Sand Dams:
A Practical & Technical Manual.


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Written by

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Dedication

This manual is dedicated to the memory of Joshua Silu Mukusya (1949-2011), a visionary and one of the original pioneers and 'early adopters' of sand dams. Joshua's knowledge and experience of sand dams was unrivalled. For over 30 years, he worked tirelessly to help hundreds of communities to work themselves out of poverty, firstly as the Founder of the Utooni Development Project in 1978, and then with a variety of international NGOs. Whilst he was undoubtedly a champion of sand dams in his tribal region of Ukambani, his work didn't stop there. His mission was to help his community to address their biggest priorities of water, food and incomes, mostly to pay school fees. This led him to champion many different farming approaches such as terracing, farm demonstration plots, tree planting, community seed banks, vegetable growing to name but 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 manual is based on the knowledge and experience of both Joshua and his son Andrew Musila Silu who along with the author have walked hundreds of kilometres up and down seasonal riverbeds in the search of solutions to support communities in the world's driest places. Without their generous and patient sharing of knowledge with the author since 1985, this manual would not have been possible.

Joshua Silu Mukusya

About the author

Simon Maddrell is the Founder of Excellent Development and was Executive Director between 2002-16. He was also Chair of the NGO Excellent Development Kenya (now Utooni Development Organisation) between 2002-9. Simon built his first sand dams in 1985 with Joshua Mukusya, leading an expedition of young volunteers from the UK. Since then he has enabled almost 1,000 dams to be built, being directly involved in over 500 of them. In addition, Simon has directly supported the transfer of sand dam technology to six different countries and contexts.

Simon has a BA Hons. in Peace Studies, majoring in Development, Radical & Environmental Economics as well as a dissertation study of the Utooni Development Project, 1989. Simon also has 10 years of experience in the corporate sector plus 8 years as a business consultant.

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The author would like to thank David Jordan and Charlie Taylor of Excellent for their proof-reading and editing suggestions; and, Texas Maragh for her *pro bono* work turning the author's hand-drawn illustrations into professional standard graphics.

Excellent Development is very grateful to the JJ Charitable Trust and the Margaret Hayman Trust for their financial support to produce this manual.

THE JJ CHARITABLE TRUST

Excellent Development & Africa Sand Dam Foundation

Excellent Development [www.excellent.org.uk] is a charity registered in England and Wales, working as an international development NGO and was founded in 2002. Since its inception, Excellent has enabled the construction of over 900 dams and helped almost 1 million people gain improved access to clean water.

The Africa Sand Dam Foundation (ASDF) [www.asdfafrica.org] is a registered Kenyan NGO founded in 2010. By March 2017 they have supported 92 communities to build 285 sand dams and 91 rainwater harvesting school tanks.

Excellent Development and ASDF have a strategic partnership based on shared values and philosophy to support the scaling up of sand dam technology worldwide. Together they are committed to community-led sustainable development and the global promotion of sand dam technology in drylands. It is their shared vision that millions of people living in drylands will transform their own lives with sand dams.

Disclaimer

This manual reflects the author's best effort to interpret a complex body of research and experience, and to translate this into a practical and technical manual. It illustrates the approach to and techniques that can be used in establishing the feasibility, siting, design and construction of sand dams. It is not intended to, and should not, be relied upon in the construction of any project, for which specialist advice on the feasibility, siting, design and construction should be obtained. Consequently, to the extent permissible by law, both Simon Maddrell, Cregneish Ltd and Excellent Development Ltd. shall not be liable for any losses or damages, howsoever caused, arising from, or in connection with, the use of information set out in this manual - whether arising in contract, tort (including negligence) or restitution, or for breach of statutory duty or misrepresentation, or otherwise.

Table of Contents

Chapter 1: Introduction

Sand Dams* are a fantastic water resource solution in drylands. However, they are not appropriate everywhere. This manual describes the process of establishing the feasibility of sand dams on a regional basis whilst also detailing other solutions suitable for seasonal rivers. The manual covers the processes and practices for specific siting, designing, building and maintenance of sand dams. It is aimed at NGO and government technical and programme management staff working in drylands who are interested in understanding more and/or implementing sand dam technology.

***Note:** Also known as Sand Storage Dams, Sub-surface Dams, Groundwater Dams, Check Dams, Aquifer Recharge Dams; technically speaking *broad-crested, contracted rectangular weir, gravity dams*.

The manual draws upon the knowledge of Excellent Development, ASDF and their partners in building over 1,000 sand dams and experience gained in Kenya, Zimbabwe, Mozambique, Swaziland, Uganda, Sudan and Rajasthan, India.

Successfully building sand dams is not an easy task, but it is based on a small number of very simple principles and rules. Consequently, you do not need to be a qualified engineer to site, design and build a robust, effective sand dam. Technically speaking, sand dams are [rectangular weir] overflow gravity dams, constructed with steel reinforced rubble stone masonry. Experience has shown us that the building and design do not necessarily follow all the rules laid out in many technical and engineering manuals. The manual attempts to balance the need for technical explanations with simple principles and practical rules and processes. What is critical to understand for designing sand dams is that it is an art as well as a science and that understanding how seasonal rivers flow is the only way to design a successful dam. This depends on local knowledge and experience as sand dams can't just be designed in offices by experts, nor by pure calculation.

Guide to the formatting of text:

- **Golden Rules & Pre-Requisites are highlighted in orange/brown.**
- **Rules to follow and important things "to do" are highlighted in green text.**
- **Risks, dangers and key "do nots" are highlighted in red.**
- **'Exceptions to the Rules' are explained in purple.**

The key to success, and challenge, lies in community engagement as this is critical to correct design and sustainability. Experience tells us that the success requires engagement with a formal civil society group who own the sand dam and their involvement with end-users to place them at the heart of the decision-making processes. How this works may vary but success relies on local knowledge and the correct application and/or adaptation of sand dam technology.

Chapter 2 introduces **sand dams, their history and their benefits and impacts** in relation to the SDGs.

Chapter 3 provides guidance on regional technical **feasibility of sand dams** and the importance of sediment profiles.

Chapter 4 describes a structured approach to introducing **sand dam technology transfer** into a new region.

Chapter 5 is a guide to **community engagement** to assess the current water access, availability and quality from different technologies and establishing the community needs and priorities with key stakeholder groups.

Chapter 6 is a step-by-step guide to the **pre-design activities** including specific siting of sand dams and abstraction options.

Chapter 7 details a structured approach to **designing sand dams** in different environments.

Chapter 8 offers guidance on **procurement** of materials and other vital pre-construction activities like **legal agreements**.

Chapter 9 is a step-by-step guide to the principles and practices for the **construction** of sand dams

Chapter 10 describes how to **manage, maintain and repair** sand dams.

Chapter 11 describes and compares **alternative water technologies** used in rural drylands

Appendices contain useful forms and checklists supporting the process of siting, design and construction of sand dams.

Notes to the New Manual:

Whilst this manual retains a similar structure, there are fundamental changes throughout this manual to the previously published guide by Excellent Development (Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013). The most substantive corrections, changes, additions and simplifications are as follows:

Chapter 2: What are Sand Dams? Complete rewrite including additional section on storage capacity, abstractable capacity and yield.

Chapter 3: Feasibility of Sand Dams: New sections on regional technical feasibility and socio-economic prioritisation using Swaziland as an example. More detail on the importance of river sediment profiles and the types of water storage sand dams can provide depending on differing hydrological conditions.

Chapter 4: Technology Transfer: Chapter completely revised to explain the importance of a structured approach to technology transfer and building technical competence.

Chapter 5: Community Engagement: Completely new dedicated chapter highlighting the importance of community engagement to assess the current water access, quality & availability and establishing the community needs & priorities with key stakeholder groups.

Chapter 6: Sand Dams: Pre-Design Activities: Chapter expanded to cover all critical pre-design activities that need to take place alongside the community: **Siting sand dams** and the importance of establishing **abstraction method** options prior to design.

Chapter 7: Designing Sand Dams: This chapter has been significantly changed and simplified, including more on the science behind sand dams.

Chapter 8: Pre-Construction Activities: This chapter has been substantially rewritten to include activities required in different contexts, especially regarding legal agreements and authorisations. More detailed Bill of Materials (BOMs) and specifications are included and more up to date costings for dams.

Chapter 9: Construction: This chapter has been completely rewritten and simplified with many new drawings explaining the construction principles, processes, risks and key rules.

Chapter 11: Alternative Water Technologies in Drylands: This chapter has been substantially restructured and simplified into **seasonal river solutions** and **other RWH solutions** with many additional new references and RWH knowledge-bases to refer to.

Appendices: Enhanced provision of legal agreements, registration and authorisation forms.

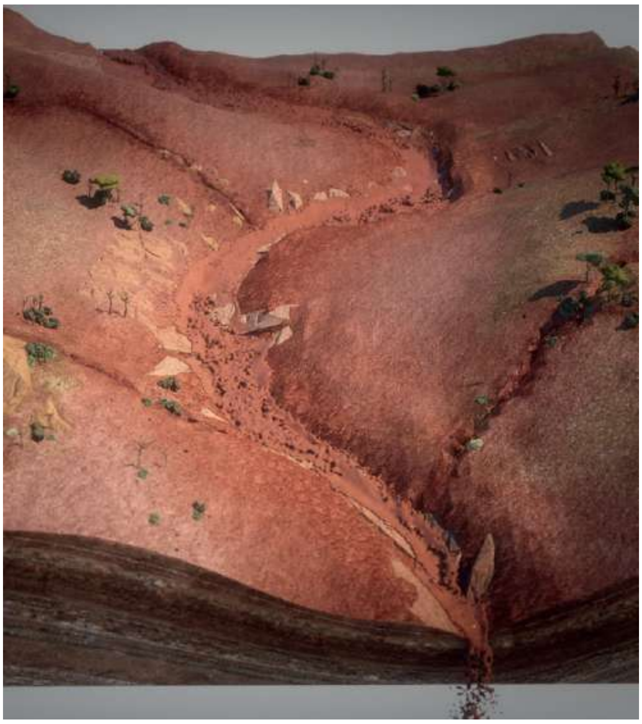
Chapter 2: What are Sand Dams?

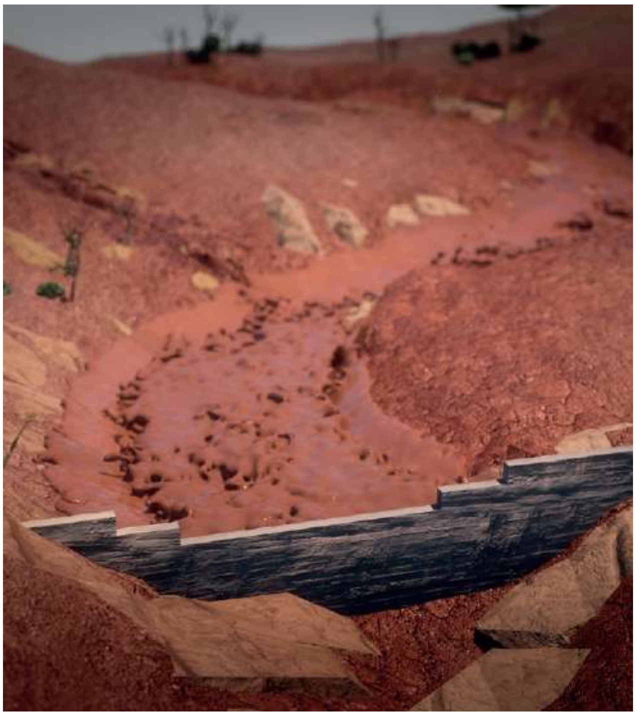
2.1 What are sand dams?

Technically speaking, sand dams (sand-storage dams) are [broad-crested contracted rectangular weir] overflow gravity dams, constructed with steel reinforced rubble stone masonry built across a seasonal, sandy riverbed and are the world's lowest-cost rainwater harvesting solution in drylands. The advantage of a gravity dam is that its structure is very durable and solid, requiring very low maintenance.

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 tree nurseries and fruit orchards. They recharge the aquifer and rejuvenate the riverine ecology enabling fodder crops to be grown along the banks. An animation explaining sand dams can be found here: https://youtu.be/SUNpjlNq2o0

2.2 An explanation of sand dams and how they work





In one or two short seasons a year, heavy rainfalls wash away vital top soil.

Most of the water ends up in the ocean, while that remaining quickly dries up.

Sand dams are reinforced concrete walls built across a seasonal riverbed. The cheapest form of rainwater harvesting in drylands.

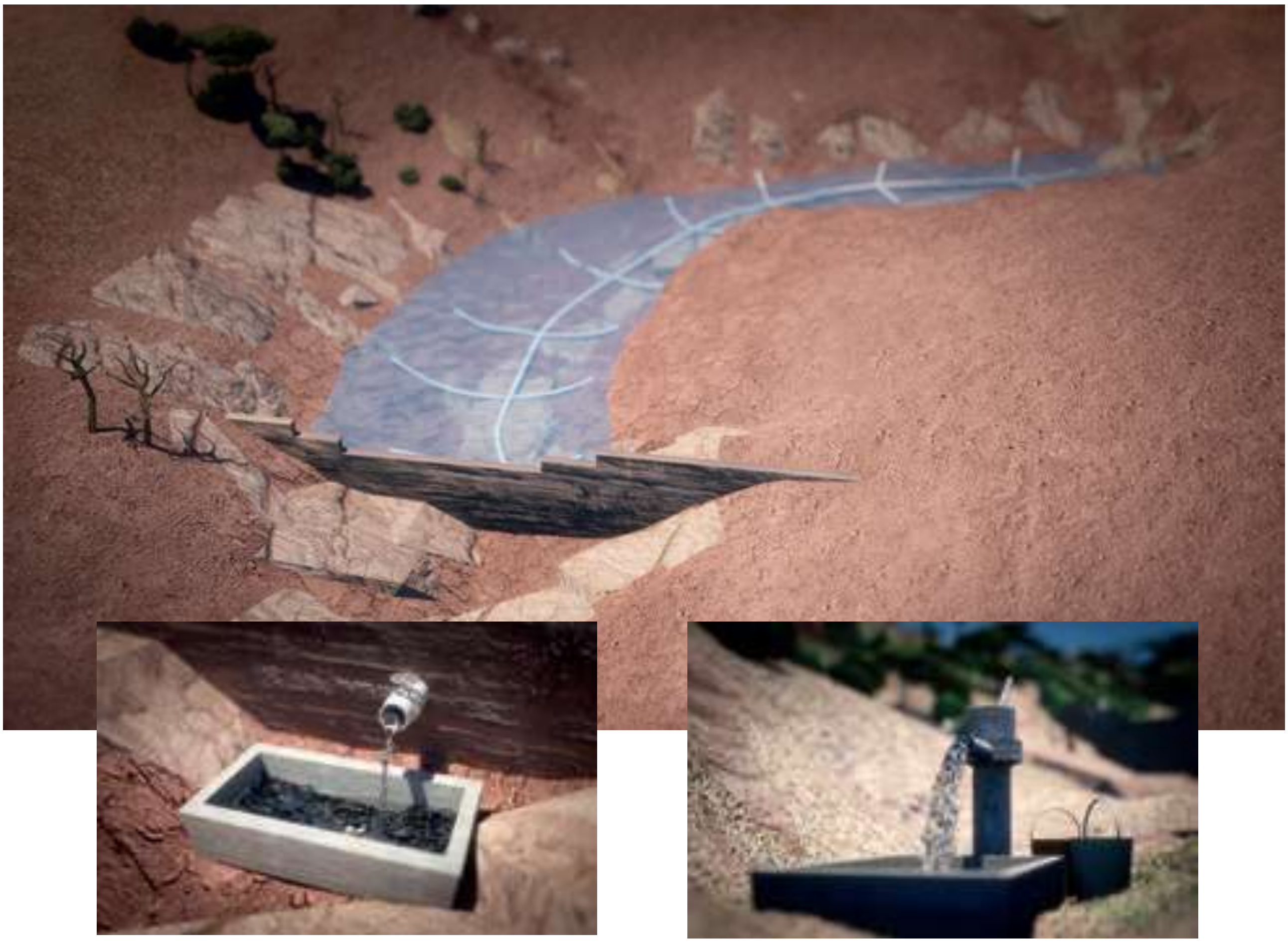
Seasonal rainstorms surge down the valley carrying water and soil. The sand in the water sinks, with most of the water and silt flowing over the top of the dam.

Within a day, or maybe two or three seasons, the dam fills with sand.

The volume of sand behind the dam holds up to 25 to 40% water - up to 40 million litres.

This protects the water from evaporation and filters it clean.

Pipework built into the dam provides easy access from a **tap or animal trough** (below left), and **shallow wells** (below right) pump water from the recharged aquifer.



2.3 The History of Sand Dams

Water retaining structures intercept or obstruct the natural flow of water in wet seasons and store water for drier periods. Water harvesting technologies, which concentrate precipitation through runoff and storage for beneficial use, have probably been in use since 9000 BC (Oweis et al., 2001). Retaining groundwater is not a new concept either. Groundwater dams were constructed on the island of Sardinia in Roman times and by ancient civilizations in North Africa (Nilsson, 1988). A specific type of groundwater dam, sand storage dams are well known in the Middle East. Such dams have also been used for water supply in the southwestern United States and northern Mexico since the mid 1800s (Van Haveren, 2004). Other examples come from Namibia (Stengel, 1968). More recent efforts include small-scale projects in many parts of the world, notably India, Africa and Brazil (Barrow, 1999). Such dams store sufficient quantities of water for livestock, minor irrigation and domestic use. The technology might be considered 'simple' but 'effective', the reason why many Non-Governmental Organizations (NGO) consider it an interesting instrument to provide drinking water to poor, rural communities (Nilsson, 1988; Van Haveren, 2004)[1].

Examples have been seen by, or reported to, the author in at least twenty dryland countries including Angola, Namibia, Zimbabwe, Swaziland & Mozambique; Mali, Tanzania, Uganda, Ethiopia, Sudan, Somalia & Somaliland; Ghana, Burkina Faso, Cameroon & Chad; Yemen & Jordan; India & Brazil. However, the highest number of sand dams over a significant period is in SE, NW & NE Kenya. According to Nissen-Petersen, E. 2006[2] the first Kenyan sand dams were built by a Eng. Classen, a District Agricultural Officer as part of the African Land Development Board (ALDEV) project in Kenya, 1954-63. However, the author has seen several sand dams in Kenya dated between 1900 and 1945. The author estimates there are currently in the region of 2,000-2,500 sand dams in Kenya. Only in the last 15 years have sand dams been the subject of significant wider adoption and research.

Most these have been built over the past 25 years by community groups supported by the CBO Utooni Development Project (since 1980) and three Kenyan NGOs: Utooni Development Organisation[3] (formerly Excellent Development Kenya) based in Machakos County (500-plus dams since 2002); Sahelian Solutions or SASOL[4] based in Kitui County (500-plus dams since 1995) and Africa Sand Dam Foundation[5] based in Makueni County (250-plus since 2010). Each of these organisations can trace their adoption of sand dam technology back to work of Joshua Mukusya.

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[1] Hut, R., Ertsen, M. et al., 2006. Effects of sand storage dams on groundwater levels with examples from Kenya, Physics and Chemistry of the Earth 33 (2008) 56–66

[2] Nissen-Petersen, E, 2006. Water from Dryland Rivers, Danida.

[3] http://www.utoonidevelopment.org/

[4] http://www.sasolfoundation.co.ke/

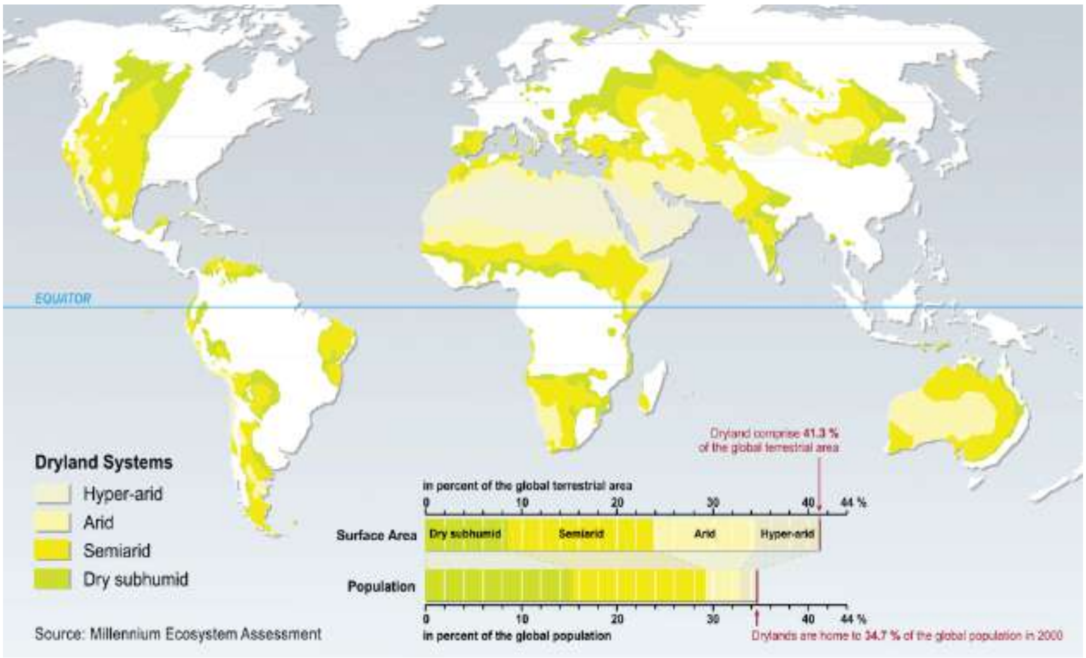
[5] http://www.asdfafrica.org/home/home

2.4 Sand Dams: A Drylands Solution

Drylands are at the frontier of some of the world's most critical human and environmental problems: water and food insecurity, climate change, desertification, conflict, displacement and loss of biodiversity[6].

