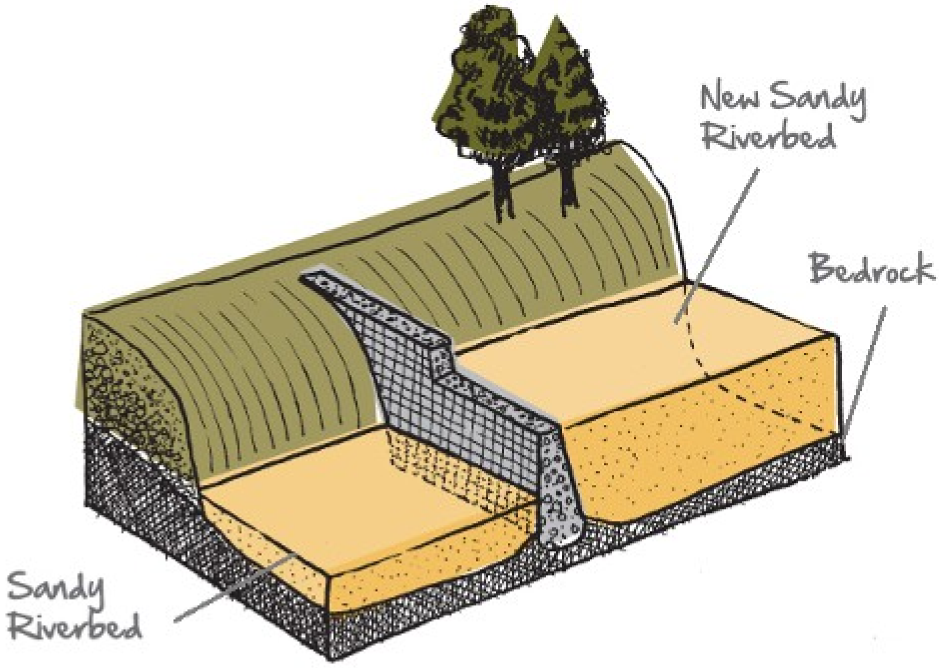


Figure 1: How a sand dam works

Seasonal rains quickly fill the dam with water containing soil. The soil is made up of silt and sand. The heavier sand sinks behind the dam, whilst the lighter silt remains suspended in the water and is carried over the dam and downstream. Sand accumulates until the dam is completely full of sand up to the spillway. Photos 2 - 5 show the different stages of a sand dam from the original dam site until the dam is matured and filled with sandy sediment.

Water is stored within the sand, making up 25 – 40 % of the total volume of the aquifer. The sand filters the water and the lack of an open water surface reduces contamination and evaporation and prevents water-borne parasites such as mosquitoes and snails from breeding.

Water is abstracted from a sand dam either by a traditional scoop-hole or an infiltration gallery is laid upstream of the dam and connected to a protected water point, such as a pipe through the dam wall, a storage tank built into the dam or a shallow off-take well and hand-pump dug in the adjacent riverbanks.

Photos 2-5: The stages of a sand dam filling with sediment

Photo 2: The original site [1]; Photo 3: Immediately following construction [2];
Photo 4: Filled with water after first rains [3]; Photo 5: Mature dam filled with sand after 2 years [4]

2.2 A brief history of sand dams

The technology is centuries old. There are accounts of similar structures from Sardinia in Roman times[1] and in Mexico in the 18th century. Examples are reported in numerous dryland countries including Namibia, Mozambique, Tanzania, Somaliland, Ethiopia, Yemen, Burkino Faso, Mali, NW Cameroon, Sudan, Turkey and Mexico. However, the highest concentration of sand dams with the strongest track record is found in Kenya. According to early Kenyan adopters, the technology was introduced to Kenya by former Kenyan officers who came across similar structures whilst serving in India during World War II. The first Kenyan sand dams were built by a District Agricultural Officer (Eng. Classen) as part of the African Land Development Board (ALDEV) project. The authors estimate there are currently in the region of 1500 sand dams in Kenya. Only recently have these been the subject of wider adoption and research.

The overwhelming majority of these have been built over the past 15 years by community groups supported by three Kenyan NGOs: Utooni Development Organisation based in Kola, Machakos County; Sahelian Solutions or SASOL based in Kitui Town, Kitui County and Africa Sand Dam Foundation based in Mtito Andei, Makueni County. Each of these NGOs can trace their adoption of sand dam technology back to work of Joshua Mukusya.

Sand dams built in Machakos and Makueni Counties, Kenya typically range from 1.5 to 4 metres in height from the bedrock to the central spillway and span river channels 10 to 30 metres wide. Dams of this size store in the region of 2-10 million litres and recharge after each significant storm. The largest dams are over 5 metres in height, span riverbeds 50 metres wide and are 100 metres in length from wing tip to wing tip, whilst the smallest are only 5 metres wide and 1 metre high. However larger sand dams have been built. For example, photo 6 shows a 22 m sand dam built on the Hoanib River in Namibia in the 1950s.

Photo 6: Tallest known sand dam on the Hoanib River in Namibia. Credit: Dr Wipplinger

1 Nilsson, A., 1988. Groundwater Dams for Small-Scale Water Supply, IT Publications

2.3 Why people build sand dams

Independent evaluations of how sand dams have impacted the lives of people living nearby and the environment in Kitui, Machakos and Makueni Counties in Kenya found the following benefits:

Indicator	With dam	Without dam
Less months of primary water source depletion	2.5	-0.2
Change in distance to primary water source	-2016 m	+23 m
Change in water use	3.44 x more	0.96 x less
Daily time saved on fetching water	100 minutes	-7 minutes
Newly irrigated land	+0.18 Ha	-0.01 Ha
New fruit trees	13	5
Change in income (€/year)	+270	-380
Malnutrition	decreased	increased

Table 1: Summary of socio-economic benefits of sand dams in Kitui, SE Kenya (Source: Aerts et al) 2

Social and economic benefits

2.3.1 Saving time for women and children

Reducing the time required to collect water is one of the main motivations for building sand dams. By siting sand dams close to where communities require water, sand dams free up hours of time and energy that farmers invest in improving their farms and incomes.

2.3.2 Increased crop and food production

Sand dams enable farmers to locally water their livestock throughout the year. A local, year-round water source, allows farmers to invest time improving their farms by terracing land and planting trees.

2.3.3 Increased vegetable production

Sand dams enable small scale irrigation of vegetable gardens on land adjacent to the dams which in turn increases the quality and diversity of peoples' diet and saves them money. Vegetables may be grown and harvested in the dry-season when prices are highest.

2.3.4 Health benefits

People who switched from traditional, unprotected water sources to sand dam water report a dramatic reduction in water-borne disease. Improved access to water results in better hygiene, food preparation and diet and reduces water-washed diseases. Unlike open water sources, sand dams do not provide a breeding ground for water-vector diseases such as malaria and yellow fever.

2.3.5 Income generation and employment

As a result of sand dams, farmers spend less on food, water and medicines and increase their incomes through small-scale enterprise such as selling tree seedlings or vegetables, block making or community fish ponds. Construction

---

2 Table 1 summarises a range of socio-economic benefits of sand dams found by Rempel (2005), Lasage (2006) and Pauw (2008) by Aerts et al, 2008. Kenya Sand Dams. Community Based Adaptation Climate Change, poster for World Water Forum 2008. [Link]. Rempel et al, 2005. Water in the Sand: An Evaluation of SASOL's Kitui Sand Dams Project; Lasage et al 2007, Potential for community based adaptation to droughts: Sand Dams in Kitui, Kenya, Physics and Chemistry of the Earth, Volume 33, Issues 1–2, 2008, p 67–73 and Pauw et al, 2008. An Assessment of the Social and Economic Effects of the Kitui Sand Dams Community based Adaptation to Climate Change, SASOL Foundation and IVM Institute for Environmental studies Vrije University, Amsterdam, [Link]

provides direct and indirect employment and the majority of funds circulate within the local economy. The skills developed building sand dams are easily transferable to other sectors of construction and the labour-intensive, semi-skilled nature of the work lends itself to on-the-job training.

Photo 7: Community fishpond filled with water from a sand dam

2.3.6 Tree nurseries

In dryland Africa, trees provide 90 % of fuel needs in rural areas and, on average, 1 to 2 hours/day are spent collecting firewood. Charcoal production is a major driver of deforestation. Trees are an essential part of both rural livelihoods and the fragile ecosystems of drylands. As well as fuel, they provide food, fruit, fodder, lumber and medicines. A sand dam provides a year round source of water that enables seedlings to be watered in the dry-season and then transplanted at the start of the rainy season resulting in a higher survival rate.

2.3.7 Reduced conflict

Where water is scarce and time consuming to collect, water may often trigger intra- and inter-community conflict. Increased water availability reduces conflict especially where ownership and water-user rights are recognized and protected within customary and statutory law.

2.3.8 Increased school attendance

Sand dams increase school attendance since children either spend less time looking for water themselves, or less time looking after their siblings whilst their mothers look for water.[3]

Environmental impacts

2.3.9 Flood control

Sand dams create a natural buffer within a catchment that reduces flood peaks. A lack of vegetation and intense rainfall means that semi-arid lands are particularly prone to flooding. For example, in the United States, 9 of the 10 largest floods in history have occurred in catchments receiving less than 250 mm rainfall per year.

2.3.10 Downstream flows and aquifer recharge

Sand dams transform the local ecology: The water held behind the dam spreads horizontally, recharging the aquifer above and below the dam[4] and enables trees to naturally colonise the riverbanks. Flow modelling on dams in Kitui County, Kenya found that 1 - 3 % of the river's discharge is retained behind a dam. The remainder continues its natural course towards the ocean.[5] The low figure is significant because it suggests no or little effect on downstream users or ecosystems. However, some caution is required since this figure will vary with geography, catchment and dam size and a higher percentage will be withheld in drier conditions. Throughout the year, some of the water held by a sand dam slowly

---

3 Mutuku, N.B., 2012. Impact of Sand Dams on Social Economic Status of the Local Inhabitants. A case of Kitui Central Division, Kenya. LAP LAMBERT Academic Publishing.

4 Hoogmoed, M., 2007. Analyses of impacts of a sand storage dam on groundwater flow and storage. MSc. Thesis, Vrije Universiteit, Amsterdam [Link]

5 Hut R et al. 2008 Effects of sand storage dams on groundwater levels with examples from Kenya, Physics and Chemistry of the Earth Vol. 33, no. 1-2, 56–66

seeps into the riverbanks and over and around the dam. This increases downstream, dry-season flows. This is particularly apparent where sand dams are built in series along a river valley. Kenyan community elders report that rivers which used to be perennial but which for several decades had been seasonal have reverted back to perennial streams as a direct result of multiple sand dams being constructed along the river course. Studies of Kitui dams found that Sand dams increase groundwater storage in river banks by 40 %[6] and groundwater is maintained throughout dry-seasons and drought. Many cities within the world's drylands rely on large reservoirs to supply their power and water. Sand dams together with other water harvesting measures increase the yield and generating capacity of downstream reservoirs.

2.3.11 Climate change resilience

Dryland regions are particularly prone to floods, droughts and extreme weather events and consequently vulnerable to water and food scarcity. Drylands are considered particularly sensitive to global climate change. The direction and magnitude of these changes is difficult to predict at the local level, although for most dryland regions, climate models predict higher temperatures, decreased precipitation, and an increase in intensity and frequency of extreme events such as droughts and heavy rainfall.[7] This vulnerability and unpredictability has led the Intergovernmental Panel on Climate Change to conclude drylands are on the frontline of climate change.

A recent study[8] shows "that vegetation biomass is consistently, significantly and substantially higher at sand dam sites than sites without sand dams through periods of water scarcity. This corroborates past research which identified related impacts on ground water, land cover, and socio-economic indicators. Sand dams enhanced the resilience of vegetation during drought disturbances, and an increase of Net Primary Productivity at sand dam sites is indicated. Both resilience and productivity increase the adaptive capacity of drylands."

When sand dams are integrated in a wider watershed management programme, they reduce the risk of flooding and the impact of droughts and support community based climate resilience. Where sand dams are planned, built and managed by community organisations, the process helps build the necessary organisational capacity for community-based resilience.

2.4 Three models of applying sand dams

2.4.1 Community based approach

The majority of Kenya's sand dams have been built by community groups supported by local NGOs. Sand dams are particularly well suited to a model where a community group builds, owns and operates the dam because:

- Operation costs are low and maintenance and repair is simple and requires little technical support. As a result they are particularly well suited to remote and poorly served regions.
- Sand dams require significant community contribution and the skills of locally trained people.

The first step is to talk with the end-users to establish their needs and to establish that in their opinion, a sand dam is the most appropriate solution. The key to their sustainability is community ownership, community involvement in decision making and ensuring the dam meets the multiple needs of end-users. They have huge potential when incorporated in a wider development programme such as food and water security, climate resilience, watershed management or social protection programmes.

2.4.2 Sand dams as combined road-river crossings and water sources

Rural roads are critical to wider development enabling people and produce to get to markets and services such as health and education to reach isolated communities. In flood prone drylands where roads cross seasonal rivers, culverts and drifts are traditionally used. Maintenance and repair of these structures is often costly and problematic. Sand dams are

---

6 Borst and De Haas 2006. Hydrology of Sand Storage Dams. A case study in the Kiindu catchment, Kitui District, Kenya. M.Sc. Thesis, Vrije Universiteit, Amsterdam; [Link], Jansen 2007; Jansen, J., 2007, The influence of sand dams on rainfall-runoff response and water availability in the semi-arid Kiindu catchment, Kitui District, Kenya. M.Sc. Thesis, VU, Amsterdam; Quilis et al, 2009 Measuring and modelling hydrological processes of sand-storage dams on different spatial scales Hoogmoed 2007; Hut et al., 2008 (Ref 5),

7 Sörensen, and Duchrow, 2008. Sustainable land management in drylands – Challenges for adaptation to climate change. [Link]

8 Ryan, C., 2012. The potential for sand dams to increase the adaptive capacity of drylands to climate change. MSc thesis, Birkbeck College, London (unpublished).

an alternative to culverts. When correctly designed, sand dams are durable and require little maintenance with the added significant benefit that they also provide an important source of water.

Photo 8 below shows a sand dam road-river crossing in SE Kenya which provides a reliable, year round water supply. The dam is 80 m wide with a spillway 3 m above the bedrock. The water flows through an infiltration gallery to a shallow off-take well and then pumped at the rate of 50 m^3 / day to 10 water kiosks, two schools and clinic. Sand dams also create important crossings and corridors for people on foot and livestock because they raise and flatten the riverbed upstream.

Photo 8: A sand dam road-river crossing, Makueni, Kenya.

2.4.3 Sand dams in nature reserves

Drylands are home to many of the most important nature reserves in the world.[9] They are major tourist attractions, focal points of bio-diversity and sources of local and national income. In Kenya, for example, 13 % of GDP comes from dryland tourism[10]. However, the animals in these reserves are regularly threatened by drought. Large, permanent water points such as boreholes may result in degradation hotspots due to the concentration of game. There is great potential for sand dams to reduce this vulnerability. Sand dams improve water availability and vegetation. Elephants can dig down to allow them and other animals to access the water. They require little maintenance and no operation costs. And sand dams, if built in series, avoid degradation hotspots.

9 Eight of the 25 global ''biodiversity hotspots'' identified by Conservation International occur in drylands. Source: Safriel and Adeel, 2005, Ecosystems and human well-being: current state and trends. The Millennium Ecosystem Assessment [Link]

10 Mortimore.et al, 2009. Dryland Opportunities: A new paradigm for people, ecosystems and development, [Link]

Chapter 3: Assessing technical feasibility

This chapter suggests some indicators and methods to assess the technical feasibility of sand dams in a new area. Having done so, it describes how to identify the areas of greatest potential, in terms of yield versus cost, within areas of technical feasibility. Chapter 4 describes the technical and non-technical factors to consider in a contextual analysis of a new area for sand dams. Having identified areas of technical feasibility and greatest potential, chapter 5 is a step by step guide to selecting specific dam sites within a chosen area.

3.1 Four pre-conditions for a suitable site

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

- **A sand dam must be sited on an ephemeral or seasonal river with clearly defined riverbanks**
- **The riverbed must be sufficiently impermeable as to retain water**
- **The river must have sufficient sandy sediment**
- **A sand dam must be sited where the bedrock or a suitable impermeable layer is accessible, usually no more than 3 metres below the existing riverbed surface.**

3.2 The location of seasonal rivers

	Aridity	Aridity index P/PET	Mean annual rainfall: Winter rainfall	Mean annual rainfall: Summer rainfall	Inter-annual variability	Population % of global total	Land area % of global total
	True desert	<0.03	Very low		V irregular	2	7
Drylands	Aridity	0.03 – <0.2	80 - 200 mm	200 - 350 mm	50 - 100 %	4	10
Drylands	Semi-arid	0.2 - <0.5	200 - 500 mm	300 - 800 mm	25 - 50 %	14	15
Drylands	Sub-humid	0.5 - <0.65			<25%	15	9
	Humid	>0.65			Total	35 *	41 *
	Per-humid	Sources: E. De Pauw, ICARDA GIS unit except * from UN Millennium Ecosystem Assessment					

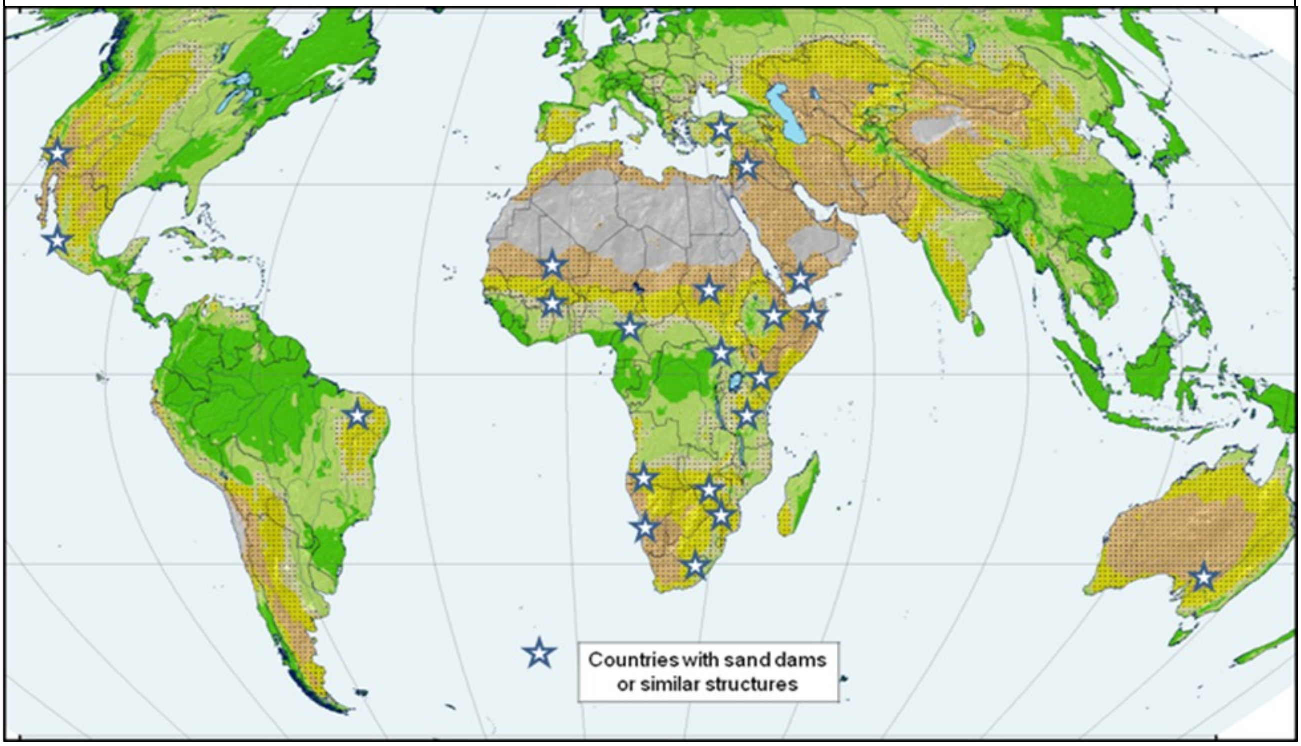


Figure 2: Map of world's dryland regions. Adapted from original by ICARDA **[Link]**

Figure 2 shows the world's drylands and the locations where there are reported examples of sand dams or similar structures. It shows a strong correlation between sand dam sites and dryland climates where most of the world's seasonal rivers are located. Dryland regions include arid, semi-arid and dry sub-humid climates and are defined as areas where the mean annual precipitation is less than two thirds of potential evapo-transpiration. They are characterised by intense storms and highly variable and seasonal patterns of rainfall. In drylands, sparse vegetation and encrusted, compacted soils mean most rainfall runs off the land, carrying valuable top soil with it, straight into the rivers.

In the Kenyan counties of Machakos, Makueni and Kitui, where the greatest concentration of sand dams is found, average rainfall ranges from 400 – 1000 mm / year and is highly seasonal. In this area sand dams are most commonly found in the upper and middle courses of the rivers in the transition between hills and plains, where streambed gradients vary from 0.2 to 5 %. As rivers join together and base-flow increases, the larger rivers flow for more of the year and gradually become perennial. However in more arid basins, all the rivers are seasonal from the source to ocean / inland delta.

A simple desk assessment may help identify the extent of seasonal rivers. Firstly, complete an internet search for documents and images of existing sand dams or water harvesting structures and a search of national water resource management policy documents for information on the extent and management of seasonal river courses. If there are examples of local sand dams that have been documented, contact the organisation involved and learn from their experience. Hydrological maps show seasonal rivers (as dashed blue lines) and climate maps will show arid regions and rainfall distribution. This may be confirmed by satellite images (such as Google Earth) combined with photos and GPS coordinates taken on the ground and interviews with local people. Google Earth can also estimate catchment area and slopes. The monthly average rainfall may be estimated with online climate tools (such as samsamwater/climate). In different countries, a sand river may be known by local terms such as wadi, wash, gulch or arroyo.

3.3 Will the riverbed retain water?

If underlying bedrock is highly permeable / fractured, much of the water flowing in the channel will percolate through the riverbed and recharge the underlying aquifer. If the watertable is close to the surface, this recharge will raise the watertable and benefit local people. A sand dam in these conditions may still be justified by the aquifer recharge. However, if this water recharges a deep aquifer, local people will derive little benefit from a sand dam.

There are several indicators as to whether a riverbed is sufficiently impermeable to retain water.

Firstly, are there scoop-holes dug in the riverbed and if so, for how long after the last rains is water retained in the river sediment? If there are scoop-holes which last for a reasonable time, this is a strong indication that sand dams are feasible.

Secondly, are there examples of shallow wells adjacent to the river and if so, how does the watertable fluctuate during the year? If the water level is close to the riverbed level for most of the year, this is again an indication that sand dams are feasible.

And thirdly, local and national water authorities may allow access to pump test or yield records from local boreholes that show the composition and transmissivity of the aquifer. Transmissivity is the rate at which water flows through the rock: The higher the transmissivity, the less the riverbed will retain water. Also consult geological survey maps.

3.4 Why sediment testing is important?

The grain size, porosity and depth of the river sediment should be tested. The ideal sediment has a high sand content (especially coarse to medium sands) and little or no silt and clay content. The higher the percentage of coarse sand and the more uniform the sediment is, the greater storage and abstraction potential from the dam. This is because, compared to silt and clays, sand:

- Has a high porosity and extractable yield.
- Has a high infiltration rate of water into the aquifer: Coarse sand more so than fine sand.
- Has a high abstraction rate of water from the aquifer: Coarse sand more so than fine sand.

- Filters the water more effectively: Fine sand more so than coarse sand.
- Has a low evaporation rate compared to finer sediments. Coarse sand more so than fine sand.

Figure 3 shows the comparative size of sand, silt and clay particles and figure 4 shows how porosity and drainable porosity (defined as the volume of water that drains from the sediment under gravity) vary according to particle size. It shows that a well sorted coarse sand stores and yields the most water.

Tests on ASDF dams found sediment that collects behind a dam is very similar to sediment in the riverbed prior to construction. It follows that a site with sandy sediment will produce a sand dam and a site with silty sediment will produce a 'silt dam' that will yield very little water. Therefore testing the particle size distribution and porosity of the sediment is an essential test of site suitability.

Particle size

1000 um = 1 mm

Gravel	> 2 mm
V coarse sand	1 – 2 mm
Coarse sand	0.5 – 1 mm
Medium sand	0.25 – 0.5 mm
Fine sand	0.125 – 0.25 mm
V fine sand	62.5 – 125 um
Silt	4 – 62.5 um
Clay	< 4 um

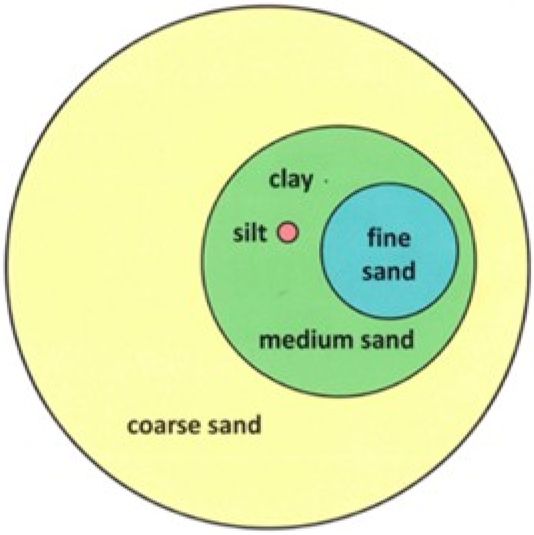


Figure 3: Comparative size of sand, silt and clay particles

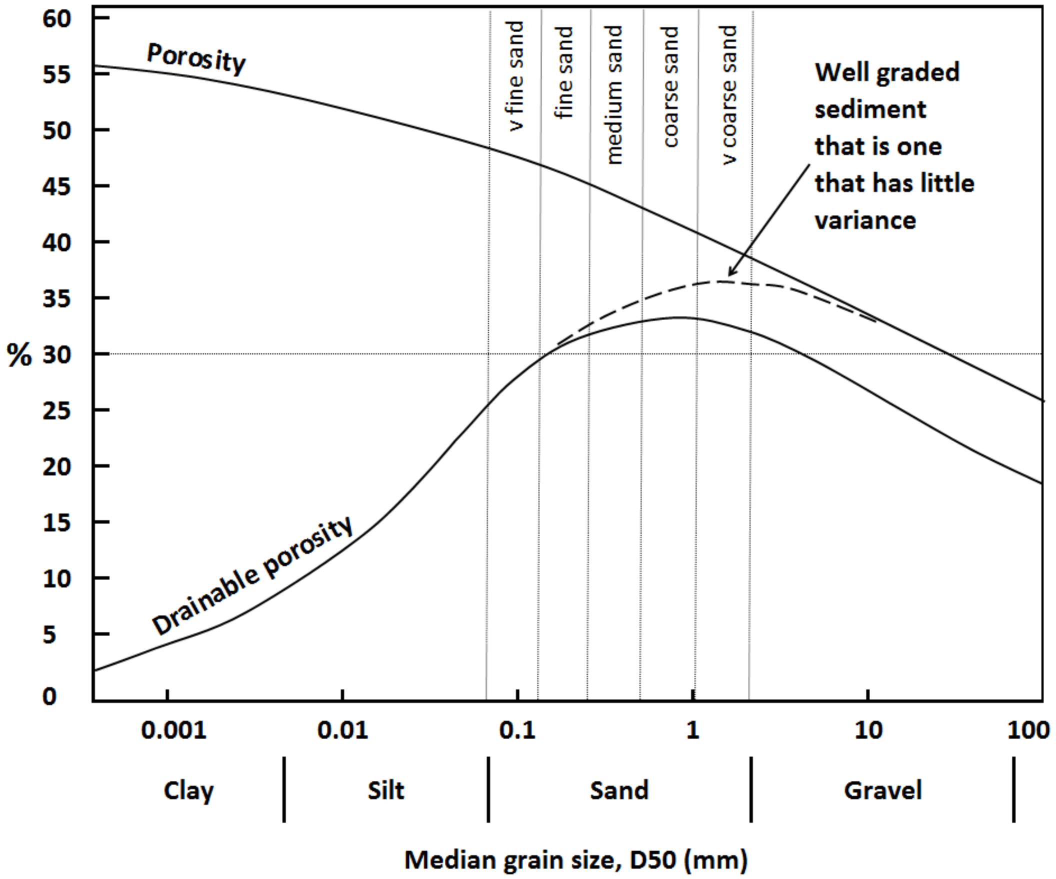
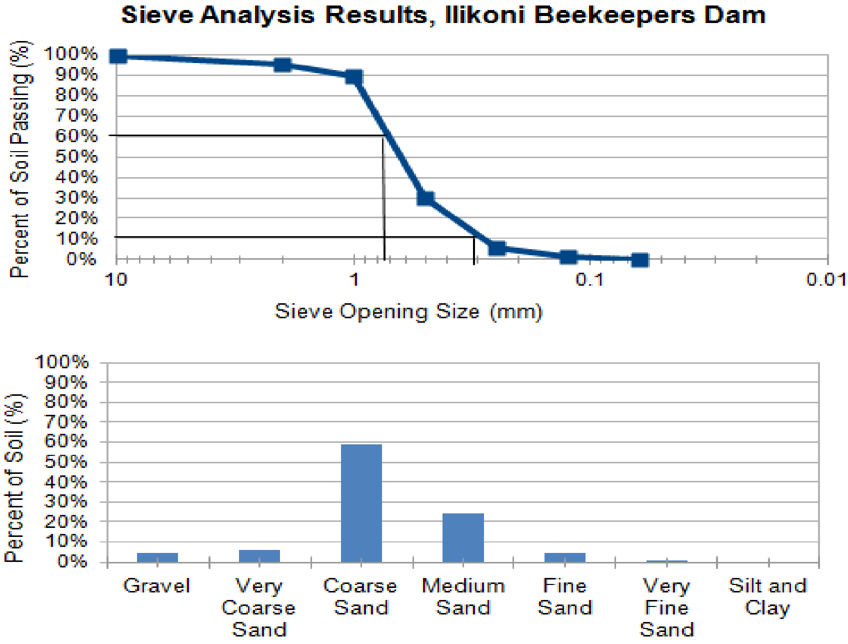


Figure 4: The impact of grain size on porosity and drainable porosity

3.5 How to test river sediment?

Photo 9: Keck sand shaker and scales



Hazens Uniformity Coefficient

Diameter (mm) with 60% of volume passing (D60):	0.82 mm
Diameter (mm) with 10% of volume passing (D10):	0.33 mm
Uniformity Coefficient (Cu = D60/D10):	2.468

Figure 5: Grain size at a site on the Kambu River, Kibwezi District, Kenya

3.5.1 Dry sieve test

By sieving the sediment, it is possible to know the size and distribution of the particles. A Keck sand shaker (photo 9) and portable electronic scales (0.1 g - 1 kg range) cost approx. US$150. Dry sediment is passed through a stack of sieves, each sieve corresponding to the international classification of particle size (ISO 14688-1, figure 3). The weight of the sediment for each class is measured and its percentage of the total sediment weight calculated (figure 5). This allows a sediment distribution curve to be produced and to calculate indicators such as D10, D60 and the uniformity coefficient that allow comparison of sediment at different sites. D_{10} is the diameter for which 10 % of the sediment (by weight) is finer. D_{10} is also called the effective size and is used to estimate permeability. D_{60} is the diameter for which 60 % of the sediment by weight is finer and the uniformity coefficient (Cu), which equals D_{60}/D_{10}, is a measure of how graded the sediment is. The lower the uniformity coefficient, the more graded the sediment is. The more graded the sediment, the higher the drainable porosity and the more suited the site is to a sand dam.