Yet, they are also places of great opportunity, home to resilient and entrepreneurial people and potentially rich and fertile lands. The realisation of this potential requires significant and sustained investment in soil and water conservation, of which appropriate rainwater harvesting technologies, such as sand dams, are a fundamental element.

Drylands comprise over 40% of the world's land surface and are home to 2.3 billion people, including 74% of the world's poor. The potential for sand dams to contribute to drylands prosperity is enormous, if they can be built at sufficient scale.



Source: Millennium Ecosystem Assessment

These linkages are best explained by the United Nations Convention to Combat Desertification. UNCCD is the sole legally-binding international agreement linking environment and development to sustainable land management. The Convention addresses specifically the arid, semi-arid and dry sub-humid areas, known as the drylands, where some of the most vulnerable ecosystems and peoples can be found. The 2008-2018 UNCCD Strategy is[7]: *"to forge a global partnership to reverse and prevent desertification/land degradation and to mitigate the effects of drought in affected areas to support poverty reduction and environmental sustainability."*

According to UNCCD the issues facing Drylands consist of:

Land and Drought[8]:

"By 2025, 1.8 billion people will experience absolute water scarcity, and $^{2}/_{3}{}^{\text{rds}}$ of the world will be living under water-stressed conditions." *(UN Water 2014)*.

Land and Climate[9]:

"Restoring the soils of degraded ecosystems has the potential to store up to 3 billion tons of carbon annually".

Land and Human Security[10]:

"Some 135 million people may be displaced by 2045 as a result of desertification[11]."

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[6] http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/Global_Drylands_Full_Report.pdf
[7] http://www2.unccd.int/convention/about-convention
[8] http://www2.unccd.int/issues/land-and-drought
[9] http://www2.unccd.int/issues/land-and-climate-change
[10] http://www2.unccd.int/issues/land-and-human-security
[11] Global Humanitarian Forum (GHF). 2009. Human Impact Report – Climate Change. GHF, Geneva.

2.5 Models for building sand dams

2.5.1 Community-based approach (Community self-supply)

Excellent's approach is for the local NGO partner to engage with a civil society organisation within a community e.g. Government registered self-help groups (SHGs) or group ranches/community conservancy trusts in Kenya and, *Jal Sabahs* with JBF in Rajasthan, India. Sand dams are particularly well suited to a model where a community group builds, owns and maintains the dam because:

- Sand dams enable a significant community contribution to be provided (collection of sand, stones and water as well as unskilled construction labour) thereby enhancing (or, arguably, enabling) community ownership.
- 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.

The first step is to map the current water resources and establish the needs and priorities of end-users and to establish the community organisation's agreement that a sand dam is the most appropriate option and solution. Depending on the local implementing NGO, they may be able to offer alternatives (e.g. Excellent partners offer a variety of options including: rock catchments, rainwater harvesting (RWH) tanks, capped springs, earth dams, underground tanks, water abstraction pumps etc.). This is discussed in more detail in Chapter 5. The key to their sustainability is community ownership, community involvement in decision making and ensuring the dam appropriately meets the multiple needs of end-users. Sand dams have huge potential when incorporated in a wider development programme such as small-scale agriculture, agroforesty, climate resilience, rangeland management, watershed management.

2.5.2 Government infrastructure: rural water supply and/or rural road crossings

In Kenya, most sand dams have been built through donors funding 'community self-supply'. However, there is great scope for investment by local and national governments in water infrastructure either through paying communities to self-build or through sub-contracting. There has been a notable increase in water infrastructure investments, for example, since budgetary control devolved to County governments in Kenya since 2013. In fact, the Kitui County government in Kenya announced in August 2016 its intention to build 2,400 sand dams throughout the region.[12] Excellent Development also supported a national pilot of sand dams in 2013-2014, which is still being evaluated. This was a UNDP and the Government of the Kingdom of Swaziland programme funded by the GEF Special Climate Change Fund[13]

There are significant opportunities for sand dams in relationship to rural road crossings. The author argues that implemented worldwide, sand dam road crossings could reduce road infrastructure costs by $0.9 billion and at the same time provide a litre of water per day to 2 billion people[14]: Other materials of this subject are available in an ICE publication[15] and at Roads for Water[16] including a summary of work by the pioneer of this approach in Makueni, Kenya Eng. Benson Masila[17] and other training materials used in Kitui, Kenya[18].

80% of damage to unpaved roads is caused by water. In rural drylands, the prevailing practice is to channel rainwater through low volume culvert (vented) bridges. Yet culverts in drylands are inherently flawed, because they cannot cope with the peak floods associated with intense and highly variable seasonal rains. As a result, they are regularly damaged, causing local flooding, water logging and erosion. This results in high maintenance, repair and replacement costs for the managing authority, and diminished access to important markets and services for rural communities.

Poor rural roads infrastructure is directly linked to poverty. It isolates rural communities and increases the amount of time spent travelling for basic human essentials, such as water and fuel. This burden falls particularly heavily on women and people for whom access to water is already severely limited. 1 billion people are living in rural areas totally disconnected from basic services and markets.

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[12] http://www.the-star.co.ke/news/2016/08/13/kitui-county-to-build-2400-sand-dams-to-end-hunger_c1402580
[13] Mhalanga, N., Sand dams: a sustainable solution for water scarce regions. International Water Power & Dam Construction. April 2014.
[14] http://www.excellentdevelopment.com/site-assets/files/resources/publications/lr_roads-brochure-final.pdf
[15] http://www.icevirtuallibrary.com/doi/abs/10.1680/dare.13.00004
[16] http://roadsforwater.org
[17] http://roadsforwater.org/wp-content/uploads/2016/01/18.-Road-crossings-as-sand-dams-Kenyan-Experience.pptx
[18] http://roadsforwater.org/wp-content/uploads/2015/07/THE-IMPORTANCE-OF-SAND-DAMS-ROADS-CROSSINGSfinal-7-04-2017.pptx

Low volume culvert bridges are inherently unsuitable for dryland environments because they do not cope with the peak floods caused by variable seasonal rains.

As a result, they suffer from three common problems:

1. **They overflow and/or get blocked by debris in the river.**
2. **They cause flooding and/or wash away, reducing access for rural communities.**
3. **They widen or divert the river, causing erosion of nearby land.**

The principles of sand dam technology can be integrated with Low Volume Rural Road (LVRR) crossings for a similar initial investment to traditional culvert bridges. However, the significant reduction in continual maintenance, repair and replacement costs, as well as the groundwater recharge function, makes them a much more cost-effective long-term solution. In Makueni County, Kenya, road drifts are already being implemented [see photo below] by Eng. Benson Masila from the rural roads authority as an improvement on the ubiquitous culvert designs. Sand dam technology offers the opportunity to maximise the cost/benefit ratio of improved rural road crossings by capitalizing on their rainwater harvesting potential. By harvesting rainwater and slowing river flows, sand dam road crossings reduce the erosion associated with road flooding and provide a more robust, climate proof infrastructure. Sand dam road crossings can be built in many dryland regions, which make up 40% of the world's land surface, support 74% of the world's poor, and where the need for cost-effective and sustainable water management solutions is greatest. In drylands, most LVRR crossings cross seasonal rivers and are therefore potential sites for sand dams. Because they are specifically designed to cope with the intense and variable rainfall associated with drylands, sand dam road crossings would increase year-round accessibility to markets and services for people in rural areas. The volume of road building in drylands is enormous. Planning and designing rural road crossings with the principles of sand dam technology would enable the recharge and retention of groundwater on a major scale, creating a buffer against drought and climate variability, and providing improved access to water in water-scarce environments at no or little additional cost.

The photo below shows a sand dam road-river crossing in SE Kenya which provides a reliable, year-round water supply. The dam is 80m wide with a spillway 3m above the bedrock. The water flows through an infiltration gallery to a shallow off-take well and then pumped at the rate of 50m^3/day to 10 village water kiosks, two schools and clinic over a 9 km radius. Sand dams also create important crossings and corridors for people on foot and livestock because they raise and flatten the riverbed upstream.

A sand dam road-river crossing, Makueni, Kenya.

2.5.3 Sand dams in wildlife reserves and community conservancies

Drylands are home to many of the most important nature reserves in the world.[19] 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[20]. Additionally, data from the IUCN Red List show that, across all biomes, over 32% of species are threatened with extinction[21].

However, the wildlife in these reserves are regularly threatened by drought. Large, permanent water points such as boreholes often 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 digging into sand to drink clean water also allows access for other animals[22]. Sand dams, if built in series, avoid degradation hotspots.

Whilst there is opportunity in government controlled and privately-owned wildlife reserves, there is also vast opportunity in community conservancies. Supporting sand dams in community wildlife conservancies and wildlife reserves will reduce human-wildlife conflict, improve tourism and other livelihoods, protect endangered species and preserve biodiversity.

For example, Excellent now supports communities in the northern Counties of Laikipia, Isiolo, Samburu and Marsabit, which contains a unique network of 20 community-owned conservancies with a population of 250,000 supported by the Northern Rangelands Trust.[23] People and wildlife live side by side, but dwindling water reserves and degrading pasture is threatening people's livelihoods and the survival of vulnerable species, often forcing them into conflict over scarce water sources and pasture. Some communities have no access to safe water at all and up to 72% of the population lives below the poverty line.

Sand dam road crossing in Lekurruki Conservancy, Laikipia, Jan 2017. [Photo Credit: David R Jordan.]

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[19] 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]

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

[21] Conserving Dryland Biodiversity. http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/drylands_bk_2.pdf

[22] Eva M Ramey, Rob R Ramey, Laura M Brown, and Scott T Kelley. Desert-dwelling African elephants (Loxodonta africana) in Namibia dig wells to purify drinking water. Pachyderm No. 53 January–June 2013. http://www.the-eis.com/data/literature/Desert_dwelling%20African%20elephants_Loxodonta%20africana_%20in%20Namibia%20dig%20wells%20to%20purify%20drinking%20water.pdf

[23] http://www.nrt-kenya.org/about/

2.6 Cost of Sand Dams

The cost of a sand dam obviously varies according to size – but also depending on the country and region of location and the specific model used to implement sand dams. However, costs are broadly similar, for example in Zimbabwe and Mozambique costs are approximately 6% higher than ASDF Kenya costs; and in Rajasthan, India costs are around 2% lower[24].

Sand Dam Costs in $ (2017)	Small	Medium	Large	Extra large
(101.5 KSh:$)	**200 bag dam**	**340 bag dam**	**520 bag dam**	**850 bag dam**
Cement (43 Grade)	1,429	2,429	3,715	6,074
Steel bars, wire & nails	310	560	740	1,130
Materials transport	270	430	860	1,450
Authorisation Permits	160	160	160	160
Timber shuttering (% allocation^)	170	370	510	640
Tools (% allocation^)	100	100	120	170
Purchased Materials Totals	**2,439**	**4,049**	**6,105**	**9,624**
Value of Community Contribution#				
Sand	166	284	367	646
Rocks & Stones	253	415	565	994
Water	236	394	394	709
Community Materials Totals	**655**	**1,093**	**1,325**	**2,350**
Skilled labour	489	1,040	1,530	2,447
Community labour§	1,927	2,531	3,135	3,910
Labour Totals	**2,416**	**3,571**	**4,665**	**6,357**
Total Costs	**5,510**	**8,713**	**12,095**	**18,331**

2017 costings for ASDF sand dams, Mtito Andei, Kenya

^ For costing purposes, ASDF spread the cost of timber over 3 dams, this is likely to range between 2-4 depending on the timber quality and the care that the craftsmen and women take (see Chapter 8.3.3). Similarly, tools last for more than one dam and their costs are spread over a certain number of dams depending on the nature of the tool (see Chapter 8.3.4).

ASDF's model is for the community SHG to provide the labour to collect the sand, rocks and water required to build the sand dam, which tend to be available in the riverbed. SHGs usually put aside one or more work days per week to collect these items over a period of 1-3 months. ASDF value this contribution at the rate it would cost to source these materials from a local supplier. Sometimes, some of the materials are not available nearby and the community raises its own funds to pay for materials.

§ ASDF's model is for the community SHG to also provide the unskilled and semi-skilled labour to build the sand dam. This is valued at the local cost of employing a casual labourer.

It is vital to understand that there are unavoidable additional costs related to the implementing organisation for a sand dam to be implemented. A pilot sand dam will have very significant additional costs, including feasibility costs, whereas organisations like ASDF who build over 50 dams per year reach the critical mass required to achieve an efficient use of the various resources. These additional costs include the need to cover community engagement and training, siting and design, project management and the skilled labour for construction as well as a contribution to the management, transport, administration, governance and finance core costs. If implementing through an international NGO, then of course there are more similar costs to be covered to manage and report on the project when total costs could range from $10-40,000.

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[24] Based on Excellent Development data 2016/17 compared to ASDF average costs. Dabane Trust in Zimbabwe 550 bag dam cost $13,581; CCM Mozambique 600 bag dam costs $14,778 and a JBF, Rajasthan, India dam costs $20,164.

ASDF photographs of different sand dam sizes:

200 cement bag sand dam:

340 cement bag sand dam:

520 cement bag sand dam:

850 cement bag sand dam:

Additionally, most sand dams have some form of abstraction technology (see Chapter 6.3), especially as it is proven that, in general, utilising scoop holes usually causes contamination of the otherwise clean water (see Chapter 2.7.3). The costs for implementing abstraction technologies obviously vary but an indication of the average additional labour and material costs are as follows:

Water Abstraction Technology Costs[25] (see Chapter 6.3):

Tap with pipe & infiltration gallery	$ 350
Tank with pipe & infiltration gallery	$ 650
Animal trough with infiltration gallery & pipework	$ 1,100
Shallow well & hand-pump	$ 1,500
Shallow well & hand-pump with infiltration gallery	$ 1,800
Rowa hand pump & animal trough	$ 1,600

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[25] Excellent Development 2017 budget data.

2.7 Impacts of sand dams

This section will explain the linkages between the impacts of sand dams and the Sustainable Development Goals (SDGs); explain in more detail the specific contributions to the SDGs including case study and research evidence from sand dam building organisations. UNCCD describe a strong linkage between the challenges of drylands and the SDGs[26]. The author has mapped out below the impacts that sand dams (as a water and environmental intervention in drylands) can support the SDGs:

Impact of Sand Dams:
Contribution to the
Sustainable Development Goals

Increased Wealth
Increased Incomes
Reduced Costs
Increased Value of Assets

Increased Food Production
Crop Diversity & Productivity
Fruit & Vegetable Production
Livestock Productivity

Sustainable Land Management
Soil & Water Conservation
Agroforestry & Horticulture
Livestock & Wildlife Grazing

Climate Change Adaptation & Mitigation
Climate Resilience
Ground Water Recharge
Increased Vegetation Biomass

Sand Dams Built in Partnership
International Governments & Institutions
Dryland National & Regional Governments
International Donors & NGOs
Dryland CBOs & NGOs

Improved Peace & Justice
- Reduced Water Conflict
- Reduced Pasture & Wildlife Conflict
- Fairer Access to Resources

Improved Quality of Life
- Improved Health
- Improved Nutrition & Diets
- Reduced Waterborne Diseases

More Time & Energy
- Women
- Young Women & Girls
- Girls & Boys at School

Clean Drinking Water
- Improved Availability
- Improved Accessibility
- Multi-Use Water Supply

Sand Dam Road Crossings
Reduced Costs
Improved Access
Disaster Risk Resilience

The linkages between the impacts of sand dams (whether built as road crossings or not) and the SDGs have clear logical steps:

- Sand dams have a direct impact on the provision of multi-use water and climate resilience.
- The time saved primarily benefits women and girls leading to greater access to education and reducing inequalities.
- Women farmers invest more time on their land leading to increased food production and reduced poverty.
- Improved diets and safe water improves health and overall quality of life.
- Human-human and human-wildlife conflicts are reduced due to better resource access.

Sand Dams & SDGs: Linkages & Steps

Improved Peace & Justice
- Reduced Water Conflict
- Reduced Pasture & Wildlife Conflict
- Fairer Access to Resources

Improved Quality of Life
- Improved Health
- Improved Nutrition & Diets
- Reduced Waterborne Diseases

More Time & Energy
- Women
- Young Women & Girls
- Girls & Boys at School

Clean Drinking Water
- Improved Availability
- Improved Accessibility
- Multi-Use Water Supply

Sand Dam Road Crossings
Reduced Costs
Improved Access
Disaster Risk Resilience

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[26] http://www2.unccd.int/issues/land-and-sustainable-development-goals

2.7.1 Climate Change Adaptation and Mitigation

13 CLIMATE ACTION

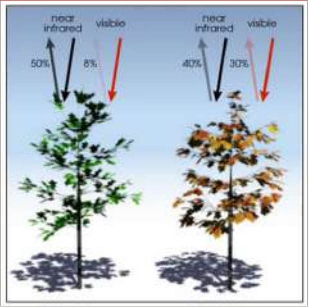
Two of the biggest strengths of sand dams are that:

- Sand dams are not just a drinking water solution – but provide water for all people's domestic needs; water for livestock and wildlife; water for vegetable gardens and tree nurseries; and, the recharging of ground water.
- Sand dams contribute towards climate change adaptation and mitigation.

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.[27] This vulnerability and unpredictability has led the Intergovernmental Panel on Climate Change (IPCC) to conclude drylands are on the frontline of climate change. IPCC's Fourth Assessment Report on Climate Change, stated that Africa is at the highest risk from climate change…. It is highly likely that in the coming years significant areas of the African drylands will see changing rainfall patterns with more frequent and more intense extreme events such as droughts and floods[28]. Another IPCC report concluded that "In the drylands of Asia a shift in dryland types is expected as a result of climate change… the least-dry land type (dry sub-humid drylands) are expected to become semi-arid, and semi-arid land is expected to become arid"[29].

Normalised Difference Vegetation Index (NDVI)

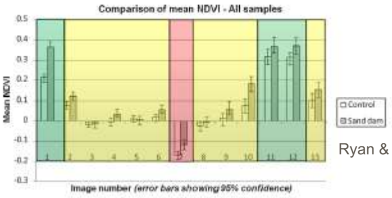
NDVI uses visible & near infrared values to establish vegetation density.



NDVI is the most commonly used index for vegetation density – measured using satellite imagery.

4 sand dam & control sites in a similar-type valley, Makueni County, Kenya during 13 drought instances 2005-2012*

Results: Mean NDVI higher over drought periods



Ryan & Elsner, 2016

NDVI at Sand Dam sites is consistently, statistically and substantially higher.

Sand Dams maintained NDVI consistently above the threshold for vegetated surfaces.
(1.22 vs 0.72 for the control)

Sand dams can contribute towards climate change resilience, adaptation and mitigation. A 2016 published study[30] utilised satellite imagery to compare changes in vegetation (measured using NDVI) between 2005 and 2012 near four sand dams compared to a nearby control valley. The study concluded that: "Sand dams are an effective approach to increase the adaptive capacity of drylands [to climate change] by increasing the resilience of vegetation through times of water scarcity."

Mean NDVI in 'Drought' & 'Extreme Drought' Conditions

Condition	Sand Dam	Control
Drought	**0.067**	**0.029**
Extreme Drought	**(0.018)**	**(0.166)**

(Ryan & Elsner, 2016)

Sand Dam Impacts:

Drought Conditions:
NDVI was 2.5 times greater

Extreme Drought Conditions:
NDVI was 1.4 times greater

Mean NDVI Results: 'Light rains' conditions

'Relative greening' effect after light rains (recovery after rains) was *much greater* at sand dam sites

Relative Greening	NDVI
Sand Dams	**0.37**
Controls	**0.283**
Kenya Arid Lands Region Ave.*	**0.32**

* Drought & non-drought periods 2004-9 (Ryan & Elsner, 2016)

Sand Dam Site NDVI typically represented *healthy savannah or woodland vegetation.*

Control Site NDVI typically represented *grass and shrubland vegetation.*

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

[28] Climate Change in African Drylands. UNDP, UNCCD and UNEP, 2009. http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/Climate%20Change%20Adaptation%20and%20Mitigation%20final.pdf

[29] IPCC, Working Group II: Impacts, Adaptation and Vulnerability http://www.ipcc.ch/ipccreports/tar/wg2/index.php?idp=430

[30] Ryan, C. & Elsner, P., "The potential of sand dams to increase the adaptive capacity of East African drylands to climate change" Regional Environmental Change, March 2016. https://link.springer.com/article/10.1007/s10113-016-0938-y

2.7.2 Clean Water: Availability and Accessibility

6 CLEAN WATER AND SANITATION

Refreshingly, the metrics for SDG 6 do include Integrated Water Management and Rainwater Harvesting (RWH) which will be addressed more in the impacts discussed in Chapter 2.7.4 and 2.7.7 on SDG 15 'Life on Land'. In terms of drinking water SDG 6.1 have been set goals at three levels by the WHO/UNICEF Joint Monitoring Programme (JMP)[31]:

1) Availability [people using safe water]
2) Accessibility [available when needed in terms of time taken to collect]
3) Quality [safe levels of faecal and priority chemical contamination, e.g. E. coli, arsenic, fluoride, salinity]

Sand dams make a life-changing difference to the supply of safe water to rural communities in drylands. Even by their own admission[32] the JMP metrics do not sufficiently reflect the biggest challenges for drylands: namely changes throughout the seasons. The focus of measurement is on there being a safe water source *in existence* rather than measuring if it supplies water all year round – this is even more difficult to measure in a pastoral context, and even more so in a nomadic one. In terms of water quality, the metrics do not consider the changes in quality that occur following the heavy rains typical of drylands. Whilst NGOs building sand dams do address some of these shortfalls in their measurement of improvements in water, in the author's opinion there is still a way to go to quantifiably demonstrate the benefits of sand dams, which are very clear from thousands of examples of anecdotal evidence. This is discussed more in Chapter 2.9.3 in terms of measurement priorities.