D60 and D10 may be calculated by either: (1) plotting the co-ordinates on log-graph paper and reading of the particle size corresponding to 60 % and 10 % or (2) inputting the data into an excel worksheet available from the authors. Although this process may appear complex, it is actually quite simple and requires no specialist knowledge. The authors can provide further advice upon request on equipment and sediment sampling and testing procedures used to analyse sediment around ASDF dams in Kenya.

In the absence of soil sieves, there are two alternatives:

3.5.2 The ball test

Drip water onto about one tablespoon of sediment in your hand. If the sediment can be rolled into a ball or thread, it has too much silt and clay content to be suitable. If the sediment remains loose and single-grained and can be heaped, but not formed, it is sand. Even the smallest sand grains can be seen with the naked eye.

3.5.3 The settlement test

- Dry sediment sample is sieved to remove small stones and roots and break down any lumps

- Place approx. 500 ml sediment in a tall 2 litre plastic bottle or container with a lid
- Add 2 tablespoons (30 ml) of dishwashing or clothes washing detergent powder (or alternatively salt). The detergent keeps the soil particles separate, resulting in a more accurate test.
- Fill the container with water (i.e. approx 25 % sediment, 75 % water) leaving a small air gap
- Shake container vigorously for 3 minutes making sure no soil is stuck to the bottom or sides.
- As the sediment settles, measure the depth after **(i)** 20 seconds (sand), **(ii)** 5 minutes (silt and sand) and **(iii)** again once the water is clear (clay, silt and sand).
- Sand settles almost immediately. Often, compared to the sand layer, the silt layer is darker and the clay layer is lighter in colour. It usually takes 24 – 48 hours to clear but may take longer. If it does take longer, this is an indication of high clay content which is undesirable.

$$\% \text{ sand} = \frac{\text{Depth of sediment after 20 seconds (sand)}}{\text{Total depth of sediment}}$$

$$\% \text{ silt} = \frac{\text{Depth of sediment after 5 minutes (silt and sand) - Depth of sediment after 20 seconds (sand)}}{\text{Total depth of sediment}}$$

$$\% \text{ clay} = \frac{\text{Total depth of sediment - Depth of sediment after 5 minutes}}{\text{Total depth of sediment}}$$

3.5.4 A test for sediment porosity and drainable porosity

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

$$\text{Porosity (\%)} = \frac{\text{Volume of water added}}{\text{Volume of sediment}}$$

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

$$\text{Drainable porosity (\%)} = \frac{\text{Volume of water that freely drains}}{\text{Volume of sediment}}$$

3.6 Testing sediment depth

Due to the cost and labour required for excavation, sand dams are rarely built where the bedrock is more than three metres below the level of the existing streambed, unless it is for a narrow stretch of the riverbed. At this stage, you are seeking to confirm that there are suitable locations where the bedrock / riverbed is either at or reasonably close to the surface. When selecting a specific site for a dam (chapter 5) more detailed probing and test pits are required. The depth of the bedrock may be estimated by measuring how deeply a tapered rod penetrates the sediment. There is usually a clearly audible sound when the rod hits the riverbed: either a clear ‘ring’ if it hits rock or a dull thud if it hits clay / mud-rock. Repeat the probing a regular points at across and along the riverbed. Sometimes a false reading is given when the probe hits a rock buried in the sediment rather than the riverbed. Wet sediment sticks to the rod giving an indication of water depth within the sediment.

Photo 10: Probing sediment depth

3.7 How to estimate storage capacity?

The volume of **sediment** stored by a dam may be estimated as

D, the maximum depth of sand (m), (i.e. the difference between the lowest point in the sand reservoir and the spillway crest level) multiplied by

W, the maximum width (m) of the sand once the dam is full multiplied by

L, the length of the sand aquifer (m) upstream of the dam, also known as the throwback divided by 4

Equation 1 $$\text{Volume of sediment} = \frac{D \times W \times L}{4}$$

The division by 4 is a constant that reflects the shape of the valley and the fact that in most sand rivers, the main river channel has a rectangular cross section. The volume of **water** stored by a dam may be estimated by multiplying the volume of the sediment by P, the average porosity of the sediment (%)

Equation 2 $$\text{Volume of water stored} = \frac{D \times W \times L \times P}{4}$$

3.8 Why storage is different to yield?

The amount of water a dam yields is not the same as its storage for the following reasons

- The dam aquifer is recharged by repeated floods. This is greatest where there are 2 rainy seasons and / or rainfall is dispersed over several months.
- The dam aquifer is recharged by base-flow through the riverbed sediments and from the riverbanks. This base-flow increases as the catchment size increases. Research on dams in Kitui found that ten times the volume of water may be stored in the banks than in the sand dam aquifer. The greater the volume stored in the banks, the more recharge will flow from the banks into the dam aquifer.
- Water is lost by evaporation. Below 60 cm depth, evaporation from sand is negligible[11]. Evaporation is greatest from fine sediments.
- Water is lost by seepage to the underlying aquifer and by seepage under or around the dam. This seepage increases groundwater levels and dry-season downstream flows but decreases the dam yield. .
- The volume of water that freely drains from sediment, the drainable porosity, is less than the porosity. Drainable porosity is greatest in coarse sandy sediments and falls rapidly as silt and clay content increases.

3.9 Factors that influence cost-effectiveness and feasibility

Provided the 4 pre-conditions are met then sand dams are technically feasible. However, their value for money and the time required for a sand dam to mature varies hugely depending on siting and design and local geography. This is true at both macro and micro scale. This section explains the factors that influence cost-effectiveness and feasibility at the macro or basin level (summarised in table 2) so that areas of greatest potential may be targeted first. A major barrier to identifying areas of greatest potential and cost-effectiveness is a lack of sufficient, reliable and comparable data that are easy to collect. **Appendix 4** suggests some simple indicators and methodologies that can be used to compare conditions between different countries and geographies and identify areas of greatest potential.

Yield	Benefits	Construction cost
Volume of dam storage	Proximity to where people live	Volume and total cost of materials and transport
Annual rainfall distribution	Population density	The need to build in stages
Recharge from upstream base-flow and the riverbanks	Quantity, quality, accessibility and reliability of water	Availability and cost of skilled and unskilled labour
Evaporation and seepage losses	Opportunities for irrigated farming, livestock watering, etc.	Local availability of sand, rock and water
Sediment grain size	Proximity to markets	Depth of foundations and length of dam wings

Table 2: Factors that influence cost-effectiveness

[11] Hellwig DHR, 1973 Evaporation of water from sand, Journal of Hydrology, 18 (1973) 317-327

In simple terms, sand dams are most cost-effective when

- **The dam is close to where people need and can make best use of the water**
- **Larger dams are built on larger rivers in larger catchments**
- **Sited in a gorge or narrow river section, where little excavation is required and the dam wings are short**
- **The riverbed slope is low and the dam aquifer extends a significant distance upstream**
- **The dam quickly fills with coarse, sandy sediment**

3.9.1 Most people live closer to small rivers than large rivers

The drainage pattern for any basin varies according to its geography: its size, climate, geology, topography, vegetation and so forth. It gives important clues as to the potential for sand dams. It shows where rivers are perennial, seasonal or ephemeral and the drainage density (stream length / catchment area) and thus how far people are from their nearest suitable stream. Although 3.9.2 shows sand dams are more cost-effective when sited on larger rivers, sites on large rivers are not always best in terms of accessibility. In any catchment, there are more small rivers than large. Often the main reason people build sand dams is to reduce the time needed to collect water and so often the best location for a dam is on a small river, close to where a majority of people need water.

This is illustrated by figure 6. It shows a fictional catchment and stream network, colour coded according to stream order. Stream order is a simple method of classifying stream segments based on the number of tributaries upstream. A stream with no tributaries is a first order stream. A segment downstream of the confluence of two first order streams is a second order stream and so forth. Hence the higher the stream order is the larger the river and catchment will tend to be.

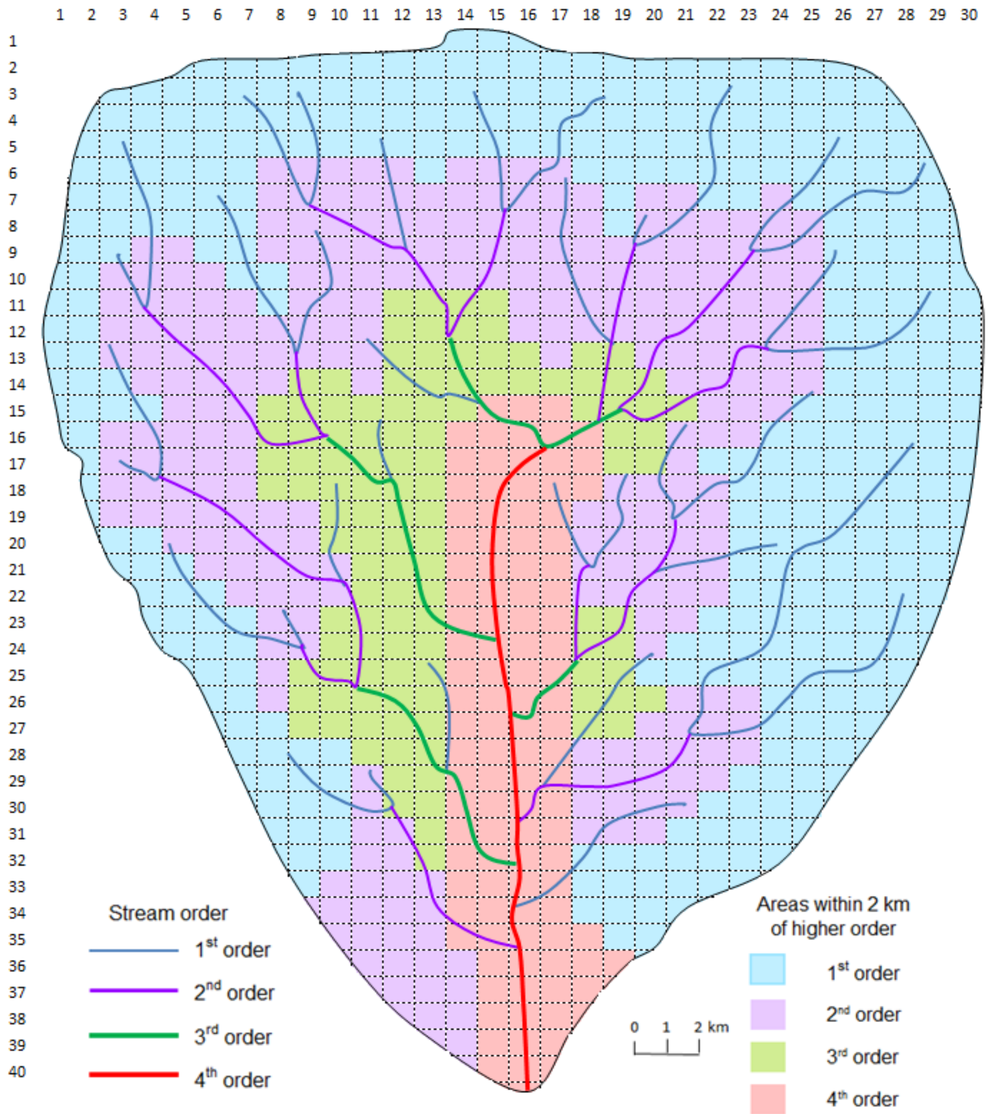


Figure 6: Proximity to streams of different size

The catchment is divided into 1 km^2 squares and coloured to show the closest stream according to stream order. Where there are more than 2 streams within 2 km, the larger river is selected. It shows that less of the catchment is within easy reach of higher order streams:

- 48 % of the catchment is closest to a 1st order stream and more than 2 km from a 2nd order stream;
- 24 % is within 2 km of second order stream and more than 2 km from a 3rd order stream,
- 15 % is within 2 km of a third order stream and more than 2 km from a 4th order stream and
- Only 13 % is within 2 km of the fourth order stream.

These percentages will vary from catchment to catchment but the overall pattern holds true.

3.9.2 Large dams on large rivers are most cost-effective

As shown in table 3, catchment size has a major impact on how much water a dam yields and its cost-effectiveness. In simple terms, large dams on large rivers yield more water and are more cost-effective than small dams on small rivers. They also mature more quickly and are less prone to siltation. To illustrate this, the distance from the watershed (stream length), cost and storage capacity of three dams (shown in photos 11-13) are compared.

They are all sited within the same basin but with significantly different catchment sizes. Table 4 shows that as the length of the catchment above the dam increases from 2 km to 24 km to 40 km, so the channel width increases from 3 m to 30 m to 50 m and the riverbed slope decreases from 1:72 to 1:118 to 1:188. The number of bags of cement required is a good indicator of cost. Although dam 2 is approx three times more expensive than dam 1, it stores approx 30 times more water than dam 1, which makes dam 2 ten times more cost-effective than dam 1 and demonstrates the relationship between cost-effectiveness and catchment size.

	Width	Depth	Throwback	Porosity	Storage	Stream length	Riverbed slope	Bags of cement
Dam 1	3 m	2 m	296 m	40 %	178 m^3	2 km	1/74	248
Dam 2	30 m	3 m	706 m	40 %	6,353 m^3	24 km	1/118	811
Dam 3	50 m	6 m	2,259 m	40 %	67,765 m^3	40 km	1/188	Unknown

Table 3: Comparison of the storage of 3 dams

Notes on methodology used: The greatest aquifer depth is assumed to equal the central spillway height. Throwback is the distance the sand reservoir extends upstream. Behind an open water dam, the reservoir surface is approximately flat (although it has a slight slope to maintain the flow through the reservoir). Behind a sand dam, the raised river bed that forms the aquifer surface is not flat. It has a slope slightly less than the original riverbed. In this example, the aquifer slope is assumed to be half the slope of the original riverbed. So in dam 1, the throwback is estimated by multiplying spillway height (2 m) by twice the inverse of the riverbed slope (2 x 2 x 74) = 296 m.

3.9.3 Factors that influence the rate of sediment transport and dam maturation

The rate at which a dam fills with sediment is determined by **(1)** the additional storage volume created by the dam and **(2)** the rate of sediment transport. The additional **storage volume** **[1]** is greatest when

- The riverbed slope is shallowest
- The additional sediment depth (as determined by the central spillway height) is greatest and
- The channel width is greatest

The **rate of sediment transport** **[2]** is determined by how long and fast seasonal rivers flow for throughout the year. This in turn is determined by how much overland flow there is and how much sediment is suspended in this flow. This is determined by many inter-related factors such as climate, topography, vegetation, soils, geology and land use. No one factor should be seen isolation but general relationships can be described. Table 4 describes some of the most important factors that influence river flow and sediment transport.

Photo 11: Dam 1, 250 bags of cement

Photo 12: Dam 2, 810 bags of cement and 30 times more storage than dam 1

Photo 13: Dam 3, 10 times more storage of dam 2

Catchment size
• As catchment increases, discharge increases and rivers become deeper and wider and flow for longer and for more of the year • As catchment increases, bank slopes decrease and wing wall lengths increase • As catchment increases, base-flow and dam recharge and dam yield tends to increase • As catchment increases, attrition reduces sediment grain size. As river sediment becomes finer, conditions are less suited to sand dams • As catchment increases, peak rainfall intensity averaged over the catchment decreases • As catchment increases, more of the dam is in the river channel holding back water and less is on the riverbanks controlling peak floods. This holds true until a point is reached when the flood plain slope is so shallow that the wings walls increase in length as catchment size increases
Slope
• As catchment slope increases, runoff, erosion and sediment load increase. Floods rise and fall more quickly and flows are more torrential but last for less time. Conditions are better suited to sand dams. • As streambed slope increases, velocity and sediment transport increases and conditions are more suitable for sand dams. However, the storage volume of the dam and hence its cost-effectiveness decreases • As river bank slope increases, dam wing wall length decreases and dams are more cost-effective
Rainfall
• As rainfall intensity increases, runoff, erosion and discharge increase, floods rise and fall more quickly and flow is more torrential. The more that rainfall is concentrated in a few intense storms and is seasonal, the more suitable the area is for sand dams. • As annual rainfall decreases, vegetation density and infiltration decrease and the percentage of rainfall that runs off the land tends to increase. High run-off causes more erosion and more sediment to be transported by overland flow • As annual rainfall decreases, more of the rivers within a catchment will be ephemeral or seasonal and hence more of the catchment is potentially suitable for sand dams • As annual rainfall decreases, annual river discharge and total annual sediment transport is less and dams will take longer to mature. Drainage density is also less and so there are less suitable rivers within a certain area • As annual rainfall decreases, a higher proportion of the total annual discharge will be held behind the dam and less will flow downstream. Research on SE Kenyan dams found that between 1 - 3 % of annual discharge is stored behind the dam
Velocity of flow
• Velocity is determined by discharge, riverbed slope and riverbed friction. Although slopes decrease as the catchment size increases, the riverbed often creates less friction and becomes more hydraulically efficient. Therefore there is not a clear relationship between velocity and catchment size and often velocity and sediment transport increase as catchment size increases • As flow velocity increases, sediment transport increases, the river sediment become coarser, a greater depth of sediment is be agitated by the flow and conditions are better suited to sand dams • As average and peak velocities increase, the river channel becomes deeper and narrower and meanders less. The channel sinuosity (river length/catchment length) and channel width/depth ratio measure this

Table 4: Factors that influence how seasonal rivers flow and sediment transport

3.9.4 Impact of catchment size on how rivers flow after a storm

Rivers with larger catchments flow for longer with greater discharge. They have greater base-flows and these base-flows continue for a longer period after a storm and into the dry-season, hence a large dam on a large river will receive more recharge compared to small dams. Because discharge is greater on large rivers, the volume of sediment transported is also greater and as a result, large dams tend to fill with sediment more quickly and are less prone to siltation. Conversely sites close to the head of a valley have less sediment transport and will be more prone to siltation (refer to section 6.4.3).

To reduce the risk of siltation and ensure the benefits are realised within reasonable time, a sand dam should fill with sediment within a reasonable time, ideally within one year and not more than three years (see section 6.4.3). Where the rate of sedimentation is low, the central spillway is raised in increments over several years to avoid siltation. Building in stages increases the cost and complexity of construction and so it follows that sand dams are more cost-effective and less risky on streams with torrential flows that carry high volumes of sediment.

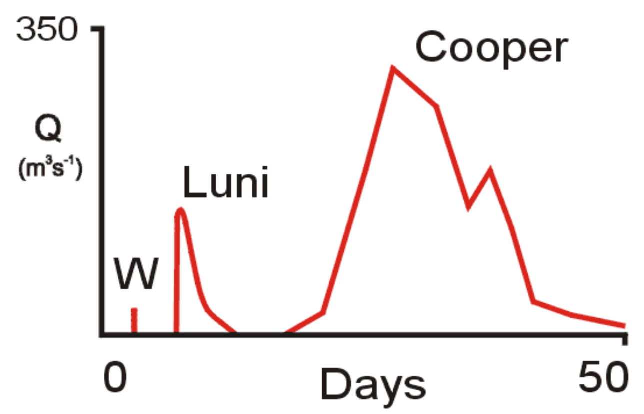


Figure 7: Storm hydrographs for 3 catchments of different size

W is Walnut Gulch, Approximate basin sizes: Walnut Gulch ~ 10 km^2; Luni River, India ~ 1000 km^2; Cooper Creek, Australia ~ 150,000 km^2. Rivers with larger basins flow over many days to weeks, with multiple flood peaks.

Chapter 4: Introducing sand dams to new areas

4.1 Introduction

All water technologies, to a greater or lesser extent, must be adapted and applied in ways that suit the local context and the intended purpose. Some water technologies suit a standard design and model of application that requires little adaptation from one place to another. Sand dams are not one of these technologies. Sand dams cannot be 'cut and pasted' from one place to another – they need to be applied so they work socially and technically. Sand dams won't work everywhere. Even the most successful dam from a technical perspective may fail through poor and inappropriate implementation. This type of failure often relates back to a failure to fully involve and gain the informed agreement of end users at all stages of the siting, construction and management of the dam.

It is recommended that if possible staff from the implementing organisation and end-user representatives visit places where sand dams have been built for some time on a structured learning visit. This is one of the best ways to start building an understanding of sand dams, their benefits and potential impacts, the amount of hard work involved and the issues to be considered in the context analysis and pilot design. Nothing convinces farmers of the benefits of sand dams more than seeing them and talking with fellow farmers about how they manage the dam and how they have benefitted from it. And nothing demonstrates the amount of hard work involved better than joining together with other groups to build a dam.

4.2 Planning a pilot dam(s)

When applying the technology in a new area, it is recommended to conduct a pilot to learn from the experience. Given the many aspects to consider in a pilot, you may consider running several pilots to test different aspects in a planned sequence. Here are the suggested stages for a sand dam pilot:

Stage 1: Pre-feasibility study: (1) Are there sites in the intended pilot region that meet the pre-conditions for sand dams? (2) Are there security risks that prevent or hinder the ability to work or travel in the region? (3) Is the pilot dam(s) part of a wider programme and if so, is the intended programme clearly understood and (4) what resources will be required and are they likely to be available?

Stage 2: Feasibility study: As the level of detail and clarity develops: (1) Identify the gaps in existing knowledge and the questions the pilot will seek to answer; (2) Conduct an analysis of the political, economic, social, technical, legal and environmental issues that the pilot(s) will consider (sometimes abbreviated to a **PESTLE** analysis) and (3) Identify and confirm the technical suitability of at least three potential dam sites.

Stage 3: Pilot design: From the three potential sites, select the optimum site with the community. Complete and document the sand dam design(s) including the bill of quantities, budget, schedule of activities and a plan to monitor and evaluate the pilot(s).

Stage 4: Construct, monitor and evaluate. (1) Construct the dam; (2) Collect and analyse quantitative and qualitative monitoring data, (3) Evaluate pilot with all stakeholders, document lessons learnt and gaps in knowledge and if required design a new pilot. A typical pilot would only build 1 - 2 dams in the first year. Progress after this depends on the capacity and priorities of the implementing organisation and the complexity of the pilot project and its context.

4.3 Political and institutional

Existing community structures: What structures and mechanisms exist for community decision making and working in groups towards a common goal - such as self-help groups or co-operatives? Do community groups have legal status and do they need to register with the government?

National and local policy environment: Is the country politically stable? Are there any specific local or national security risks? Is the government supportive of small scale farming? To what extent is food and water security in drylands or watershed management a government and international donor priority? What policy frameworks and documents exist to manage water resources, support rural food and water programmes and adapt to climate change? Is there a national rainwater harvesting association or other similar professional network? What laws and regulations exist for national and international NGOs? Is approval required to work in a certain area and on a certain issue? To what extent do national and local government agencies work with and support NGOs and community organisations? How might sand dams reduce or increase conflict?

Government co-ordination of development in Uganda: The extent to which the activities of NGOs are regulated and approved by government differs from country to country. In Uganda, local authorities co-ordinate and authorise development activities in their area. This includes approving technology choices and requiring that NGO plans align with and contribute to local government's own plans. This affects the order and depth of stakeholder engagement required with the government consulted prior to direct engagement with community structures.

4.4 Economic

Economic stability: What is the risk and potential impact of hyper-inflation and exchange rate instability? How stable are material prices, especially cement, timber and steel?

Beneficiary income: What are the typical sources of employment and income, typical income levels and distribution of income (within households, communities)? What livelihood or employment opportunities exist and how is this changing? Are incomes or diets so low that community members cannot spare the time or energy to build a dam or their capacity is significantly limited? To what extent do young men migrate for work or grazing livestock in the dry-season?

Infrastructure: What is the level of infrastructure such as roads, electricity and communications? How does this impact the programme? How accessible are local markets? How does this impact transport logistics and costs?

4.5 Social

Culture, tribes and language: What different cultures or tribes exist in the area (if any) and what are the implications? For example: are there different languages or is there any history of conflict between groups especially over water and land and what are the implications of this? What traditions and customs exist that may impact the pilot or programme? For example, in SE Kenya, there is a tradition called Mwethya, the concept of helping others, and others then helping you in return. Does this type of concept exist in your area? If not, how difficult or easy is it to get local people to work together? Are there any groups in the community that are less able or likely to co-operate and how might this affect the pilot or programme?

Livelihoods: What is the population density, settlement patterns and household size? How will the water from the dam be used: domestic, irrigation, livestock watering, aquaculture or a combination of these? What is the annual cycle of farming? Are people settled or do they migrate? Are they pastoralists? What are the implications for building sand dams? For example, in the dry-season, when dams are built, do pastoralists migrate in search of water and grazing? How would the dam be managed for multiple uses? How would settled and migratory populations co-operate?

Conflict in Karamoja region, N.E. Uganda: Life in Karamoja revolves around cattle. There is deep seated conflict between different tribes of pastoralists fuelled by cattle thefts and clashes over grazing and water access. In this context, sand dam water has the potential to fuel or reduce this conflict depending on the dam's siting and how livestock watering is managed.

Community participation: Is there a history, tradition or accepted practice of communities or groups working together to deliver a result, and / or different communities coming together to help each other out and reciprocating when needed? To what extent do other NGOs pay community members to work on similar programmes? How easy or difficult will it be to mobilise a community to work together? Has the government, past or present, sought to impose the concept of 'volunteering' and community labour?

Community structures in Mozambique: Following independence from Portugal, in the 1970s and 1980s, the government followed a policy of collectivisation and large scale state-enterprises in farming. During this time, the state promoted 'volunteerism' to improve the land on the state-managed smallholder cooperatives. Over time many farmers grew to resent this policy and the legacy is still felt today. Community structures remain closely linked to local government structures. The concept of freely volunteering your labour to improve the common good of a particular group or community is viewed with suspicion in many areas, especially in areas where the current ruling party, FRELIMO, is less supported.

4.6 Technical

Availability of generic or dam building skills: To what extent do general building skills exist in the community? What experience does the implementing NGO, local workforce and community have in general construction and building dams or using stone-masonry in particular? For example, are people used to building walls, water tanks or working with concrete or mud? Skills development should be built into any pilot. What is the level of education (such as literacy, numeracy, languages, ability to think creatively and acquire new skills, etc.)? What impact will this have?

Lack of appropriate skills in Sudan: In South Kordofan, Sudan, there is little knowledge or experience amongst pastoralists of how to excavate or use cement or mud in construction. As a result, training in construction skills and their wider use was incorporated within a pilot project.

Are there seasonal rivers suitable for sand dams in the area? Do people collect water from scoop-holes? What is the depth and grain size of the river sediment? Do sites exist where the bedrock is at or near the surface? What is the availability and suitability of local rock, sand and water?

Availability and quality of materials: cement, steel and timber: Is there cement manufacture within the country? Where can cement be bought from and how far will it need to be transported? How does the quality and availability vary between suppliers?

Lack of suitable timber in Zimbabwe: The lack of availability and high cost of hardwood timbers suitable for formwork has meant a sand dam pilot has experimented with the use of steel sheets that can be bolted together to make the dam formwork. These sheets are relatively expensive but can be reused many times over.

4.7 Legal

Statutory and customary law: Are laws respected and enforced? How relevant is customary law?

Land ownership: What are the legal requirements for building dams (and wing-walls) and gain access to it? Are there any dam building requirements/restrictions, such as height restrictions?

Land ownership in Mozambique: Some factors can be both inhibiting and enabling. For example, in Mozambique, most land is state owned. As a result, individual farmers have little incentive to or experience of terracing land or conserving soil and water on 'their' farms. Shifting agriculture and 'slash and burn' clearance of land is common place. This is an inhibiting factor to promoting terracing and gulley reclamation in the dam catchment. However, state ownership of land eases the process of allocating small parcels of land close to the dam to individual farmers for small-scale irrigated farming.

Dam ownership and regulation: The ability for the community to own the dam has a significant bearing on the sustainability of the solution. Is it possible for the dam to be owned by the community or community group? What is the legal context of ownership and regulation - when people build a dam, what does the law say about who owns it and manages it? For example, in Kenya, communities register the dam with the Water Resource Management Authority. The community does not officially own it - it does not have legal deeds to the dam - but for all intents and purposes the community owns it, controls access and manages it. The government retains the right to take 'back' the dam, if, for example, they wished to build a road bridge at that point but in reality this is very unlikely.

Access rights to dams: Will all local people have appropriate access to water? If not, what needs to be done to secure this? Are legal agreements to cross private land been secured (where needed)?

Commercial development: What local development plans exist, particularly upstream? For example – are their mining or forestry consents and if so what plans are in place to protect water quality?

Water rights law: How are water rights recognised and protected in law? What legal mechanisms, both statutory and customary, are open to community groups to safeguard and enforce their water rights and how effective are they? How is bulk abstraction controlled? Are water fees to be charged?

Sand harvesting regulation: Sand from rivers is often used for small scale brick production and local construction. This is seldom done on a scale that requires control. However commercial sand harvesting for the construction industry does require control. Is commercial sand harvesting common? What are the laws and regulations around sand harvesting and are they enforced?