In Machakos and Makueni Counties, the 700-plus sand dams built since 2002 by Excellent Development Kenya (now Utooni Development Organisation) and since 2010 by Africa Sand Dam Foundation (ASDF) have provided safe water to almost 1 million people and reduced the time taken to collect water to between 30-90 minutes. Previously water collection typically took 3.5 to 5.5 hours and up to twelve hours during droughts. In Lekurruki, Laikipia, sand dams have transformed safe water availability from 0% to 100%.

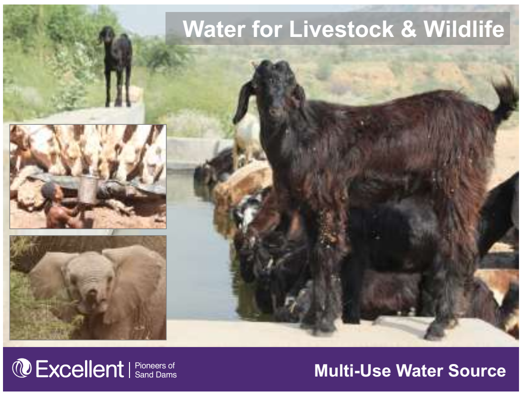
A study by ASDF of 2,533 beneficiaries[33] showed significant improvements in both the time to collect and distance from safe water:

ASDF Impact Data	Baseline	Evaluation
Distance to water <1km	35%	54%
Distance to water 3+km	35%	8%
Time fetching water <1hr	33%	75%

This is consistent with comparative results in Kitui County where local NGO, Sahelian Solutions (SASOL) have built over 500 sand dams since 1995[34].

Sand dams in Kitui, SE Kenya[35]	No Dam	With Dam
Change in primary water source availability	(6) days	+75 days
Change in distance to primary water source	+23m	(2,016) m
Relative change in water use (Base 100%)	96%	344%
Daily time saved on fetching water	(7) mins.	100 mins.

The contribution of sand dams to the supply of water for livestock and wildlife should equally not be underestimated, especially in agro-pastoral areas like Kitui.



Goats in Rajasthan; camels and elephants in Laikipia.

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[31] http://www.unwater.org/sdgs/indicators-and-monitoring/en/
[32] JMP answer to question by Simon Maddrell at RWSN conference, Cote d'Ivoire, November 2016.
[33] Africa Sand Dam Foundation impact data from 2,533 beneficiaries (805 interviewed) as of 31st March 2016
[34] http://www.sasolfoundation.co.ke/our-work/sand-dams/
[35] Summary of a range of socio-economic benefits of sand dams found by Rempel (2005), Lasage (2006) and Pauw (2008) by Aerts et al, 2008.. 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]

2.7.3 Clean Water: Quality

The SDG quality metrics cover safe levels of faecal and priority chemical contamination, e.g. E. coli, arsenic, fluoride, salinity, etc. However, the most common objective is to measure faecal coliform water quality. Sand dam water quality results for faecal coliforms are very good and represent no health risks. In fact, sand dams compare very favourably with other water sources (see table on the next page).

WHO guidelines state drinking water should have zero TTC/100ml [thermo-tolerant coliforms/100 millilitres] of faecal coliforms present, making this the bench mark for water quality. However, it is widely understood that such targets may not be attainable in many countries e.g. Uganda has set its limit to 50 TTC/100ml of drinking water[36] Having said that sand dams until recently have not been routinely tested for water quality but especially with a wider range of abstraction methods now used (Scoop holes, infiltration systems with pipes and taps, shallow wells and Rowa pumps) it has been important to understand any differences to enable community decision-making on abstraction methods. Elephants know that water from sand scoop holes is cleaner than open water[37]. Furthermore, sand dams have been perceived not to be a clean or safe water source, whilst other water sources like "boreholes and piped water, which are typically perceived as high quality and lower risk."[38] However, evidence demonstrates that faecal coliform water quality from sand dams is very good and represents no health risks.

Water quality study from ASDF sand dams (2014)[39].

From the 29 dams tested[§], 82.74% of samples had 0 TTC/100ml. Two samples tested positive for 1 TTC/100ml, a further two tested positive for 2 TTC/100ml, and one sample had 3 TTC/100ml.

Percentiles	TTC/100ml	Level of risk
83%	0	None: in conformity with WHO guidelines
17%	1-10*	Low risk (*Actual results were 1-3TTC)
0%	11-100	Intermediate risk
0%	101-1000	High risk
0%	1000	Very high risk

[§] The water quality of these dams was assessed by digging a fresh access hole and abstracting water from this area. This means that the water tested has no contamination from outside sources and is a reliable representation of the water quality of each dam.

Water quality from ASDF Shallow Wells (Cranfield University Study, 2016)[40]

A total of 36 sand dams[§] were tested all using shallow wells as an abstraction method. Out of the shallow well dams that were tested: 27 had 0 TTC, 6 were low risk, 2 had an immediate risk and 1 was high risk.

Percentiles	TTC/100ml	Level of risk
75%*	0	None: in conformity with WHO guidelines (*100% for 2012 built sand dams)
17%	1-10	Low risk
6%	11-100	Intermediate risk
3%	101-1000	High risk
0%	1000	Very high risk

[§] Note that this data was collected in June/July 2016 with sand dams built between 2012 and 2014.
100% of the sand dams built in 2012 had 0 TTC per 100ml. Some sand dams can take 3-4 years to mature (i.e. are completely filled with sand) thereby filtering the water through less sand. The hypothesis, to be tested, is that mature sand dams store safe water, or more likely to do so.

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[36] https://dspace.lib.cranfield.ac.uk/bitstream/1826/8639/1/An_assessment_of_microbiological_water_quality-2010.pdf

[37] Eva M Ramey, Rob R Ramey, Laura M Brown, and Scott T Kelley. Desert-dwelling African elephants (Loxodonta africana) in Namibia dig wells to purify drinking water. Pachyderm No. 53 January–June 2013.
http://www.the-eis.com/data/literature/Desert_dwelling%20African%20elephants_Loxodonta%20africana_%20in%20Namibia%20dig%20wells%20to%20purify%20drinking%20water.pdf

[38] http://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1001644

[39] Orlando Avis, MSc Dissertation, London School Tropical Medicine and Hygiene, 2014 (unpublished)

[40] https://www.cranfield.ac.uk/research-projects/sand-dams

Water quality data collected by Dabane Trust, Zimbabwe.

A total of 37 sand dams were tested all using Rowa hand pumps as an abstraction method. Out of the 37 samples that were tested: 25 had 0 TTC, and 12 were low risk. In accordance with the previous data sets, these results testify that water from sand dams is fit for human consumption and that Rowa hand pumps are an effective abstraction technique.

Percentiles	TTC/100ml	Level of risk
68%	0	None: in conformity with WHO guidelines
32%	1-10	Low risk
0%	11-100	Intermediate risk
0%	101-1000	High risk
0%	1000	Very high risk

Comparison to other water solutions (Cranfield University, NE Uganda Study, 2010)[41]

A significant opportunity is to have sand dams declared as a JMP defined 'improved water source'[42] by WHO/UNICEF, which would help significantly with institutional funding and that related to the SDGs. This is particularly true when "whilst this study does suggest that 'improved' water sources are 'safer' than unimproved sources, not all 'improved' sources are 'safe'." Sand dams compare very favourably with this study as two of the sand dam studies had 0% above 50 TTC/100ml and only between 3% and 9% in the Cranfield study on sand dams.

Water Source	% TTC=0	% TTC≤50	Median TTC	Sample Quantity
Sand dams§	**75%**	**98%***	**0**	(* 98%≤10TTC) **102**
Boreholes	69%	89%	0	71
Protected springs	14%	61%	18	49
Roof rainwater harvesting	33%	63%	12	49
Covered hand dug wells	17%	26%	235	70
Open hand dug wells	0%	4%	1,070	24
Open water	6%	6%	1,200	83

§ The sand dam results for Kenya have been added by the author as an amalgamation of the three sets of data shared above with 102 sand dams in the sample. 76 results had a TTC=0; 23 results 0-10TTC; and 3 had a result >10TTC. Hence 98% sand dams had ≤10TTC compared to 89% boreholes having a TTC≤50.

Incidentally, the importance of water quality has long been a hot topic and bone of contention, particularly in Uganda. Hon. Maria Mutagamba, Minister for Water and Environment, Uganda, in her opening remarks at the 6th RWSN Forum in Kampala, Uganda, November 2011[43] very forcefully urged international NGOs to focus first on providing people with water first and worrying about water quality later. She commented that she was sick of being lectured to by the West about water quality when her people were dying of thirst[44]. Uganda has set its limit to 50 TTC/100ml of drinking water[45] rather than 0 TTC/100ml set by WHO. Similarly, the author once asked a dryland farmer why they drink water from a contaminated pool and he replied, "I will die of thirst before I die of anything else. What do you want me to do?"[46].

Salinity and sand dams in Rajasthan, India

A sand dam was built in Rajasthan, India in partnership with the Jal Bhagirathi Foundation (JBF) in 2013. The sand dam has had enormous impact on reducing salinity. Having drunk the water before and after the dam was built the author can testify to the change in salinity. Due to political sensitivity around the fact that a Public Health Department (PHD) well was distributing brackish water, it is has so far proven impossible to get the previous salinity data but the PHD official at the facility verbally confirmed that the water was not saline anymore[47]. At the time of writing, there is a study underway by JBF into the water quality.

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[41] https://dspace.lib.cranfield.ac.uk/bitstream/1826/8639/1/An_assessment_of_microbiological_water_quality-2010.pdf Journal of Water and Health, 2010, Volume 8, Number 3, Pages 550–560

[42] https://www.wssinfo.org/definitions-methods/watsan-categories/

[43] https://rwsnforum.files.wordpress.com/2011/08/6-rwsn-forum-final-report-high-res.pdf

[44] Simon Maddrell anecdote from RWSN 6 in Uganda, 2011.

[45] https://dspace.lib.cranfield.ac.uk/bitstream/1826/8639/1/An_assessment_of_microbiological_water_quality-2010.pdf

[46] Simon Maddrell talking to a famer in Iviani, Makueni, Kenya in 2007.

[47] Interviews carried out on visit by Simon Maddrell to Rajasthan, December 2015.

2.7.4 Water: Integrated Water Resource Management

6 CLEAN WATER AND SANITATION

The other areas of the SDGs related to water and sand dams are Integrated Water Resource Management (IWRM); protecting and restoring [dryland] eco-systems; and, the participation of communities[48].

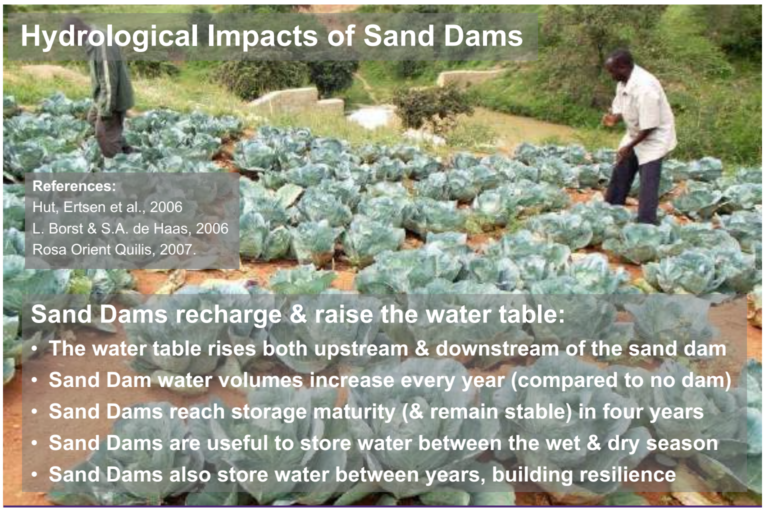
SDG Target 6.5: Implement integrated water resources management.

SDG Target 6.6: Protect and restore water-related ecosystems.

SDG Target 6.b: Support and strengthen the participation of local communities in improving water [and sanitation] management.

IWRM and eco-system restoration

While the impacts of community actions in IWRM will be discussed in Chapter 2.7.8, it is worth acknowledging the direct impacts of sand dams on groundwater, both upstream and downstream from the dam.



Hydrological Impacts of Sand Dams

References:
Hut, Ertsen et al., 2006
L. Borst & S.A. de Haas, 2006
Rosa Orient Quilis, 2007.

Sand Dams recharge & raise the water table:

- The water table rises both upstream & downstream of the sand dam
- Sand Dam water volumes increase every year (compared to no dam)
- Sand Dams reach storage maturity (& remain stable) in four years
- Sand Dams are useful to store water between the wet & dry season
- Sand Dams also store water between years, building resilience

Sand dams can transform the local ecology: The water held behind the dam spreads horizontally, recharging the aquifer upstream and downstream of the dam[49] 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.[50] This low figure is significant because it suggests no or little negative effect in terms of water supply 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 of water will be withheld in drier conditions. Throughout the year, some of the water held by a sand dam slowly 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 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%[51] and groundwater is maintained throughout dry-seasons and drought.

A sand dam was built in Rajasthan, India in partnership with the Jal Bhagirathi Foundation (JBF) in 2013. The sand dam has had enormous impact on the ground water levels and output from both private and government tube wells both in terms of volume and salinity. Output from government tube wells has increased by 50% and water availability increased from several hours to 24 hours per day. The impacts originally affected tube wells for 23 farmers but be 2015 it was discovered that 109 private tube wells in the area were positively impacted. Water levels reported by local farmers in the tube wells previously were at 75m but reduced to 60m by 2015 and 45m in 2016[52].

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[48] http://www.unwater.org/sdgs/indicators-and-monitoring/en/

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

[50] 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

[51] 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),

[52] Interviews carried out on visit by Simon Maddrell to Rajasthan, December 2016.

Community participation

The participation of local communities is integral to the sand dams that Excellent Development, UDO and ASDF have supported communities to build. This can be demonstrated from the independent external evaluation of an Excellent Development/ASDF programme in SE Kenya (2013-16)[53]:

The report noted: *"the rigorous and principled stance that ASDF takes in insisting that members take full ownership and responsibility for investing in their own development."*

"The supported SHGs have achieved much more than participating in the construction of sand dams... They have not only maximised the benefits from the improved and sustainable water supplies, but have gone on to improve agricultural production, nutrition and income within their communities."

On SHGs and sustainability: *"Through the contribution of members complete 'ownership' of the developments are assured."*

2.7.5 Gender Empowerment and Equality

In most dryland countries, women are primarily responsible for meeting the most basic livelihood needs (water, food, and fuelwood) and are more reliant than men on natural resources. Women produce 80% of the food consumed in these regions[54]. The burden on women to support families is growing as more and more people are affected by land degradation. About 1.8 billion were projected to be negatively affected by land degradation by the year 2025, but already, more than 2.9 billion people are affected[55].

Support for women must be central to the achievement of the SDGs in drylands, especially relating to land and water[56].

Reducing the time required for women and children, most often girls, 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 2-10 hours of time and energy per day. Farmers, again mainly women, are then able to invest more time in managing their land and improving their farms.

For example, ASDF's work with registered self-help groups has a prime focus on activities with the prime direct benefit to women even though their membership is more gender-balanced at 66% women members with 50% of committee members being female. The DfiD external evaluation report demonstrates the changes in terms of gender empowerment[57].

"Women, in particular, confidently and proudly claim that 'there is no men's and women's work around here'."

"What is being experienced by individual community members is an increase in the sense of being able to initiate and complete tasks and initiatives previously considered beyond them."

The report noted *"the rigorous and principled stance that ASDF takes in insisting that members take full ownership and responsibility for investing in their own development."*

"The knowledge and skills do not only remain with members but are passed on and shared with other members of the community as they work together."

These results are also echoed by a Canadian Foodgrains Bank (CFGB) gender analysis of UDO in September 2010[58].

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[53] External evaluation 'Excellent Development/ASDF DfID/UK Aid Global Poverty Action Fund (GPAF) programme 2013-16' Sept. 2016.
[54] http://www2.unccd.int/issues/land-sdgs/gender
[55] 2017, Samandari, A. Working Paper on Gender, Global Land Outlook, paper p2.
[56] http://www2.unccd.int/publications/turning-tide-gender-factor-achieving-land-degradation-neutrality [Available in English, French and Spanish].
[57] External evaluation 'Excellent Development/ASDF DfID/UK Aid Global Poverty Action Fund (GPAF) programme 2013-16' Sept. 2016.
[58] http://www.utoonidevelopment.org/our-impact/family-community/

2.7.6 Improved School Attendance

Sand dams increase school attendance since children (mainly girls) either spend less time looking for water themselves, or less time looking after their siblings whilst their mothers look for water.[59] Most schools require children to bring water to school for drinks, lunches and washing. Sand dams mean that children can efficiently collect water on the way to school (and complete their daily chores of water collection on the way home). Often school time is interrupted by teachers having to take children on a two-hour excursion solely with the purpose of collecting water. Sufficient water also enables children to be more engaged.

4 QUALITY EDUCATION

2.7.7 Sustainable Land Management

Arguably as important as the provision of safe water, sand dams save farmers hours of time, which can be invested in sustainable land management activities. In drylands soil and water conservation is the biggest challenge facing farmers – mitigated by terracing land and planting trees, which create a virtuous cycle of conservation. Kenyan NGOs UDO and ASDF have been supporting these practices since 2002 and 2010 respectively. A recent external evaluation of ASDF's work highlighted two points:

15 LIFE ON LAND

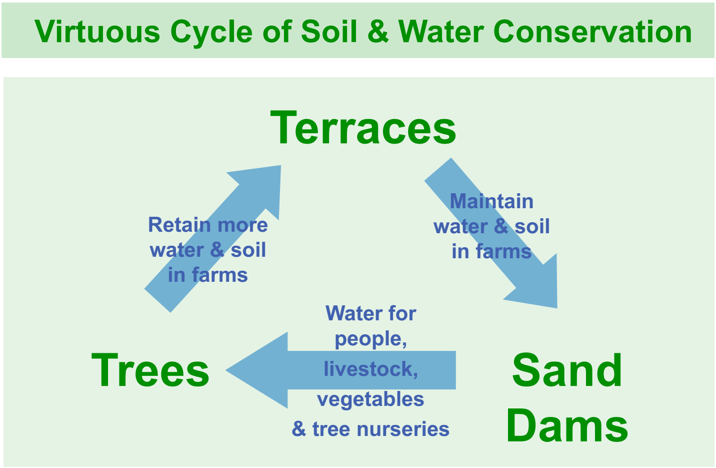
"A major contribution to environmental sustainability is achieved through soil conservation practices."

In addition to the activities of the self-help group members themselves, these practices proliferate through word of mouth and copying of effective practices in the wider community. The comparative success of this is demonstrated by the research below:

Adoption of Sustainable Land Management Techniques	East Africa (EA) regional averages§	Farmers supported by ASDF
Agroforestry	50%	89%
Terracing land	16%	95%

§ East Africa adoption rates sourced from a CGIAR study[60]

Sand dams and the associated sustainable land management activities are a key tool in addressing SDG 15.3 on Land Degradation Neutrality (LDN)[61] promoted by UNCCD in in collaboration with a dozen bilateral and multilateral partners[62].


Virtuous Cycle of Soil & Water Conservation

Terraces

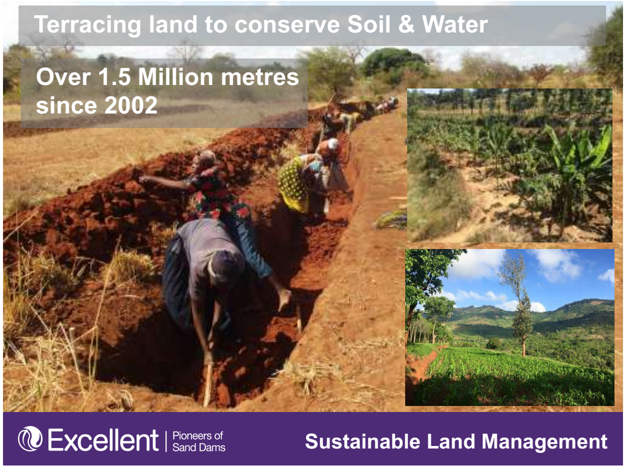
Retain more water & soil in farms

Maintain water & soil in farms

Trees

Water for people, livestock, vegetables & tree nurseries

Sand Dams



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[59] Mutuku, N.B., 2012. Impact of Sand Dams on Social Economic Status of the Local Inhabitants. A case of Kitui, Kenya. LAP LAMBERT Academic Publishing.
[60] East Africa adoption rates sourced from a CGIAR study: 'Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa.' Kristjanson et al. Food Security, volume 4. 2012.
[61] http://www2.unccd.int/land-degradation-neutrality See a video explanation of LDN at https://youtu.be/DPgtdEw5lgI
[62] http://www2.unccd.int/actions/ldn-target-setting-programme

2.7.8 Increased Food Production

Improvements in land management combined with improved agricultural techniques enabled by the water provided and time freed up by sand dams make a significant difference to farm production. Without water for irrigation during the drought periods tree nurseries and vegetable nurseries are impossible. While such activities because of sand dams also happen with Excellent Development's partners in Zimbabwe and Mozambique this summarises the impacts achieved by UDO, ASDF and SASOL in Machakos, Makueni and Kitui counties as well as a significant breakthrough in the arid lands of Rajasthan, India. The impacts can be briefly summarised as follows:

- Crop Diversity & Productivity
- Fruit & Vegetable Production
- Livestock Productivity

"The supported self-help groups have achieved much more than participating in the construction of sand dams... They have not only maximised the benefits from the improved and sustainable water supplies, but have gone on to improve agricultural production, nutrition and income within their communities."[63]

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 cause 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 germinated and propagated in the dry-season and then planted at the start of the rainy season resulting in a significantly higher survival rate.

Summary of socio-economic benefits of sand dams in Kitui, SE Kenya (Source: Aerts et al) [64]	With sand dam	Without sand dam
Change in area of irrigated land	+ 0.18 Ha	(0.01) Ha
New fruit trees per family	13	5

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.

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[63] External evaluation 'Excellent Development/ASDF DfID/UK Aid Global Poverty Action Fund (GPAF) programme 2013-16' Sept. 2016.

[64] Summary of 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]

Many NGOs working with sand dams also directly support improvements in agriculture especially ASDF[65] and UDO[66] in Kenya, Dabane Trust[67] in Zimbabwe and CCM in Mozambique[68]. The adoption rates for improved ('climate smart') agricultural techniques is phenomenal compared to the east Africa regional averages as set out in the table below:

Adoption of Climate Smart Agricultural Techniques	East Africa regional averages§	Farmers supported by ASDF
Agroforestry	50%	89%
Inter-cropping	50%	88%
Planting drought-tolerant crops*	50%#	94%*
Storing agricultural water	10%	100%

50% farmers planting at least **one variety** of drought-tolerant crops.

* 94% of farmers supported by ASDF are planting **seven varieties** of drought-tolerant crops.

§ East Africa adoption rates sourced from a CGIAR study[69]

Climate-smart Agriculture:
- Agroforestry
- Drought-tolerant crops
- Intercropping
- Cover crops
- Use of manure

Excellent | Pioneers of Sand Dams

Sustainable Agriculture

The table below also shows the impacts of the improved practices translate into improved livestock and crop output.

ASDF Evaluation Data	Baseline	Evaluation
Tree survival rate	<30%	78%
Communities supported by livestock	6%	21%
Farmers with increased harvest	-	66%
Farmers attributing increased harvest to improved terracing	-	77%
Farmers attributing increased harvest to improved knowledge and skills	-	69%

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[65] http://www.asdfafrica.org/what-we-do/food-security
[66] http://www.utoonidevelopment.org/
[67] http://www.dabane.org/what-we-do/activities/food-productionlivelihood-food-and-nutrition
[68] http://mennoworld.org/2015/07/06/feature/urgent-search-for-water-in-mozambique/
[69] East Africa adoption rates sourced from a CGIAR study: 'Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa.' Kristjanson et al. Food Security, volume 4. 2012.

Transforming agriculture in the Thar desert, Rajasthan, India.

A sand dam (6m subsurface and 0.9m above-surface) was built in Thumba ka Goliya, Jalore, Rajasthan, India in partnership with the Jal Bhagirathi Foundation (JBF) in 2013. The sand dam has had enormous impact on the ground water levels and output from both private and government tube wells both in terms of volume and salinity.

Output from government tube wells has increased by 50% and water availability increased from several hours to 24 hours per day[70]. The impacts originally affected tube wells for 23 farmers but be 2015 it was realised that 109 private tube wells in the area were positively impacted. Water levels reported by local farmers in the tube wells previously were at 75m but reduced to 60m by 2015 and 45m in 2016[71].

The salinity reduction has enabled a change of agricultural crops from castor to vegetables and even Thai apple. The nearest farmer to the sand dam, Mahavir Singh, who originally transitioned his farming to chilies and carrots could now expand his area of cultivated land by ten-fold[72]. In 2016, with the help of the India Government horticulture department, he is now growing Thai Apple *for the first time ever in Rajasthan*. The farmer will not get a proper crop for twelve months but already has an order for his whole crop destined for a supermarket in Delhi. As his son Kushpal Singh said, "It's the Thar Desert and we are growing Thai Apple - it's a great achievement." Kushpal added that it would double his father's income. "It's a cropping revolution!", added his best mate Jaideep. Over 100 farmers in the area are transforming their agriculture because of the dam.

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[70] Interviews carried out on visit by Simon Maddrell to Rajasthan, December 2015.
[71] Interviews carried out on visit by Simon Maddrell to Rajasthan, December 2016.
[72] http://www.excellentdevelopment.com/articles/people-amp-communities/this-time-i-am-successful

These activities and impacts serve to increase the wealth and quality of life of communities – all quotes in these two sections come from the external evaluation of ASDF[73].

2.7.9 Increased Wealth

Approximately 50% of dryland farmers are fully subsistent relying entirely on their own land for income. In this scenario, increased crop production and new production of fruit and vegetables makes a huge difference to family finances and the local micro-economy. Farmers spend less money outside of the local area by reduced spending on 'imported goods' like fruit, vegetables and staple crops. Those farmers growing a surplus bring money into the local micro-economy. Some communities have transformed into 'net exporters' locally whilst others even supply vegetables for export to Europe[74].

In summary, the key impacts are as follows:

- Increased Incomes
- Reduced Costs
- Increased Value of Assets (e.g. farm land, trees, livestock, wildlife.)

Summary of socio-economic benefits of sand dams in Kitui, SE Kenya (Source: Aerts et al) [75]	With sand dam	Without sand dam
Change in income per family (€/year)	+ €270	€ (380)

2.7.10 Improved Quality of Life

In the author's experience the overall impact of a holistic sand dam programme does far more than just contribute to the direct improvements of reduced water-borne illnesses and malnutrition. The lives of dryland farmers are transformed, primarily because they are transformed by themselves, having taken advantage of the potential created by sand dams. Having met thousands of people over 30 years the author can attest to the anecdotal stories but also the look in the eyes of people filled with hope and pride. Excellent and ASDF have developed a set of 'quality of life' metrics covering hope, confidence, empowerment, pride and freedom so that these changes can be quantifiably measured in future.

The following data comes from the work of ASDF and SASOL in Kenya.

ASDF Evaluation Data	Baseline	Evaluation
Beneficiaries with improved diets since baseline	-	75%

Summary of socio-economic benefits of sand dams in Kitui, SE Kenya (Source: Aerts et al) [76]	With sand dam	Without sand dam
Malnutrition	Decreased	Increased

The results are also echoed by a Canadian Foodgrains Bank (CFGB) impact analysis of UDO in September 2010[77].

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[73] External evaluation 'Excellent Development/ASDF DfID/UK Aid Global Poverty Action Fund (GPAF) programme 2013-16' Sept. 2016.

[74] Africa Sand Foundation evaluation data.

[75] Summary of 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, 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]

[76] 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]

[77] http://www.utoonidevelopment.org/our-impact/family-community/

The ASDF external evaluation highlighted these ‘quality of life’ changes that go beyond the physical impacts[78]:

“What is being experienced by individual community members is an increase in the sense of being able to initiate and complete tasks and initiatives previously considered beyond them.”

“[We observed a] *significant shift in an individual’s relationship to life, a move away from being a dependent victim to being an active participant in, and even an initiator of, change.”*

“The change from passive victims to active and engaged builders of dams and futures.”

2.7.11 Improved Peace and Justice

“It is no coincidence that more than 75% of the world’s conflicts occur in dryland areas - home to only 35% of the world’s population.”

Bianca Jagger, Founder of the Bianca Jagger Human Rights Foundation

Climate change and desertification put extreme pressure on water and land resources and create tension between the needs of people and animals – often through migration. Whether the conflict be intra-community or inter-community, like pastoralists and agriculturalists, they often escalate into serious conflict even war. The same issues exist between wildlife and people, again where land is degraded or areas are suffering from drought. Sand dams alleviate conflict by increasing water availability and enabling investments in sustainable land management and better management of resources.

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[78] External evaluation ‘Excellent Development/ASDF DfID/UK Aid Global Poverty Action Fund (GPAF) programme 2013-16’ Sept. 2016.

2.8 Sand Dams: Dam Capacity, Water Storage Capacity and Yield.

It is standard engineering and government agency practise to insist that dam designs include a calculation for the capacity of the dam. It is therefore important to be able to calculate this for sand dams even though it is the volume of ground water recharge and/or yield to users that is the prime purpose of building sand dams. The effective contributions to increased water supply that a sand dam can make is discussed more in Chapter 3.3.

It is therefore important to understand the differences in terms of capacity; water storage and water yield that sand dams have compared to conventional open water dams to properly understand their impact on water supply.

Dam Capacity is the additional volume that is held behind the dam. For open water dams this is, initially at least, the same as the water storage capacity of the dam before the effects of siltation over time.

Water Storage Capacity is the maximum volume of water stored behind a dam. For an open water dam this is the dam capacity less any volume lost to siltation. For a sand dam this is the maximum volume of water held within the sandy sediments behind the dam, which is calculated by measuring the *porosity* of the sediment.

Water Yield is the volume of water that can be (or is) abstracted from the dam over time. For an open water dam, this is calculated form the water storage capacity less evaporation. For a sand dam, depending on the sediment profile – the water storage capacity is higher than the water that can be abstracted because some of the water adheres to the finer particles (calculated by measuring the *drainable porosity* of the sediment). Drainable porosity, technically speaking, is 19-50%[1] of the dam capacity, although more typically for a sand dam it is 25-40%.

This yield from sand dams also varies according to the abstraction method: an infiltration system will abstract water from the water storage capacity behind the dam only. A shallow well, depending on its depth, will also abstract water held in the original river basin in addition to the new volume the sand dam provides.

Water Yield is greater than Water Storage Capacity because yield is a measure over time and dams, as a rainwater harvesting technology, will continue to refill when the river flows over time. In fact, most sand dams also continue to refill outside of rain periods due to underground flows of water from the upper catchment. Where a deeper well is used, the yield from a sand dam is also the additional volume abstracted because of ground water recharge.

2.8.1 How to estimate dam capacity and water storage capacity[79].

The dam capacity (volume of sediment) stored by a sand dam can be **estimated** using the following measures

D, the maximum **depth** of sand (m).

W, the maximum **width** (m) of the river channel.

L, the **length** of the sand aquifer (m) upstream of the dam

$$\textbf{Dam Capacity} = (D \times W \times L) \div 3$$

Notes:

Estimated: This is an approximate calculation, therefore estimates of D, H, L are fine where difficult to measure exactly.

Depth (D): At minimum this would be the height of the dam main spillway (including the depth of foundation). However, in many cases, especially where the dam is built on surface bedrock, the depth of sand will be greater than this,

Width (W): This will often be wider than the width of the channel at the site of the dam.

Length (L): This distance is also known as the dam throwback. With sand dams, because of sand accumulation this is further than the exact point upstream that is level with the dam spillway, but this measure can be used for ease.

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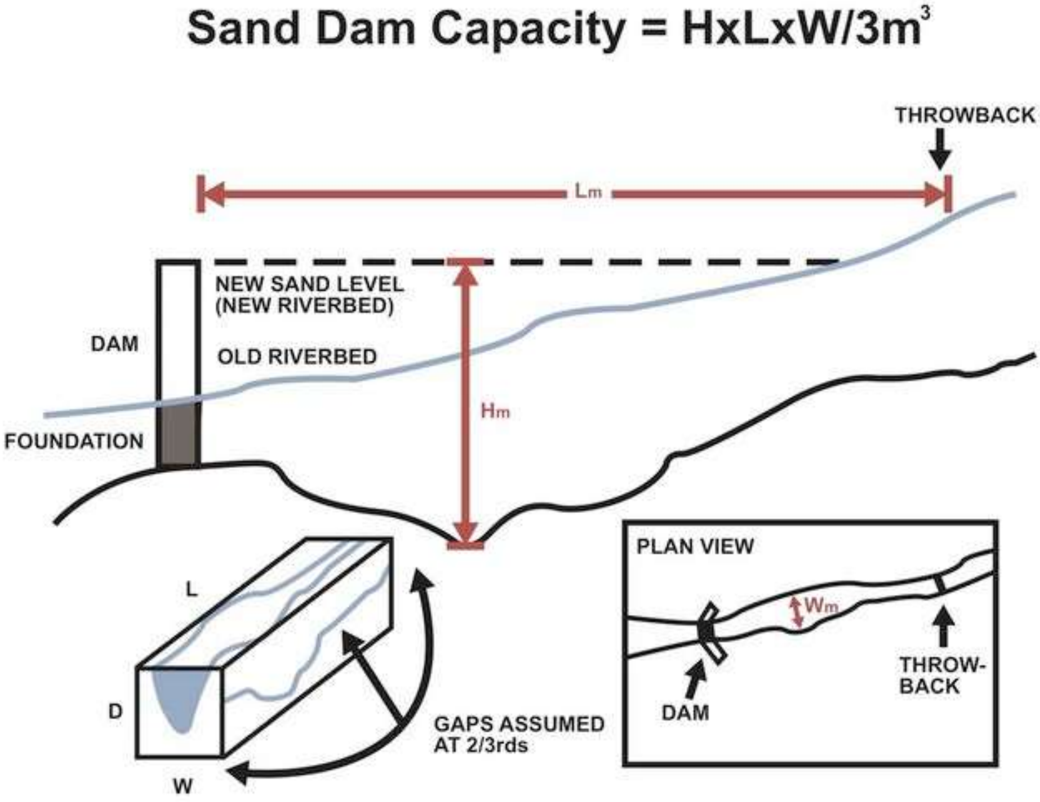
[79] Nissen-Petersen, E. 2000. Water from Sand Rivers: A manual on site survey, design, construction, and maintenance of seven types of water structures in riverbeds., Nairobi: Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida), 2000.

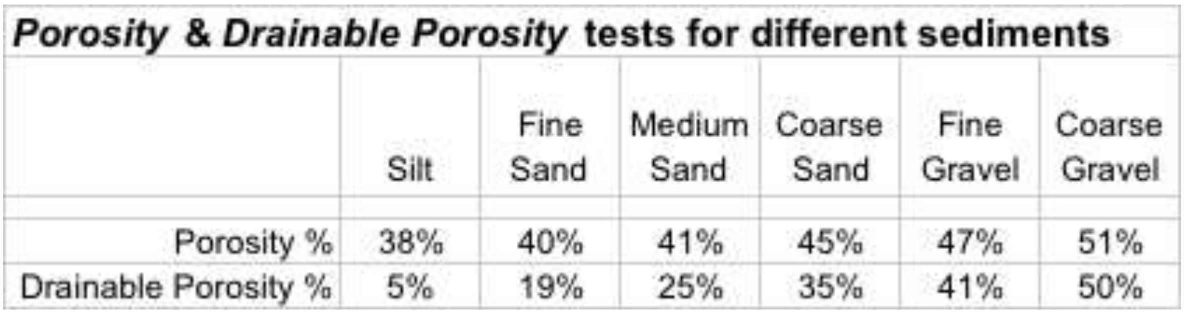

Sand Dam Capacity = HxLxW/3m³

This total volume is reduced by a factor of 3 [some models divide this by 4] because the maximum measurements have been used and the valley shape reduces the total volume of the rhomboid that makes up D x H x L.

The water storage capacity of the dam is calculated by factoring the average *porosity* of the dam sediment (%) whilst the abstractable water is calculated by factoring the *drainable porosity %.* The table below shows the result of an actual test of 20 litres of different grades of sand[80]. The author would estimate that for sand dams 40-45% of the dam capacity is water; and that 25-35% of the dam capacity is abstractable water, especially if using a shallow well or Rowa hand pump.

Water Storage Capacity = Dam Capacity × Porosity %

Abstractable Water Storage Capacity = Dam Capacity × Drainable Porosity %


***Porosity* & *Drainable Porosity* tests for different sediments**

	Silt	Fine Sand	Medium Sand	Coarse Sand	Fine Gravel	Coarse Gravel
Porosity %	38%	40%	41%	45%	47%	51%
Drainable Porosity %	5%	19%	25%	35%	41%	50%

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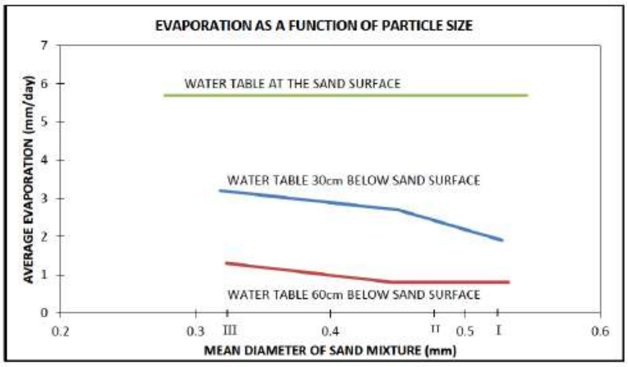
[80] Nissen-Petersen, E. 2000. Water from Sand Rivers: A manual on site survey, design, construction, and maintenance of seven types of water structures in riverbeds., Nairobi: Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida), 2000.

2.8.2 Why Water Yield is much higher than Abstractable Water Capacity

The amount of water that a dam yields will almost always exceed its abstractable capacity for the following reasons:

- The dam aquifer is recharged by repeated river flows. This is greatest where there are two rainy seasons and/or rainfall is dispersed over several months. For example, rain-water harvesting tanks can yield 3-4 times the capacity of the tank due to this alone.
- 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. Open water evaporates at a rate of 7-10mm per day in the tropics. However, water held in sand evaporates at a lower rate. In fact, below 60 cm depth, evaporation from sand is negligible[81].
- Water is lost by seepage into the underlying aquifer or under and around the dam. This seepage increases groundwater levels and dry-season downstream flows but decreases the direct yield from the dam (although this may not reduce the effective yield of the dam from surrounding wells).



2.9 Value for Money

Chapter 2.7 discussed the benefits and impacts of sand dams, albeit demonstrating that there is more research required into the wider socio-economic benefits realised through sand dams. In this chapter, the focus will be on the specific relationships between the 'value for money' for sand dams, looking specifically at the relationship between size of dams and cost; compared to other technologies; and, between cost and water accessibility.

2.9.1 Value for money and the height of sand dam

Chapter 2.8 described at length about the relationship between dam sizes and capacity, water storage and abstractability and how massively variable the yield can be in relationship to dam size. Yield only be measured afterwards and Excellent Development and ASDF are seeking to enable yield measurements for dams to improve the knowledge and understanding of this subject. As a reminder, in calculating volume, it is important to differentiate between dam height and water height. If the dam is utilising scoop holes or infiltration galleries, then height of dam = height of abstractable water. Obviously, if a dam site is chosen with an existing underground dyke, value for money increases. If a shallow well is used down to bedrock or impermeable layer – then the height of the water is the dam height plus distance down to that layer. Once that is established, as a rule of thumb, a doubling of dam height will treble the volume stored because the length and width of the dam container will increase disproportionately. The table below shows this as well as the flooded area. Obviously, for a specific dam site there will be either a maximum possible spillway height and/or a maximum cost effective height (because the width of the dam crest [i.e. the wings] would have to be so wide as to increase the cost disproportionately). This is modelled in the graph below that. Bearing in mind that the purpose of sand dams is to supply safe water to under-served rural communities, dam heights should be as high as technically possible or feasible to maximise storage and yield. Because water does evaporate in sand, albeit more slowly, up to 60cm below the surface, sand dams should have a water height of at least 1-1.5m. In summary, the higher a dam the more cost-effective or value for money the dam is. Unless the guidance for sand dam designing is broken, this is true up to the maximum height a sand dam can be built. Depending on the exact hydrology, a shallow well will maximise the abstractable volume of water from the sand dam, thereby increasing the value for money further.