4.8 Environmental

The environmental factors that determine the feasibility, yield and cost-benefits of sand dams were discussed in chapter 3. In addition consider how these factors shape the environmental impacts of sand dams, such as aquifer recharge, improving the yield of adjacent wells, rejuvenation of the riverine ecology, downstream dry-season flows and impacts on downstream biodiversity, wetlands and ecologically sensitive areas. Research in Kenya has found sand dams have only beneficial impacts on aquifer recharge and downstream dry-season flows. However impacts will vary according to local geography and downstream impacts (both positive and negative) should be monitored.

Chapter 5: How to site a sand dam

Assuming the feasibility assessment has identified suitable seasonal rivers and areas of greatest potential for a pilot dam, this chapter explains the key considerations in deciding where to site an individual sand dam within a stretch of river. It assumes that:

- The implementing organisation already works with communities in dryland regions, addressing water and food issues and has agreed with one such community to pilot a sand dam
- An analysis of the local context has been completed.

5.1 Start with the community

The aim is to select an optimum site. In this context optimisation means to maximise the available water and benefits that result from a given investment of resources. Good siting and design is critical to this optimisation. Two dams may contain the same volume of materials and cost the same amount of money yet deliver hugely different amounts of water and benefits. Benefits are often determined by the proximity of the dam to peoples' homes and access to land adjacent to the dam, so the optimum site is not necessarily the best from a technical point of view.

The first step is to talk with the intended users to establish their needs and whether a sand dam is the most appropriate solution. If the technology choice and site selection does not take into account the community's knowledge and needs, it will not be sustainable. Chapter 10 describes alternative water technologies used in rural drylands that should be considered alongside sand dams. Where the preferred solution is a sand dam and the dam is to be built, owned and operated by a community or community group, it is critical the end-users agree to the choice of site.

The role of the implementing organisation is to facilitate discussions so the community makes an **informed choice**. The following people should be involved in this process:

- Community representatives
- Dam designer
- An independent, impartial person who is known and trusted by the community or community group to facilitate discussions well

Some social factors to consider include:

- How much time and physical labour is the community prepared to invest? Sand dams are very labour-intensive
- How close is the site to peoples' homes and lands?
- Is there legal agreement with the statutory and customary authorities for the dam's construction including the legal right of the community or community group to operate and manage the dam?
- Where adjacent land is privately owned, is there legal agreement with the owners to allow access to the dam and its water and for the dam wings to be built on the private land (where applicable)?
- Where it is planned to use the water for irrigation, fish ponds, etc., is the land adjacent to the dam suitable and is there agreement to use the land for this intended purpose?

Part of this role is to explain how technical variables and decisions impact upon the costs and benefits. Table 5 lists some of these factors. Selecting the optimum site is an **iterative process:** Investigations become more and more detailed as the selection of sites is narrowed. Identify and walk along suitable river courses asking questions of local people who are familiar with the rivers and making observations. Eliminate obviously unsuitable sites and then conduct more detailed investigations considering both social and technical factors. These factors vary and have differing importance according to the local context.

The benefits and opportunities created by sand dams are usually greatest for people living closest to the dam. Because the choice of site has the potential to create tension within a group and undermine the sense of shared ownership, there is a strong case to work with existing community groups or structures that already have a track record of working well together and taking collective decisions. In this sense, the Kenyan NGOs working in Machakos, Makueni and Kitui benefit from the long tradition of successful community groups that exists in the area. In Kenya, where land adjacent to the dam is privately owned, there is often agreement with the land owner to allow the community or community group to use and / or rent some of this land in exchange for their help to build the dam. Often the land owner is also a member of the community group and the group will select a site on the understanding that another site that will benefit other group members more, will be selected in the future.

Technical variables	Impact on cost and benefits
Increased spillway height	Increased dam aquifer and volume of water If too high, increased risk of dam siltation, stream diversion or prohibitively long and expensive wings
Increased sediment grain size and porosity	More abstractable water and reduced abstraction time
Decreased gradient of riverbed	Increased dam aquifer and yield
Decreased gradient of riverbanks	Increased length and cost of dam wings Adjacent land more suited to irrigation and fish ponds
Increased catchment and stream size	The dam fills with sediment more quickly Increased recharge from base-flow
Increased depth of foundation	Increased construction cost and labour
Immediate catchment is protected	Reduced silt in dam aquifer and more recharge
Increased distance to transport materials including rocks and water	Increased construction cost and labour
Increased depth of sediment upstream	Increased dam aquifer and volume of water

Table 5: How technical variables and choices impact upon costs and benefits

5.2 What to look for during siting

5.2.1 Existing scoop-holes

Local people will often already collect water from scoop-holes in sandy riverbeds. Ask which scoop-holes last longest into the dry-season as they are often immediately upstream of a natural dyke that often makes an ideal sand dam site. If there are no scoop-holes, seek to understand why. Is this evidence that the riverbed does not hold water for long and the underlying geology is unsuitable? Is there other evidence that the river does not hold water for long such as fractured or friable bedrock or a deep and fluctuating watertable level? Is there evidence of old riverbeds near the present river channel which could be exploited to allow sub-surface flow around the dam?

5.2.2 Vegetation on riverbanks

Look for the presence of trees that require large amounts of water as this indicate a good local source of water. This will vary from place to place. In Kenya an example is the Fig tree. Ask which trees require the most water, where they are located and how else they identify sources of water.

5.2.3 Rocky outcrops

Natural gorges, where the valley sides steepen and the river channel narrows, are ideal sites for dams. Gorges indicate points of relatively harder bedrock, where the bedrock is close to the surface. They can often be identified using Google Earth. Photos 14 & 15 show rock outcrops on both banks indicating bedrock close to the surface. Ideally the rock is strong, impermeable with no or few fissures and at or close to the surface. Use a tapered iron bar (at least 3 metres long) to probe and confirm the sediment depth. Once confident a site is otherwise suitable, excavate test pits to confirm the depth of excavation required.

Photo 14: Rocky outcrops indicate a promising site

Photo 15: Test pits and probing confirm depth of bedrock

Sometimes upon excavation, it is found that the bedrock does not follow the assumed profile, but instead dips down sharply and deeply. Generally speaking it is not cost-effective to dig down more than 5 metres and even then only over a small portion of the riverbed, where there is a narrow fissure or crack between two rock outcrops. In some cases, the additional work and cost make the site uneconomic and the site should be abandoned.

5.2.4 Upstream riverbed slope and sediment depth

For a given height of dam, the steeper the gradient of riverbed, the less the throwback will be and the lower the capacity of the dam. It follows that a dam will be more cost-effective when it is sited immediately downstream of a relatively flat section of riverbed. The capacity will be significantly increased if the height of spillway is sufficiently high to allow the throwback to extend to cover this relatively flat section. When walking along the river probe the riverbed at regular intervals. A dam sited downstream of a point where the sediment is deepest will have a greater capacity.

5.2.5 Open water dams in catchment

If there are open water dams sited on seasonal rivers within the basin or region where sand dams are being considered, these dams should be identified (using satellite images such as Google Earth), visited and assessed. The presence of open water dams indicates that the riverbed is sufficiently impermeable for a dam.

What are the dimensions of the dam, its catchment and its reservoir? How does the catchment and reservoir size compare with the proposed sand dam? Who designed and built it? Are there lessons to be learnt in terms of how the agency estimated the design flood and designed the spillway? Are there any records of flood flows over the dam and rainfall data? How deep are the dam foundations? What is the height of the spillway above the original riverbed level? Most importantly, what can be learnt about the rate of sediment transport? Is it possible to estimate the rate of sedimentation? By how much is the depth of sediment behind the dam increasing each year? If the sediment level is rising quickly, such an open water dam may turn into a sand dam once it is full. There are several known examples of dams that were originally designed to be open water dams but which are now sand dams.

A dam sited on a small river close (say less than 4 km) to the head of the valley may take many years or decades to fill with sediment due to the limited discharge and sediment transport on a small catchments. This does not mean successful sand dams cannot be built lower down the same catchment. However, when an open water dam is sited on a larger catchment and has a low rate of sedimentation, this indicates limited sediment transport and an increased risk of dam siltation. Take this into account when designing the central spillway height (6.4.3). Furthermore, if there are open water dams above a proposed sand dam site, this will trap most of the sediment and reduce the amount of sediment flowing into a sand dam. Once a dam is full of sediment, it will no longer act as a barrier to sediment transport.

5.2.6 Ownership, slope and suitability of adjacent land

How would the slope of the riverbanks impact on the length and cost of the dam wings? How would the slope of land upstream of the dam impact on its suitability for irrigation or other productive uses? Do adjacent land owners agree to this land being used for access, dam construction and / or productive uses? Are there low spots immediately upstream of a potential site where a smaller channel or gulley joins the main river? Gulleys wash finer sediments into the dam aquifer and would need to be reclaimed prior to any construction. A dam causes the upstream riverbed to rise and allows the river to exploit an upstream low spot and divert around the dam. This could be the factor that determines the maximum height of the spillway on any potential dam. This is only liable to be an issue on shallow valleys with slopes less than one percent. Ensure there are no bridges, drifts or other dams upstream of a potential site that could be partially buried as a result of a new dam.

5.2.7 Availability of local construction materials (sand, water, stones)

Is there sufficient, suitable sand, stone and water available at the dam site? If there is not, where are these materials available from and does the community understand and agree to provide the labour required to collect and transport these materials? How does the location impact on the cost of transporting other construction materials such as cement, timber and steel reinforcement?

5.2.8 Calcate or rock salt

Calcate or rock salt is usually a whitish rock that livestock lick for their salt content. Where bedrock contains calcate, there is a risk that these salts will leach into the water held by the sand dam. In Machakos and Makueni Counties of Kenya, 1 - 2 % of dams produce water that is considered too saline for domestic purposes. In these cases the water is still used for livestock watering and sand dam water is often less saline than water from surrounding wells. Ask local people if scoop-hole water or groundwater is saline and to what extent this is a problem. Ask if there are local calcate deposits. Regular irrigation on saline and / or sodic soils may increase soil salinity and reduce fertility. In the absence of soil testing, soil salinity is indicated by the presence of white salt deposits on the surface and licking a small sample of soil to taste for the presence of salt.

Chapter 6: Sand dam design: a step by step guide

6.1 Three golden rules of sand dam design

1. **Sand dams must be built on bedrock or a suitable impermeable foundation to a point at least 1.5 metre wider than the annual flood width of the river**
2. **Sand dams must not change the river's course**
3. **The spillway height must not prevent the river flowing over the dam or cause dam siltation**

6.2 Common causes of failure

Provided the golden rules and design principles are respected, a sand dam will withstand the forces acting upon it for many years with little or no maintenance or repair. Common causes of failure include:

- The site does not meet one of the four pre-conditions for a suitable sand dam site
- The river undercuts the dam wall due to the lack of an adequate apron
- Water flows under the dam and undermines the foundation due to poor seal between the dam and bedrock.
- The river changes course due to poor positioning and / or insufficient capacity of the spillway
- Dam silts up because the central spillway is too high relative to the rate of sedimentation. This is most common on small catchments.

Photo 16: A failed dam near Mtito Andei, Kenya

The dam shown in photo 16 failed because the river over-topped the dam, eroded the left-hand bank and ultimately changed the river's course. This resulted from the failure to extend the foundation and wings into the left-hand bank and the inadequate capacity of the spillway.

6.3 Understanding the river's flow

An understanding of how the river flows is essential to design a sand dam. Models can estimate peak flood flows but their accuracy relies on sufficient, accurate rainfall and catchment data, such as its size, shape, and slope and run-off characteristics. This data is seldom easily available and using this approach is liable to act as a barrier to mass adoption. Fortunately experience from Kenya shows robust sand dams can be built relying solely on local knowledge and observation of the river channel and banks.

At the potential dam site and at other points upstream and downstream of the site, ask people to identify the points on both banks that correspond to the flood levels shown in figure 8 and mark these points. Choose people, especially elders, who live near the river and who have a detailed knowledge of the river over many years and who know the historical picture as well as the current situation. Is there a consistent picture from site to site and from one respondent to the next? Are the answers consistent with what can be physically observed? Look for debris (flotsam) carried by recent floods and deposited in trees and rocks along the banks as shown in photo 17. Look for high water marks and signs of where the river has smoothed rocks on the banks. Look for any evidence of changes in the river's course. How will upstream bends and rock outcrops deflect the main flow away from the centre of the river towards either bank? Will sand deposited behind the dam cover these upstream rock outcrops and so shift the position of the main flow?

Photo 17: Flotsam carried by recent flood indicate peak flood level

Photo 18: A Baobab trunk gives an indication of the size of peak flood flows

The measurements taken during a site survey are marked by red dots in figure 8. The flood levels determine the position, width and height of the central and flood spillways. The survey also records the frequency and duration of these floods. The measurements include:

- The depth of bedrock or suitable foundation
- The width of the riverbed
- The width and depth of the mean or 'normal' flood flow defined as the average depth of flow when the river is flowing
- The width between the top of the riverbanks and their height above the riverbed
- The width and depth of the annual flood
- The width and depth of the 'lifetime' or 50 year flood. What is the largest flood anyone remembers? When did it occur? How frequently do floods of similar magnitude occur? What is the largest object washed down river?

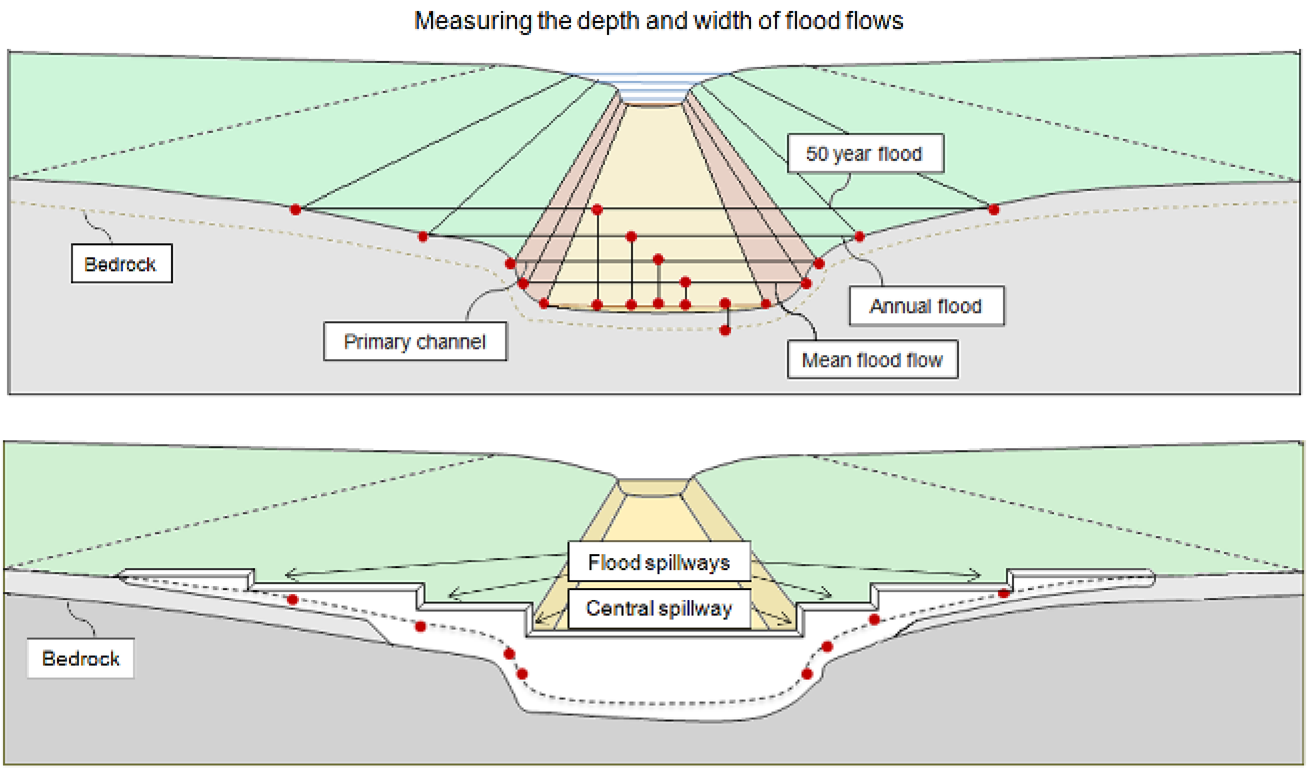


Figure 8: The dimensions measured during a site survey and their position in relation to the dam spillways

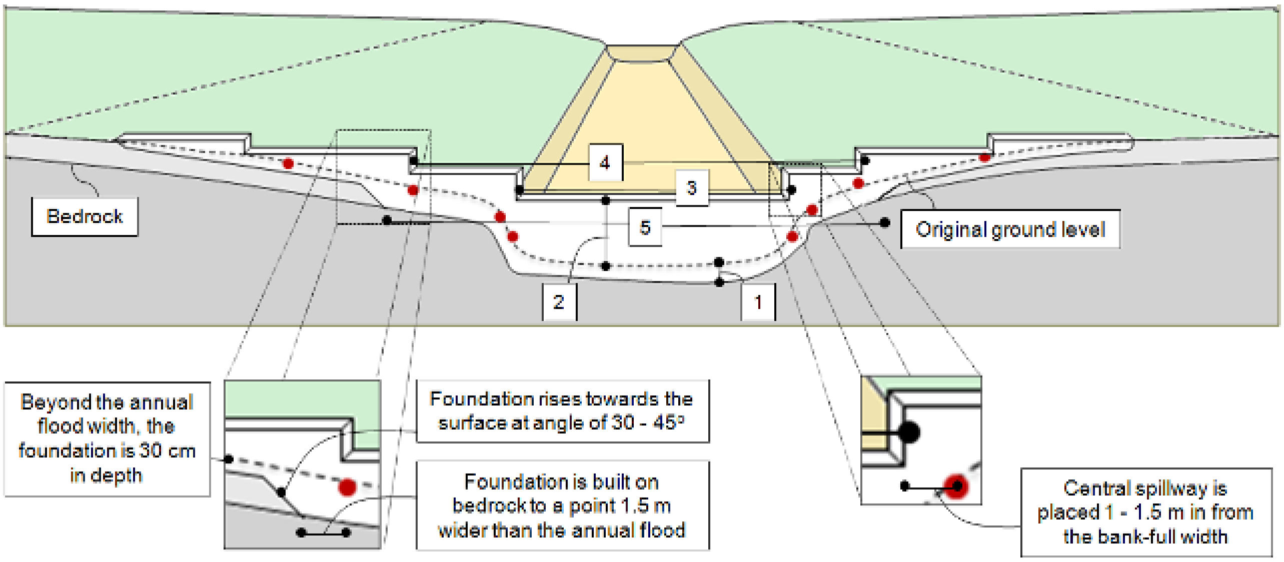
Take account of changing climate: The impact of climate change is predicted to be greatest in tropical drylands. There is considerable uncertainty over what local change is expected and the extent to which local change is driven by global or local forces. In the tropics climate scientists predict increased rainfall in some areas and decreased rainfall in others as well as increased temperatures and evaporation and more intense and less predictable storms. Agencies supporting farmers, as well as farmers themselves, should seek to monitor and understand local climate change and factor this into dam design. Ask local people whether rainfall and flood patterns have changed and whether the river channel, course and sediment has changed recently, particularly if this is in response to extreme floods. If there is evidence of more frequent and more intense storms and floods, increase the safety margin in the spillway design.

6.4 Design decisions

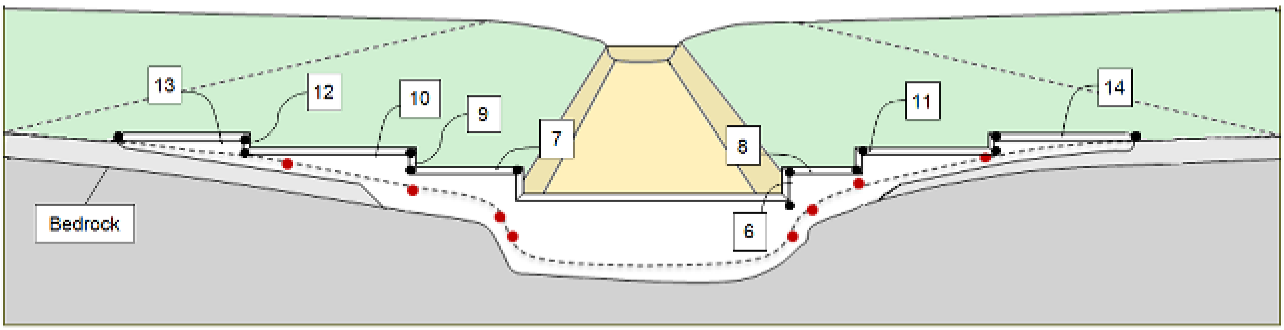
The key design decisions, in the order that they are made, are:

- Positioning and angle of the dam and its foundation
- Width and depth of the foundation **[1, 5]**
- Height of the central spillway above the foundation **[2]**
- Width, height and positioning of the central spillway/s **[3, 6]**
- Width, height and positioning of flood spillway/s (if required) **[4, 7-14]**
- Width and placement of an apron (if required)
- Thickness of dam
- Placement and design of steel reinforcement
- The protection and reclamation of the land in the immediate catchment of the dam

The numbers **[in blue, in section, 6.4]** correspond to the numbers in figure 9. The red dots correspond to the flood dimensions measured during the site survey in figure 8 and the dotted line shows the original ground level.



1	Depth of bedrock or suitable foundation below the original river bed	2	Height of central spillway above the original river bed	3	Central spillway width, placed 1 - 1.5 m in from both river banks
4	Annual flood spillway width, placed in the same position as the annual flood	5	Foundation on bedrock is 1 - 1.5 m wider than the annual flood width on both banks		



6	**Central spillway height** is designed to accommodate bank-full flow	7	**Length of annual flood spillway** on left hand bank (Upstream view: USV)	8	**Length of annual flood spillway** on right hand bank (USV)
9	**Annual flood spillway height** is designed to accommodate annual flood	10	**Length of 50 year flood spillway** on left hand bank (USV)	11	**Length of 50 year flood spillway** on right hand bank (USV)
12	**50 year flood spillway height** is designed to accommodate 50 year flood	13	**Length of dam wing** on left hand bank (USV)	14	**Length of dam wing** on right hand bank (USV)

Figure 9: Dam design dimensions

6.4.1 Positioning and angle of the dam and its foundation

Ideally and in the most cases, the dam is perpendicular of the main river flow. When this is the case, the wing-walls are angled slightly (approx 15 degrees) upstream (fig. 10). This directs the flow back towards the centre of the main channel.

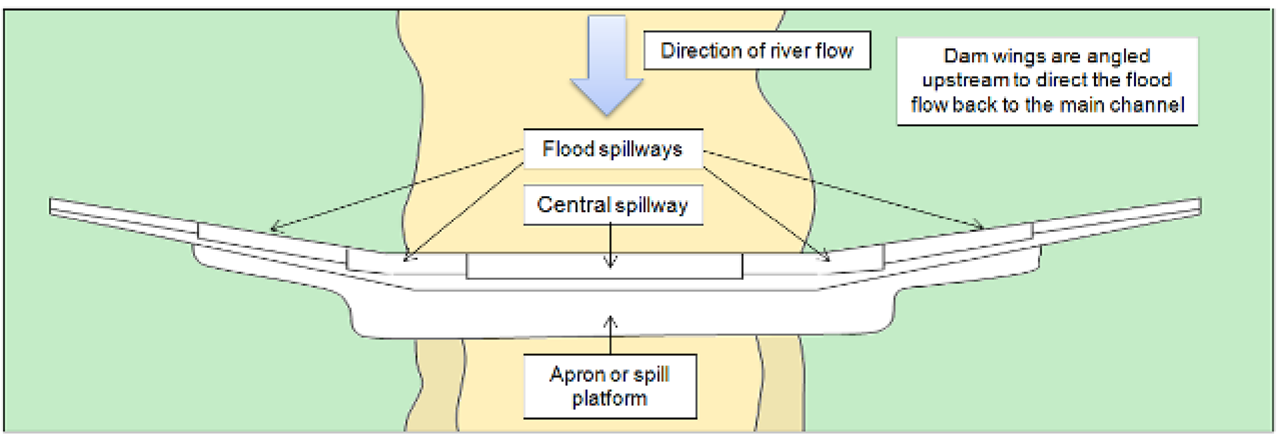


Figure 10: Dam wings angled upstream

When the dam is sited on a rock spur that is not perpendicular to flow, the dam will channel the flow towards the downstream bank. In order to bring the flow back towards the central spillway, the downstream wing is angled upstream as shown photo 19.

Photo 19: Dam angled to follow the bedrock and bring the flow back to the centre of the river

6.4.2 The depth and width of the foundation

Golden Rule 1 states the foundation of the dam must be built on bedrock or a suitable impermeable foundation to points 1.5 m wider than the width of the annual flood. It then continues at a depth of 30 cm for the remainder of the dam wings. This rule ensures that the dam is not undercut and prevents water flowing underneath the dam. If seepage is not prevented, it may develop into a steady flow, which ultimately will undermine the dam's foundation and divert the river's course. Where the riverbed consists of heavily compacted, impermeable clay sub-soil, it is still possible to build a sand dam provided its foundation is excavated at least 1.5 metre into this sub-soil. Beyond the point 1.5 m wider than the annual flood, the foundation rises gradually to the surface at an angle of 45 degrees in consolidated, compact soils and 30 degrees in less consolidated soils until the foundation is 30 cm from the surface (as shown in fig. 9)

6.4.3 Height of the central spillway [2]

The spillway height is critical since it determines

- The length of throwback
- The capacity of the dam
- The length of the dam wings
- The volume of materials required and the cost-benefits of the dam
- The risk of dam siltation and the time required for the dam to mature

As a rule of thumb, **the central spillway height** on ASDF dams is

More than the Mean Flow depth and

Less than the Mean Flow depth + 2/3 (Annual Flood depth - Mean Flow depth)

The aim is to capture as much water as possible without increasing costs beyond what is justified. In simple terms, this means putting the spillway as high as possible whilst obeying the Golden Rules. **Often but not always, this coincides with the top of the banks.** Later, once the dam has matured, the spillway and dam wings may be raised further. The final central spillway should be at least 1.5 m above the bedrock in order to capture sufficient water and sediment to be worthwhile.

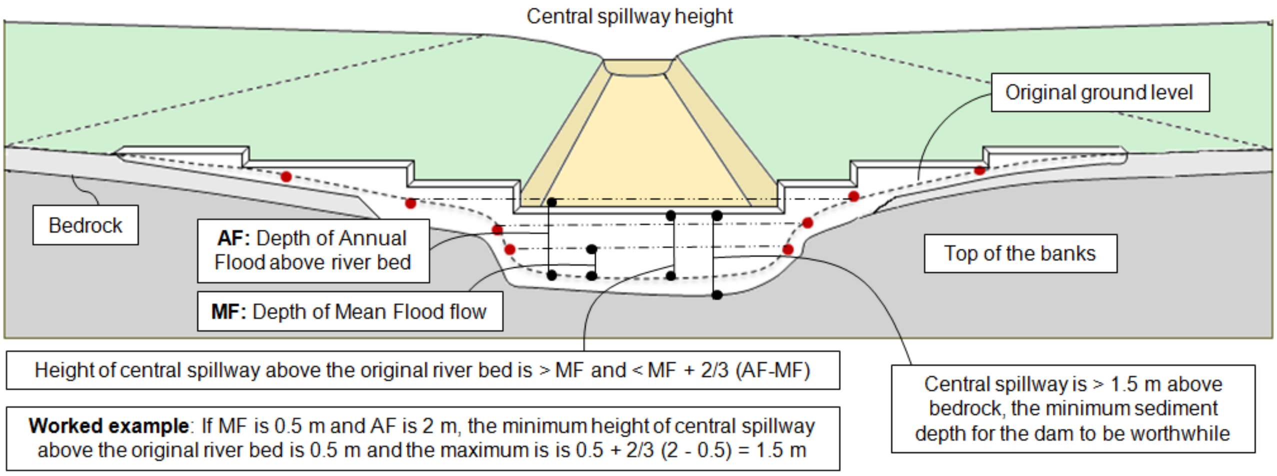


Figure 11: Central spillway height

6.4.3.1 Avoiding dam siltation and / or excessive time for dam to mature

Does the catchment create sufficient flow and sediment transport to fill the dam and flow over the spillway? On small catchments with limited discharge, if the spillway is too high, there will be insufficient flow to wash the silt in the sediment over the dam and it will be necessary to build in stages. Since it is easier to build a dam in one go rather than over several years, the aim is to minimise the number of stages required whilst avoiding siltation or excessive time before the benefits of a sand dam are realised. Several technical guides[12] recommend that to avoid siltation (1) the spillway should always be raised in small incremental steps (approx 30 - 100 cm) and (2) sand dams must be built a minimum distance (7 km) from the head of the catchment. This is based on the belief that a dam with a higher spillway will fill with silt rather than sand reducing the storage capacity of the dam. However, this is an oversimplification: If the original river sediment has high silt content, the dam sediment will always have similarly high silt content regardless of spillway height or catchment size and if the original river sediment is sand, the risk of siltation varies with spillway height, catchment size, slope and rainfall as explained in 6.4.3.2.

The time required for a dam to mature (i.e. fill with sediment) is a good indicator of siltation risk.

Factors that influence how long a dam takes to mature

The time required for a dam to mature is determined by (1) the volume of the dam aquifer to be filled with sediment and (2) the volume of sediment transported each year which in turn are determined by:

- Spillway height: the higher the spillway, the larger the dam aquifer and the longer it takes the dam to mature
- Catchment size: the larger the catchment, the greater the discharge and sediment transport and the quicker the dam matures
- Slope: the more shallow the catchment slope, the less runoff and sediment entering the stream, the less peaky the hydrograph and the larger the dam aquifer. So on shallow slopes, not only is the discharge and sediment transport less but the volume of sediment required to fill the dam is more
- Rainfall: the lower the annual rainfall, the less discharge and sediment transport there is. This is partially offset by higher rates of runoff, erosion and sediment load generated by peak storms in more arid climates.

Sediment tests in SE Kenya

In Machakos and Makueni Counties, Kenya, ASDF dams on larger rivers usually fill in one season, sometimes after just one intense storm. On smaller catchments, dams take several seasons to fill and a surface layer of silt is deposited immediately behind the dam after each season. This is expected given how dams fill with sand (from back to front) and

12 Nissen-Petersen, 2011, Sand dams or silt traps, Sand dams or silt traps? [Link]

how sediment settles (sand first then silt). However, as this top layer of silt dries out it is blown away or with the next major rains, it is churned up in the torrential flow and carried over the dam. Tests on dams in Machakos and Makueni Counties in Kenya found that where dams mature in less than 3 years, the sediment that collects behind the dam has very similar grain size and porosity to the original river sediment with no horizontal layers of finer sediment. This is true even when the dam is built in one go and the spillway is 2 -3 metres above the original riverbed level.

When introducing sand dams to a new area:

The minimum stream length and maximum spillway height to avoid siltation problems varies according to geography. Where dams take more than 3 years to fill and/or where there is a higher percentage of silt in the river sediment (compared to the less than 0 - 0.5 % typical in SE Kenya), it is possible the silt layer that accumulates will be too thick to be removed by subsequent floods. Since there will be no data on how long it takes for sand dams to mature, look for other indicators that the stream has a relatively low discharge and sediment transport, such as:

- Finer river sediments
- Vegetation growing in the river sediment
- A broader, shallower channel with low riverbanks
- Lower flood flow depths

In this situation, take a cautious approach:

- Build pilot dams on larger catchments where the risk is less and
- Raise the central spillway in stages
- As the annual rate of sedimentation is better understood, adjust the increase in spillway height accordingly.

Other factors to consider in designing the central spillway height:

1) **The impact on evaporation losses:** Evaporation from sand is negligible once the water level is 60 cm below the surface. The lower the spillway height, the less the depth of sediment behind the dam and the greater evaporation losses relative to the volume of water stored. Therefore, it is recommended that **the final spillway height should be at least 1.5 metre above the bedrock** in order to collect sufficient depth of sediment.

2) **The impact on the length of the wings:** Will the spillway height require exceptionally long wings resulting in unacceptable labour and cost? If so reduce the spillway height accordingly. The impact is greatest where the slope of the adjacent riverbanks is shallow (less than 1 %).

3) **The risk of upstream diversion:** As the spillway is raised, the riverbed upstream will rise. What will be the impact upstream? Given the lifetime flood, is there a risk that the river will breach its banks at a relative low spot upriver and cut a new course? This risk is greatest in wide flat valleys where the gradient of the streambed and valley sides is low (less than 1 %). Look for evidence that the river has changed course in the past. Consider the risk that a sand dam could cause the river to exploit the old river course and change direction.

4) **The risk of covering upstream land or structures:** Is there a risk the raised riverbed will result in upstream farmland being covered in sand or damaged by floods? Note, as the bed rises, Vetiver or Napier grass and bananas may be planted along the banks. Vegetation slows the flow and results in sediment deposition and new banks to be formed. This prevents the river from spreading beyond its original course and protects the banks from erosion. If, despite this, the concerns of upstream farmers cannot be addressed, reduce the spillway height and build in stages or select an alternative site.

5) **The risk increased water pressure results in seepage under / around the dam:** As the spillway height increases, so the depth of water held by the dam increases and the water pressure acting on the riverbed and banks increases. Is there a risk this pressure results in seepage under or around the dam that undermines the dam's stability? In Kenya a precautionary approach is taken. When the final spillway is more than three metres above the original streambed, the dam is built in stages and that the **first stage is not more than three metres**.

Dams on incised river channels: There is a risk that the dam will cause unconsolidated banks to collapse into the river channel immediately behind the dam. This risk is greatest where the river channel is incised into sedimentary deposits. If the spillway is higher than the top of the riverbanks, turbulence immediately behind the dam could cause banks to collapse, depositing soil behind the dam and reducing the storage capacity. In these circumstances, the spillway should initially be built at or slightly below the height of the banks and if necessary raised later on, once sand is deposited behind dam.

6.4.4 Width and position of central spillway and height of spillway step

Usually the central spillway is centrally positioned within the channel and with its ends 1 to 1.5 metres in from the riverbanks. However, when upstream bends cause the main flow to move towards the outer bank of the bend or when a major upstream rock outcrop directs the main flow towards the opposite bank, the position of the spillway should reflect this. In this case, when there is a significant difference between the width of the mean flow and width of the banks, there may be two spillways within the river channel: one corresponding to the position of the main flow (where the velocity is greatest) and a second wider spillway 1 to 1.5 metre in from the banks.

Once the width **[3]** and position of the central spillway/s is known, the height of the central spillway step **[6]** is determined by the need for the spillway/s to accommodate the bank-full flow (when the main river channel is flowing full). The X-sectional area of the central spillway/s is slightly less than the X-sectional area of the river channel since (1) the capacity of a spillway with smooth sides is greater than a river channel with the same cross sectional area with rough riverbanks and (2) as water flows over a broad crested weir (such as a sand dam), it speeds up (and flows in a state called super-critical). This is because the water is falling under gravity. These three videos show super critical flow over a weir [Link to video 1] [Link to video 2] [Link to video 3]. This increase in velocity is greatest when the riverbed slope is shallowest. As a result, the capacity of spillway is more likely to be over-designed when the upstream riverbed slope and velocity of flow is lowest. (See appendix 5 for fuller explanation).

In simple terms (based on Kenyan experience), **the height of the spillway step [6] is either 1 metre or (0.75) x the height of the riverbanks, whichever is greater.**

6.4.5 Width, height and positioning of flood spillway/s

The central spillway/s controls the river when the flow is less than bank full. The wings beyond the river channel form the flood spillways and are designed to control the annual and lifetime floods. The decision on the number of flood spillways is driven by the difference in the widths of annual and lifetime floods. On larger rivers and where the dam wings are relatively long, such as in wide, flat valleys, several spillways will be used. In v-shaped valleys with relatively steep valley sides and little difference in flood widths, only one or two spillways are used.

The width and position of the first flood spillway corresponds with the width and position of the annual flood. Its height **[9]** is designed so that the spillway approximately accommodates and controls the annual flood**. In Kenya, this step is typically 0.5 – 1 metre.** We use the term approximately because on ungauged rivers, without reliable rainfall data, the estimation of flood flows is necessarily imprecise and because, in dryland regions, annual floods vary significantly from year to year.

Controlling exceptional floods: The extent to which an additional spillway is designed to cope with the maximum lifetime flood is made on a site by site basis and determined by (1) the vulnerability of the riverbanks beyond the dam wings to erosion and (2) the frequency and magnitude of exceptional floods, meaning floods that significantly exceed the annual flood. There are two points of risk: the flood erodes the soil at the end of the dam wings or the flood erodes the sub-soil beneath the dam wings at the point where the wings are no longer built on top of the bedrock.

The community or supporting NGO should start to keep rainfall data. The community should monitor and record these levels and together with the supporting NGO, assess whether the spillway capacity is sufficient to manage the design floods. If not, clearly the dam wings should be raised and extended. The peak flood each year usually leaves a high water mark on the upstream dam wall in the case that it actually overtops the dam, on the soil at the end of the dam wings.

Where additional protection is required, an additional step is added to the wing at the point where it meets the ground level. If the major flood does cause some minor erosion or the banks lack a vegetation cover and are vulnerable to erosion, this may be protected or repaired using sand bags or an earth embankment at the end of the dam wings. In assessing the risk, it should be noted that in the event of the flood overtopping the crest of a dam (at the point where the dam wings end), the flow will (1) be significantly slower than the main flow of the river and (2) only reach this level for a relatively small length of time.

Because the forces acting on the top and sides of the dam are significantly less than at the base of the dam in the centre of the spillway, the thickness of the dam wings may be tapered and the strength of the mortar mix may be weakened (from 3:1 to 4:1 wheelbarrows of sand to bags of cement) in order to save materials.

Where the dam is sited in a gorge with rock outcrops forming the riverbanks, these will control the annual and lifetime floods and no flood spillway is required.

As a general guide, **the height of the spillway steps on ASDF designed dams rarely exceeds 1 metre.**

6.4.6 Dam Apron

A concrete apron or slab downstream of the dam is required whenever the dam foundation is not at the surface and is excavated into the river sediment. Without an apron there is a risk the dam foundation will be undermined causing the dam to topple over and / or leak. The river will scour away the sediment beneath the dam, reducing water availability immediately downstream and / or create a pond beneath the spillway. A pond will prevent access to a piped outlet if a pipe runs through the dam and create an open water source that is liable to be polluted, provide a breeding ground for mosquitoes and create a risk of drowning.

The concrete apron is **10 - 15 cm thick built on top of a rock foundation and extends 2 - 3 metres from the base of the dam extending across the full width of the foundation.** Only on larger rivers would reinforcement be used and this reinforcement should never be joined to reinforcement in the main dam.

6.4.7 Thickness of dam

The thickness of the dam at its base is determined by its height. The dimensions and formula for calculating this thickness is based on the field experience of ASDF and the ability of dams designed in this way to resist the forces acting upon them for many years. The thickness of the dam base is 90 cm plus 30 cm for every metre the spillway is above the foundation so that the

Thickness of dam base (in metres) = 0.90 + (Height of dam from base to spillway (m) x 0.30)

From base to spillway, the thickness of the dam reduces by 30 cm for every metre increase in height and from the spillway to the crest, the thickness tapers further. At its crest, a typical ASDF dam is 40 cm thick and at its spillway 90 cm thick. Figure 12 shows how the thickness of the wings also tapers towards the ends of the wings. Note the upstream face of the dam is vertical.

Height from base to spillway	Base thickness
0m	90 cm
1m	120 cm
2m	150 cm
3m	180 cm
4m	210 cm
5m	240 cm

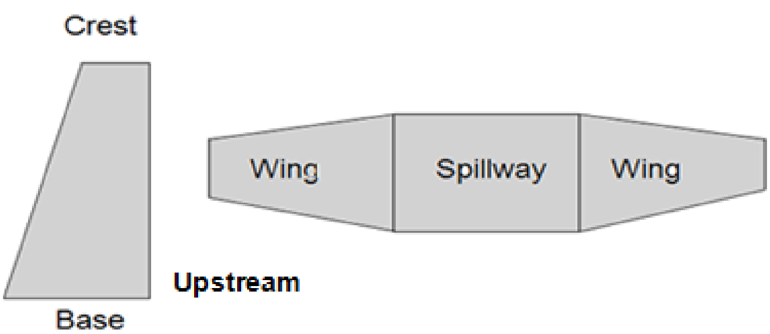


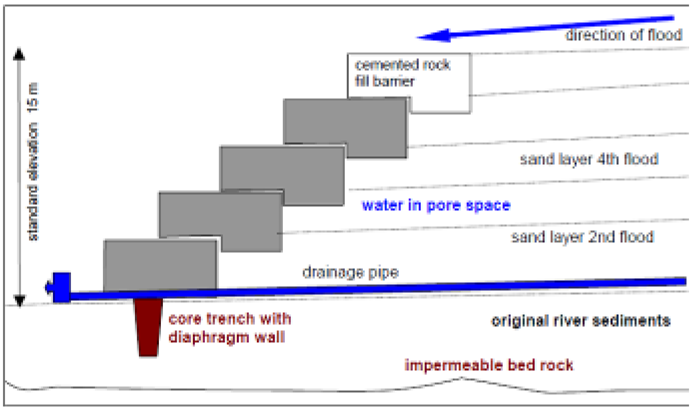
Figure 12: Dam thickness

6.4.8 Reinforcement

The dams are reinforced with Y25 (25 mm thick) steel bars which are placed vertically and **spaced approx. every 1.5 m** in a zig-zag pattern. The dam is reinforced across the full width of the foundation. Holes are chiselled by hand and the bars are embedded at least 10 cm within the bedrock and extend to the full height of the dam. The steel is placed 15 cm from the formwork. Once in the dam, the steel must not be exposed to air or water. At 50 cm height intervals, horizontal lines of barbed wire are used to connect the steel bars. A second line follows an opposing zig-zag line and wrapped around large rocks (fig. 20). The barbed wire extends across the full width of the dam and joined together at the ends of dam wings (fig 18).

6.4.9 Sand dam extension design

When constructing a dam which will be extended later, small stones should be embedded into and stand out from the spillway and wings. This gives a good key for the new mortar to bond to. Holes are chiselled into the original dam and the reinforcement in the dam extension is embedded in the original dam. An alternative method used in Namibia is shown in photo 20 and involves constructing a staircase.



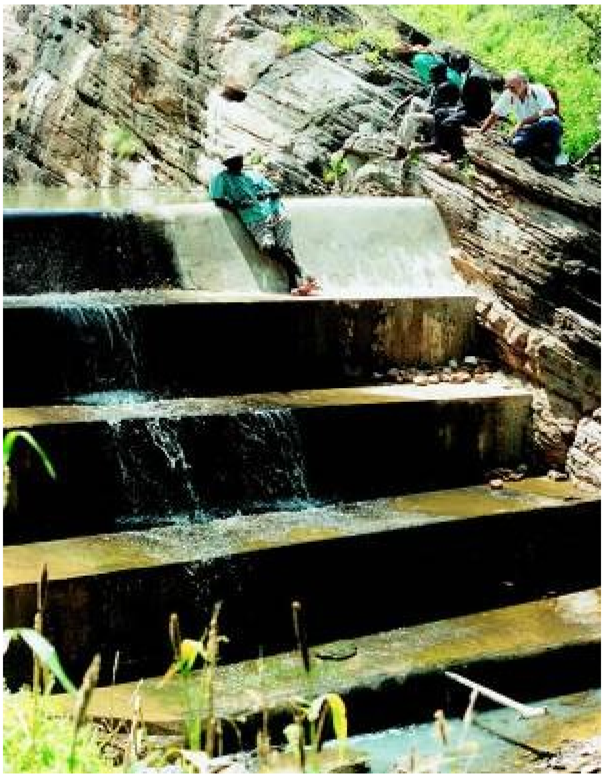


Photo 20: Stepped spillway: alternative method for progressive extension of central dam spillway

Credit: Diettrich T.

6.4.10 Sand dam design form

Stakes are hammered into the ground on both riverbanks to show the points the river reaches in the annual and lifetime floods. Once the dam design is complete, stakes are also driven into the ground on both riverbanks to show where the completed dam will end and at the points where the dam wall changes angle. At each point 2 stakes are used to indicate the upstream and downstream position of the dam. These provide common reference points from the design to the corresponding site positions and enable accurate setting out of the formwork to ensure the dam is built to design. ASDF's designs always show the dam as viewed upstream from below the dam. This is referred to as the upstream view. The dimensions that describe the flood flows and the dam dimensions are entered in the Dam Design Form, App.6.

6.5 Soil and water conservation immediately above the dam

The purpose of soil and water conservation immediately above the dam is threefold:

- Prevent erosion around wings
- Increase the infiltration of water into the riverbanks
- Prevent fine silts being washed into the dam aquifer

This protection consists of gulley reclamation, terracing, river bank stabilisation through planting trees and grasses and promoting conservation farming and planting trees as shown in figure 13.

6.5.1 Terracing

Terraces reduce soil deposition behind the dam and recharge the riverbanks. Good land management in the upper catchment (such as conservation farming, terracing and tree planting) increase the yield of the dam as a result of base-flow and recharge of the dam over a longer period. If the land immediately above the dam has been terraced and / or covered in trees and vegetation, erosion is likely to be minimal and no further protection is required. When the catchment is vulnerable to erosion, then up to three lines of terraces at least 1 metre deep and 1.5 metre wide are dug.

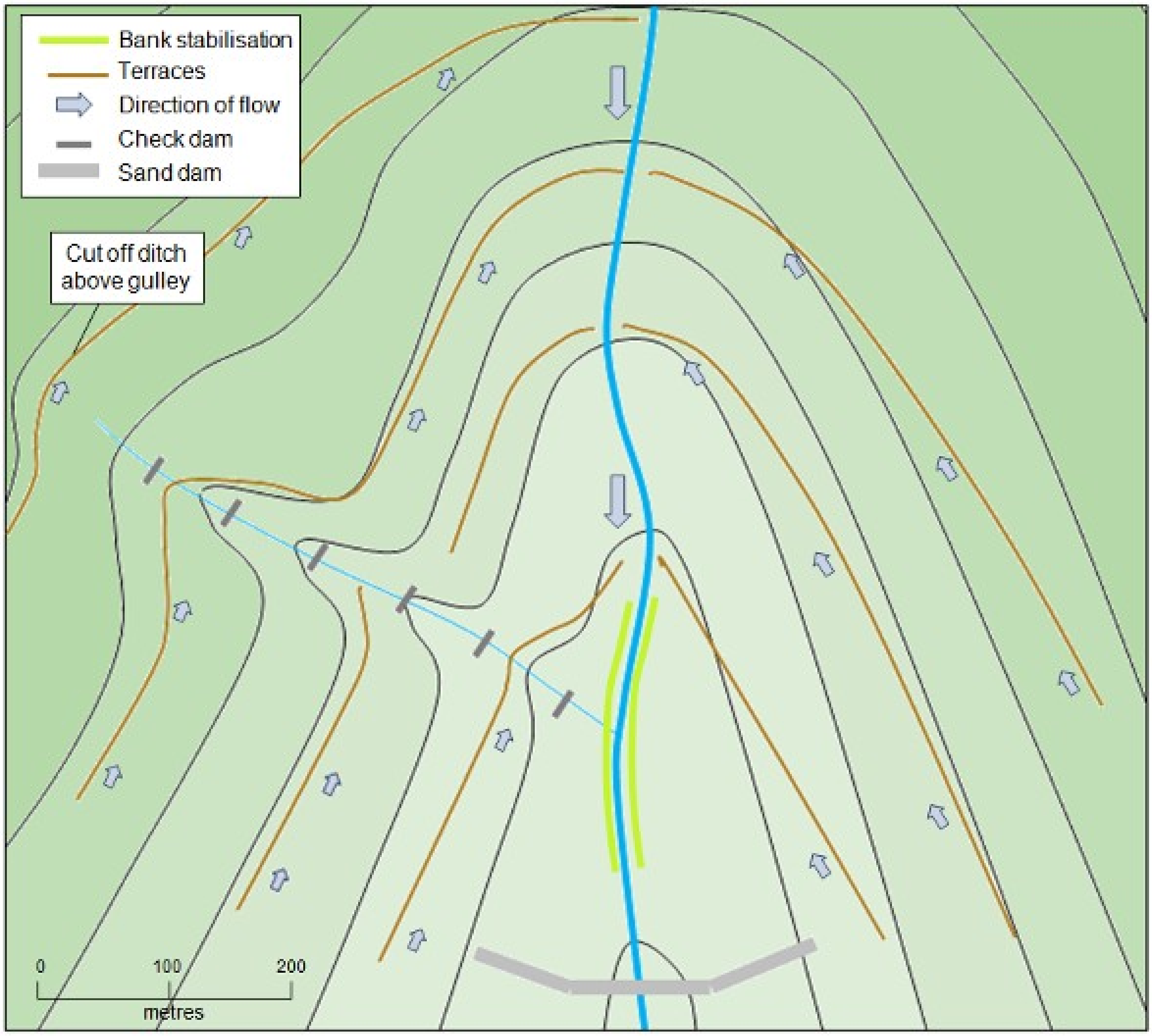


Figure 13: Layout of typical conservation measures in dam catchment

These are approx.150 metres long that follow the contours of the riverbanks but with a gentle gradient so that the flow enters the river upstream of the dam. As shown in photo 21, small bunds within the channel encourage water to pool and infiltrate into the banks. Trees and Napier grass are often planted to stabilise the terrace banks. The length, number and spacing of terraces is dependent on slope and how well the land has been conserved immediately around the dam and its vulnerability to erosion.

Photo 21: Bunds in the terrace channel encourage infiltration

Photo 22: Terraces control runoff, increase infiltration and recharge and reduce gulley formation and erosion around the wings

6.5.2 Gulley reclamation

It is important to manage erosion in the immediate catchment of the dam. Gulleys close to the dam may undermine the wing foundations. Footpaths or cattle paths should avoid the edges of the dam where they could cause erosion and gulley formation. Gulleys may be reclaimed by:

- Improving land management above the gulley to reduce runoff
- Digging a cut-off ditch above the head of the gulley to reduce runoff entering the gulley. The ditch should have a slight gradient up in order to carry the runoff away and into the river upstream in a controlled manner as shown in figure 13.
- Building check dams with live stem cuttings or vegetation such as Sisal, wooden stakes, stone gabions or bags filled with soil, pegged together. Check dams should be dug into the gulley sides with a central spillway. As the gulley silts up, progressively raise the barriers.

Photo 23: Upstream gulley

6.5.3 River bank stabilisation

Seasonal river valleys have clearly defined channels. During flood, the river flows outside this channel. With the construction of a dam, the upstream riverbed will rise causing the river to flow beyond its banks more often. To prevent the river channel spreading beyond the position and width of the previous riverbanks, the banks are planted with trees, bananas and Vetiver and Napier grasses. This vegetation prevents bank erosion and slows the river flow, which in turn, causes sedimentation and new banks to be formed. It also provides bananas, wood and fodder.

Dams may accelerate erosion both above and below the dam. The banks should be protected wherever there is a risk of erosion. If the banks are rocky, protection is less critical. If they are mainly soil, they need protection. In extreme cases, failure to protect the banks may result in farming land being washed away and / or changing the river course. Bank protection is particularly important if the central spillway is higher than the riverbanks or if the channel is cut into unconsolidated alluvial deposits. On such rivers, the spillway must initially be lower than the top of the banks to prevent bank collapse. Once the channel is filled with sand and there is no longer a risk of bank collapse, the spillway may be raised further. Particular attention should be given to protecting the banks on outside of a bend in the river. On upstream bends, especially in flatter valleys, the rise in riverbed may increase bank erosion on the outside of the bend and without protection cause the bend to widen.

Photo 24: Grasses act to stabilise riverbanks and provide year round fodder

6.6 Abstraction methods

When a dam is owned and managed by a community group, the choice of abstraction technology is made by the users along with agreement that they accept responsibility for the maintenance and repair of the technology. In this case, the role of the NGO or supporting organisation is to advise the community group so they may make an informed decision. They should explain how the choice of abstraction method determines:

- How much water is available and how it can be used
- How easy it is to manage and maintain including preventing unauthorised bulk abstraction and separating different water uses such as water for people and water for cattle or for production
- The cost and complexity of maintaining the abstraction point/s
- The ability to meter and charge water users
- On smaller dams more careful management is required to prevent the dam from being exhausted. The abstraction choice may help or hinder this management.

6.6.1 Scoop-holes

Photo 25: A traditional scoop-hole

Photo 26: Scoop-hole protected by Acacia to keep livestock out

Traditionally, people have collected water from sand rivers using simple holes scooped into the sand (photo 25). Where the hole is used for domestic purposes, Acacia and thorns are often used to keep livestock out of the hole, (photo 26). Scoop-holes need to be re-dug after each flood. To improve water quality, existing water is scooped out and discarded and then fresh water seeps into the hole. Often separate cattle watering points are established below the dam with abstraction of water for people located above the dam. This reduces livestock traffic over the sand aquifer and around the dam, erosion around the dam and water contamination. On larger dams, where small scale irrigation is possible, the inlet pipe for small pumps is placed directly into a large scoop-hole.

6.6.2 Infiltration gallery

Photo 27: Installation of infiltration gallery

An infiltration gallery, shown in photo 27, is a horizontal pipe or network of pipes, usually plastic, with slots or holes drilled into the top two thirds of the pipe that is placed in the riverbed during construction. As the dam matures the pipe is buried by sand. Because it is significantly easier to install the gallery prior to the dam filling with sediment, it is recommended to over-design the gallery rather than have to expand the system later. The pipes should be laid on a layer of sand and covered with a layer of gravel. The infiltration gallery is connected to either a tank built into the dam wall, a pipe running through the dam or a shallow well in the riverbank. Water enters the pipe through the sand, flows along a gentle slope and is abstracted either through **(1)** a pipe through the dam, **(2)** a tank built into the dam wall or **(3)** an off-take well or hand-pump located on the adjacent river bank. The benefit of infiltration galleries is that the water is filtered as it passes through the sand. Samples of sand dam water abstracted through infiltration galleries was tested and found to have no thermo-tolerant coliform, a recognised measure of bacteriological quality. Further research is required to confirm this testing.

In order to maximise the yield of the gallery, the pipes should:

- Be laid in the deepest part of the aquifer behind the dam
- Be laid on a slight gradient to carry water to a tank or sump at the base of an off-take well
- Be laid in a branched or herringbone network across the riverbed
- Have sufficient capacity for the anticipated demand and the capacity of any pump to be fitted
- Be overlain with a layer of small stones, gravel, medium stones and then covered with sand.

Size of holes or slots in the Infiltration gallery: Slotted pipes may be purchased pre-fabricated (available from borehole screen suppliers) or self fabricated. In self fabricated screens, slots are cut with a saw or small holes drilled or melted with a hot poker in the top two thirds of the pipe. The holes should be as close together as possible without compromising pipe strength. As water is first pumped from an infiltration gallery, finer sediments are drawn into the pipe. Over time coarse sediment will be left around the pipe and this will form a natural screen that prevents further finer particles being drawn into the pipe as shown in figure 14. If the holes are too large, this natural screen will not develop and finer sediment will be continuously drawn into the pipe and could enter the pump and damage the internal parts. In medium to coarse sand, the holes should be no more than 1 mm in diameter or the pipe should be wrapped in a geo-textile.

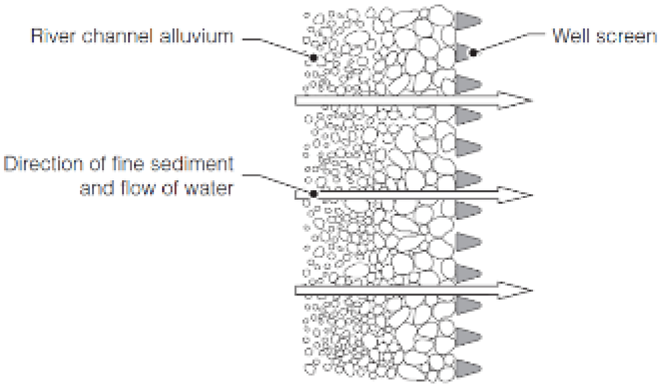


Figure 14: A natural screen develops around a slotted pipe

Photo 28: A no-fines concrete caisson
Credit: Dabane Trust

Alternative design 1: U shaped channel made of rocks and mortar, filled with gravel and covered with layer of no-fines concrete that acts as an infiltration gallery.

Alternative design 2: A caisson / large concrete ring made from no-fines concrete (photo 28). This method provides a large infiltration area and may be made using pre-fabricated or locally manufactured formwork or built from blocks. No fines concrete is porous and is made by reducing the sand content so that the ratio of cement: sand: coarse aggregate is 1:1:4. Porous concrete is considerably less dense and strong than conventional concrete and should be handled carefully.

6.6.3 Infiltration gallery connected to a tank or pipe

Photo 29: Tank built into wall of dam

A small reinforced concrete tank connected to the infiltration gallery may be built into the wall of the dam. Water is abstracted using a rope and bucket or from a pipe running through the dam. An alternative to using an infiltration gallery is to construct the bottom section (50 cm) of the tank walls from no-fines concrete that allows water to seep into the tank. The tank wall above the no-fines concrete must be reinforced. Alternatively, the infiltration gallery may be directly connected to a pipe running through the dam to an outlet on the downstream side of the dam. The advantage of a tank over a pipe is that it is easier to limit the use of water and reduce risk of the piped outlet being left open. One way to control this is to place the pipe at level relatively high up the dam wall. In this way, water from the pipe can only be abstracted when water level is relatively high.

Photo 30: Piped outlets

6.6.4 Infiltration gallery with shallow well

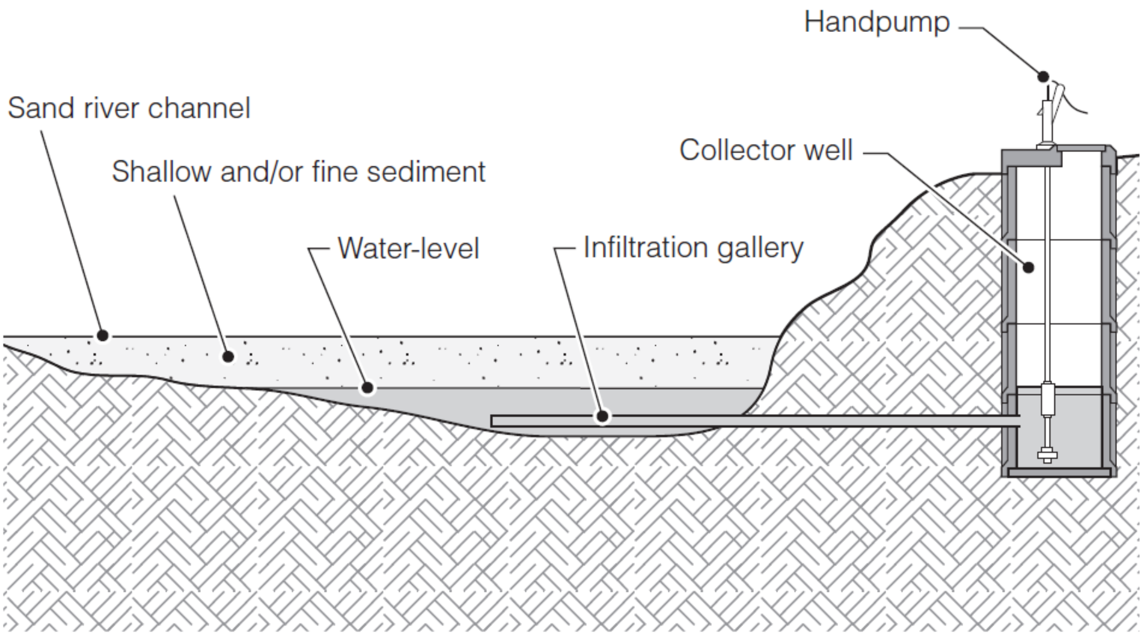


Figure 15: Infiltration gallery, shallow well and hand-pump. Credit: Dabane Trust / Ken Chatterton

The infiltration gallery may be connected to a shallow hand dug well in the adjacent riverbank. The well should be located for good access. A shallow well connected to a sand dam will typically be 5 to 10 metres deep. The well is excavated at the same time or shortly after the sand dam is constructed, during the dry-season. During this time and in the absence of the sand dam, the watertable is usually well below the bottom of the well. In stable ground, above the watertable, the well is often excavated without a lining and then lined after excavation is complete.