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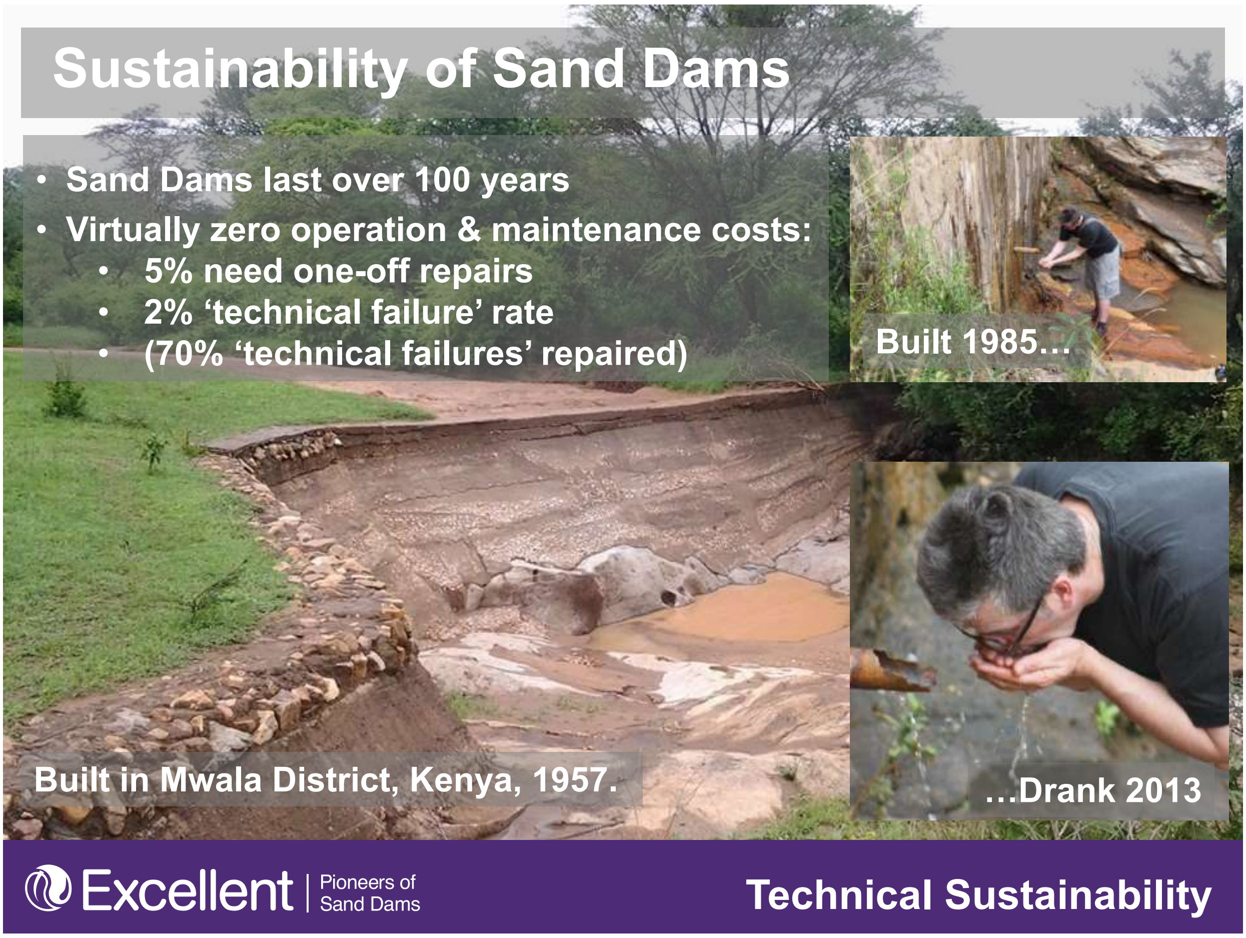
[81] Hellwig DHR, 1973 Evaporation of water from sand, Journal of Hydrology, 18 (1973) 317-327

2.9.2 Value for Money: Comparison with other RWH solutions

In relationship to other rainwater harvesting (RWH) solutions, sand dams and sub-surface dams are dramatically more cost-effective, according to Desta et al, 2005 and Nissen-Petersen, 2000 (see table below). The author has not been able to source the more accurate measures of lifetime costs comparisons per m^3, which would show a better comparison because capital investments would be amortised over life and yield rather than capacity would be used in the calculations. There are few comparisons with boreholes despite yields usually being much easier to measure. However, there are difficulties due to the enormous differences in capital costs (e.g. a borehole can take up to six drillings before a suitable supply is found), the variances in yield and the differences in operation and maintenance costs[82]. When linked to the fact that a 1997 World Bank study found that 90% of boreholes in Mali were inoperable just one year after installation[83]. A 1994 study estimated that 40-50% of hand pumps in Sub-Saharan Africa were not working[84]. This shows how average lifetime costs per m^3 are extremely variable when some boreholes can yield 100m^3 per day for years. In contrast, sand dams can last 100 years with very little maintenance.

From an implementation perspective, sand dam costs can also be measured based on actual expenditures. For the 896 sand dams that Excellent enabled up to March 31st 2016 – the total ‘supply chain’ expenditure averages at $13.50 per beneficiary and $13,110 per sand dam.[85] (Note: This includes all the UK add-on costs for fundraising, marketing, governance and support costs – but excludes the cost of labour where this has been provided free of charge).



Sustainability of Sand Dams

- Sand Dams last over 100 years
- Virtually zero operation & maintenance costs:
  - 5% need one-off repairs
  - 2% ‘technical failure’ rate
  - (70% ‘technical failures’ repaired)

Built 1985…

Built in Mwala District, Kenya, 1957.

…Drank 2013

Excellent | Pioneers of Sand Dams

Technical Sustainability

One of the biggest advantage of sand dams is the very low maintenance and repairs required if designed and built well – the author has seen a sand dam that was built over a hundred years ago.

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[82] Borehole Sustainability in Rural Africa: An analysis of routine field data. Harvey, P.A., UK. 30th WEDC Conference. http://hydrologie.org/redbooks/a265/iahs_265_0367.pdf

[83] World Bank (1997) Mali Rural Water Supply Project. Performance Audit Report No. 16511, World Bank, Washington DC

[84] Diwi Consult and Bureau d’Ingénierie pour le Développement Rural (BIDR) (1994) Etudes d’ Réhabilitation des Points d’ Eau Existants.

[85] Excellent Development, Sept. 2016. Annual Report 2015/16. http://www.excellentdevelopment.com/site-assets/files/resources/publications/annual_report-201516-website-version.pdf

Cost per m^3 (1,000 litres) of water of different rainwater harvesting technologies*

(Adapted from Desta et al, 2005[86]; Nissen-Petersen, 2000[87])

Rainwater harvesting technologies	Min $	Max $
Sand dams & sub-surface dams	$0.2	$0.8
Run-off: Open reservoirs	$3.0	$8.0
Underground tanks	$4.0	$15.0
Run-off: Closed reservoirs	$4.0	$23.0
Above ground tanks	$30.0	$130.0
Rock catchments	$46.0	$110.0

Whilst average costs give a great picture of the relative merits of a technology, there are certain traps that should be avoided. In simplistic terms, the poorer a community, the more remote it tends to be and therefore the less densely populated the area is likely to be. To deliver sand dams, even at a lower 'service level' (see section on accessibility and availability), is more expensive per person (less densely populated) and per dam (higher materials transport and relative construction costs). However, this doesn't make it less 'value for money' regardless of what some donors or economists may say. This is because the alternative solutions need to be compared 'like for like' where they may be implemented.

Additionally, it is extremely important to understand what any water supply solution delivers – not just for drinking water but multi-use supply. SDG 6.1 on drinking water measures availability, accessibility and quality and it is the ability of a technology to meet all three of these needs that is important, rather than just yielding y m^3 per day when it is implemented – the point of which is discussed in the next section.

2.9.3 Value for Money: Water accessibility and availability

One distinct advantage of sand dams is that people are situated close to the seasonal rivers that they are built in. Certainly, in semi-arid and tropical sub-humid drylands (84% of dryland populations) there are seasonal rivers close by to people as they are a traditional water source during wet seasons and for a period thereafter. Philosophically, as with all rain water harvesting, sand dams work based on keeping water close to where it lands and where people are – rather than allowing it to flow away and employ expensive technologies to bring it back. Economically it makes sense. The cost of UK water in the 1850's was split 90% abstraction and 10% transmission. By the 1950's these percentages had switched at a considerable infrastructure cost. Such an investment to provide piped water to the whole of the world's population is quite simply unachievable. Therefore, the author contends that the SDGs on water will not be achieved without a highly significant focus on rain water harvesting, which enables water to be supplied close to home rather than letting water disappear from areas of need and then investing significant sums of money to 'bring it back'.

One issue is that the SDGs do not fully take account of the unique challenges of water supply in dryland environments. The metrics for SDG 6.1 on drinking water has split them down to three levels by the WHO/UNICEF Joint Monitoring Programme (JMP): a) *Availability*, b) *Accessibility* and c) *Quality*. Most dryland government Ministers of Water and almost all drylands people would prioritise them in this order. The targets are very high and almost unachievable for rural drylands. The availability target is within 30 minutes round-trip and the *accessibility* target is 'when needed' i.e. year-round supply. Measurement of *availability* and *accessibility* becomes even more difficult in a pastoral context, and even more so in a nomadic one. In fact, measurements

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[86] Desta, L, Carucci, V, Wendem-Agenehu, A, Abebe, Y (2005) Community based participatory watershed development: a guideline, part 1. Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia

[87] Nissen-Petersen, E. 2000. Water from sand rivers. A manual on site survey, design, construction and maintenance of seven types of water structures in riverbeds. RELMA. Technical Handbook No. 23. Nairobi.

concerning water supply for livestock are difficult to place. The *quality* targets have, rightly, set the bar higher than the MDGs that specified 'improved water sources' rather than 'safe' (with safe levels of contamination by coliforms, arsenic, fluoride, salinity etc.) as they are two very different things. By their own admission to the author[88], the JMP targets have not been able, so far, to address the nuances to both *quality* and *accessibility* that are specific and critical to drylands. This highlights the importance for implementers and managers of rain water harvesting and other water technologies in drylands to address this gap and demonstrate their true value for money. For example, sand dams in the experience of ASDF and UDO in Kenya, provide water within 30-90 minutes round-trip for communities. To bring that to 30 minutes for everyone would require a triple investment of sand dams or, more realistically, 30-130 times the investment per m^3 by building domestic rain water harvesting tanks. However, domestic rainwater harvesting tanks, even at that cost would be unable to provide a year-round supply of water due to the size of roofing that would be required to supply sufficient volumes to cover dry periods of 3-8 months in most dryland countries.

In summary, when considering different technologies and evaluating 'value for money' (and cost-benefit) *accessibility* and *availability* potential and capability should be taken into consideration as well as the specific and extra challenges drylands have in achieving the Water SDGs due to its volume of rainfall and degree of seasonality. In implementing sand dam programmes the author would emphasise the importance of implementing monitoring and evaluation covering *accessibility*, *availability* (including yield and multi-use benefits) as well as the relevant water *quality* testing for that area.

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[88] Rural Water Supply Network Conference, Côte d'Ivoire, Dec. 2016.

Chapter 3: Sand Dam Feasibility Assessment

This chapter covers:

- **The three technical pre-conditions for sand dams and how to assess them at different stages.**
- **Case study: A national feasibility study for sand dams, including socio-economic prioritisation:** Excellent Development's National Feasibility Study[89] for UNDP and the Government of the Kingdom of Swaziland in 2013-2014 funded by the GEF Special Climate Change Fund[90]
- **Testing methodologies for sediments.**
- **The types of water storage sand dams can provide depending on differing hydrological conditions.**

3.1 Three technical pre-conditions for sand dams

1. Sand dams must be sited on a sufficiently seasonal river.

2. The seasonal river must have a sufficiently sandy sediment.

3. Sand dams must be sited where there is accessible bedrock.

The rest of this chapter will explain the pre-conditions (and their linkage to the golden rules of design) in more detail, but for now here is a brief explanation:

Note 1: The seasonal (*ephemeral*) river needs to be sufficiently seasonal for the sand dam to fill with suitable sediments that enable the abstraction of water. Whilst this can be offset by building a dam spillway in stages, there still needs to be peak flood flows rather than flows associated with a semi-perennial river.

Note 2: The purpose of a sand dam is hold water for later abstraction and/or groundwater recharge. The ability to abstract water (*drainable porosity*) depends on the sediment type behind the dam. If correctly designed, a sand dam will hold the same (or very similar) sediment that already exists in the river, hence the river sediment needs to be one with a sufficient *drainable porosity*.

Note 3: Sand dams must be built on sites with accessible bedrock (within 4-6m of the surface of the riverbed). This is because, the dam needs to withstand the downward forces on the dam, which is mostly its weight. Otherwise the dam wall will sink causing it to crack. The river will then immediately, or eventually, flow through the dam causing complete failure.

Also, to be effective, the sand dam needs to create a near water tight seal across the valley to:

a) ensure that water does not flow directly underneath or around the dam, thereby either under-cutting the dam and causing complete failure;

b) maximise ground water recharge; and

c) hold water behind the dam.

Therefore, the sand dam should be built onto bedrock at least 1.5m wider than the flood width of the river. **However, there is an exception to this, which is explained in Chapters 9.3 and 9.15.1.**

Feasibility of sand dams should be established at a regional, river catchment and then site specific level (see Chapter 6.3) as part of a systematic process (see Chapter 4.1). Chapter 6.3 covers establishing specific sand dam site suitability. Depending on data availability for that area, quick 'pre-feasibility' desktop studies can establish high-level feasibility for regions and river catchments. A mixture of GIS, Google Earth and physical surveys can establish sub-catchment or local level feasibility. Assessing site level suitability requires physical visits including establishing local knowledge of how the rivers flow and some form of testing the river sediment.

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[89] Excellent Development presentations, 2013-2014

[90] Mhalanga, N., Sand dams: a sustainable solution for water scarce regions. International Water Power & Dam Construction. April 2014.

3.2 Pre-feasibility desktop studies

A mixture of data analysis, GIS and Google Earth can establish an initial feasibility for sand dams according to the three pre-requisites for sand dams discussed in Chapters 3.3.1 to 3.3.3.

There are many potential data sources for this available internationally and nationally where level and accuracy of data varies significantly from country to country:

In 2006, ICRAF published a GIS manual: "Mapping the Potential of Rainwater Harvesting Technologies in Africa" including assessments for sand dams, in Africa, specifically for ten African countries.[91]

Rain Foundation's "A practical guide to sand dam implementation" details the potential data types and resources available as follows[92]:

Pre-feasibility map and data types:

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

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

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

4. Aerial photographs and satellite images:
Aerial photographs and satellite images can support locating sandy riverbeds based on the morphology. Aster satellite images can also be used to indicate sandy riverbeds and different types of geology through the remote sensing techniques as used by Gijsbertsen (2007)[93].

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

6. Flood data:
Flood data can provide information on rainfall seasonality. It also provides information on discharge characteristics of a catchment during a flood event.

Rain Foundation pre-feasibility data sources:

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

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

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

The geology of Kenya and Ethiopia is available from USGS. This map is part of the open file report 97-470A, version 2.0 2002, scale of 1: 5,000,000. The dataset is an interim product of the U.S. Geological Survey's World Energy Project (WEP) and can be freely downloaded from the internet. The New_LocClim program from the United Nations Food and Agriculture Organization (FAO) can be utilized to assist with the rainfall-runoff calculations, data on precipitation, evaporation and runoff. New_LocClim is a freely available and easy-to-use spatial interpolator for agro-climatic data. It uses the FAO's Agromet database which contains climatic data from over 30000 stations across the world. The New_LocClim program accesses this dataset and can provide the required information on average precipitation, evaporation, and runoff. The download set (which allows access to the Agromet database) can be downloaded http://www.fao.org/NR/climpag/pub/en3_051002_en.asp LocClim also provides rainfall data (Freely available) http://www.fao.org/sd/2002/EN1203a_en.html

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[91] ICRAF. Mapping the Potential of Rainwater Harvesting Technologies in Africa: A GIS overview and atlas of development domains for the continent and ten selected countries. Bancy Mati, Tanguy De Bock, Maimbo Malesu, Elizabeth Khaka, Alex Oduor, Meshack Nyabenge & Vincent Oduor. 2006.
http://www.worldagroforestry.org/downloads/Publications/PDFS/MN15297.pdf

[92] Rain Foundation. A practical guide to sand dam implementation (2.0), 2011.
http://www.bebuffered.com/downloads/PracticalGuidetoSandDamImplementation_April_2011.pdf

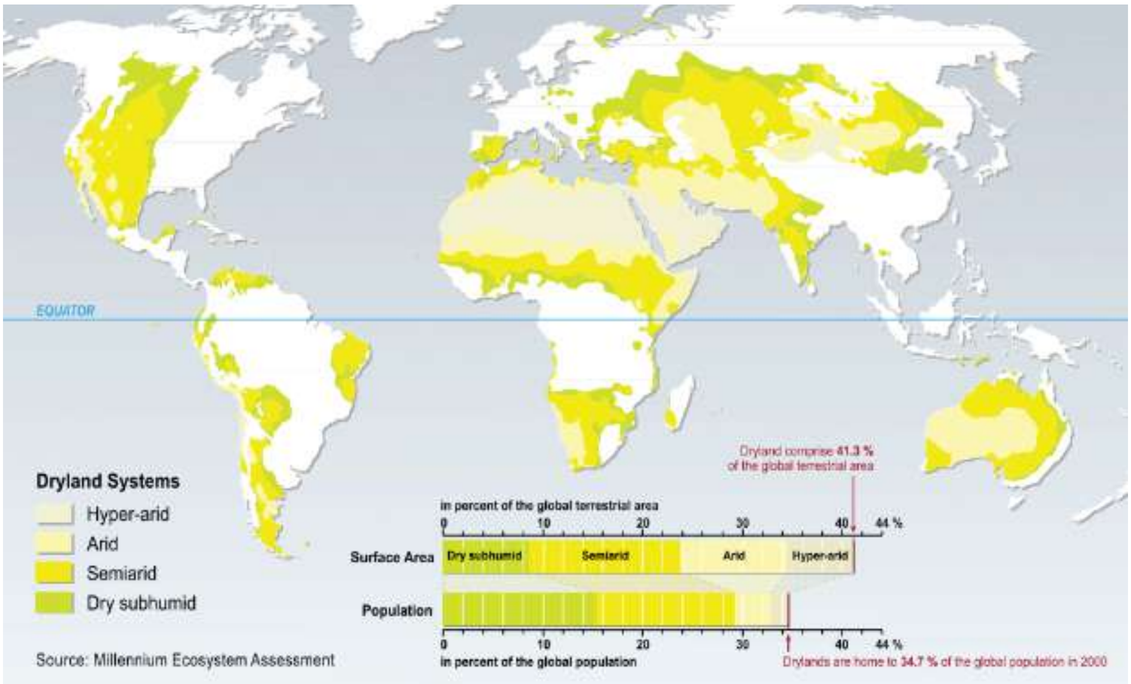
[93] Gijsbertsen C. Study to upscaling of the principle and sediment transport processes behind sand storage dams, Kituï District, Kenya. Vrije Universiteit, Amsterdam. 2007.

3.3 Feasibility Technical Pre-Conditions

3.3.1 Sand dams must be sited on a sufficiently seasonal river

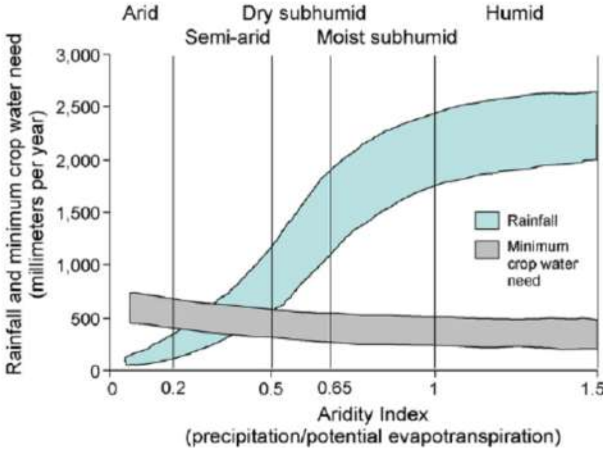
The seasonal river needs to be sufficiently seasonal (preferably *ephemeral* rather than *intermittent*) for the sand dam to fill with suitable sediments that enable the abstraction of water. Whilst this can be offset by building a dam spillway in stages, there still needs to be peak flood flows rather than flows associated with a semi-perennial river.

Drylands are the home of seasonal (*ephemeral* and *intermittent*) rivers, which are required for sand dams to be effective. Consequently, the first step of feasibility is to understand where the world's drylands are:



Source: Millennium Ecosystem Assessment

Dryland systems are defined as areas with <0.65 Aridity Index signifying variable, seasonal rainfalls. 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 evapotranspiration. 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. It is these hydrological processes that create the pre-conditions for sand dams.



Seasonal rivers and drylands climate can be identified utilising rainfall and aridity data – often in a more user-friendly manner utilising Geographical Information Systems (GIS) showing seasonal river systems and agro-ecological or climatic zones. In the diagram overleaf, there are a range of indicators for river seasonality, which accumulatively create a good indication of sand dam suitability. A low indicator on its own does not preclude sand dam feasibility e.g. an area with 200mm rainfall but very high monthly variance in a fast-flowing 3rd order river would likely to be suitable.

River Seasonality Indicators

High & Low Likelihood of Suitability for Sand Dams

600-1,200mm	Annual Rainfall	0-200mm
1-2 months	Months of Rainfall	4-5 months
Ephemeral	River Type*	Intermittent
Very High	Rainfall variance between months	Very Low
High	Rainfall variance within months	Low
High >1.2	**Seasonality Index§**	**Low <0.6**
Very Steep	Catchment Slope	Shallow
Steep	Riverbed Slope	Fairly Flat
Large	River Flow Height Variance	Small
High	River Flow Speed	Low
2nd & 3rd Order	Stream Order#	1st or >5th Order
Medium/Large	Upstream Catchment Size	Small or Very Large

River Type*:[94] **Intermittent** (seasonal streams) flow during certain times of the year when smaller upstream waters are flowing and when groundwater provides enough water for stream flow. Runoff from rainfall or other precipitation supplements the flow of seasonal stream. During dry periods, seasonal streams may not have flowing surface water. **Ephemeral** (rain-dependent streams) flow only after precipitation. Runoff from rainfall is the primary source of water for these streams. Ephemeral streams have greater seasonality.

Stream Order# is a simple method of classifying segments of streams based on the number of tributaries further upstream. A stream with no tributaries is 'first order' therefore the higher the stream order the larger the river catchment will be. Whilst a first order stream may have high seasonality it will have a relatively low flow of water to carry sediment.

Seasonality Index§

The Seasonality Index indicates the degree of difference in individual monthly rainfalls throughout the year, thereby measuring seasonal contrasts. This simple measure of relative seasonality of rainfall is "the sum of the absolute deviations of mean monthly rainfalls from the overall monthly mean, divided by the mean annual rainfall".[95] The higher the index the greater the seasonality typical of dryland climates with more seasonal the river flows and longer dry-season(s). Calculators are available on line[96]. As indicated in the table, a Seasonality Index over 1.00 is a good indicator of sand dam suitability, whilst an index of 0.60-0.99 may indicate suitability. According to the author, this is not an absolute measure and does not define a 'degree of suitability'. This is because, in suitable dryland climates, the rainfall variability within the rainfall months (or more specifically the variability of river flows, which are linked but not the same) is a bigger indicator of sand dam suitability. It is this next level of understanding that is key to establishing sand dam suitability and/or siltation risk, which is discussed in Chapter 6.