Safe Excavation: In the unlikely event that the bottom of the well requires excavation below the watertable, the well above the watertable should first be lined before continuing the remaining excavation. Excavation below the watertable should be done within a pre-cast concrete ring that is lowered into the well and has a smaller diameter than the lined well diameter. As material is excavated from below the ring, the ring is lowered into the watertable.

Once the dam is built, the watertable immediately after the rains will be at or above the height of the spillway. The sides of well below the watertable may become unstable and prone to collapse. In order to prevent collapse, the well must be lined. Bricks or rocks plastered with mortar or ferro-cement (mortar plastered onto chicken wire) are the most commonly used linings. Even large tractor tyres may be used.

Well sump: The well extends below the level of the inlet pipe from the infiltration gallery. This sump acts as a buffer, filling up and storing water at night and times of low demand. The size of the sump required depends on the volume pumped daily and the difference between the rate of pumping and the flow into the sump from the infiltration gallery. For a shallow well fitted with a hand-pump, a sump of 1 - 2 metres depth will be adequate. When large quantities (20 – 100 m^3 / day) are pumped, for example, to supply a larger piped network, a larger buffer is created either by using a larger diameter or deeper well sump or increasing the capacity of the infiltration gallery or caisson.

Photo 31: Safe excavation inside pre-cast concrete rings, Nepal. Credit: WaterAid / Caroline Penn

Photo 32: Shallow well with hand-pump and cattle trough, Kenya

Well head and pumps

It is desirable for the well head to rise 1 metre above the surrounding land to prevent overland flow from entering the well. The well head is built on top of concrete rings. Any space between the concrete rings and the surrounding land is backfilled with puddled clay or concrete to prevent contamination. The surrounding land should slope away and any surface water channelled away from the well. The well head should allow access for pump maintenance and well de-silting (if required) and to allow people to continue to withdraw water when the pump breaks down.

Water may be abstracted by a bucket and rope / windlass above an access hole or a hand-pump. Bucket and rope or windlass is more prone to contamination. A hand or human powered pump can serve up to 300 people and pump up to 5,000 litres / day (assuming daylight pumping only). There is a wide range of pump options including commercial pumps such as the India 2 or locally fabricated pumps such as treadle, rope and washer and rower pumps. A comprehensive overview of pump choices, their design, installation and maintenance and relative advantages is given in Chapter 6 of Water from Sand Rivers by S Hussey, WEDC publications [Link]. Also refer to UNICEF Technology Information Package: [Link] and Erich Baumann 2011: Low Cost Hand Pumps, RWSN Fieldnote No 2011-3 [Link].

The final choice of pump should be made by the community or user group and be based on:

- The flow rate and lift required
- Installation and repair costs
- Reliability
- The availability of pumps, spare parts and the ease of repair and maintenance and
- The availability of people with the required technical knowledge.

Long term maintenance, repair and replacement of the pump should be covered by a plan agreed with the community. In Kenya, this agreement normally requires users to pay a nominal fee to take water from a shallow well and the self-help group is responsible for collection and management of these fees and the management, maintenance and replacement of the pump. This does not prevent anyone from getting water from scoop-holes.

Chapter 7: Pre-construction activities

This chapter describes the activities to be completed prior to construction including:

- Planning schedule of activities
- Calculating materials
- Pre-procurement activities including legal agreements
- Procurement and logistics.

7.1 Planning

As soon as the timing of construction is driven more by the needs and schedule of the supporting organisation or NGO than by the needs and schedule of the community, the potential benefits and the extent to which the community feels ownership for the dam are greatly reduced.

To prevent this, the pre-construction preparations must be planned with the community. It should not place an unrealistic burden on the community bearing in mind other demands such as farming. In order to ensure a dam is built to the agreed schedule, a process is required to monitor progress in achieving the pre-construction activities. Construction coincides with the dry-season when farming commitments are lowest. Dams that require significant excavation or where there is uncertainty over the depth of the bedrock should be scheduled when there is least risk of an unexpected flood filling in the excavated works. Table 6 shows the typical schedule of activities involved in constructing a sand dam and the level of work or number of people involved. To minimise construction time, all materials should be collected prior to construction. Purchased materials (cement, timber and steel) should only be delivered to the site once the community is ready to construct, otherwise the problem of storing and safeguarding the cement and pushing for the completion of pre-construction activities becomes the supporting NGO's problem and a degree of ownership transfers away from the farmers towards the NGO. Building sand dams is hard work. Before committing to build a dam, ASDF requires all pre-construction activities are completed and if it is a new group the new group is expected to help an existing group to build a dam. This demonstrates group commitment and cohesion, builds solidarity between groups and ensures new groups understand the amount of work involved.

Pre-construction	Construction	Post construction
Technical feasibility	Excavations	Cure
PESTLE analysis and Pilot Design	Prepare foundations	Inspect after first rains
Identify 3 or more potential sites	Collect water	Routine maintenance
Technical feasibility of selected sites	Construct formwork	
Dam design and sign off	Place steel	
Bill of quantities	Construct dam	
Legal agreements	Remove formwork	**Work intensity / # on site**
Agree construction schedule	Plaster	Low
Collect sand and stone	Construct apron	Medium
Terrace and protect catchment	Construct infiltration gallery	High
Dam registration and approval		
Procurement & delivery of materials		

Table 6: Schedule of activities and intensity of work

7.2 Calculating materials required

7.2.1 Materials checklist

- Cement
- Y25 steel bar and barbed wire
- Sand, rocks and water
- Materials for infiltration gallery and abstraction
- Tools including surveying equipment (see table 9)
- Timber (replaced every 4 dams).

7.2.2 Estimating material costs

ASDF build approx 40 sand dams a year and budget according to 4 dam sizes based on using 190, 340, 550 and 1,000 bags of cement. To illustrate dam size, photo 12 shows a dam that used 810 bags. It is 50 m in length, spans a 30 m river channel with a central spillway 3 m above the bedrock. Table 7 shows the material costs for different sizes of sand dams based on 2013 prices in Mtito Andei, Kenya in US dollars.

Material and permit costs in USD (2013)	Small 190 bag dam	Medium 340 bag dam	Large 550 bag dam	Extra large 1000 bag dam
Cement	1,690	3,000	4,880	8,860
Steel bars, wire & nails	310	560	740	1,130
Transport	270	430	860	1,450
Permits	160	160	160	160
Timber	170	370	510	640
Tools	100	100	120	170
Total	**2,700**	**4,620**	**7,270**	**12,410**

Table 7: 2013 standard materials budget for an ASDF sand dam, Kenya

Cement is the most expensive item, equal to approx 60 – 70 % of the total cost. In order to estimate costs in a new area, use the cost of cement as your guide and increase or decrease the costs in proportion to the local cost of cement against the price in Mtito Andei, where a 50 kg bag of cement costs USD 8.8.

At each dam site, extra materials (approx. 20 %) are delivered to act as a buffer in case of minor changes to the design during construction or an increase in the foundation depth once excavation is completed. A careful inventory of materials is maintained and the surplus materials, tools and timber transported to the next site.

In addition, the budget should include:

- **Material costs of abstraction technology:**
  - Infiltration gallery and pipe through dam — USD 300
  - Infiltration gallery and tank with pipe through dam — USD 640
  - Infiltration gallery and shallow well with hand-pump — USD 1,460
- **Skilled labour:** the cost of ASDF field staff (artisans, dam designer, and community group field officer) to support the siting, design and construction is approx 13 % of total. However ASDF are experienced in building dams quickly. Where there is little experience of sand dams, the initial pilot dams will probably require more technical support and take longer to build.
- **Programme management:** An allocation towards the NGO's programme and support costs including planning, monitoring and evaluation, finance, governance, grant management and fund-raising.
- **Unskilled labour:** Dams are labour-intensive. The contribution of labour from the community (based on local day labourer rates) is equal to **40 % of the total cost**.

7.2.3 Calculating cement, sand, rock and water requirements

Based on the experience and construction process (described in chapter 8) of ASDF, the following rules and assumptions are used:

- **The ratio of sand and cement in the mortar is 3 level wheelbarrows (approx. 3 x 40 litres) to one bag of Portland cement (50 kg or 32 litres).** By volume, this is equivalent to 4 parts sand to 1 part cement.

- Approx. **3.5 bags of cement (110 litres) are required for every cubic metre of dam (1,000 litres)**. Additional cement is used to form a strong seal between the dam and bedrock, to fill cracks in the bedrock and to plaster the dam after the formwork has been removed. An additional 20 percent contingency is assumed.
- Since cement fills the voids in the sand, the volume of sand required equals the volume of mortar. Based on actual dams, the **volume of mortar is approximately equal to 45 % and the volume of rocks is approximately 55 %** of the volume of the dam. By breaking the dam up into blocks, multiplying the height, width and thickness and summing the totals, it is possible to calculate the approx. volume of the dam.
- As much rock as possible is used in the dam without the rocks touching. Ideally as many large rocks as possible are used, especially near the base of the dam. Medium and small rocks are used to fill the gaps between the large rocks. For the sake of quantification, a uniform ratio is assumed. However, the proportion of mortar increases slightly where few large rocks are available.
- **Water for the mortar is approximately equal to three quarters the volume of cement.** Significant water is also required for cleaning the bedrock and rocks, cleaning tools, wetting the formwork and curing the dam.

7.2.4 Calculating steel and timber requirements

Timber and steel budget	Assumed life (in # of dams)	Small	Medium	Large	V large
Timber boards (150 mm x 25 mm x metre length)	3	170 m	300 m	400 m	530 m
Timber supports (100 mm x 50 mm x metre length)	3	100 m	240 m	340 m	400 m
Nails 2.5" & 4" (kg)	1	15	24	30	40
Y25 (25 mm diameter) twisted steel bar x 12 m	1	3	5	7	12
25kg barbed wire (approx 180 m length)	1	2	4	5	7

Table 8: Timber and steel budget for 4 standard dam sizes

7.2.5 Calculating tools and equipment requirements

Tools and equipment	Assumed life (in # of dams)	Small	Medium	Large	V large
Wire brush	1	1	1	2	3
Hard broom	1	1	1	2	3
Wheelbarrows	6	4	4	6	8
Shovels	20	20	20	25	30
Metal buckets	6	6	6	6	8
Hacksaw	10	1	1	1	1
H. speed hacksaw blades	1	2	2	3	4
200 litre water drums	25	6	6	6	8
Large sledge hammers	20	4	4	4	6
Pick axes for excavation	6	6	6	6	8
Grease for tools (kg)	1	1	1	1	2
Claw bars (large)	10	4	4	4	6
Claw bars (medium)	20	2	2	2	2
Line level and 50 m line	6	2	2	2	3
Tape measures	6	2	2	3	4
Tapered probing rod > 3 m	> 25	1	1	1	1

Table 9: Tool budget

7.3 Pre-procurement activities

As with any project, there should be phased milestones: design, quantification, collection of materials and so forth, etc. So, for example, the schedule will ensure the design is completed 2 - 3 months prior to construction to allow sufficient time to collect the materials and prepare the site and there should a process in place to check the right volume and quality of materials has been collected. Poor logistics results in:

- Increased time required to build the dam
- Increased time demands imposed on community
- Increased complexity of managing the construction as more activities must be taken into account
- Increased risk of theft or waste and loss of materials.

It is recommended that the procurement process requires that materials are not purchased until the following requirements are met:

Signed legal agreements: Do not order materials unless the legal agreements required to build the dam are in place. These are determined by local land ownership, tenure and access rights. Legal agreements must cover all those impacted by the dam, not just the owners of land for the dam wings but all those impacted upstream. This is usually just a couple of farmers but may be as many as five or six.

A signed-off design: It is not sensible to purchase materials without a signed-off design that includes quantification of materials. Accurate quantification is important is to minimise transport costs which are generally very expensive. In Kenya, transport of cement, steel and timber from local suppliers to the dam site typically adds 20 % to the cost. In more remote locations this percentage will be significantly higher.

Traditional or cultural approvals: Although not necessarily a statutory requirement, in many societies, traditional or customary leaders should be informed and their consent sought. This is particularly important where land has no formal legal title or is communally owned such as in pastoralist areas.

Authorisation from government authorities: In Kenya, all ASDF designs are signed off by the most senior dam designer and authorised off by the District Water Officer.

Gulley reclamation and terracing completed (where required).

Collect rock and sand: The community require clarity on the amount and type of rock and sand required. Getting this detail right will maximise the strength of the dam, minimise costs and minimise the time and effort required to collect materials. If it is likely to rain, rock and sand should not be placed in the river channel. The type, size, shape, strength and angularity of rocks and coarseness and angularity of sand should be regularly inspected: The more angular the sand, the better. If no rocks are found near the surface, it is unlikely rocks will be buried in the sediment. Seek the advice of an experienced artisan in order to plan the time required to collect materials. It may be necessary to use fire and sledge hammers to break large rocks/rock outcrops into suitable sizes or to transport rocks from a more distant location.

7.4 Procurement

When specifying, selecting and ordering materials, the following factors should be considered:

Include a small contingency (20 %) and deduct any materials remaining from previous dams.

Timber formwork: Select hardwoods such as cypress rather than softwoods. Although more expensive, hardwood is more durable and cost-effective. Do not select endangered species. Select mature, aged timber, not fresh, green timber that has higher moisture content and is weaker and more flexible. The quality of the timber boards determines the spacing of supports. In Kenya, the maximum height of formwork filled within one day is 1.5 metre. In the absence of suitable timber, it is possible to construct two stone-masonry walls and in fill the gap between them or use sections of steel sheeting bolted together.

Steel: Depending on the manufacturer, the strength of steel and steel products may vary significantly. Seek local advice from construction firms on this variance. It is usually a false economy to use low grade steel bar, wire and nails. Cheap nails ruin timber. ASDF use Y25 twisted steel bar.

Tools: Similarly, cheap tools are generally a false economy. The items that fail most frequently are shovels followed by wheel barrows. It is recommended to monitor for how many dams different tools last in order to select the best value, most durable tools.

Cement: Ordinary Portland cement is used. Cement quality may vary with manufacturer. Seek local advice on which manufacturers and local suppliers have the best reputation for high quality cement and reliable supply and transport. Over time cement absorbs water and losses strength. Cement should ideally be used within 6 months of manufacture, be stored in dry conditions on pallets off the ground no more than 10 bags high and be used on a first in/first out basis.

Age of cement	3 months	6 months	12 months	24 months
Loss of strength	20 %	30 %	40 %	50 %

7.5 Logistics

Efficient logistics relies on a site plan that identifies where materials should be collected / delivered to (refer to Figure 15). The fewer days required for construction, the less the work is a burden to the community and the easier it is to mobilise people. A clear process is required for accepting responsibility for and monitoring the delivery and use of supplies. In Kenya, the self-help group committee is responsible for accounting for all materials. The committee appoints a committee member to jointly check and sign the delivery note and monitor use of steel and cement together with the group's field officer.

Cement is the most valuable (and desirable) material used. It should be delivered as close to the start of construction as possible to minimise the risk of theft and damage. If there is a very low likelihood of rain and a short construction period planned, cement should be delivered and stored directly to the dam site. In this case, it should be stored off the ground and covered with a water proof cover. A local group member must be tasked with staying on-site overnight. Otherwise it should be stored in a suitable secure building (usually in the compound of a group member) and transported to the site daily. Due to the high storage cost and limited lifespan, cement is purchased as required. It is rarely cost-effective to tender for cement in bulk. Tender agreements require an inflation clause and being committed to one supplier, limits opportunity to negotiate if quality varies. When quality is inadequate, the return costs are significant. It is better to use multiple quotes and retain the flexibility to change suppliers if price, availability or quality change. There are very low margins on cement supply so it is rarely worth going direct to the manufacturer and paying the additional transport costs. Planning may be disrupted if the supplier is unable to supply and deliver the required quantity at the required time. Consider the cost to the farmer if they have to wait for delivery due to being tied to one supplier. The real cost = the price x quality. In most countries NGOs are exempt from paying VAT (Value Added Tax) on materials purchased for charitable purposes, provided they register for VAT exemption. The average VAT rate in Africa is 16 %.

Chapter 8: The construction of a sand dam

8.1 Site management and supervision

The two main causes of dam failure are (1) incorrect design and (2) failure to build to design such that the dam is able to resist the forces acting upon it. To ensure the dam is built to design, the responsibility for site management needs to be clear. The correct decision makers need to be identified and in place throughout construction. Constructors need to understand the design principles and Golden Rules, the main ways a dam may fail and the critical factors during construction that may lead to failure, as summarised in table 10. Seldom is a dam built exactly to design because during the design stage, assumptions are often made about bedrock depth. If construction supervisors do not understand these principles and rules, they will struggle to adapt the design when required to.

Risks due to poor construction	Risk mitigation
Poor quality stone, sand and water	Clear guidance and checks on the quality of materials required and collected. All organic matter removed
Poor quality cement, timber and steel	Only use trusted suppliers. Procurement systems clearly specify and check the quality of materials. Cement is kept dry and used within 6 months
Incorrect mortar mix	A person is designated within each mixing group with responsibility for counting and checking the volume of sand and cement used. Tight inventory controls prevent theft of cement. The artisan(s) control the wetness and quality of mortar
Dam and its dimensions not correct	Ensure (i) the formwork is correctly positioned in reference to the permanent benchmarks, (ii) the formwork is level and corresponds to the design dimensions and (iii) the formwork does not shift and is able to resist the weight of the stone and mortar during construction
Water flows under the dam	Ensure foundation extends 1.5 m wider than the width of the annual flood. Ensure bedrock is clean with a good sound key so a good seal is formed with the bedrock. Cracks and fissures are sealed
The dam cracks	Reinforcement is insufficient and / or not drilled into the bedrock. Experienced artisan(s) are responsible for the placement of stone and mortar. This reduces the risk of planes of weakness caused uneven layers of rock and mortar, rocks not interlinking, weak rocks used, rocks touching each other or poor compaction resulting in air pockets.
The dam undercut due to inadequate apron	Ensure apron built when it is required and that it has a solid foundation of rocks and spans the full width of the dam foundation
Inadequate curing	Ensure dam is plastered and fully wetted morning, noon and evening for 30 days

Table 10: Causes of failure due to poor construction

8.2 Site safety

The site supervisor is responsible for managing health and safety on site. The common risks to consider include:

- Collapse of excavations in unstable sediments.
- Irritation of skin, lungs and eyes from handling cement
- Lift and crush injuries from handling heavy materials or supplies
- Bites and stings from snakes and scorpions particularly when disturbing rock piles

The implementing agency should put in place adequate measures to manage these risks. These typically include but are not limited to:

- Site safety briefings for all workers including safe lifting and excavation and use of protective equipment such as boots, gloves and hard hats
- First aid kit and trained first aider on site

- Access to transport and mobile communications in case of an emergency
- Any excavation in unconsolidated sediments deeper than 1 metre is highly dangerous. Unconsolidated sediment either side of the excavation must be removed to create a gentle slope or held back with shuttering or sand bags. Once stable, consolidated sub-soil is reached and there is no risk of collapse, excavation may continue vertically, unsupported. If in doubt, shutter the sides.
- Cement is hazardous to eyes and skin. When handling cement gloves should be worn.

8.3 Principles of concrete and stone-masonry construction

The construction method described in this guide is the method used by ASDF and is an adaptation of rubble stone-masonry. Alternatives are described in section 8.13. Rubble stone-masonry consists of using mortar (a mix of sand, cement and water) to bond together large rocks in order to construct a wall. This method has been adapted as follows.

- Formwork (also known as shuttering) is used to hold the materials in place during construction and removed after 24 hours once the cement is cured sufficiently to allow the dam wall to stand freely without support
- Steel bars and barbed wire is used to reinforce the dam and to anchor the dam to the bedrock.

A mix of large, medium and small rocks is used. This increases strength and reduces the amount of mortar required. Unlike concrete, mortar contains no stone or gravel. The strength of the mortar is critical to the overall strength of the dam. Its strength is determined by the quality of the raw materials used, the quality of mixing and proper curing. Sand dams are gravity dams that rely on their mass (weight) for their stability.

8.3.1 Sand and rock

Mortar will be stronger when coarse sand derived from crystalline rocks with sharp angular edges is used compared to finer, more rounded sand. Ideally the sand is well graded with a mix of particle sizes from fine and coarse sand up to fine gravel with little (< 1 %) or no silt or clay content. Organic matter like twigs and roots must be removed. Mortar that uses fine sand will need more cement to achieve the same strength. The stronger the rock used, the stronger the stone-masonry will be.

8.3.2 Cement

The sourcing and storage of cement is critical. It is essential cement is kept dry prior to use. Older cement absorbs moisture from the atmosphere so ideally cement should be used within six months of its manufacture. If cement does get wet, it will harden and contain lumps. Such cement should be rejected or cement with a few lumps, sieved and the cement only used in non critical parts of the dam such as the end of the wing-walls, where the forces are less. Only cement from reputable manufacturers should be used. Experience shows cement quality varies enormously according to manufacturer. In Kenya, cement is delivered direct to the dam site immediately prior to construction, safeguarded by the community and used within 1 week of delivery. Where such prompt construction is not achievable, cement should be stored securely nearby but away from the site and transported as required. Cement should be stored on pallets off the ground to minimise absorption of moisture, covered with tarpaulin and if stored for more than a week, should be stacked no more than five bags high. The principle of 'first in, first out' should be used so that the oldest cement is used first.

8.3.3 Mixing

Most sand dams are in remote, rural areas and so are built by hand, with no machinery. In order to ensure consistent ratios, standard measures are used. In Kenya, sand is measured in standard wheel barrows, which contain approx. 40 litres of sand when level. A 50 kg bag of cement contains 32 litres. The normal ratio is 3 wheelbarrows of sand to 1 bag of cement, which is equivalent to 4 parts sand to 1 part cement by volume. This ratio varies on large dams with a stronger mix used at the base beneath the central spillway and a weaker mix towards the end of the dam wings (refer to figure 19).

Initially, sand and cement is dry mixed in batches of 20 - 30 bags of cement at a time. Then water, approx. three quarters of the volume of the cement, is added and progressively mixed along a 'conveyor belt' getting closer and closer to the dam. Mortar should be sufficiently wet as to be pliable and easily mixed by hand, with an allowance made for absorption of water by the rocks and formwork. Adding too much water weakens the mortar. The water must be clean and free from silt, clay and organic matter. The artisan is responsible for the placement of the stone and mortar in the dam and controlling how wet the mortar is. The time taken from adding water to the mortar to placing it in the dam should be kept to a minimum and should be no more than 60 minutes. At the same time, a human 'conveyor belt' of rocks is created so that there is a constant supply of mortar and rocks entering the dam at different sections throughout the day. It is essential that there are at least two experienced artisans on site during construction, rising to three on larger dams, who constantly supervise the placement of rocks and mortar. The teams mixing mortar range from 6 to 12 people and are typically 8 to 10 people. A 'buddy system' is often adopted (5 minutes on / 5 minutes off). There will also be a team collecting water and if required, teams collecting additional sand and rocks or breaking large rocks into smaller rocks.

8.3.4 Reinforcement

Concrete and stone-masonry are strong under compressive forces, that is, forces acting vertically due to gravity, but weak under lateral or tensile forces. If the dam moves it will crack. The sand and water behind the dam push the dam laterally. The steel reinforcement is embedded in the bedrock and prevents lateral movement. The steel should not be exposed to air to prevent corrosion and weakening and stones should not touch each other.

8.4 Site planning

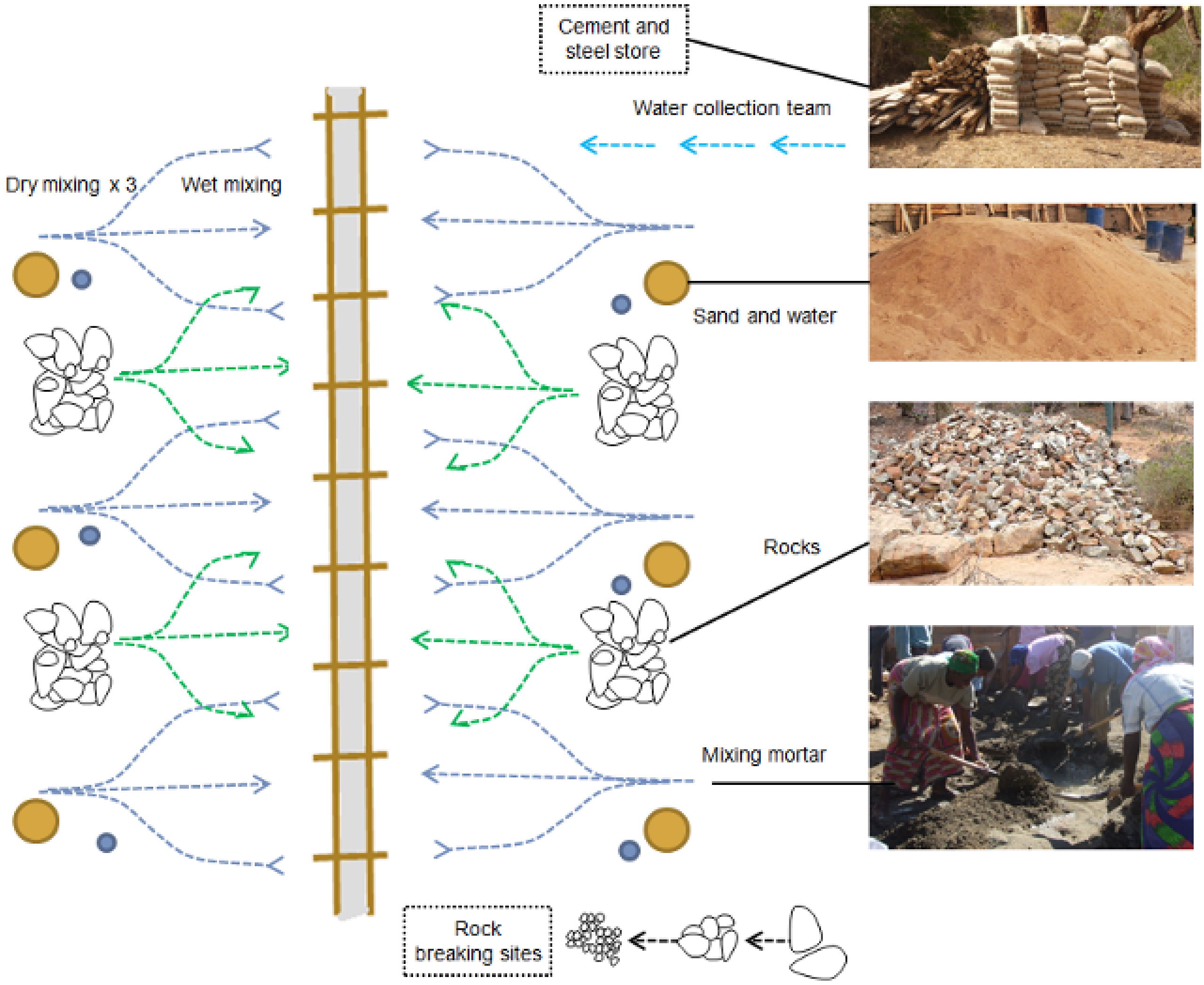


Figure 16: Bird's eye view of a typical dam construction site

Good site planning greatly speeds up construction. Identify as many good sites for mixing mortar as possible. Good sites are flat, close to the dam and on both upstream and downstream sides of the dam. Materials should be collected and delivered as close as possible to their point of use. Sand and stones should only be placed in the riverbed if it is highly unlikely to rain prior to construction.

Typical construction timeline in Kenya				
Prepare foundations	Erect formwork	Construction	Plastering	Watering dam
1 – 3 days	1 day	2 - 10 days	1 - 2 days	30 days
Few people	Few people	Everyone	Few people	Few people

Table 11: Stages of sand dam construction

8.5 Excavation for foundations

During design, the position of the dam is marked by pegs in the ground. Probing and test pits are used initially to estimate the position and depth of bedrock, but the full picture is only apparent once the foundation is fully excavated at this stage. Sometimes, there are deep fissures or sections where the bedrock is deeper than assumed during the design stage and occasionally a site is abandoned if the additional excavation and materials required are not justified. If there is uncertainty over the depth of bedrock at a site, it is prudent to schedule construction well in advance of the rains to allow time for any additional excavations. It is false economy to short cut these excavations but the temptation is greater if the rains are imminent.

If there is no clearly defined bedrock, a sand dam may still be built on heavily compacted clay sub-soil provided these formations have a low permeability. When building a dam on **compacted clay sub-soil**:

- **Dam foundations are dug at least 1.5 metre into this sub-soil**
- Dam thickness does not increase with depth in this section
- The base of the dam is reinforced horizontally with steel bars that are tied to the vertical steel reinforcement
- In the absence of any bedrock, **horizontal reinforcement extends to a point 1.5 m wider than the annual flood** on both riverbanks. This prevents the dam from sinking under its own weight and / or cracking, as seen in photo 33.
- Ensure the dam is built on the clay riverbed and not on an intermediate clay lens formed within sandy sediment.

Photo 33: A sub-surface dam that cracked due to subsidence

8.6 Foundation preparation and laying

There is always some seepage from a sand dam aquifer. In preparing the foundation, the aim is to minimise seepage immediately under and around the dam to prevent water loss and most importantly to prevent the dam being undermined and ultimately failing.