Seasonality Index (SI) (Walsh and Lawler (1981) [97]:

SI classes	Rainfall regime
≤ 0.19	Rain spread throughout the year
0.20-0.39	Rain 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 drier season
1.00-1.19	Most rain in <3 months
≥ 1.20	Extreme seasonality, with almost all rain in 1-2 months

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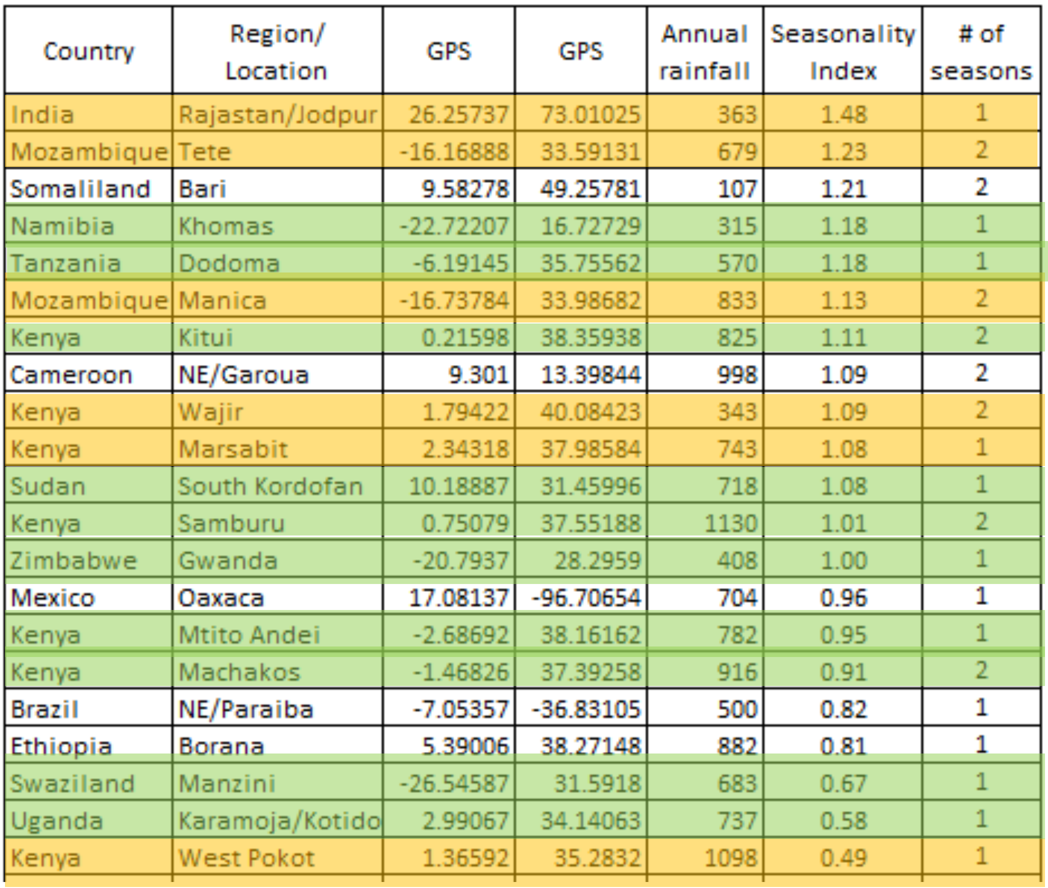
[94] United States Environmental Protection Agency. https://archive.epa.gov/water/archive/web/html/streams.html

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

[96] https://www.researchgate.net/file.PostFileLoader.html?id=5677cf535dbbbdf4bd8b4567&assetKey=AS%3A310502356389888%401451040938053

[97] Walsh, R. and Lawler, D.M. Rainfall seasonality: description, spatial patterns and change through time. Weather 36:201-208 · July 1981 https://www.researchgate.net/publication/243936748_Rainfall_seasonality_description_spatial_patterns_and_change_through_time_British_Isles_Africa

The table below illustrates the general seasonality indicator of suitability and the point about greater detail of intra-month variability being important. The table below shows seasonality indices in descending order for a range of locations. Where the author has knowledge, the locations have been coded yellow and green for their relative 'net suitability' for sand dams. Yellow means there isn't suitability for sand dams throughout the area but that effective sand dams are possible, sometimes by building in stages because of risks of siltation. Note that the 'home of sand dams' in Kitui and especially Machakos and Makueni (shown as Mtito Andei) have relatively low seasonality indices compared to other regions where care over sand dam siting and design is strongly advised. In other words, Seasonality Index is only an indicator and needs to be considered along with other factors of rainfall seasonality and sediment suitability.



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

Seasonality Index for locations with potential for sand dams[98]

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[98] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013. Colour-coding added by Maddrell, S. 2017.

3.3.2 The seasonal river must have a sufficiently sandy sediment

The purpose of a sand dam is to hold water for later abstraction and/or groundwater recharge (aquifer recharge). The ability to abstract water (*drainable porosity*) depends on the sediment profile contained in the dam. If correctly designed, a sand dam will hold the same (or very similar) sediment that already exists in the river, hence the river sediment needs to be one with a sufficient *drainable porosity*.

The ability for water to flow into the aquifer or to abstract the water is defined as the *drainable porosity* and depends on the relative mix of sediment types behind the dam. The ideal sediment has a high sand content (especially coarse to medium sand grains) and with 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. If correctly designed, we know* that a sand dam will hold the same (or very similar) sediment that already exists in the river, hence it is this current river sediment that should be assessed for a sufficient *drainable porosity*. It follows like day follows night, that a site with sandy sediment **can** produce a dam holding sand and a site with a silty sediment **will only** produce a 'silt dam' that will yield very little water.

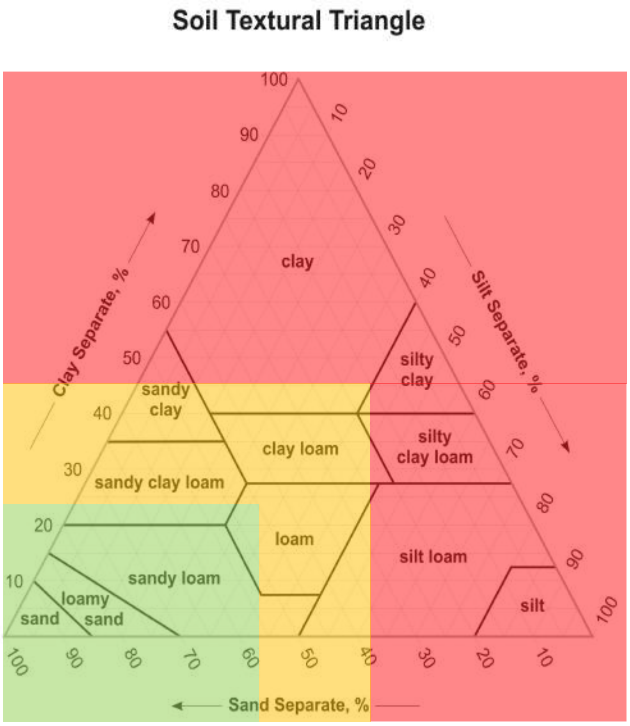
*** Sediment tests in SE Kenya In Machakos and Makueni Counties, Kenya[99]:** Tests on 39 dams in Machakos and Makueni Counties found that where dams mature in less than 3 years, the sediment that collects behind the dam has very similar grain size and porosity to the original river sediment with no horizontal layers of finer sediment. Despite the almost universally accepted conventional wisdom that sand dams must be built in small incremental heights, siltation did not occur when the dam is built all at once in one season and the spillway is up to 3 metres above the original riverbed level.

Whilst the conditions in the dry sub-humid areas of Machakos and Makueni are ideal, this is not true throughout the world's drylands. Differing river sediments, rainfall profiles, sediment load and other factors can make sand dams either unsuitable or highly prone to siltation.

In terms of assessing the suitability of the river sediment for sand dams there are four stages of assessment proposed depending on what stage of the programme you have reached i.e. Pre-feasibility, Feasibility or Pilot Planning & Design (see Chapter 4.2):

- **Assessing sediment proxies (soil and rock types)**
- **Assessing actual river sediments**
- **Measuring on-site river sediments**
- **Assessing against a *Sediment Profile Index*[§]**

Assessing sediment proxies: Soil types are often available through GIS Maps, enabling a desktop study (or see Chapter 3.5 for tests). The nature of the soil type in drylands is correlated to the type of river sediment that you will get, even though the river characteristics discussed in Chapter 3.3.1 will determine the extent to which the land soil differs to the river sediment. The soil textural triangle pictured right[100], shows the range of soil types sediments of sand, loamy sand and sandy loam being ideal for sand dams and high silt/clay being unsuitable.



[§] A ***Sediment Profile Index*** does not yet exist but the author believes it is a critical enabler of scaling up sand dam technology to create an index that, following research on both current sediment characteristic knowledge and actual sand dams, would combine all the relevant sediment measures to create an index that could define a 'Red/Yellow/Green Suitability Chart' for sand dams generically, but also depending on its purpose, use and abstraction technology deployed.

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[99] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013

[100] Figure 2.5 modified from Dura, 1982 http://www.fao.org/docrep/field/003/E7171E/E7171E02.htm Further colour-coded by Maddrell, S. 2017.

Sandy River Sediment Suitability Indicators

High & Low Likelihood of Suitability for Sand Dams

Sandy/Loam	Surrounding Soil Type	Clay/Silt
Granite/Quartz	Surrounding Rock Types	Basalt/Rhyolite
Coarse Sand	River Sand Type	Fine/Very Fine Sand
Very Low Silt	Sediment Silt Content	Medium/High Silt
30-40%	Sediment Porosity %	<25% or >45%
25-35%	Sediment Drainable Porosity %	0-15%
<20%	Specific Retention %	25-45%
<2.60	Uniformity Coefficient*	>4.00
TBA	**Sediment Profile Index§**	**TBA**

* Range of suitable values needs further research.

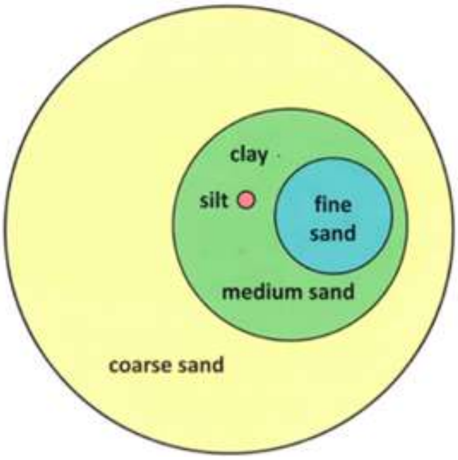
§ Sediment Profile Index not yet created but important to be empirically defined.

Assessing actual river sediments: Secondly, it is more definitive to understand the actual river sediment profile, which should be of high sand content (the coarser the better) and low clay/silt content, which causes water to adhere to the sediment preventing its abstraction. Below are two summaries of the range of sediments and defined sizes commonly used (note they vary!).[101]

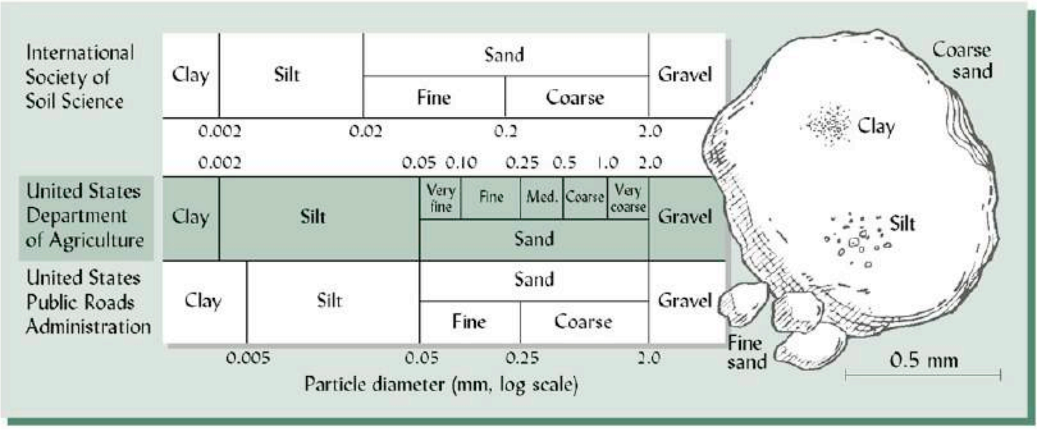
Particle size

1000 µm = 1 mm = 10^{-6} m

Gravel	> 2 mm
Very coarse sand	1 - 2 mm
Coarse sand	0.50 - 1.0 mm
Medium sand	0.25 - 0.50 mm
Fine sand	0.125 - 0.250 mm
Very fine sand	62.5 - 125.0 µm
Silt	4.0 - 62.5 µm
Clay	< 4 µm



Comparative size of sand, silt and clay particles[102]



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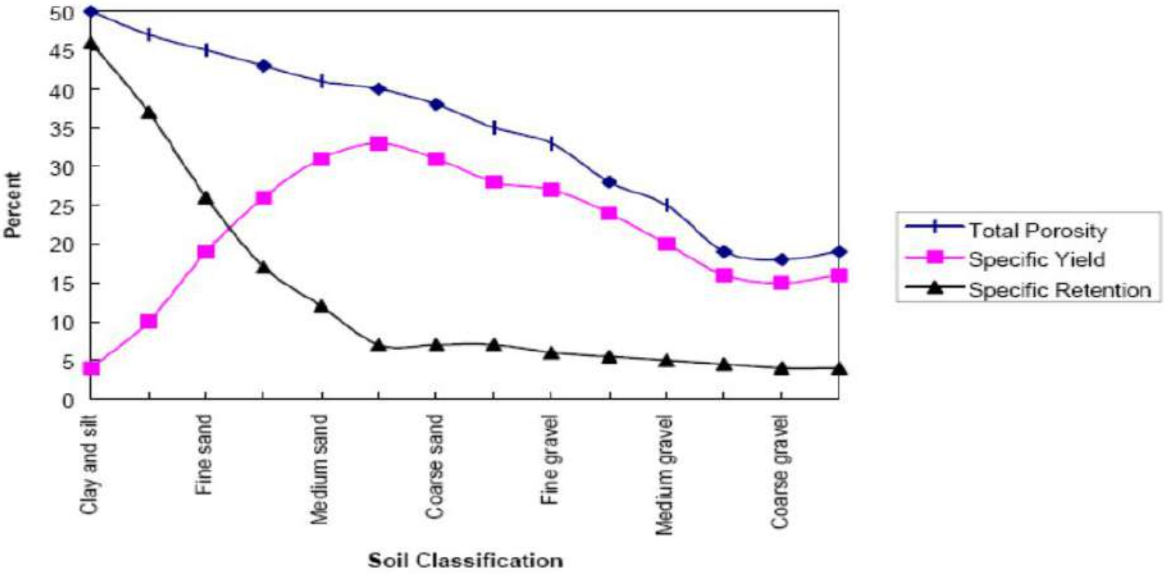
[101] HYDROGEOLOGY-GEOHYDROLOGY Published by Winfred Beasley http://slideplayer.com/slide/4623740/

[102] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013

Note: It is important that suitable sediment extends from the surface to the bedrock i.e. it is not a thin (5-25cm) layer of sandy sediment over a clay/murram river bed as can be seen, for example, in parts of Rajasthan, India and Baringo County, Kenya) unless the intent of the dam is solely to provide what will be a relatively small water catchment for abstraction that will not recharge the aquifer to any large degree.

The diagram below[103] illustrates the specific yield (*drainable porosity*) of sediments and the important point of drainage speed very applicable to the chapter on abstraction (see Chapter 6.1 & 6.2). The additional measures of sediments are *porosity* (how much water is held in the sediment and the *specific retention* (the amount of water held within the sediment).

The table below[104] shows the average relationship between *total porosity %; drainable porosity % and specific retention %* for the range of different sediments.



The table below[105] shows the results of an experiment by Nissen-Petersen to test for *drainable porosity %* of a range of sediments (see Chapter 3.5.4 for a methodology). The author estimates that for the most effective sand dams, sediment *porosity* is 30-40% and *drainable porosity* is between 25-35%. To maximise yield from the sand dam it is best that the *specific retention %* to be low as possible i.e. at minimum medium-coarse or coarse sand.

Drainable Porosity **tests for different sediments**						
	Silt	Fine Sand	Medium Sand	Coarse Sand	Fine Gravel	Coarse Gravel
Drainable Porosity %	5%	19%	25%	35%	41%	50%

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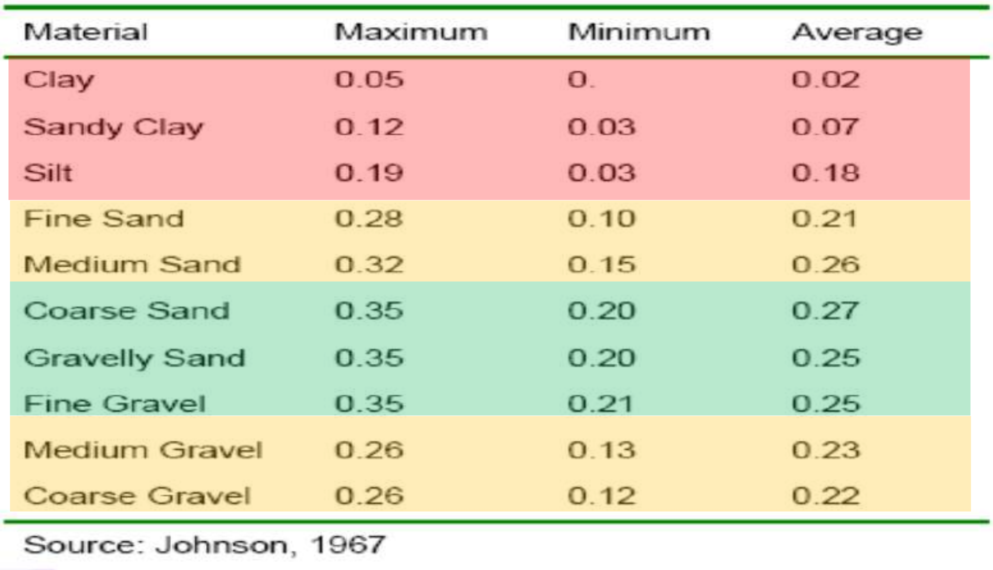
[103] http://waterinfotech.com/Grwater/physical%20properties.pdf

[104] HYDROGEOLOGY-GEOHYDROLOGY Published by Winfred Beasley http://slideplayer.com/slide/4623740/

[105] Nissen-Petersen, E. 2000. Water from Sand Rivers: A manual on site survey, design, construction, and maintenance of seven types of water structures in riverbeds., Nairobi: Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida), 2000.

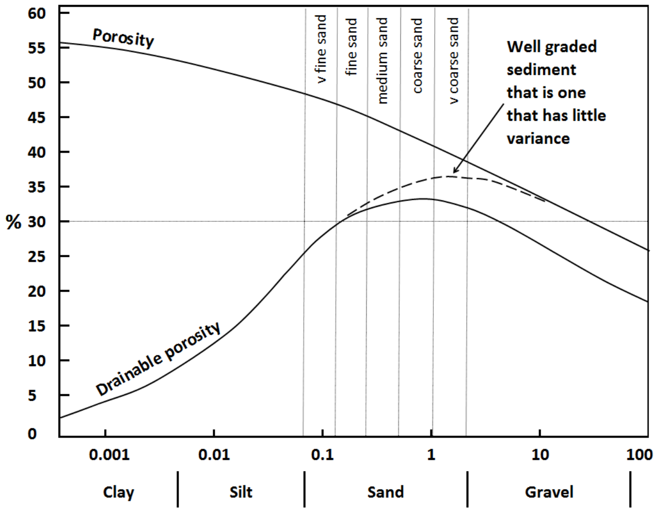
Each sediment type has a range of sizes – and consequently a range of drainable porosities. The table below[106] shows the range of *drainable porosity* values for different sediments, marked up with their red/yellow/green suitability for sand dams. It is worth reiterating that sediments have a *porosity* and *drainable porosity* range and that sediments are almost always a mix of sediments (see Chapter 3.5.3 for details of sieve testing to establish the % mix of sediment types in a river sediment).



Material	Maximum	Minimum	Average
Clay	0.05	0.	0.02
Sandy Clay	0.12	0.03	0.07
Silt	0.19	0.03	0.18
Fine Sand	0.28	0.10	0.21
Medium Sand	0.32	0.15	0.26
Coarse Sand	0.35	0.20	0.27
Gravelly Sand	0.35	0.20	0.25
Fine Gravel	0.35	0.21	0.25
Medium Gravel	0.26	0.13	0.23
Coarse Gravel	0.26	0.12	0.22

Source: Johnson, 1967

An additional factor with drainable porosity is how graded a sediment is (i.e. the *uniformity coefficient*, see Chapter 3.5.3 for the calculation methodology). The lower the *uniformity coefficient*, the more graded the sediment is. The more graded the sediment, the higher the *drainable porosity* that can be achieved (see graph below[107]) and the more suited the site is for a sand dam.[108] Whilst it is another area of understanding about sand dam suitability that would benefit from research, a 37-sample study where sand dams are effective in SE Kenya, showed a *uniformity coefficient* of between 1.72 and 3.00 with a median of 2.42 to give an indication of suitability.