- Remove all sediment from any fissures and then wash out and seal with mortar
- If the bedrock is at the surface, look for horizontal fissures that may extend above and below the dam. These fissures need to be filled with mortar or if the fissures are extensive, it may be necessary to prise the whole section of rock above the fissure away using large crow bars. Fire and rapid cooling with water may be used to break up and remove very large boulders (> 1 metre in diameter) or rock outcrops which have fissures running beneath them
- There is often a weathered layer of bedrock. Any loose and weathered rock must be chipped away and removed
- Once the foundation is sealed, the whole foundation is washed and the surface is pitted and roughened with a chisel or hammer to provide a key
- Holes for the steel reinforcement bars are chiselled by hand using a cold chisel for the full width of the foundation. The holes should be at least 5 cm deep and as close in diameter as possible to the 25 mm diameter steel bars. This is a long and arduous job in hard crystalline rock, but essential for the dam's strength
- A thin layer of 100 % cement is sprinkled on the surface to produce a water tight seal between the rock and the dam
- Sometimes very large rocks are rolled into place at the base, prior to the formwork being erected. Once the formwork is erected these rocks would be too heavy to lift into place. In this case a 15 – 20 cm thick layer of mortar is placed on top of the foundation before any large rocks are rolled on top of the mortar and the formwork is erected

8.7 Formwork construction and setting out

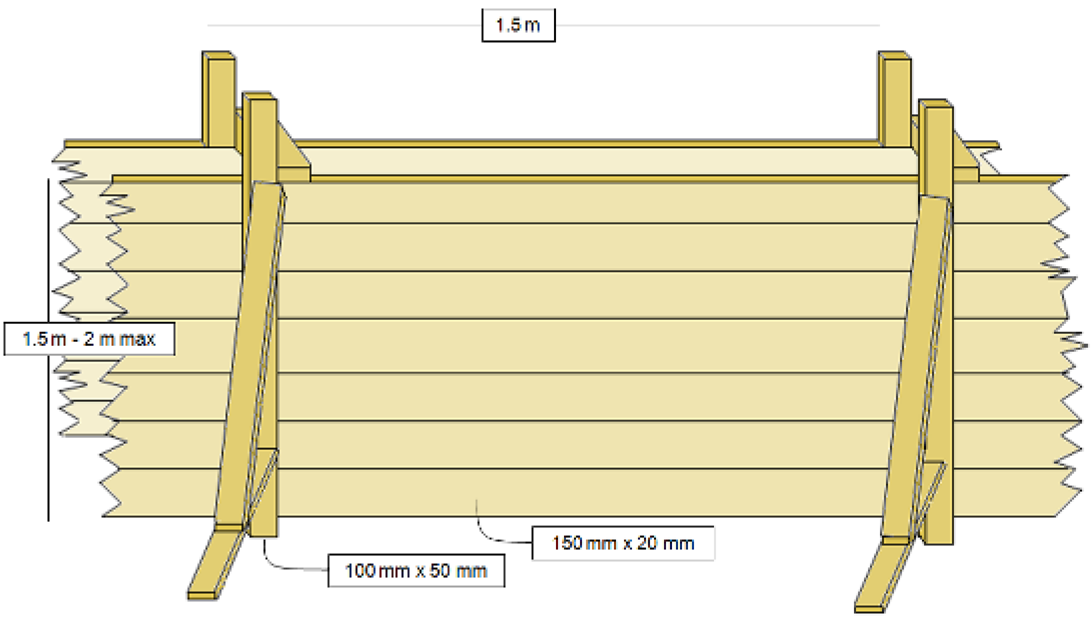


Figure 17: Typical timber sizes and spacing used as formwork in Kenya

The quality of timber boards determines the spacing of supports. In Kenya, the formwork is made up of horizontal 6 metre lengths of 150 mm x 20 mm cypress wood planks, supported by vertical 100 mm x 50 mm supports placed every 1.5 metre (Figure 17). The maximum height of formwork that is filled in one day is 1.5 – 2 m. The formwork is removed and raised up the following day. Each time a new layer of stone-masonry is added to a previous hardened layer, there is a potential weak spot in the dam. Therefore ideally the dam should be built in as few days as possible. The number of days is minimised by placing formwork across the full width of the dam and filling it to the maximum height in one day, although this relies on having sufficient timber and labour to achieve this. The upstream formwork is vertical and the downstream formwork has a slope. Barbed wire ties the two forms together at the base and braced at the top by horizontal supports as shown in photo 34. This prevents the formwork shifting and determines the dam is the correct thickness. By leaving the head of the nails slightly protruding, this helps in dismantling the formwork and reusing of nails. Once formwork is removed, any exposed wire must be plastered over to prevent corrosion and possible seepage.

Photo 34: Formwork creates a mould for the stone masonry

Photo 35: Where the dam sits in a trench, the trench walls are used as formwork (NB flip flops)

8.8 Placement of steel bars

Steel bars are placed vertically and fixed in the holes chiselled in the bedrock using a 2:1 mortar. **The bars are spaced every 1.5 m across the full length of the foundation**. Where horizontal reinforcement is used, the vertical reinforcement is tied to this horizontal reinforcement. Thinner reinforcement bars may be used, but as the diameter of the bars reduces, the spacing between the bars is also reduced. This will require more holes to be chiselled into the bedrock. The bars are placed 10 – 15 cm in from the sides of the formwork and are cut to length so that they extend from the bedrock to 5 - 10 cm below the top of the dam. None of the reinforcement should be left exposed or else it will corrode.

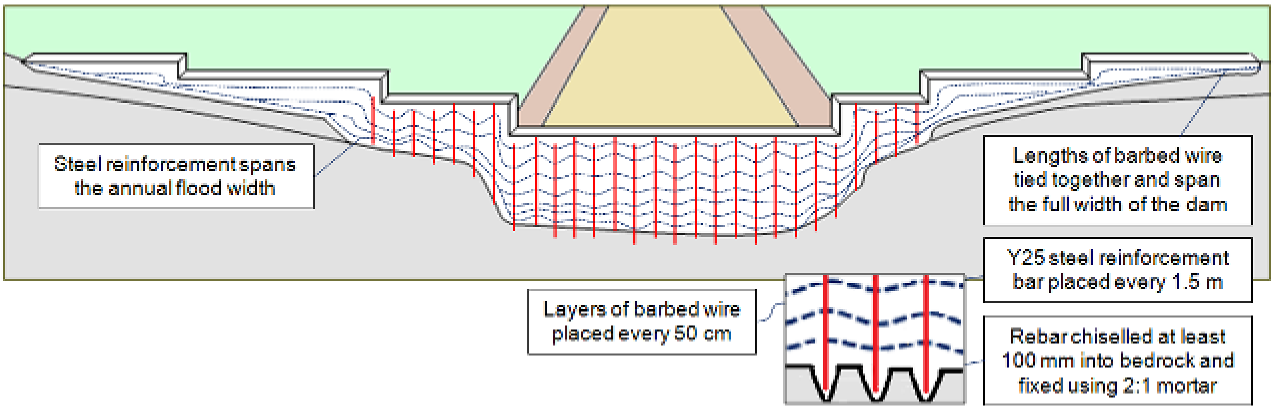


Figure 18: The placement of steel reinforcement bars and barbed wire

8.9 Mortar ratios

The forces acting on a dam are highest at the base and in the centre of the dam. On large rivers, **where the river channel is 30 metres or more across, the strength of the mortar is increased to a ratio of 2:1 in the first 1 metre depth of the dam.** Towards the edges of the dam and towards the crest or top of the dam, the ratio may be weakened. The mortar must not be too wet or too dry. The mix should be constantly monitored. Experienced artisans will be able to judge and control this, but **typically 25 litres of water is added to 1 bag of cement**. If the mortar is being thrown into the dam from a shovel, the mortar will completely slide off the shovel and stay in one clump, if the mix is correct. The mortar should be workable and air pockets easily removed upon compaction. If a lot of water is driven to the surface during compaction, reduce the water content of the mortar.

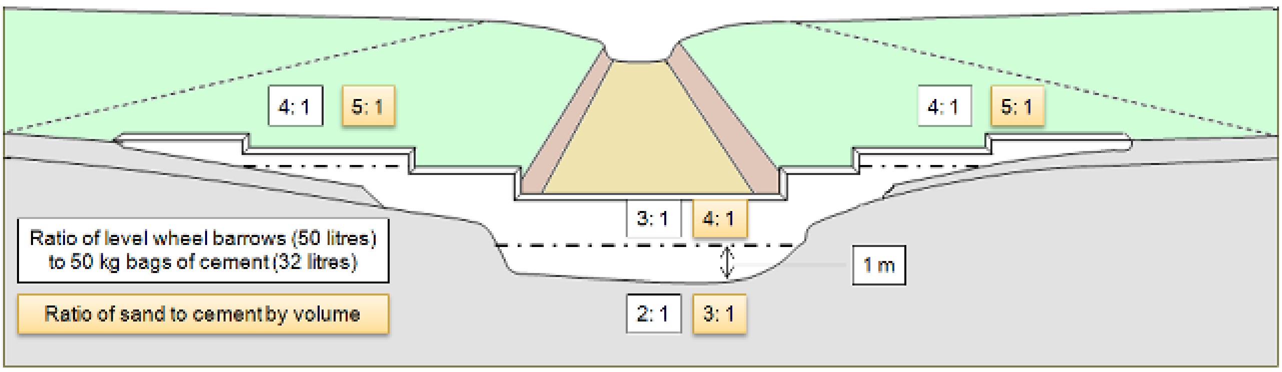


Figure 19: The changing strength of the mortar mix on larger dams

8.10 Rock, mortar and barbed wire placement within the form work

Ideally, both from a strength and a cost perspective, as much rock and as little mortar should be used in the dam. This is achieved by having a mix of different size rocks: the smaller stones filling the gaps between the larger rocks. The rocks should be as large as can be safely lifted into the formwork or prior to the erection of the formwork, as large as can be safely rolled into position. The amount of rock is limited by the requirement that:

- **There are no air pockets.**
- **The rocks do not touch each other or the bedrock**
- **The rocks are 2 – 5 cm away from the formwork. Any exposed rock will have to be plastered.**
- **The rocks are evenly spaced and overlap each other vertically** as shown in figure 20.

On top of the washed and prepared bedrock, 20 cm of mortar is placed. Then rocks are thrown in. The rocks must not touch the bedrock. The largest rocks are placed first, the pointed end down, then progressively smaller rocks added. The rocks should be clean and if necessary washed or brushed with a wire brush first. After the rocks are added, they should protrude 15 - 20 cm above the level of the mortar before the next layer of mortar is added. The mortar should cover the rocks by 15 cm before the process is repeated by adding more rocks. If the mortar layer covers the rocks by more than 15 cm, there is a risk the rocks will not penetrate deeply enough and there will be a plane of weakness where there is more mortar and less rock than required. In each section where rock and mortar is flowing into the dam, an experienced and skilled artisan must continuously supervise and control the placement of rock and mortar.

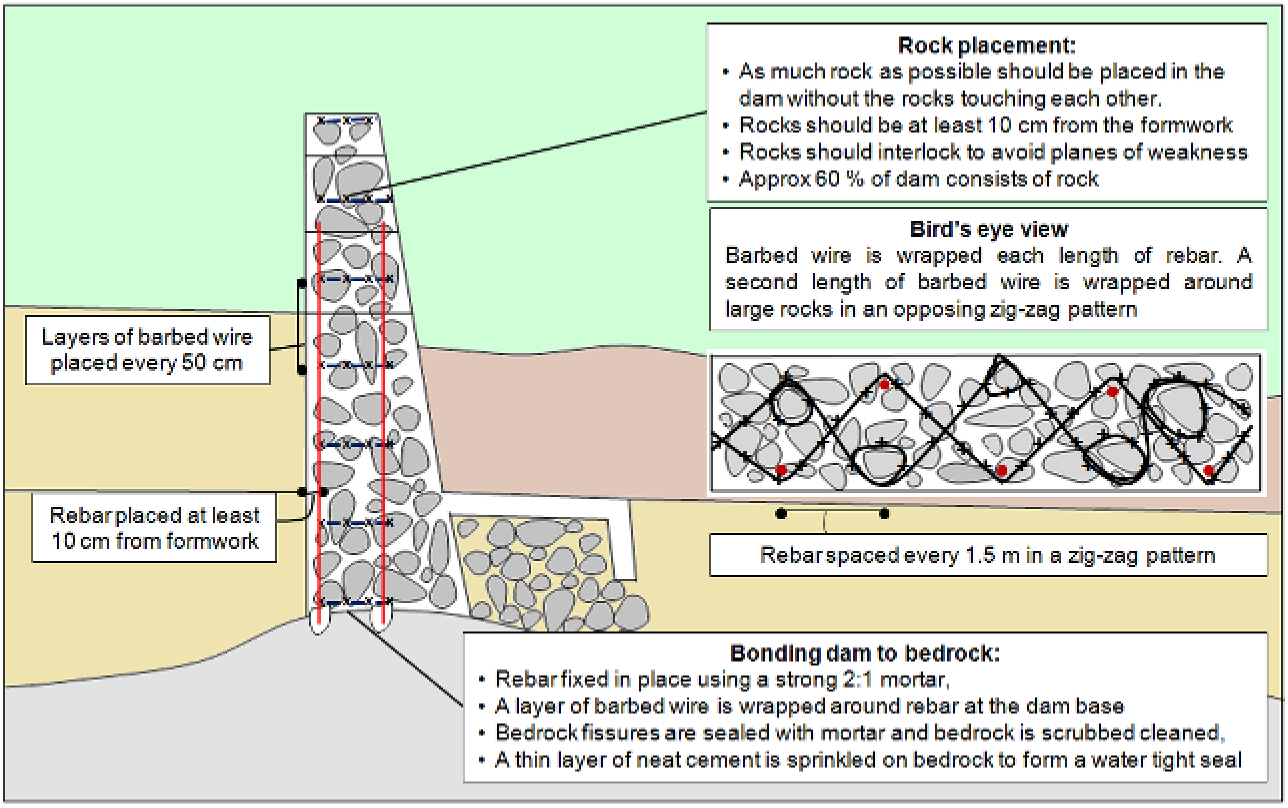


Figure 20: X-section through base of dam showing placement of layers of mortar and rocks

Barbed wire is wrapped around the steel bars in a zig-zag pattern and a second length of barbed wire runs in a counter zig-zag pattern, wrapped around the large rocks as shown in figure 20. These layers are repeated after every second layer of rock (approximately every 50 cm). The barbed wire runs across the full width of the dam and the ends tied together.

At the end of each day's construction and at the top of the finished dam, there should be rocks protruding to provide a good key for the following day's construction or in the case of the finished dam, to provide a good key for any possible future extension. Each day the dam should be built in horizontal layers rather than blocks. After the formwork is filled, the formwork is removed on the following day and move upwards and the next layer is constructed. When moving the stuttering up, wet the top and sides of previous layer to assist curing. As you move to the top of the dam be aware of any tapering of the dam wings or changes in the strength of the mortar. If there is a risk of rains during construction, construct from the outside and move towards the centre of the river to avoid any risk of diverting the river should it rain during construction. Start construction on the most vulnerable river bank first.

Photo 36: A raised platform allows the mortar to be thrown into the formwork

The spillways and wings must be built exactly level to the design height and the wings must be the same height on either side. Often community members will push for the spillway to be higher or narrower in the mistaken belief this will give more water and without understanding the potential consequences.

8.11 Apron construction

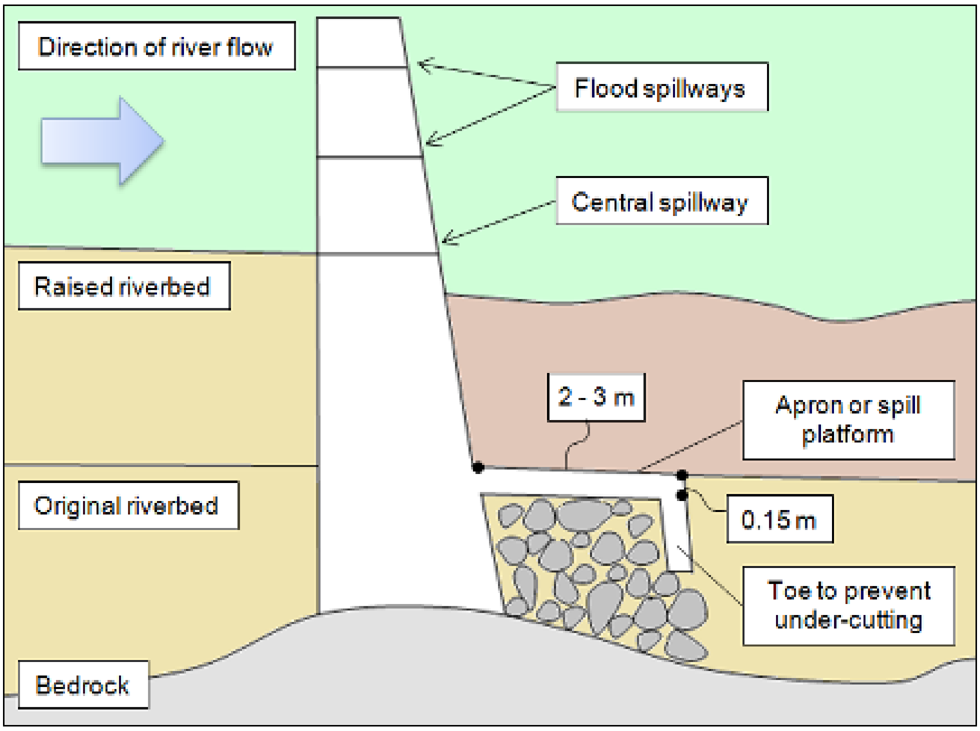


Figure 21: X-section of a sand dam with an apron

As water flows over the dam it speeds up. The apron is the platform below the dam that protects the base of the dam from being undercut (fig. 21). **The apron is slightly wider than annual flood spillway and typically extends 2 - 3 m from the base of the dam**. The apron is constructed at the level of the original riverbed. The apron is built on a sound foundation of large and small rocks with a toe to prevent the apron itself from being undercut as seen in photo 25. Where the bedrock is less than 1 metre below the level of the apron, the rock foundation is made directly on top of the bedrock. If the bedrock is deeper than 1 metre and there is limited availability of rock, river sediment may be used to backfill until 1 metre below the level of the apron and then a 1 metre thick rock foundation made on top of this sediment. A fairly fluid, wet mortar mix is poured over these rocks. This penetrates and bonds the top layer of rock. Then the apron is finished with a 15 cm thick layer of concrete which on large rivers is reinforced under the spillway. The reinforcement should not be tied into the dam. Note that dams may increase erosion immediately downstream of the dam. This is greatest whilst the dam is filling with sediment since sediment load in the water flowing over the dam is reduced. This may be controlled by planting vegetation on the downstream banks.

Photo 37: Examples of poorly constructed dam aprons

8.12 Quality control checklist

- Sufficient and adequately skilled supervision
- All the cement ends up in the dam
- Fissures in bedrock sealed
- Bedrock washed
- Rocks are evenly spaced and overlap vertically
- Dam is wetted morning and evening for 4 weeks
- Sand has little or no organic matter or silt
- Sufficient durable rock content
- No air pockets
- Spillway and wings are level
- Apron has solid foundation
- Cement is dry and good quality
- Rocks do not touch each other
- Mortar is not too wet or too dry

8.13 Construction alternatives

The construction method described is not the only method that can be used. Provided the dam obeys the pre-conditions and Golden Rules and is sufficiently strong to withstand the forces acting on it, it will work. Here are some alternative methods.

Stone-masonry formwork: Two parallel thin walls are constructed of stone and mortar. These walls form the outside of the dam and take the place of the formwork. Lines of barbed wire are placed in the trench at the base of the dam. The space between the two walls is then in filled with more stone and mortar. The outer walls are then plastered or grouted. Steel reinforcement is used on larger or higher dams. The advantage of this method is that it does not require timber formwork. However, experienced artisans are needed to build the formwork walls and the walls must be strong enough before filling in the middle. Because of this, dams built using this method take longer to build.

Steel sheet formwork: In Zimbabwe where durable hardwood timber is expensive and hard to find, sheets of steel bolted together has been used as formwork. Although more expensive to buy initially, this will be offset by their durability in the long run.

8.14 Post construction: plastering and curing the dam

Formwork may be removed on the day after construction is completed. On removal of the formwork, cut the barbed wire that has been used to secure the formwork. After the shuttering is removed, any holes, exposed rocks or reinforcement on the faces of the dam are plastered with mortar. The upstream face is the most critical. This prevents seepage and corrosion of steel within the dam. Once the dam is complete, the trench dug into the riverbed or riverbanks is back filled. The soil is wetted and compacted every 30 cm to reduce the opportunity for seepage beneath or around the dam. Upstream of the dam, any excavated soil remaining on the banks or in the river channel is removed to prevent it being washed behind the dam and so reducing its capacity.

Curing: A chemical reaction between cement and water, called hydration, allows the cement and sand particles to bond to each other. This chemical reaction continues over many weeks and months provided sufficient water is available, although 90 % of its final strength is reached within the first 4 weeks, so this period is most critical. If water is no longer available, the reaction will stop and once it has stopped, it cannot be restarted. During construction, water is absorbed by the rocks and formwork and used in the reaction. The reaction generates heat which increases evaporation losses. So a layer of sand and / or a covering of cement bags, sacking or vegetation are placed on the top of the dam to reduce evaporation and keep the dam wet. **For 4 weeks, three times a day (morning, noon and evening),** this layer is watered with watering cans (or similar) and the upstream and downstream sides are splashed with water. After 4 weeks, the frequency of wetting is reduced. Correct curing allows concrete to continue to gain in

Strength of concrete kept wet constantly for 28 days	
Kept wet for 28 days	100 %
Kept wet for 7 days	90 %
Kept wet for 3 days	80 %
No wetting	55 %

Table 12: Importance of curing
Source: Portland Cement Assoc.

strength beyond 28 days.

8.15 Special circumstances

8.15.1 Only small stones are available

When only small stones are available, then the depth of the mortar and rock layers is reduced from 15 cm to 10 cm. With smaller rocks, the ratio of mortar to rocks increases. Additional cement and reinforcement will increase the cost. Sometimes, rocks will need to be transported to the site and / or large boulders broken into smaller rocks.

8.15.2 Water in river

At times there will be sites that have significant base-flow within the existing river sediments. When this occurs and the sediment is not too deep, the flow may be diverted using ‘sand bags’. Shuttering is placed across half the river channel and the dam is built around the diverted flow. Keep the shuttering in place for 2 days, then divert the flow again and build the dam on the other side of the river, leaving a small section in the middle. If the flow is significant, in the final stage, where the centre of the dam is filled in, a large pipe may be used to channel the flow through. The pipe is then filled in and sealed as the last step.

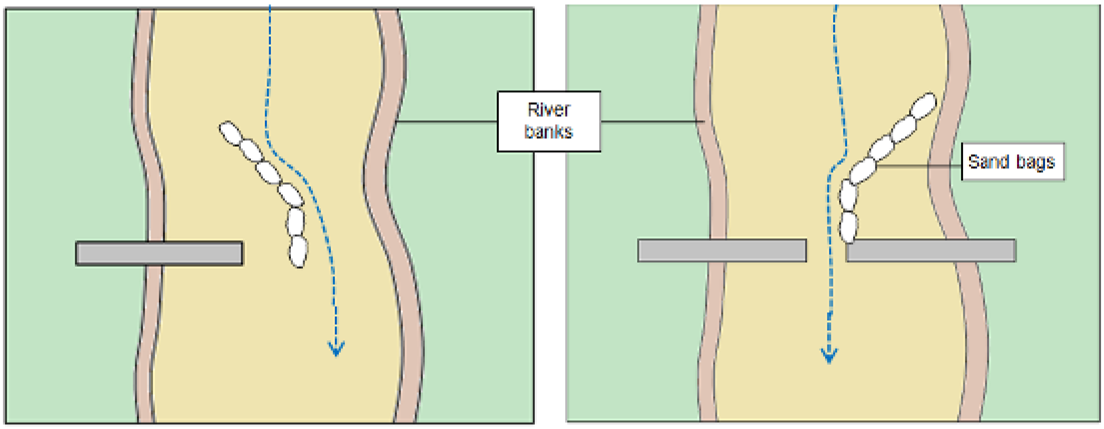


Figure 22: Bird’s eye view of the diversion of base-flow to allow construction in stages

8.15.3 Water scarcity

When water is scarce in the immediate vicinity of the dam, temporary storage, such as a simple brick lined open tank, should be built. This allows the community to collect, transport and store water at the site in the weeks prior to construction. Bulk transport such as oxen carts, tractors or bicycles may reduce the burden this places on people. One strategy that reduces the work required is to build the dam in two stages. The first stage, a small sub-surface dam, is built a few weeks prior to the rainy season. The rains then fill this dam with a limited amount of water, sufficient to complete the dam after the rains.

Chapter 9: Maintenance and management of sand dams

9.1 Warning signs of sand dam failure

A well designed and constructed sand dam requires zero or minimal maintenance. The community group must regularly inspect the dam for damage, especially after major rains during the first year after construction. The community group should be able to identify and implement repairs and preventative maintenance themselves and have the expectation that this is their responsibility. However the supporting NGO or implementing organisation should remain available to provide advice and support as required.

The warning signs of failure:

- Erosion outside the wings
- Erosion of riverbanks
- Cracks and leakages through the dam wall and at the base of the dam
- Undercutting of apron
- Erosion around the wings

9.2 Monitoring and preventative maintenance

9.2.1 Monitoring spillway capacity and preventing erosion outside wings

Very occasionally, water may flow over the dam wings. It is essential to monitor the depth flow over the dam especially immediately after particularly heavy rains and / or during the first few years of the dam's life. The peak flood level is usually clearly identifiable by the muddy deposits on the upstream face of the dam wings or in extreme cases when the flood over tops the dam by signs of water flow and erosion at the end of the dam wings. This flow should only occur for a brief period and should not cause significant erosion. However, if the erosion is not repaired, it may result in failure of the dam. If the erosion is minor and the flood which caused the erosion was particularly large, sand bags placed at the ends of the wings may be sufficient. However, if the erosion is more significant or flood not unusually large, then the spillway is too small and the dam wings must be raised and extended urgently. If in doubt, extend the dam wings.

9.2.2 Monitoring bank erosion and changes in river course

A clear picture of how the dam affects river flows is only gained once the dam is full of sediment. Some erosion is a natural part of a river's life. However any erosion caused by the dam must be managed. The upstream and downstream banks are inspected for erosion and grasses planted to protect banks and keep the river flowing in its original position. If the erosion cannot be managed by planting vegetation, the river's flow must be managed by (1) extending or raising the wings or (2) altering the positioning of spillway(s) to control the position of the main flow of the river.

9.2.3 Sealing cracks and / or leaks

In the first few weeks, there may be some minor seepage through the dam as shown by the wet patches in photo 38. This is normal and not a cause for concern. This seepage decreases over time and within a few months will cease completely. If the seepage continues especially at the base or if there is any visible crack, this will need to be repaired.

Open the crack, removing any loose mortar, wash and wet it and seal with neat cement for very fine cracks or mortar for slightly wider cracks. For any leakage at the base between the dam and the bedrock or for any large crack (> 5 mm) a 15 cm by 15 cm concrete block is created around the crack or leak on both the upstream and downstream side of the dam, as shown in figures 23 and 24.

Photo 38: Monitoring leaks

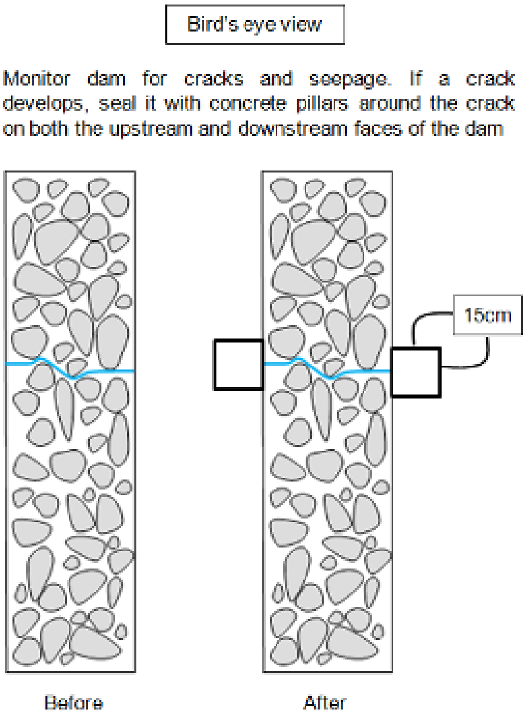


Figure 23: Bird's eye view of a repair to a crack through the dam

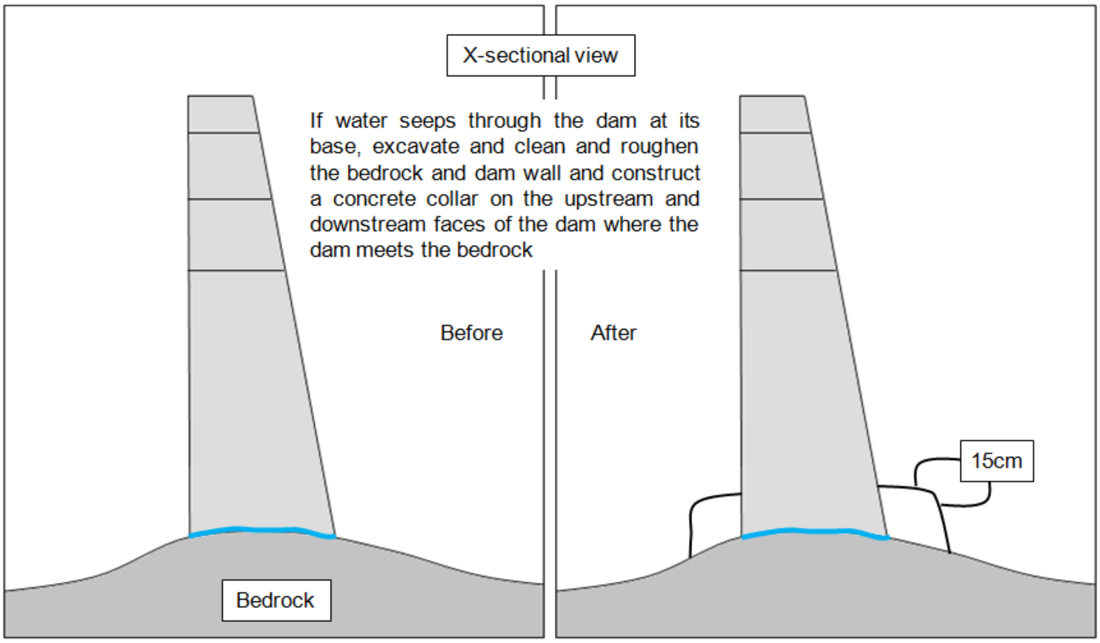


Figure 24: X-section of a repair to the base of dam

9.2.4 Monitoring and preventative maintenance of apron and wings

Any damage to the apron or its foundation (as seen in Photos 39 and 40) must be repaired urgently. Protect the land around the base of the dam wings from erosion. People and animals walking around the dam may cause footpath erosion which in time could result in a gulley. If this is a risk, overland flow must be channelled away from the dam wings and thorns used to prevent people and animals creating further erosion. Any low spots must be back filled with compacted soil or sand bags. Erosion of the wing foundations may result in dam failure.