There is a need for specific research being important is also that the sediment profile required also relates to the exact purpose or use of the sand dam. If the sand dam is creating a catchment of water for abstraction by pipe or shallow well, then higher *drainable porosity* is required to enable abstraction at a sufficient rate. However, where the dam is recharging the groundwater in a deeper aquifer, the lower *drainable porosity* fine and medium sand can be suitable, as it is *permeability* that is key to recharging the ground water aquifer. The different types of sand dam functions and hydrological processes are discussed more in Chapter 3.6. This is also where the author's suggestion of creating a *sediment profile index* would add great value in assessing generic sand dam suitability but also mapped against sand dam type, and abstraction technology options. With sufficient research a definitive Red/Yellow/Green suitability system could be established for tested river sediments, including defining siltation risk.

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[106] Johnson, 1967. Accessed from http://waterinfotech.com/Grwater/physical%20properties.pdf Colour-coding by Maddrell, S. 2017.
[107] Nissen-Petersen, E. 2000. Water from Sand Rivers: A manual on site survey, design, construction, and maintenance of seven types of water structures in riverbeds., Nairobi: Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida), 2000.
[108] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013

3.3.3 Sand dams must be sited on accessible bedrock.

Sand dams must be built on sites with accessible bedrock (within 4-6m of the surface of the riverbed). This is because, the structure needs to withstand the downward forces on it, which are mostly its weight. Otherwise the dam wall will sink causing it to crack. The river will then immediately, or eventually, flow through the dam causing complete failure. Also, to be effective, the sand dam needs to create a near water tight seal across the valley to:

a) ensure that water does not flow directly underneath or around the dam, thereby either under-cutting the dam and causing complete failure;
b) maximise ground water recharge; and
c) hold water behind the dam.

Therefore, the sand dam should be built onto bedrock at least 1.5m wider than the flood width of the river.

However, there is an exception to this, which is explained in Chapters 9.3 and 9.15.1.

Available surface bedrock is easy to assess on site, but it is necessary to be able to do more remote assessments of bedrock availability through Google earth and GIS. This is discussed more in the case study in Chapter 3.4.

River Bedrock Suitability Indicators

High & Low Likelihood of Suitability for Sand Dams

High	Medium	Low
Across Riverbed	Riverbed Bedrock	None
Both Sides	Riverbank Bedrock	One Side/None
0-4m	Depth of Bedrock	>6m
Granite/Limestone	Bedrock Type	Shale/Gravel
Solid	Bedrock Condition	Vertical Fractures

Rock and sediment permeability

The rock type is also important in relation to a) and b) above. i.e. whether the dam is primarily going to maximise ground water recharge or hold water behind the dam. Permeability is the capability of a porous rock or sediment to permit the flow of fluids through its pore spaces. The permeability of sediments and rock confining layers of aquifers is very important - especially when considering a sand dam as either an 'artificial groundwater recharge scheme'[109] or to recharge a 'perched aquifer' close to the river bed depth to provide a water source for direct abstraction. Thereby the river sediments and aquifer confining beds permeability is important as to how effectively a sand dam will recharge groundwater and the most appropriate type of abstraction that may be chosen.

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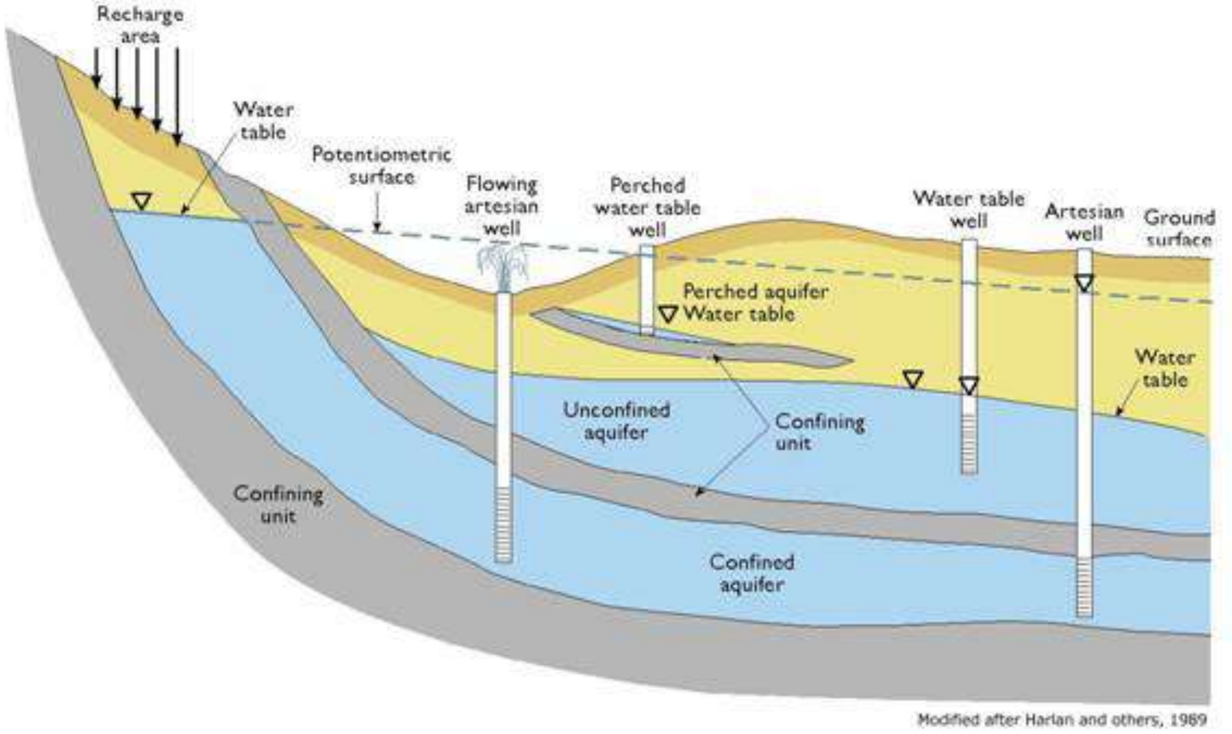
[109] Hofkes, E.H. and Visscher, J.T., 1986. Artificial Groundwater Recharge For Water Supply Of Medium-Size Communities In Developing Countries. International Reference Centre for Community Water Supply and Sanitation

Permeability of some types of rock (Campbell & Lehr, 1973)[110]

Type of Sediment/Rock	Permeability (md)	Possible positions in Aquifer[111] [for purposes of illustration]
Gravel	100-1,000	Unsaturated Zone, Perched or Unconfined Aquifer
Mixed sand & gravel	50-100	Unsaturated Zone, Perched or Unconfined Aquifer
Coarse sand	20-100	Unsaturated Zone, Perched or Unconfined Aquifer
Fine sand	1-5	Unsaturated Zone, Perched or Unconfined Aquifer
Fractured or weathered rock	0-30	**Confining Bed:** Perched or unconfined aquifer
Sandstone	0.1-1	**Confining Bed:** Perched, unconfined or confined aquifer
Clay	0.01-0.05	**Confining Bed:** Perched, unconfined or confined aquifer
Shale	negligible	**Confining Bed:** unconfined or confined aquifer
Limestone	negligible	**Confining Bed:** unconfined or confined aquifer
Solid rock	negligible	**Confining Bed:** unconfined or confined aquifer

The SI unit for permeability is m^2. A practical unit is the *darcy* (d), or the *millidarcy* (md) (1 darcy 10^{-12}m^2).



Modified after Harlan and others, 1989

Diagram: Showing different aquifer types in Denver Basin[112]. **Source:** Colorado Geological Society

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[110] Hofkes, E.H. and Visscher, J.T., 1986. Artificial Groundwater Recharge for Water Supply of Medium-Size Communities in Developing Countries. International Reference Centre for Community Water Supply and Sanitation

[111] Proposed by Maddrell, S., (2017) to help explain the different types of aquifers that a sand dam may interact with.

[112] http://www.douglas.co.us/water/water-supply/what-is-an-aquifer/

3.4 Case Study: A National Feasibility Study for Sand Dams

Excellent Development's National Feasibility Study[113] for UNDP and the Government of the Kingdom of Swaziland in 2013-2014 funded by the GEF Special Climate Change Fund[114] utilising GIS.

- **Technical Feasibility**
- **Socio-Economic Prioritisation**

Whilst an effective and efficient sand dam is very specific to a given location, it is important to recognise that sand dam feasibility can be established at a regional level with GIS prior to the more expensive fieldwork of finding specific locations. What follows is the process Excellent used in a feasibility study of Swaziland, including observations of what additional data would have been useful.

Technical Feasibility:

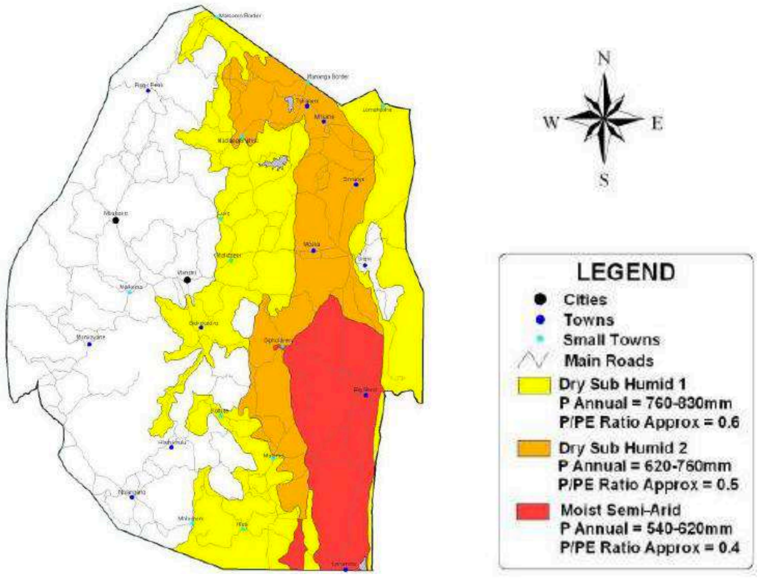
- **Dryland Climate**
    - Aridity
    - Agro-ecological/climatic zones
- **Sufficiently Seasonal Rivers**
    - Seasonal river maps
    - Annual rainfall data
- **Sandy Sediment & Accessible Bedrock**
    - Soil type
    - Rock type

Socio-Economic Prioritisation:

- **Land**
    - Land tenure
    - Land use
- **Poverty**
    - Poverty severity %
- **Water Availability**
    - % Access to safe water

3.4.1 Dryland Climate

3.4.1.1 Aridity[115]



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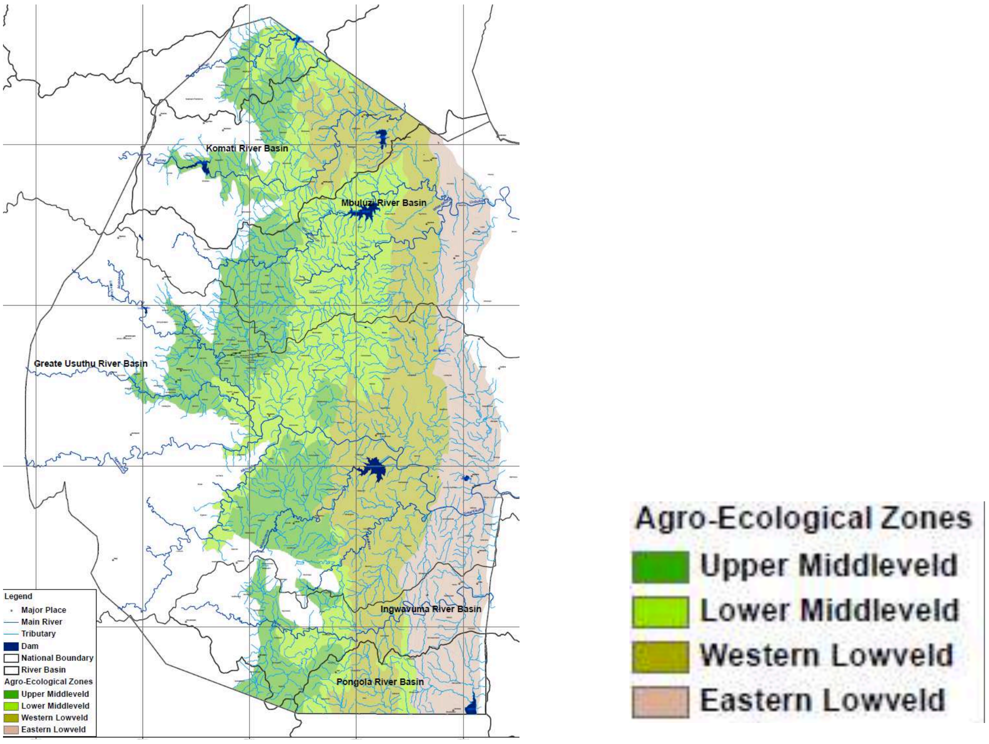
[113] Excellent Development presentations, 2013-2014

[114] Mhalanga, N., Sand dams: a sustainable solution for water scarce regions. International Water Power & Dam Construction. April 2014.

[115] *GoS-NMS, 2010. Second National Communication to the UNFCC, p7*

3.4.1.2 Agro-ecological zones

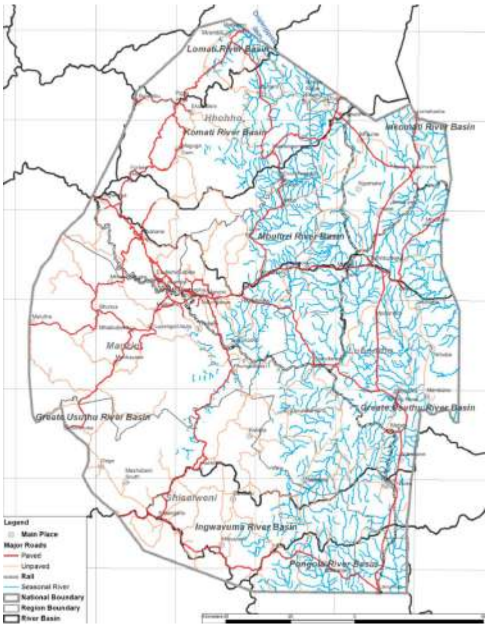
The climatic conditions range from sub-humid and temperate in the Highveld to semi-arid in the Lowveld. The national long-term average rainfall is 788 mm/year. The Western Lowveld and Lower Middleveld are tropical sub-humid and semi-arid environments suitable for sand dams[116].



3.4.2 Sufficiently seasonal rivers

3.4.2.1 Seasonal river map

Seasonal rivers cover a similar area to the target agro-ecological zones.



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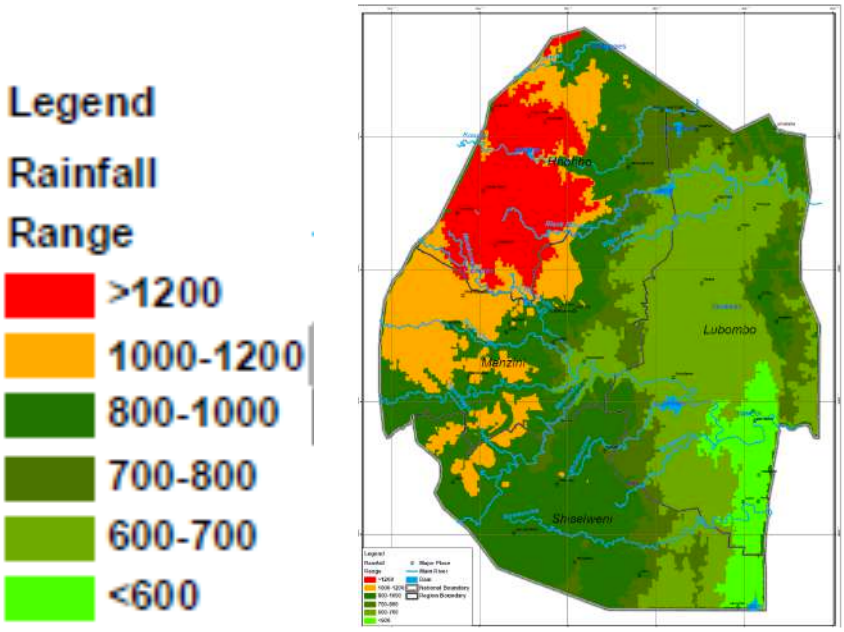
[116] http://www.eeas.europa.eu/archives/delegations/swaziland/documents/eu_swaziland/swaziland_country_environment_profile_june_2006.pdf

3.4.2.2 Annual rainfall

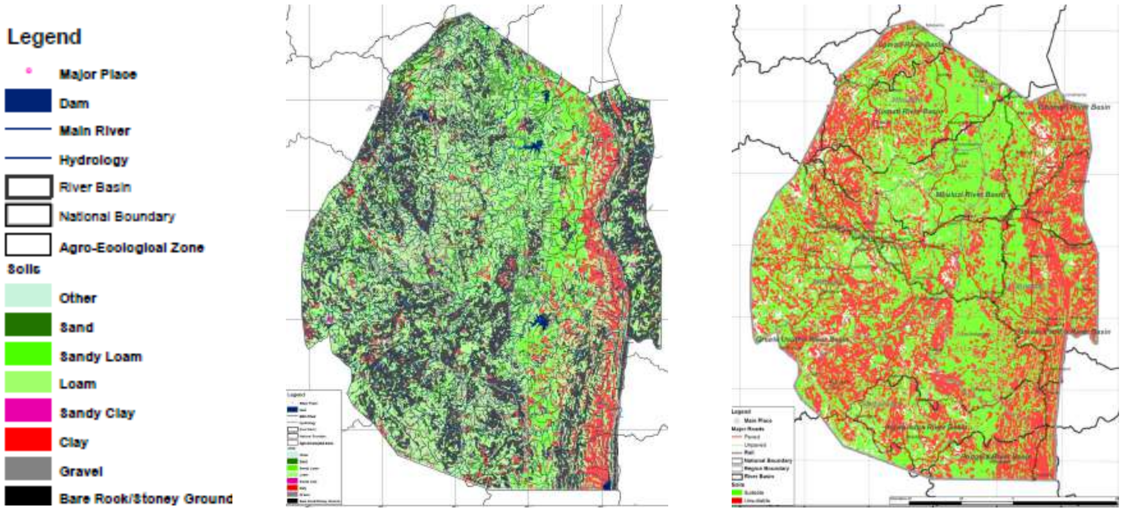
Unfortunately, because daily rainfall data was manually collected (and therefore subject to errors and gaps) the data was not released to us, despite the fact it would be possible to smooth the data and retain statistically accurate integrity. An understanding of monthly variability, which can be used to establish the Seasonality Index is absolutely critical. In addition, variability within month is much preferred to properly establish "sufficiently seasonal rivers" and is desirable to be understood prior to field visits.



3.4.3 Sandy sediment and accessible bedrock

3.4.3.1 Soil types

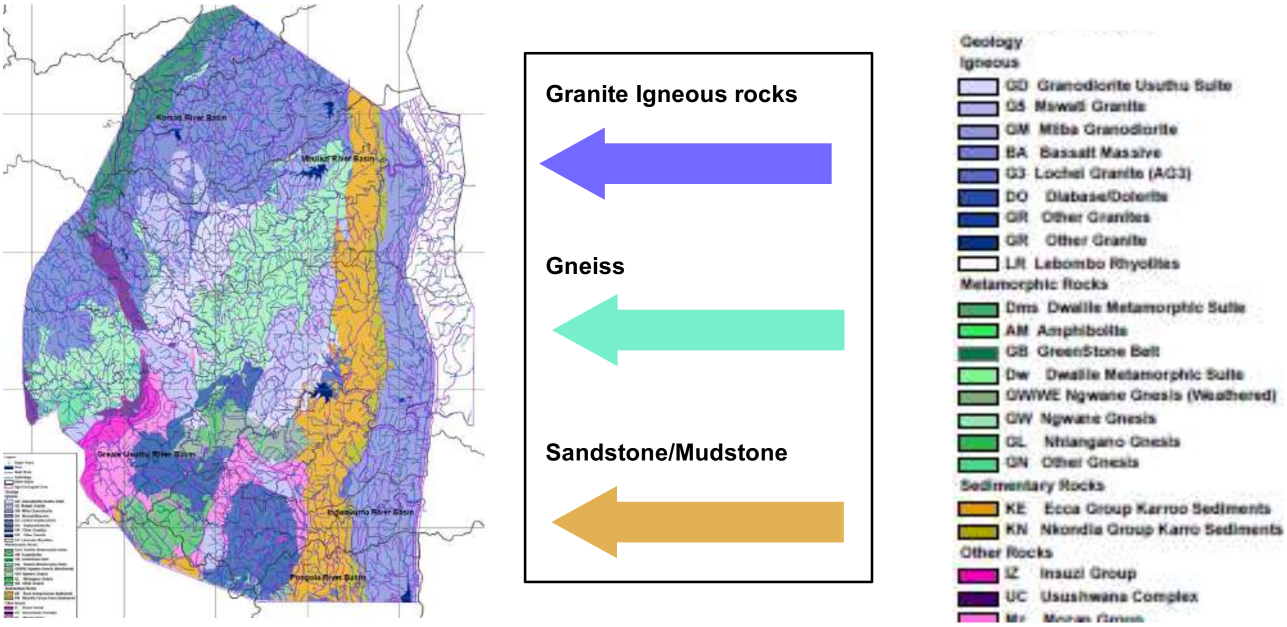
Soil type is also related to the parent rocks in the catchment and have a big influence on the river sediments, especially in areas of high erosion, which is typical of most dryland zones. Therefore, soil mapping is also very useful with an obvious preference for sand, loamy sand, sandy loam and some types of loam. This mapping can also have the advantage of identifying areas of bare surface rock (technical pre-condition 3).