Photo 39: Erosion of left hand bank shows the foundation and apron do not extend into the riverbanks

Photo 40: Sections of the apron have been undermined due to foundation and size of the apron being inadequate.

9.2.5 Monitoring and managing gulley erosion

Catchment management needs to be monitored and if necessary extended. Continue gulley reclamation by raising the level of check dams and / or vegetation barriers and inspect and if necessary maintain terraces and cut-off ditches.

9.3 Sand dam management

Clear management is essential for sustainability and maximising the benefits.

9.3.1 Registering the dam with relevant authorities

The legal registration process differs from country to country. In Kenya, authorisation from the Water Resources Management Authority is required before developing any water resource including sand dams. This usually consists of having the technical design approved but may also involve site visits and assessments. Upon satisfactory construction, a water permit is issued. This recognises the group's rights to abstract water for different specified uses and enables the group to use customary or statutory law to manage the water resource including control of water abstraction and sand harvesting. In Kenya, customary law is often the most appropriate and accessible route and the place where traditionally disputes over water, land and grazing rights are addressed.

9.3.2 Controlling large scale abstraction of sand

Small scale sand abstraction for construction is not a problem. However, large scale sand harvesting by commercial contractors reduces the sand and water levels in the river and increases bank erosion and must be controlled. Large scale abstraction is most common at sites close to large towns and cities. In Kenya, commercial sand abstraction is only legal if a permit is obtained. However, in reality the law is seldom enforced. Community groups are better able to manage this problem if the dam is legally registered to them and the importance of managing sand harvesting is recognised by the wider community.

9.3.3 Controlling large scale water abstraction and water scarcity

A common concern of community groups is preventing unauthorised bulk abstraction. The group must monitor water usage and levels and where necessary use legal and physical means to control water abstraction. Anyone is permitted to take water from scoop-holes provided the water is not pumped. At times of scarcity the group often control abstraction of sand dam water from wells, tanks or pipes by locking / controlling access to the taps, pumps and access covers and restricting the use of petrol powered pumps for taking water in bulk from scoop-holes. The need to physically control abstraction often influences their choice of abstraction method.

9.3.4 Monitoring and managing livestock usage

In Kenya, people use Acacia thorns to keep livestock out of scoop-holes used by people and construct separate cattle watering troughs. However, a reliable water source in a dry area attracts people and animals from a wide area and the group will need to monitor and manage livestock usage through negotiation, charges and the use of customary law.

9.3.5 Management and maintenance of abstraction technologies

Where the dam is registered and owned by a community group, the group is responsible for monitoring and managing water abstraction and collecting money for repairs. This includes monitoring:

- Water usage including any bulk abstraction for irrigation and use by animals
- Water levels in scoop-holes, off-take wells and tanks and agreeing maximum abstraction rates. Any difference in water level between an off-take well and a neighbouring scoop-hole indicates the infiltration gallery is clogged or has insufficient capacity and will need inspection and expansion or overhaul
- Incidence of water-borne illness amongst users and water quality testing where capacity exists. Simple water quality indicators include any change turbidity (the cloudiness of the water), salinity, taste, colour and odour. In addition, it is highly desirable to monitor bacteriological quality. However, this usually requires external support. The district authorities may advice on water testing
- Any damage to pipes, tanks, well heads, pumps or taps. During construction and installation, group members should be trained in routine maintenance and repairs such as pump priming and replacement of pump valves and taps. Water charges (if applicable) and expenditure on maintenance and repair.

9.3.6 Managing payment and maintenance systems

Decisions over payment and maintenance systems and how the dam water will be used must be made prior to any decision to build a dam. Two major advantages of sand dams are (1) they have little or no maintenance and operation costs and (2) through livestock watering, vegetable and tree nurseries, fishponds and block making, they significantly improve incomes. As a consequence, users are willing and able to pay the costs of repair and maintenance. As part of managing the dam and any abstraction system, the group puts a system in place for funding this work. Because the cost is often small, unpredictable and one-off, users may agree to contribute as required rather than through regular payments. When the costs of operation and maintenance are on-going and predictable, the group introduce water charges. When group members come together to irrigate land, they agree a system to pay for the pump and its operation and maintenance. If a sand dam is used to supply a piped network of taps / water kiosks, the whole system will require a planned maintenance and management plan. Such a plan will describe:

- Day-to-day operation including metering and recording all flows and sales
- Routine maintenance, repair and replacement of the powered pump
- The repair and scheduled replacement of pipes, tanks and taps including (where required) the use of external contractors / NGOs. Suppliers can advise on maintenance schedules and typical design lives
- An annual budget for income and expenditure including staffing of water kiosks and reserves for major repairs and
- The governance and management of the system.

Chapter 10: Alternative water technologies

10.1 Introduction

This chapter summarises some common water technologies used in rural dryland regions. When considering whether to construct a sand dam, it is important to assess alternative technologies and their relative merits. Many of the factors and questions discussed in the chapter 4 (Applying sand dams in a new area) will be relevant. In addition, take account of the following information:

- **Water resource mapping:** Which technologies are technically suited to the hydrology, geology, climate and topography of the region? Which water technologies/sources are most common in the region? Where are they and how are they used? What is the yield, quality, reliability, cost and accessibility of the different water sources? How long does it take people to collect and transport water and how does this change during the dry-season and during years of extreme drought?
- **Water users' survey:** How does water availability impact local people and how will increased water availability improve their lives. What are their development priorities? What are the likely environmental, economic and social impacts? What wider opportunities and benefits will be created? What are local peoples' opinions on where water is needed, on shared or individual ownership and on past experience of existing technologies?
- **Skills and capacity survey:** What local skills, materials and experience are available? What is the willingness and ability of local people to contribute their skills, labour or money? What is the technical feasibility of the technology and what level of technical support is required to build and operate it?
- **Policy environment:** What local and national policies and laws exist that govern water, the environment, land rights or working with community groups?
- **Value for money analysis:** What are the capital investment cost (per cubic metre of water) and the operation, maintenance and replacement costs (per cubic metre of water) of the technology?
- **Sustainability:** How financially and environmentally sustainable is the technology? How socially and culturally appropriate is the technology and what do local people think about the usefulness and quality of the water provided?

10.2 In-channel structures for harvesting water

There is a range of structures that harvest, store and / or abstract water from seasonal sandy rivers. Figure 26 shows how the suitability of in-channel structures changes within a catchment. The suggested limits to feasibility for each technology will vary from basin to basin according to its geography. However, in general terms, lower in a catchment/basin, where slopes are shallower, structures such as water spreading weirs and spate irrigation which divert flow onto adjacent land for irrigation purposes are most likely to be appropriate. Where potable water is required, water pumped through an infiltration gallery from a sub-surface or sand dam or sand river abstraction gallery is most likely to be appropriate.

- **Check dams** are small, permeable barriers that capture sediment and slow flow in small streams and gulleys (refer to 6.5.2)
- **Sub-surface dams** (refer to 10.3) and **sand dams**
- **Sand river water abstraction** covers a range of technologies that draw water from sandy river sediments through an infiltration gallery to hand or powered pump. Abstraction points are sited where the sediment is deepest on large rivers with significant base-flow. Further information on Water from Sand Rivers is available online.
- **Water spreading weirs** are long barriers across seasonal rivers that divert flood flows and sediment from seasonal rivers onto the flood plains before flowing over and back into the seasonal river channel. This water and sediment

raises the watertable and irrigates and fertilises the flood plains. Further information on water spreading weirs is available online.

- **Spate or diversion irrigation** is similar to water spreading weirs. They are in-channel structures that divert some of the flood waters from the river channel onto the surrounding flood plains for irrigation. Any surplus is channelled back into the river downstream. Both technologies are only suited to broad valleys with shallow slopes and extensive flood plains. Further information is available from the spate irrigation network.

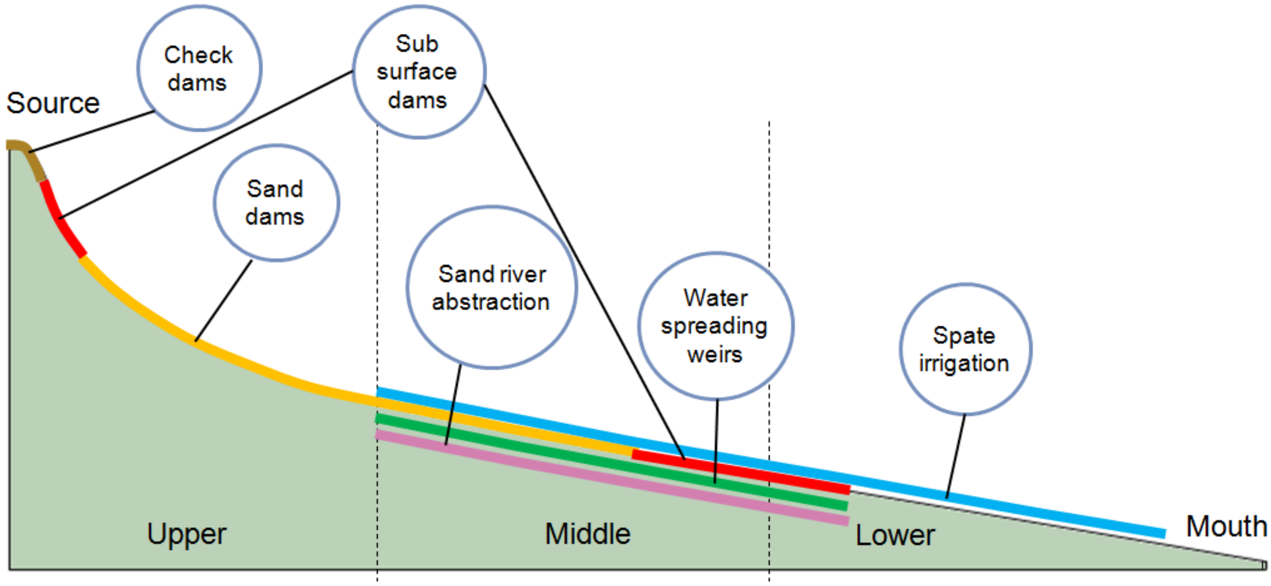


Figure 25: Long profile of river channel showing the position of in-channel water harvesting technologies

10.3 Sub-surface dams

Sub-surface dams differ from sand dams in that they do not cause a rise in the riverbed level. Because riverbed sediment provides lateral support to the dam wall, sub-surface dams may be thinner and use less material than a sand dam. They are less prone to flood damage and simpler to design and build than sand dams. They may be made from any impermeable material including compacted clay, tar-felt, corrugated iron sheets, injected resins, bitumen sheets or bricks as well as concrete or stone-masonry. However, sub-surface dams capture less water and have higher evaporation losses relative to sand dams. In India, impermeable sub-surface barriers have been installed across the full valley width of a flood plain to raise the watertable level sufficiently that crops can access the soil water. The water level is controlled with sluice gates.

Advantages

- Very durable
- Very little maintenance required so particularly suited to remote locations where little external support is available
- High yield compared to ground, rock and roof rainwater harvesting solutions
- Low capital and operation costs. Low cost per cubic metre of water especially over the full life time of the dam
- High water quality when water is abstracted through an infiltration gallery
- Mosquitoes and other water-borne vectors are unable to breed.

Disadvantages

- Some technical knowledge required, although less so for sub-surface dams than sand dams
- Labour-intensive to construct
- Only applicable to seasonal rivers

10.4 Earth pans and earth dams

Earth pans and earth dams capture and store run-off in an open surface reservoir on gently sloping land. **Earth pans**, called haffirs in Arabic, occur in natural depressions where rain water collects or enhanced by excavation and embankments to increase their storage capacity. Pans form where the water table is close to the surface, with water usually dissipating through evaporation, rather than outflow to a stream or river. Traditionally earth pans have been dug by hand, but larger pans are more often constructed with earth moving machinery. A typical earth pan is 2 - 8 metres deep with a capacity of 5,000 – 30,000 m^3. **Earth dams** vary considerably in size, from a few metres to over 100 metres across in width, impounding from several hundred cubic metres to more than a million. Here we consider small dams that can be built by hand or using oxen or tractors that store from 100 m^3 to 10,000 m^3 of water. They may be built across a hillside or sloping land ('hillside dams') or built across wide, shallow valleys ('valley dams)'. Hillside dams are considered to be the cheapest and simplest to site, design, construct and maintain.

Earth pans are suited to:

- Natural depressions in 'flat' or very gently sloped land
- Places where there are no 'rivers' as such – just runoff water
- Soils with high clay content that suit paddling and sealing
- Unfarmed land with low silt/sediment in run-off
- Often used for livestock watering so suit pastoralist areas

Earth dams are suited to:

- Gently sloped hillsides and valleys
- Valley dams suit small catchments with shallow slopes unless significant dam design and construction experience is available

Advantages

- Maximises the use of topography and natural slopes to create water points
- When combined with treatment (such as a slow sand filter) and off-take wells, water used for domestic purposes

Disadvantages

- Open water results in high evaporation losses (up to 50 %) and water-vector diseases such as malaria and bilharzia
- High risk of contamination from livestock, if area is not fenced off with separate livestock watering points
- Dams are prone to rapid siltation that requires frequent excavation, sometimes as often as every 6 years
- Earth dams are individually sited and designed and required technical knowledge to so correctly
- Large dams and pans require machinery to construct and maintain them
- Earth dams are prone to failure if peak floods exceed spillway capacity. Failure of open water dams result in significant danger to life and property downstream
- Concentration of livestock may degrade the environment unless access is closely managed
- There is a risk of conflict over access and water rights unless there is clear ownership and management

Photo 41: Earth dam, Kenya. Credit: UDO / EDK

Photo 42: Hillside Dam, Kenya. Credit: E. Nissen-Petersen

Photo 43: Natural earth pan, Kenya.

Credit: E. Nissen-Petersen

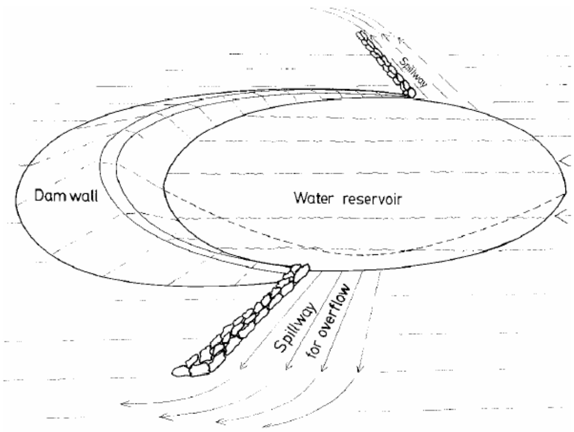


Figure 26: Bird's eye view of hillside dam.

Credit: E Nissen-Petersen

10.5 Underground Tanks

Lined, underground tanks (with silt trap inlet) are used to store runoff from a fenced and uncultivated catchment. Typically 50 – 100 m^3 in capacity, they may be built from ferro-cement (mortar plastered on wire mesh), bricks or stone-masonry, with or without a roof. Water is drawn by a bucket or hand-pump. Open ground tanks with no roof are called berkads in Somalia. Open tanks are simpler to build but lose more water to evaporation than tanks with roofs. Underground tanks are suited to remote, pastoralist areas with low population density and per capita water consumption. They are not suited to cultivated areas or areas with higher population density or water demand.

The catchment vegetation is maintained to minimise erosion and should be fenced off and 'policed' to reduce contamination by animals. A typical catchment area for an underground tank is approximately 10,000 m^2 although this depends on the amount of rainfall, as rainfall reduces, catchment size increases. Underground tanks are best suited to strong, stable soils: that is soils that do not collapse during construction nor expand and shrink excessively with moisture (due to high clay content). The silt traps should be cleaned out annually, any tank cracks plastered over and the catchment fences maintained. Many pastoralists/nomads are not familiar with using mud as a plaster or working underground and the use of ferro-cement is not commonly understood. This may create issues in construction.

Photo 44: Berkad, the Somali name for a lined ground tank. Credit: Erik Nissen-Petersen

Photo 45: Run-off is channelled into a silt trap before entering the Berkad. Credit: Erik Nissen-Petersen

Advantages

- Structurally strong with a long life span of up to 40 - 50 years.
- Widely applied in pastoralist areas
- May be constructed with unskilled labour although significant labour is required for large tanks

- Effective in low rainfall areas as the fenced catchment size may be increased to compensate

Disadvantages

- Prone to cracking if built in unstable soils and / or poorly built and maintained

10.6 Roof rainwater harvesting

Rainwater is channelled from roof/s by guttering and a down flow pipe into a storage tank. The tank, which is usually above-ground, is made from a range of materials such as reinforced concrete, stone-masonry, ferro-cement, bricks plastered with mortar, plastic (uPVC) and corrugated iron. A typical tank size is 50 – 100 m^3. The size depends on the roof area and the amount and annual distribution of rainfall. They may be combined with simple water treatment such as chlorination, slow sand filters or SODIS (solar disinfection). They are best suited to permanent buildings with non thatch roofs, where water consumption is low such as individual homes and schools. They are more suited to areas of high rainfall that is evenly distributed over the year. The highly seasonal rainfall in drylands reduces their suitability, but it is still one of the most appropriate ways of providing water to schools or individual households. The first rainfall of a season must be diverted away from the tank to ensure that the roof area is washed clean of debris and dirt, ensuring that subsequent rainfall is captured with minimal contamination. The tanks should be washed out and cleaned annually. The inside of the tank should be sealed and kept dark as much as possible to prevent algae growth and minimise mosquito breeding. Further information and design tool available at www.samsamwater.com/rain.

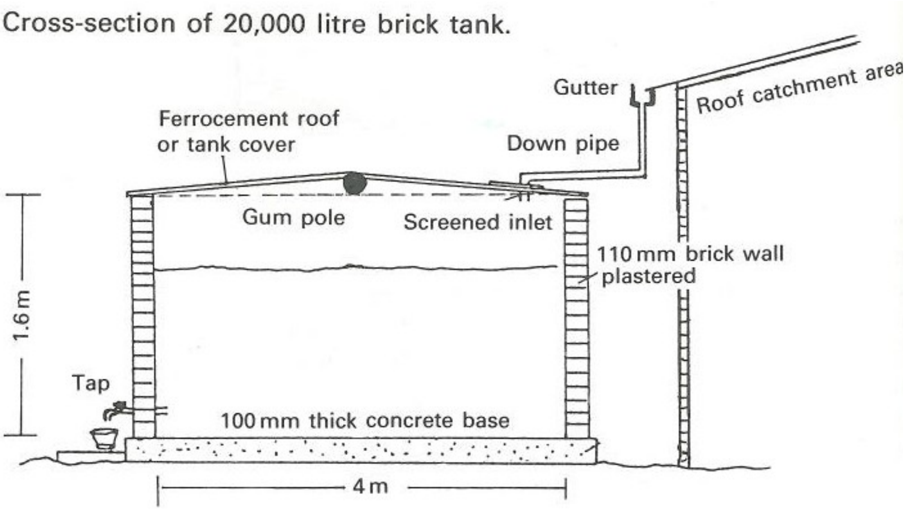


Figure 27: Roof –catchment rainwater tank. Credit: Erik Nissen-Petersen

Advantages

- Proximity of water to point of use makes it well suited to domestic and school water supply
- Clear ownership makes maintenance, treatment and use of water simple to manage
- Relatively simple to design and build, makes it suitable for self-supply and small contractors
- Low operation and maintenance costs

Disadvantages

- Relatively high cost of construction per cubic meter of water supplied
- Yield is limited and dependent on roof size and the amount, reliability and annual distribution of rain
- Regular maintenance and cleaning of guttering and tanks required to minimise contamination
- Water often requires some treatment

10.7 Rock catchments with open storage or tanks

Low stone-masonry walls, typically 30 cm high, impound and channel rainwater falling on an impervious, bare rock face and then storing the water either in an open tank within the rock catchment or channelled / piped into tanks. As with roof catchments, the tank size and annual yield depends on rock catchment area and the amount and annual distribution of rainfall. The rock face must be bare and free from major sources of contamination e.g. animal / human excrement. Soil and vegetation should be cleared and any cracks sealed with mortar. As with roof rainwater harvesting, the first rainfall of a season should be diverted away from the tank and the tanks should be washed out and cleaned annually. Water treatment is usually required. The inside of the tank should be sealed and kept dark. Rock catchments are best suited to:

1. Gently sloping rock faces. A maximum slope of 20 - 30 degrees at the position of capturing walls is recommended, although this may be steeper at the 'take off' point

2. Areas of medium – high rainfall that is not too seasonal. Less suited to areas of low, irregular and seasonal rainfall

Photo 46: Rock catchment and storage tanks

Advantages

- Significantly larger catchment and yield compared to roof catchments
- No operating costs and low maintenance costs
- Relatively simple to design and build, makes it suitable for self-supply and small contractors

Disadvantages

- Relatively labour-intensive and high cost of construction per cubic metre of water supplied
- Require individual siting and design. Limited number of suitable sites
- Yield is limited and reliant on the amount, reliability and annual distribution of rainfall
- High evaporation losses from open water tanks sited on the rock surface
- If water is stored in tanks with roofs below the rock catchment (photo 46), evaporation losses are lower

10.8 Shallow wells

Three types of well are included in this section:

- Hand-dug, open wells with rope & bucket
- Hand-dug covered wells with a hand-pump
- Tube-wells with a hand-pump

Hand-dug wells are excavations with diameters typically 1 – 2 metres across that extend below the water table. They are suited to relatively shallow water tables, typically 7 – 30 metres and may be operated with or without a hand-pump. They should be lined with ferro-cement or bricks and have a raised, sealed platform

Hand-dug, open wells with a bucket

Advantages

- Simple technology that is well understood across all arid and semi arid lands
- Requires minimal technical support and may be sited close to the point of demand
- Easy to maintain. Low cost, both in construction and maintenance

Disadvantages

- Prone to contamination
- Labour-intensive to construct and abstract water and abstraction rate is limited
- Excavation may be dangerous if safety measures not followed

Hand-dug closed well with a hand-pump

Advantages

- Relatively simple technology that is well understood across many parts of arid and semi arid lands
- Requires minimal technical support and relatively easy to maintain
- Significantly less contamination than with open wells
- Abstraction rate is greater and less labour-intensive than from a well with a bucket
- Well may be downgraded to simple bucket extraction if the pump breaks
- May be sited close to point of demand

Disadvantages

- Labour-intensive to construct
- Higher construction and abstraction costs (pump maintenance) than a open well
- Some technical skill needed to maintain pump and maintenance costs usually result in a small charge for water

Tube-wells fitted with a hand-pump

Tube-wells are drilled rather than excavated and are significantly narrower (10 - 20 cm) than hand dug wells. Because of their smaller diameter, the same depth of tube-well in the same ground yields less water than a hand dug well. However greater depths may more easily be achieved, which more than compensates for this. Tube-wells must be fitted with a pump. This may either be a hand-pump or a motorised pump. Hand-pumps typically suit wells that are 5 to 50 metres deep, but some hand-pumps are able to lift water more than 100 metres. Hand-pump yield varies according to the model and depth of the watertable, but typically they serve the domestic needs of 300 people. Tube-wells are quicker, safer and cheaper to sink than hand dug wells and are more hygienic than hand dug wells that use a bucket and windlass.

Advantages

- Lower risk of contamination than other types of well
- Less labour-intensive to abstract water than well with bucket only
- May be quicker and safer than hand-dug wells
- May be sited close to point of demand

Disadvantages

- High cost of drilling equipment, well casing, well head and pump
- Water may only be abstracted by pump
- Abstraction rate is limited by pump
- Significant technical skill needed to site, drill and equip the well and to a less extent, maintain the pump
- Maintenance costs usually result in a small charge for water

The drilling method depends on the rock formation and depth of aquifer. In loose sedimentary formations, tube-wells may be drilled using a hand auger and tripod. In very limited circumstances, in loose sediments where a water supply is available, jetting may be used. In harder formations and at greater depths, percussion and rotary percussion drilling rigs are used. The siting and drilling of tube wells and boreholes is not a job for amateurs and experienced, proven contractors should be hired. **Application:** All three types of well extract water directly from ground water and are therefore suited to any location where the aquifer is within reach and has sufficient yield. Hand dug wells are suited to areas with a relatively shallow water table. All rely on sufficient recharge and permeability of the aquifer.

10.9 Boreholes fitted with a powered pump

The only distinction between tube-wells and boreholes is that boreholes is the usual name given to deep, machine drilled wells (typically 40 – 100 m but may be more) that usually have a wider diameter and capacity and are fitted with a powered pump. In rural drylands, rotary pumps powered by a diesel engine are the norm, but solar or wind pumps would suit some lower yield applications. Electric pumps are suitable if reliable power is available, which it seldom is. The yield of the borehole is determined by the hydro-geology (and in particular the depth, transmissivity and recharge of the aquifer and proximity of other boreholes), the diameter and depth of the borehole and the depth and size of the pump fitted. Assessing the potential of an aquifer and siting, drilling, testing, equipping and developing a borehole all require significant expertise and experience that is beyond most community groups or development agencies. Specialist contractors are usually engaged. A geological survey is needed before making the decision that a borehole is the preferred solution and even then, in some geological formations, there is considerable uncertainty as to the yield a borehole will deliver until it is drilled and test pumped. Relative to the other technologies boreholes are the most expensive. However when correctly sited, drilled and constructed, boreholes provide high, reliable yields (2 – 10 m3 / hour are typical) of high quality water and as such they are suited to areas of heavy per capita consumption, where a bulk supply of water is needed. They are less suited to areas of low demand and population density. They have significant operation and maintenance costs that increase in remote areas. Cattle-grazing is often concentrated around boreholes and this may significantly degrade the environment. Over-pumping lowers the watertable and reduces the yield of neighbouring, shallower wells, sometimes to the extent that they dry up completely in the dry season.

Advantages

- Usually excellent water quality
- Reliable bulk supply, suits high demand, urban and peri-urban applications
- Deep aquifers (> 100 metres) may be reached
- Year round, drought-proof supply provided borehole is not over pumped

Disadvantages

- High capital costs and unpredictable yield
- High operation and maintenance costs make it poorly suited to remote, poorly served communities
- Low rates of functionality due to inadequate repair and maintenance
- Water levels require monitoring to prevent over-pumping.

10.10 Managed aquifer recharge

Many aquifers in drylands are being over-pumped, resulting in falling water table levels, reduced yields and increased pumping costs. Where this is the case, there are numerous ways in which recharge may be enhanced including many of the technologies described already such as pans, dams, sand dams and water spreading weirs as well as in-field water harvesting and land management techniques such as conservation farming, terracing and enhanced storage using zai pits, contour bunds, stone lines and swales. Aquifers may also be recharged by channelling overland flow directly into boreholes and recharge tubes. Further information is available from International Association of Hydro-geologists - Managed aquifer recharge group: [Link]

10.11 Comparison of Water Solutions

Table 13 compares the different water solutions considered in this chapter and scores their suitability in rural drylands in relationship to what we believe to be the three major areas of importance: cost, quality and sustainability. Cost takes into account total life costs: investment, operational, maintenance and replacement costs. In terms of sustainability, it is important to consider environmental impacts and functionality: i.e. how much of the time is the technology functioning adequately? Yield considers not just the volume of water but how accessible the water is and its reliability throughout the year. The table is based on the authors' knowledge and is purely indicative. Values will vary depending on application and the local context.

10.12 Further reading and resources

Akvopedia: on-line guidance on WASH technologies in general: [Link]

Hussey, S.W. (2007), Water from Sand Rivers: Guidelines for abstraction. WEDC, UK. [Link]

Jordan T D Jnr., (1984), A handbook of gravity–flow water systems, IT Publications

McDonald A et al., (2005), Developing Groundwater: A Guide for Rural Water Supply, IT Publications.

Pacey A and Cullis A, (1986), Rainwater Harvesting, IT Publications

SamSamWater Library. [Link]

Smet J et al., (2002), Small Community Water Supplies: Technology, people and partnership. [Link]

Watt S B, (1978), Ferrocement Water Tanks and their construction, IT Publications.

Watt S B and Wood W E, (1977), Hand dug wells, IT Publications.

WaterAid, (2007), WaterAid Technology notes. Accessed June 2012 [Link]

Skinner B and Shaw R, WELL Technical Briefs, Buried and semi-submerged tanks, WEDC, UK. [Link]

WOCAT, (2011), SLM (Sustainable Land Management) in Practice - Guidelines and Best Practices for Sub-Saharan Africa. [Link]

WOCAT, (2007), Where the land is greener. [Link]

WOCAT, (2013), Water Harvesting – Guidelines to Good Practice. [Link]

In-channel structures	Yield	Capital costs	Capital costs / m3 of yield	Operation and maintenance	Water quality	Environmental sustainability	Reliability	
Sand dams with infiltration gallery	★★★★☆	★★★★☆	★★★★★	★★★★☆	★★★★★	★★★★★	★★★★☆	89%
Sand dams with scoop holes	★★★★☆	★★★★☆	★★★★★	★★★★★	★★★☆☆	★★★★★	★★★★★	89%
Infiltration galleries in sand rivers	★★★★☆	★★★★☆	★★★★★	★★★★☆	★★★★★	★★★★★	★★★★☆	89%
Sub-surface dams	★★☆☆☆	★★★★☆	★★★★☆	★★★★★	★★★☆☆	★★★★★	★★★★★	80%
Spate irrigation	★★★★★	★★★★☆	★★★★★	★★★☆☆	☆☆☆☆☆	★★★★★	★★★★☆	74%
Water spreading weirs	★★★★☆	★★☆☆☆	★★★★☆	★★★☆☆	☆☆☆☆☆	★★★★★	★★★★☆	63%

Off-grid water sources	Yield	Capital costs	Capital costs / m3 of yield	Operation and maintenance	Water quality	Environmental sustainability	Reliability	
Protected spring	★★☆☆☆	★★★★★	★★★★☆	★★★★★	★★★★★	★★★★★	★★★★★	89%
Rock catchment	★★☆☆☆	★★★★★	★★★★☆	★★★★★	★★☆☆☆	★★★★★	★★★★★	80%
Open hand dug well	★☆☆☆☆	★★★★★	★★★☆☆	★★★★☆	★☆☆☆☆	★★★★☆	★★★★★	66%
Hand dug well with hand pump	★☆☆☆☆	★★★★☆	★★★☆☆	★★★☆☆	★★★★★	★★★★☆	★★★☆☆	66%
Hand augered well with pump	★★☆☆☆	★★★☆☆	★★★☆☆	★★★☆☆	★★★★★	★★★★☆	★★★☆☆	66%
Roof rainwater harvesting	★☆☆☆☆	★★★★☆	★★☆☆☆	★★★★☆	★★★☆☆	★★★★★	★★★★☆	66%
Earth dam / pan / haffir	★★★★☆	★★☆☆☆	★★★☆☆	★★☆☆☆	☆☆☆☆☆	★★★☆☆	★★★★★	54%
Boreholes with powered pump	★★★★★	★☆☆☆☆	★★☆☆☆	★☆☆☆☆	★★★★★	★★☆☆☆	★★☆☆☆	51%

Table 13: Comparison of water supply technologies (Excellent Development, 2013)

Chapter 11: In conclusion

Sand dams are a low cost, durable solution to the age old problem of water scarcity in arid and semi-arid regions. They have huge potential to kick start development whilst safeguarding precious water resources for future generations. They may be built anywhere that the 4 pre-conditions are met: a seasonal river with sufficient sandy river sediment, a suitable accessible foundation and a sufficiently impermeable riverbed. However the choice of site has a huge impact on the cost-benefits of a dam.

The ideal site is in a gorge where the river channel narrows, the riverbanks are steep and the bedrock is close to the surface on a river that experiences torrential flows and significant sediment transport. When siting, check if the sediment is sandy; the banks are stable and ideally at least a metre high and if there are scoop-holes upstream of the site. In small catchments especially where slopes and riverbanks are shallow and floods less torrential, sand dams will take longer to mature and the spillway will need to be raised in small increments. In these conditions there is a risk of siltation. If water is intended to be used for drinking, it is best that it is abstracted through an infiltration gallery buried in the sand and separate cattle watering points established below the dam.

The key to a successful design is that the spillway height is such that the dam fills with sand within 3 years, the foundation is watertight and is anchored to bedrock or impermeable clay to point 1.5 metres wider than the annual flood width and its spillways channel the flood flows in such a way that the river continues to flow on previous course. This means positioning the central spillway in the main channel with the spillway ends slightly in from the main riverbanks. The width of flood spillways corresponds to the width of the annual and lifetime (or 50 year) floods. Unless the dam is built directly onto bedrock it must have an apron (or spill platform) downstream of the dam to prevent undercutting of the foundation.

A smooth construction process relies on clarity over the ‘ownership’ and management of and access to the dam and its water that is documented in legal agreements and recognised by the local and traditional authorities. Construction should only commence once all the local materials (sand, rocks and water) are available on site and the catchment above the dam is protected. Construction should be scheduled during the dry-season at a suitable time taking account of local farming demands. Skilled artisans who are familiar with stone-masonry must be on site to supervise construction at all times. The foundation must be cleaned and well prepared in order to form a water tight seal and steel reinforcement chiselled into the bedrock. The formwork must be carefully set out to be level and to correspond with the design dimensions. The dam is filled in such a way that the dam contains as much rock as possible without the rocks touching each other or the formwork and with no planes of weakness. The ratio of sand, cement and mortar must be carefully monitored and the storage and use of cement tightly accounted for.

Once the dam is built it is plastered and then must be watered 3 times a day for the first 4 weeks to ensure it cures correctly. Once it rains it is carefully checked for cracks and leaks and to ensure the spillway accommodates the flood flow. If there are any cracks or flows under or around the dam, this must be repaired immediately. If the flood flows around the dam, the dam spillway is too small and must be extended before the next rains.

Finally, please document the experience and share details of the dam’s location, design and performance including before and after photos (see app. 6 for a template). Excellent Development will catalogue and share any examples sent to us on our website. Good luck.

Appendices

1. Technical support services from Excellent Development and ASDF
2. Sample legal agreements
   - Sand Dam Construction Agreement
   - Access agreement
   - Application form for registration of Self-Help Group / Project in Kenya
3. Variations in river and sediment characteristics with distance from the head of the valley
4. Indicators and methodologies for assessing technical feasibility
5. Flow over a broad crested weir
6. Templates for recording dam design and siting data

Appendix 1: Excellent Development and ASDF technical support

At every stage in the pilot and programme development process, Excellent and ASDF offer a range of learning resources, training and advisory services to meet your needs. Implementing organisations may choose the level of support that suits them. We work with organisations active in dryland regions. Primarily this is with organisations that aim to improve food and water security and watershed management for subsistence farmers and pastoralists. The support may be fully funded by the implementing organisation or fully funded by Excellent and ASDF or both organisations share the costs.

Our services include:

- Provision of sand dam guide and technical advice by phone and email.
- Learning Visits and staff training in Kenya.

  In country consultancy including:
- Feasibility studies, contextual analysis and pilot design.
- Technical advice on sand dam siting, design and construction.
- Programme design and capacity building
- Organisation strategy and development support.
- Joint advocacy and research

Types of organisations we support:

- Dryland development organisations.
- Organisations conserving and managing dryland game reserves.
- Organisations and contractors responsible for rural road engineering.
- Commercial farming organisations.

Programme sectors we work in:

- Drought resilient farming and agro forestry.
- Rainwater harvesting and soil and water conservation.
- Peace building and conflict management.
- Integrated water resource management and managed aquifer recharge.
- Disaster risk reduction in drylands including flood management.
- Climate change adaption and the food-water-energy nexus in drylands.

Appendix 2: Legal agreements

Appendix 2.1: Sand dam construction agreement

We, the members of ____

S.H.G. (Self-help Group) on this day _________ month ______________ year __________

agree that we are going to take part in the construction of the sand dam(s) we requested to

be supported with from NGO XXXXXX, Kenya.

We do therefore commit ourselves to the underlying conditions towards the construction of the sand dam and to enable its/their effective performance.

Terracing of the sides of the river valley where the sand dams(s) is to be constructed in advance.

Collecting sufficient stones, water, and sand towards the construction of the sand dam(s) in advance.

Availing ourselves for the unpaid labour during the actual sand dam(s) construction

Putting in place the necessary sand dam agreements from the involved land owners to allow the construction of the sand dams(s) and to allow accessibility for the use of water from the sand dam(s)

Applying and receiving the sand dam registration with relevant authorities (e.g. Ministry of Water).

Sand dam(s) GPS location ____

Sand dam design reference number ____

Village ________________ Sub-location _________________ Location _____________

Division ______________________ District _______________________________________

Signed by:

COMMUNITY REPRESENTATIVES:	IN PRESENCE OF:
CHAIRMAN	
______________________________	______________________________
ID # ___________________________	ID # ___________________________
SECRETARY	
______________________________	______________________________
ID#____________________________	ID # ___________________________
TREASURER	
______________________________	______________________________
ID#____________________________	ID # ___________________________

NGO XXXXXXX KENYA REPRESENTATIVES:

1.) ____________________________ 2.) ____________________________

Note: Attach dam design and a copy of members' names, ID Numbers, and signatures.

Appendix 2.2: Access agreement

Republic of Kenya: Agreement for passage of sand dam, wings and terraces

This agreement is made: __________ day ________________ month ________ year

Between: Name: ID NO. P.O. Box

1. ______________________________ _________________________ ________________________________
2. ______________________________ _________________________ ________________________________
3. ______________________________ _________________________ ________________________________
4. ______________________________ _________________________ ________________________________

In the aforesaid Republic (herein after referred to as the **"PROPRIETORS"** which expression shall where the context so admits include their heirs, personal representatives and assigns) of the one part ____________________________ S.H.G. represented by its chairman, secretary, and treasurer of Post Office Box Number ________________ in the aforesaid Republic (herein after referred to as the **"COMMUNITY REPRESENTATIVES"** which the expression shall where the context so admits include their personal representatives and successors) of the other part.

WHEREAS the proprietors are the registered and / or beneficial owner of plots situated within ___________________ Sub-location, __________________ Location, __________________ District **AND WHEREAS** the proprietor has upon request of the local community agreed to permit it (local community) through ____________________ S.H.G. to let the sand dam and / or wings and terraces pass through their respective plots to ______________________ upon terms and conditions herein after appearing.

NOW THIS AGREEMENT WITNESSETH AS FOLLOWS:

The proprietors have undertaken irrevocably to provide reasonable path of access of the sand dam and / or wings and terraces.

The proprietors have unlimited access of the passage of sand dam and / or wings provided he/she does not endanger the continuity and safety of the sand dam and / or wings and terraces.

The proprietors have undertaken irrevocably to allow reasonable access through their land to the sand dam for the purposes of reasonable water collection.

The proprietors have undertaken irrevocably to disallow access through their land to any person(s) for the purpose of sand collection.

The undersigned indemnify NGO XXXXXXXXXXXXXX Kenya from any claims or compensation for any losses and / or injury incurred as a result of providing access detailed within. **IN WITNESS WHEREOF** the parties have respectively set their hands on the agreement the day and year first herein after mentioned. Signed by the **"PROPRIETORS"**:

Name	Address	ID No.	Plot No.	Signature

IN THE PRESENCE OF:

Name: _______________ Signature: _________________ ID No. _______________________ Occupation ____________________

REGISTERED GROUP NAME: ______________________________________ REGISTRATION NUMBER: ___________________

ADDRESS OF GROUP: ____

COMMUNITY REPRESENTATIVES OF REGISTERED GROUP

Name	ID No.	Signature	Position

IN THE PRESENCE OF: Name: _____________________________ Signature: _______________________________

ID No. ______________________________________ Occupation: _______________________________

Appendix.2.3:Application form for registration of Self-Help Group / Project in Kenya

Revised 2008

Republic of Kenya

MINISTRY OF GENDER, CHILDREN AND SOCIAL DEVELOPMENT

DEPARTMENT OF GENDER & SOCIAL DEVELOPMENT

APPLICATION FORM FOR REGISTRATION OF SELF-HELP GROUP/PROJECT

DISTRICT ....

1. Name of Group/Project .... Type of Group/Project ....
   Division .... Location ....
   Sub-Location .... Postal Address ....
   Physical Address .... Date of formation ....
   Meeting Venue .... Meeting Days .... Time ....
2. Membership at the time of registration: Women .... Men .... Total.........
   Number of Persons with Disabilities: Women .... Men ...... Total ....
   Date elections were conducted ....
   Supervised by .... Title ....
3. Management committee:-
   - i) Chairperson / Chairman............. ID No. .... Tel. ....Email ....
   - ii) Secretary .... ID No. .... Tel. ....Email ....
   - iii) Treasurer .... ID No. .... Tel. ....Email ....
   - iv) Vice Chairperson .... ID No. .... Tel. ....Email ....
   - v) V/Secretary .... ID No. .... Tel. ....Email ....
   - vi) Member .... ID No. .... Tel. ....Email ....
   - vii) Member .... ID No. .... Tel. ....Email ....
4. Group/Project objectives:-
   1. ....
   2. ....
   3. ....

Revised 2008

5 (a) Current Activities:-
   1. ....
   2. ....
   3 ....
   4. ....

   (b) Future plans activities:-
   1. ....
   2. ....

   (c) Source of Assistance ....
6. How does the group/Project intend to fund its activities ....
7. Assistance received so far .... Type ....
8. Recommended and certified by:-
   - i) Chief .... Signature .... Date ....
   - ii) Relevant Ministry / Dept. ....Signature .... Date ....
   - iii) Location / Division SDA .... Signature .... Date...............
   - Official Stamp Date ....
9. Approved and registered under registration No. ....
   Name of DGSDO ....

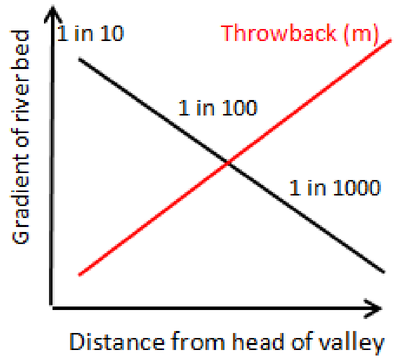
Signature and Official Stamp Date ....

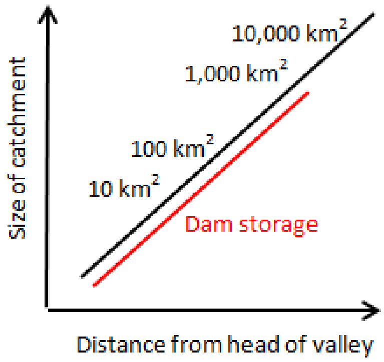
IMPORTANT

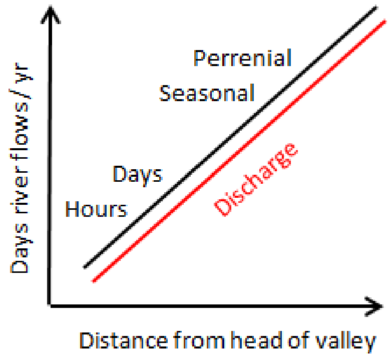
1. Minutes of the meeting seeking registration and showing elected officials must be attached to the application forms
2. List of members duly signed with ID/No. must be attached to the application forms
3. This form must be accompanied by the group BY-LAWS / RULES
4. Once registered, certificate shall be renewed annually
5. Once the group is registered it shall be required to submit quarterly report
6. Allow accessibility of records to the registering authority
7. Pay approved Registration fee

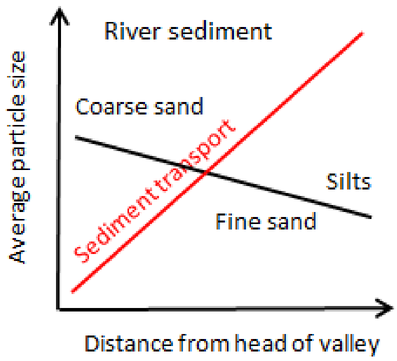
Note: Failure to adhere to the above conditions will lead to non-registration / or Deregistration.

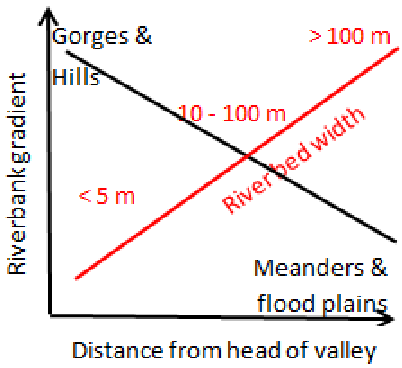
Appendix 3: River and sediment characteristics with distance from head of valley

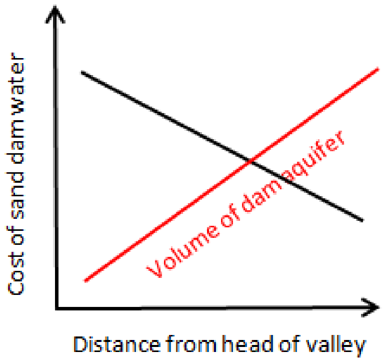


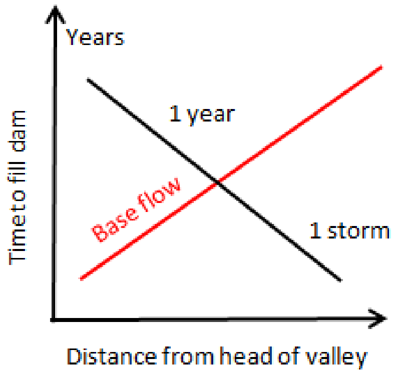


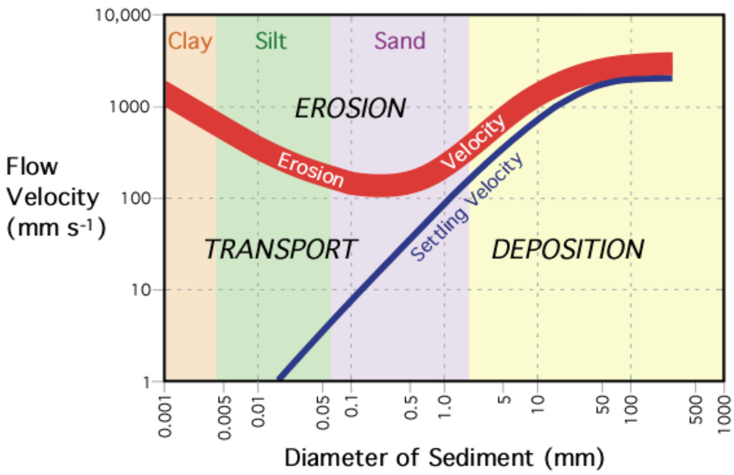


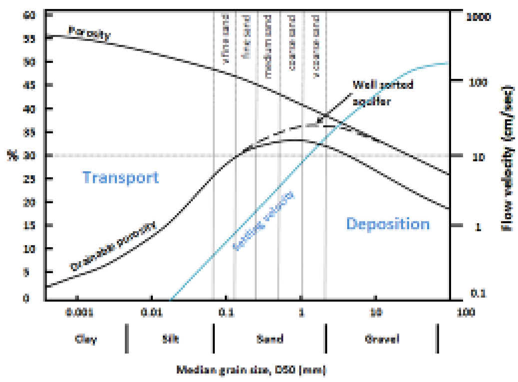












Appendix 4: Towards a simple set of indicators

TO BE COMPLETED

A major barrier to identifying areas of greatest potential and cost-effectiveness is a lack of sufficient, reliable data and indicators that are easy to collect and compare. For example, it is not feasible to empirically measure runoff, soil erodibility and sediment transport on a large number of sites. However, there are other simple indicators that may be used to infer the rates of runoff, erosion and sediment transport. Chapter 5 and section 6.3 suggests some indicators that are used to assess local conditions and to site and design specific dams. This appendix suggests some simple indicators that may be used at a larger scale to compare different countries and geographies.

Slope

Average catchment slope: A quick way to estimate and compare catchment slopes between basins is to use Google Earth: (1) Superimpose a grid or lines of longitude and latitude over the catchment[13]; (2) Record the elevation for each of the points in a spreadsheet; (3) Use the statistical function to calculate standard deviation and (4) Divide the result by the distance between grid points to calculate the average slope. As well as average slope, **riverbed slope** and valley cross section / **riverbank slope** may be estimated using Google Earth.

Riverbank slope:

Drainage density:

Climate

Drylands are characterised by highly variable, seasonal patterns of rainfall. Rainy seasons are typically short (3-4 months) and all the annual rainfall is delivered in intense storms over short periods, followed by long periods with no rainfall (8-9 months). Droughts are frequent and irregular (Millennium Ecosystem Assessment, 2005), although more severe droughts have occurred in the last decade than previously recorded (Zhao and Running, 2010).

Number of rainfall days/year:

Average annual and monthly rainfall data is available for any location at this website: samsamwater/climate.

A measure of **rainfall seasonality** is the standard deviation of monthly rainfall / mean monthly rainfall.[14] Dryland climates tend to have highly seasonal rainfall. The greater rainfall seasonality is, the more seasonal the river flows will be and the longer and the longer the dry-season. Rain gauges are simple and cheap to manufacture and can estimate **rainfall intensity** (mm/hour) and average **number of rainy days/year** (above a minimum threshold of 2 mm/day). **Drainage density** is the ratio of total stream length to unit area (km/km^2) within a catchment. It is determined by catchment characteristics (such as slope, land management, vegetation, geology, soils and run-off) and rainfall characteristics. In simple terms, the greater the run-off and the greater the drainage density, the greater the potential for sand dams will be.

Seasonality Index (SI), derived by Walsh and Lawler (1981):

---

13 At the equator the length of 1 degree of longitude and latitude are approx equal (111 km). With increasing latitude the length of 1 degree of longitude decreases, although within the tropics, not significantly. At 30 degrees latitude, the length of 1 degree of longitude = 96 km (87% of the distance at the equator.

[14] http://www.unibas.it/desertnet/dis4me/indicator_descriptions/rainfall_seasonality.htm Desertification Indicator System for Mediterranean Europe

Sii	Precipitation regime
<0.19	Precipitation spread throughout the year
0.20-0.39	Precipitation spread throughout the year, but with a definite wetter season
0.40-0.59	Rather seasonal with a short drier season
0.60-0.79	Seasonal
0.80-0.99	Marked seasonal with a long dry-season
1.00-1.19	Most precipitation in <3 months
> 1.20	Extreme seasonality, with almost all precipitation in 1-2 months

Country	Region/ Location	GPS	GPS	Annual rainfall	Seasonality Index	# of seasons
India	Rajastan/Jodpur	26.25737	73.01025	363	1.48	1
Mozambique	Tete	-16.16888	33.59131	679	1.23	2
Somaliland	Bari	9.58278	49.25781	107	1.21	2
Namibia	Khomas	-22.72207	16.72729	315	1.18	1
Tanzania	Dodoma	-6.19145	35.75562	570	1.18	1
Mozambique	Manica	-16.73784	33.98682	833	1.13	2
Kenya	Kitui	0.21598	38.35938	825	1.11	2
Cameroon	NE/Garoua	9.301	13.39844	998	1.09	2
Kenya	Wajir	1.79422	40.08423	343	1.09	2
Kenya	Marsabit	2.34318	37.98584	743	1.08	1
Sudan	South Kordofan	10.18887	31.45996	718	1.08	1
Kenya	Samburu	0.75079	37.55188	1130	1.01	2
Zimbabwe	Gwanda	-20.7937	28.2959	408	1.00	1
Mexico	Oaxaca	17.08137	-96.70654	704	0.96	1
Kenya	Mtito Andei	-2.68692	38.16162	782	0.95	1
Kenya	Machakos	-1.46826	37.39258	916	0.91	2
Brazil	NE/Paraiba	-7.05357	-36.83105	500	0.82	1
Ethiopia	Borana	5.39006	38.27148	882	0.81	1
Swaziland	Manzini	-26.54587	31.5918	683	0.67	1
Uganda	Karamoja/Kotido	2.99067	34.14063	737	0.58	1
Kenya	West Pokot	1.36592	35.2832	1098	0.49	1
UK	London	51.48371	0	652	0.13	0

Figure 28: Seasonality Index for locations with potential for sand dams (except London)

Hydrology and channel morphology

Comparative mapping of river **sediment depth, porosity and grain size** in relation to catchment size give an indication of flood discharge and velocity. Finer sediments indicate lower flood flow velocities. Vegetation growing in the main channel indicates low sediment transport and velocities. Torrential flows will cut a relatively deep, narrow and straight channel. Conversely less torrential flood flows will cut a wide channel, with finer sediment and lower riverbanks that will tend to meander more. Hence a relatively high hydraulic radius (or channel width to depth ratio) and high river sinuosity (a measure of the extent a river meanders) are indicators of low sediment transport and velocities. In these conditions, dam siltation is more of a risk.

As sand dams are built, the depth, width and duration of flows over the dam may be measured using either a piezometer or simple observation of high water marks to produce flood and annual hydrographs and the time required for the dam to fill with sediment and the slope and extent of the sand aquifer created by the dam may used to calculate sediment transport rates.

There is an argument for placing a pipe through the dam at a level 50 cm below the level of the central spillway in order to intentionally lower the water level in the dam aquifer and reduce the risk of contamination due to an open water surface. Measuring the rate of flow through an open pipe over time will give a measure of dam yield and transmissivity of the dam sediment.

Bank width/bank depth ratio:

Median grain size with stream length:

Catchment size:

Stream length:

Stream order:

Stream sinuosity:

Discharge:

Discharge / catchment size or stream length:

Further research: The authors are keen to collaborate with other organisations working in dryland areas to develop, test and map these indicators further and to use them to develop a classification of seasonal rivers that may be used to assess the potential of seasonal rivers for water harvesting.

Appendix 5: Flow over a broad crested weir

TO BE COMPLETED

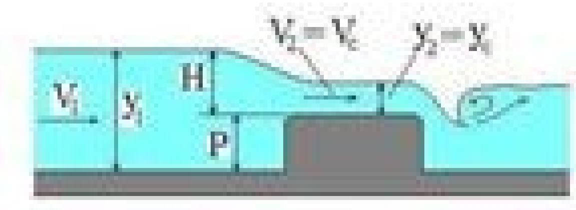
Excel Spreadsheets for Broad Crested Weir Flow Rate Calculations

Written by: Harlan Bengtson • edited by: Lamar Stonecypher • updated: 11/6/2010

Broad crested weir flow rate calculations may be made with the Excel spreadsheets that may be downloaded from this article. The open channel flow rate can be found using a broad crested weir equation for critical flow over the weir, along with the minimum weir height needed for critical flow.

Broad Crested Weir Background

A broad crested weir, as shown in the picture at the left, is typically a flat topped obstruction used to measure open channel flow rate. The Excel spreadsheets that may be downloaded from a link later in this article can be used for broad crested weir flow rate calculations. The spreadsheets can also calculate the minimum height needed for a broad crested weir in order to ensure critical flow over the weir crest. Additional background and example calculations are available in the article, "Open Channel Flow Measurement 3: the Broad Crested Weir."



Broad Crested Weir

Equations for Broad Crested Weir Flow Rate Calculations

The equation for calculating broad crested weir flow rate is quite straight forward: $Q = 1.6\ L\ H^{3/2}$, where Q is the flow rate in cfs, L is the length of the weir in ft, and H is the head over the weir (as shown in the diagram at the right) in ft. This simple equation comes with a caveat however. There must be critical flow over the weir crest in order for this equation to be used.

The four following equations, based on fundamental open channel flow principles, can be used to calculate the minimum weir height, P (see the diagram), needed to ensure critical flow over the weir crest. The four equations are:

- $y_1 + V_1^2/2g = y_2 + P + V_2^2/2g$, an expression of the energy equation, using variables shown in the diagram. P, y_1, and y_2 are in ft, V_1 and V_2 are in ft/s, g = 32.17 ft/sec^2.
- $V_1 = Q/y_1B$, from the definition of average velocity in an open channel, assuming that the channel is approximately rectangular in cross-section. B is the width of the channel, typically equal to the weir length, L.
- $V_c = Q/y_cB$ - This is the same as the previous equation, but for the flow over the weir crest.
- $y_c = [Q^2/gB^2]^{1/3}$, based on the fact that the specific energy is a minimum for critical flow conditions.

The Broad Crested Weir Article mentioned above gives more detail on these equations and an example calculation of P for specified values of Q, y_1, and B.

- **Excel Spreadsheets for Broad Crested Weir Flow Rate Calculations**

The image at the left shows an Excel spreadsheet that can be used to calculate the minimum broad crested weir height needed for critical flow, with specified channel width, B, maximum anticipated flow rate, Q_{max}, and approach depth of flow, y_1. The Excel formulas will also calculate the open channel flow rate for a specified head over the weir, H, assuming that critical flow takes place over the weir.

The Excel spreadsheet shown and the equation given are for U.S. units. The four equations given for calculating P remain the same for S.I. units, with flow rate in m^3/s, velocities in m/s, depths and widths in m, and g = 9.81 m/s^2. The equation for flow rate becomes: $Q = 0.886\ L\ H^{3/2}$, with Q in m^3/s, and L and H in m. The spreadsheet shown is available in either U.S. or S.I. units through the following links.

Click here to download this Excel spreadsheet in S.I. units.

- **References**

References for Further Information:

1. U.S. Dept. of the Interior, Bureau of Reclamation, *Water Measurement Manual*, 2001 revised, 1997 third edition.

2. Munson, B. R., Young, D. F., & Okiishi, T. H., Fundamentals of Fluid Mechanics, 4th Ed., New York: John Wiley and Sons, Inc, 2002.

3. Chanson, Hubert, *Hydraulics of Open Channel Flow: An Introduction - Basic principles, Sediment Motion, Hydraulic Modeling, Design of Hydraulic Structures,* Second Edition, New York, Elsevier, 2004.

Excel Spreadsheets for Open Channel Flow Measurement Calculations

These contain Excel spreadsheets that can be downloaded for open channel flow measurement devices, such as V-notch weirs and rectangular weirs. The Excel spreadsheets can be used as a weir flow calculated in each case.

1. Calculations for Rectangular Weir Flow Equations
2. Open Channel Flow over V-Notch Weir Calculations

3. Calculations for Parshall Flume Equations

4. Excel Spreadsheets for Broad Crested Weir Flow Rate Calculations

- See more at: http://www.brighthubengineering.com/hydraulics-civil-engineering/94528-excel-spreadsheets-for-broad-crested-weir-flow-rate-calculations/#imgn_2

Appendix 6: Templates for recording dam design and siting data

Community Group		
Sub-district, District and County		
GPS: Longitude (DD.DDDD) Latitude (DD.DDDD)		
Date built: (YYYY/MM/DD)		
Measuring flow and flood heights (in metres)		
Width of the current riverbed		
Approx. average depth of bedrock from the current riverbed		
Approx. height of mean flow above the current riverbed		
Height of the top of river banks above the riverbed		
Width of the river channel (top of river bank to river bank)		
Height of annual flood above the current riverbed		
Width of annual flood		
Height of lifetime flood above the current riverbed		
Width of lifetime flood		
Measuring the dam dimensions		
Description	Reference number in Figure 7	(m)
Height of central spillway above the current riverbed	2	
Height of central spillway above bedrock	1+2	
Width of central spillway	3	
Height of the first step	6	
Length of the left hand side step of central spillway (if applicable)		
Length of the right hand side step of central spillway (if applicable)		
Height of the second step of central spillway (if applicable)		
Length of the flood spillway on the left hand side	7	
Length of the flood spillway on the right hand side	8	
Height of the first flood spillway step	9	
Length of the second step of the flood spillway on the left hand side (if applicable)	10	
Length of the second step of the flood spillway on the right hand side (if applicable)	11	
Height of second step of the flood spillway (if applicable)	12	
Length of final wing on the left hand side	13	
Length of final wing on the right hand side	14	
Width of apron		
Length of apron from base of dam		

Table 14: Dam design form