Map of suitable and unsuitable soil types (shown in green and red respectively on the map upper right).

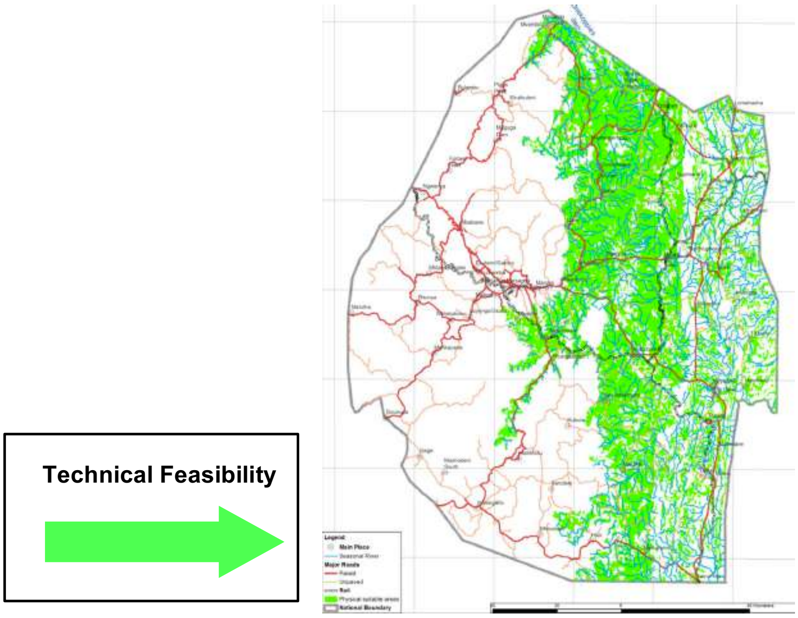
3.4.3.2 Rock types[117]

The deposition character of sediment influences construction of sand dams in river beds. Sediments originate from parent rocks in the catchment area through weathering and erosion. Coarse sand and gravel particles are desirable in the reservoir. The most favourable rocks are granite, quartzite and sand stone, but also dams constructed in gneiss and mica-schist areas have been successful. Areas with the class of sandstone/mudstone can be marginal, whilst those underlain by basalt tend are less favourable.[118]



3.4.4 Technically feasible areas for sand dams

Overlaying these filters, identifies the areas where sand dams may be appropriate and need more detailed Google Earth investigation and field visits to establish definite feasibility. If river slope data had been available easily, along with a greater understanding of the correlation between soil types, the scattered area to the east of the country would also have been discounted. As can be seen below, however, a 66% success rate was established in site visits, which would have been higher if there were not 'political' reasons for the number of site visits in the north (a lower Poverty Index %).



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[117] http://www.sandatlas.org/rock-types/
[118] Ministry of EnvIgneous Rockironment, Water & Natural Resources, Kenya, 2015.

3.4.5 Socio-economic prioritisation using GIS

For potential regional programmes, GIS can also be used to identify the feasibility of sand dams in the areas where the potential programme wants to focus. Obviously, if doing this as a local NGO already with experience of the needs and priorities this is less appropriate. However, there is still some applicability of this approach regardless.

In the case of the UNDP/Swaziland Government the GEF climate change adaptation programme was focused on these goals:

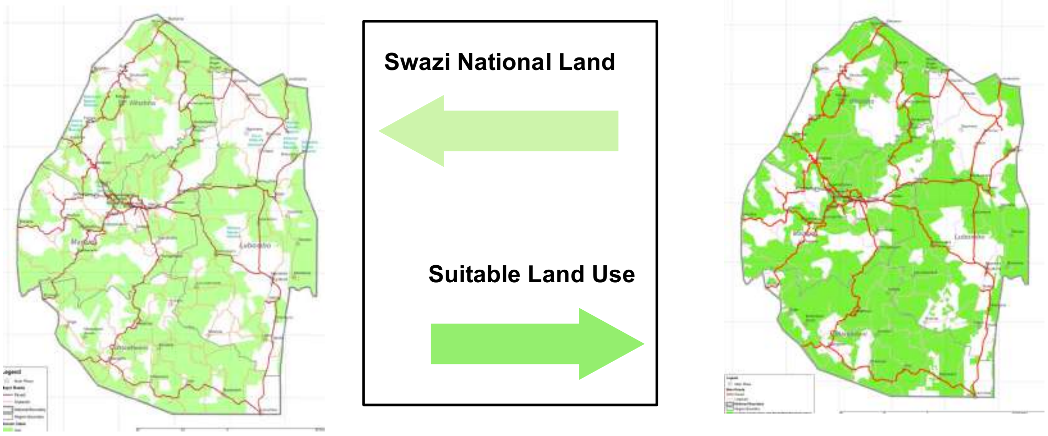
1) **Ensuring access to potable water to all citizens by 2022 (GoS, 2014)**

2) **Supporting sustainable livelihoods (UNDP, 2012)**

Consequently, GIS was used to identify appropriate land tenure, land use, poverty levels and current accessibility to safe water to further narrow down target areas. Whilst water accessibility was very useful it would have been useful to have current water point mapping available, which is available in some countries, for example Uganda. This would of course help identify both sand dams and other water harvesting or abstraction technologies in use to further enable feasibility and prioritization assessments.

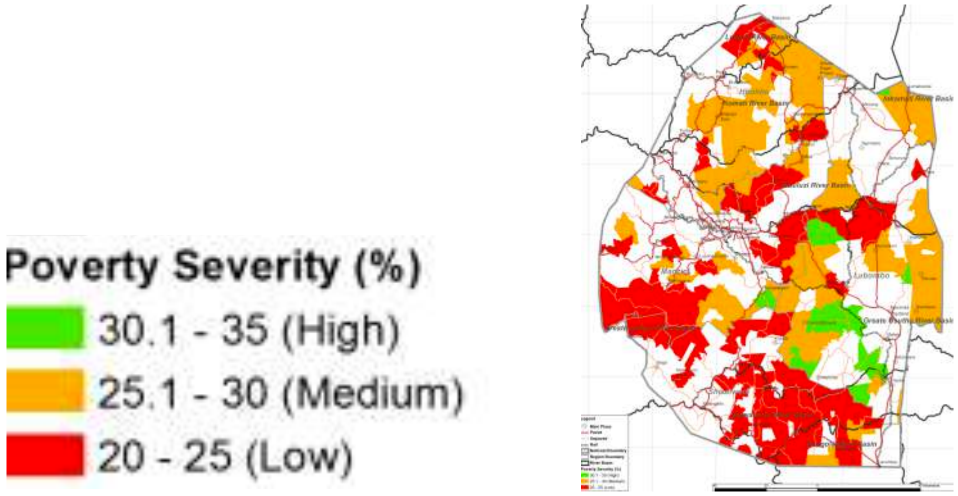
3.4.5.1 Land tenure and land use

About 70% of people and most of Swaziland's poor live on Swazi National Land (IFAD, 2013), shown in green on the map below left. The map to the right is very similar showing appropriate areas of land-use that includes communal grazing and small-scale rain-fed agriculture that benefit greatly from sand dam technology.



3.4.5.2 Poverty severity

This utilised the Multidimensional Poverty Index used in Swaziland[119] with priority focus on Poverty over 25%.



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[119] Oxford Poverty and Human Development Initiative Country Briefing (2011) http://www.ophi.org.uk/wp-content/uploads/Swaziland1.pdf

3.4.5.3 Access to safe drinking water

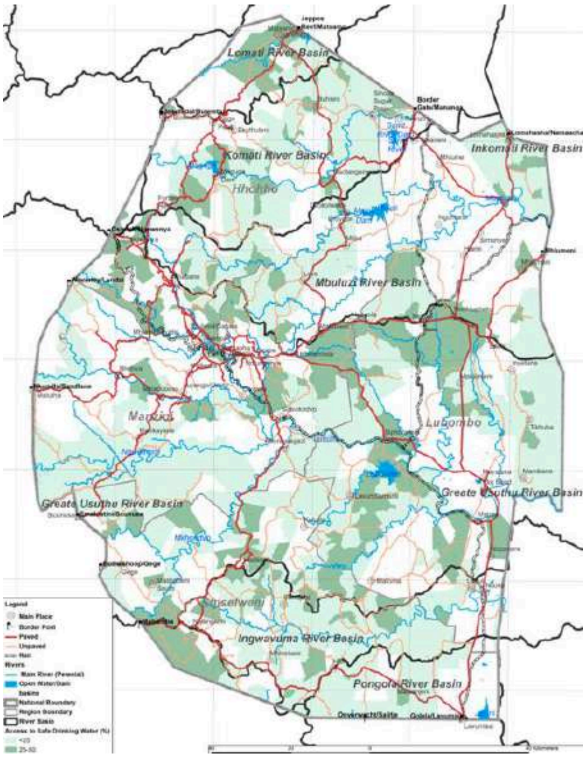
Rather counter-intuitively, light grey/green shading equals 0-25% of the population with access to safe drinking water and mid-grey/green showing 25-50% access.

0-25% Access to Safe Water

🟩

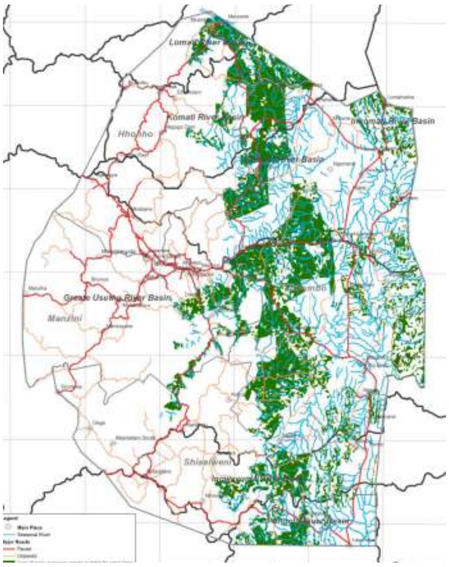
25-50% Access to Safe Water

🟩



3.4.6 Socio-Economic Priorities versus Technical Feasibility

The overall conclusion was that an area of 5,500km^2 were feasible for sand dams with the potential to build between 250-500 sand dams at least – over 1,000 if sand dam rural road crossings were included.

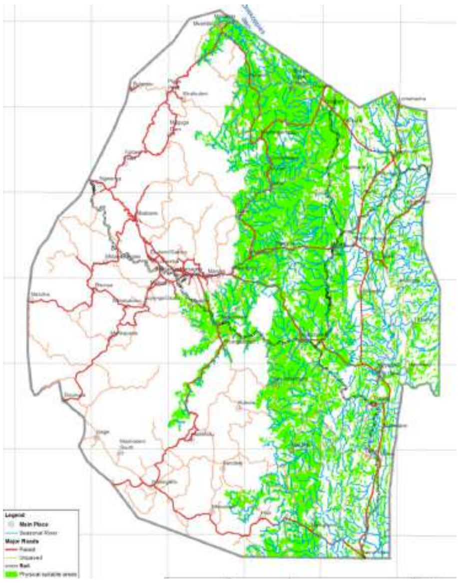


Socio-Economic Priority

←

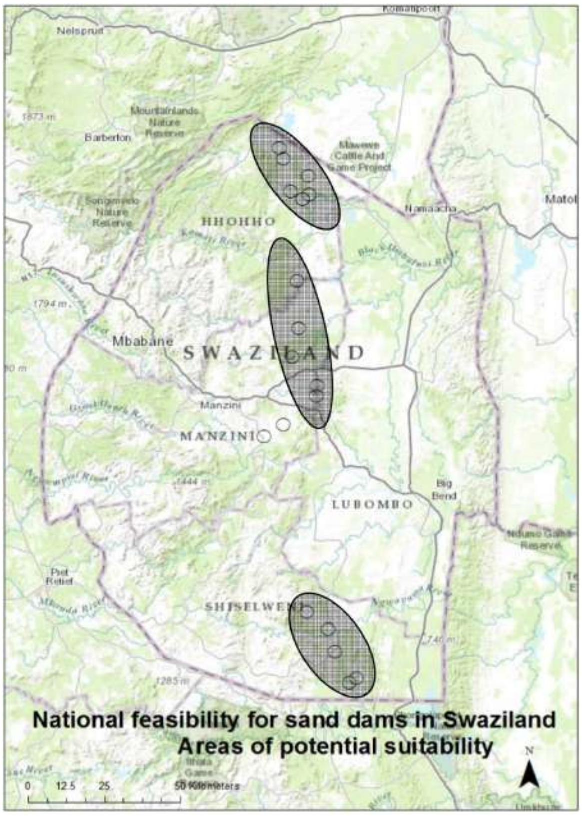
Technical Feasibility

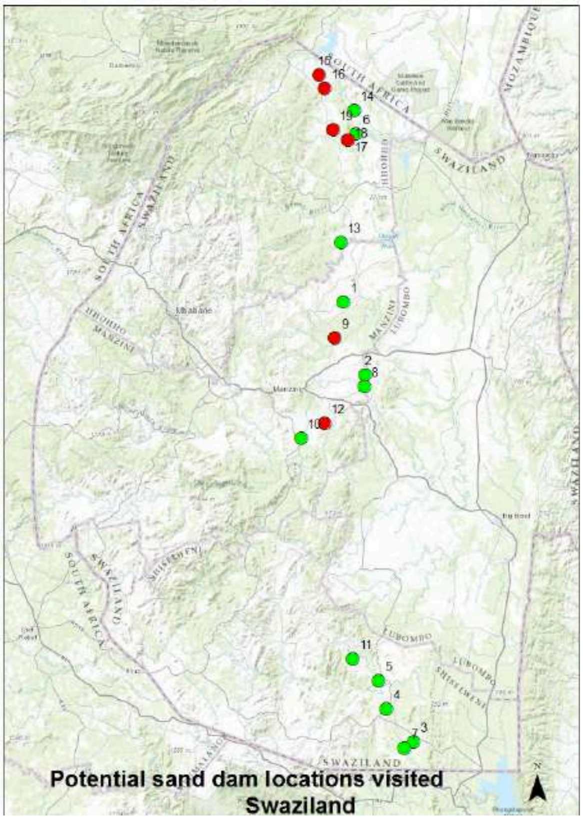
→



3.4.7 Siting Feasibility & Pilot Dams

The agreed focus areas for establishing pilot sand dams is indicate din the grey areas on the map below left. The 19 sites visited are marked red and green for suitability. The overall conclusion was that an area of 5,500km^2 were feasible for sand dams with the potential to build between 250-500 sand dams at least – over 1,000 if sand dam rural road crossings were included.



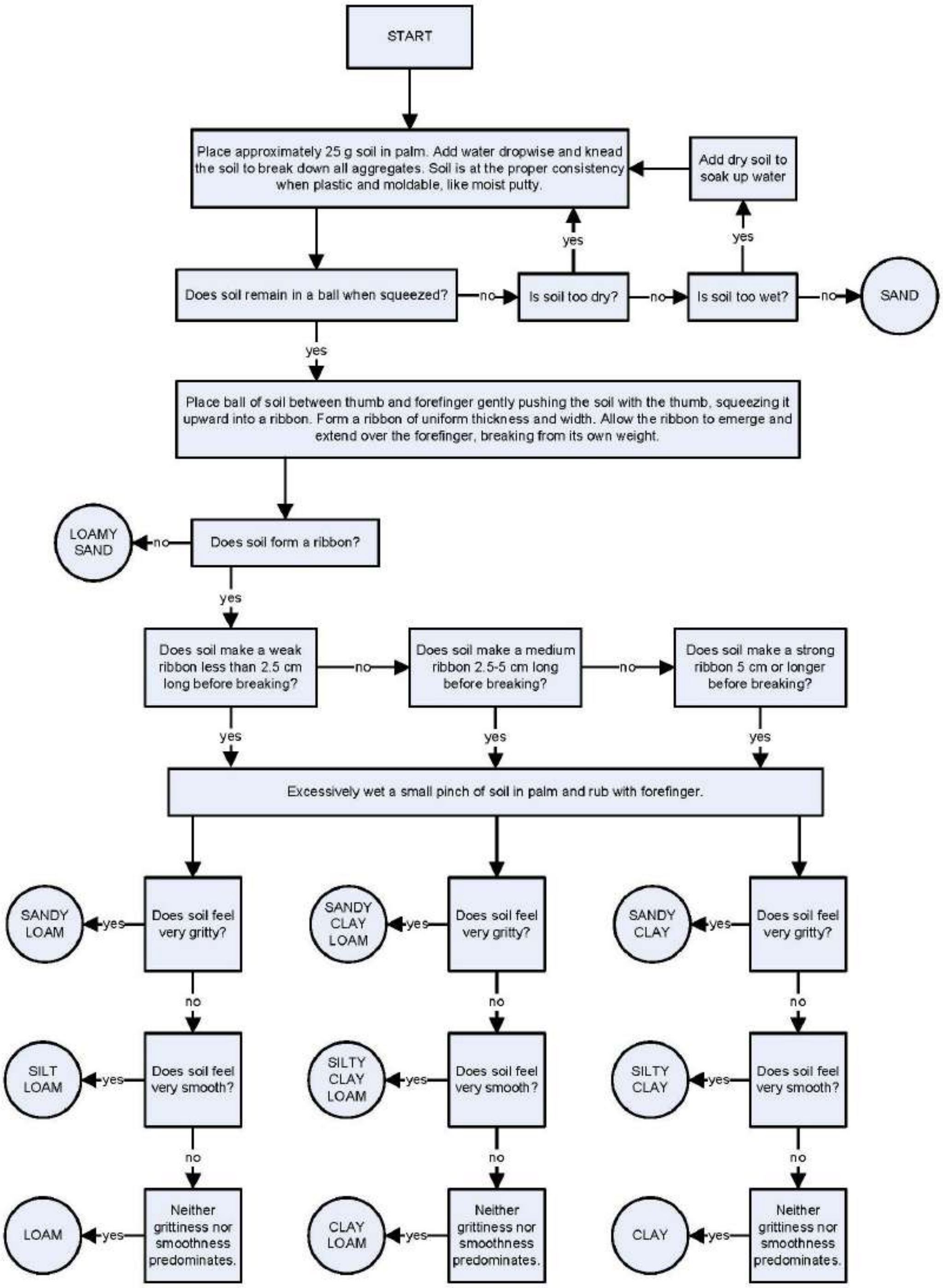


3.5 The testing of soils and/or riverbed sediments.

This section summarises the methodologies for testing river sediments both in the field and in a laboratory. They can be used to measures sediment profiles, uniformity, porosity, drainable porosity and permeability:

- Feel method, including ball and ribbon method.
- Sediment settlement test.
- Dry sediment sieve test.
- *Porosity* and *drainable porosity* tests.

3.5.1 The feel method (or ball and ribbon method)[120]



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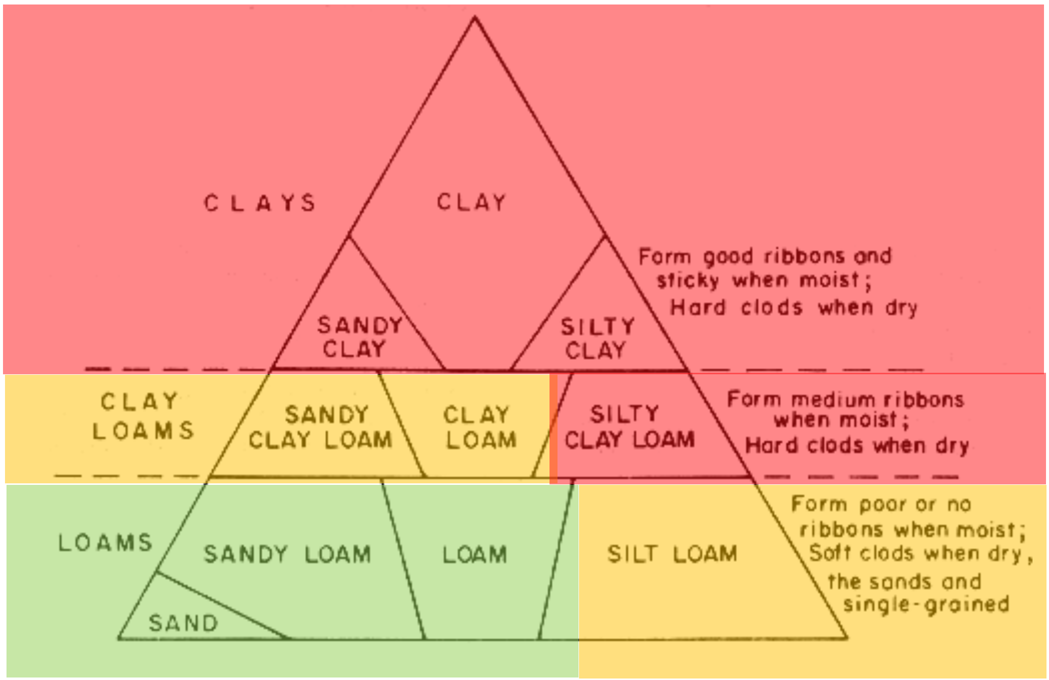
[120] Modified from S.J. Thien. 1979. *A flow diagram for teaching texture by feel analysis.* Journal of Agronomic Education. 8:54-55. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311

The diagram below[121] links together the tests with sediment types and their crude relative suitability in red, yellow and green shading (added by the author), which shows a sediment preference for sand and sandy loams:



3.5.2 Sediment settlement test

This is a crude method of measuring sediment profile BY VOLUME

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

$$\textbf{\% sand by volume} = \frac{\textbf{Depth of sediment after 20 secs. (sand)}}{\textbf{Total depth of sediment}}$$

$$\textbf{\% silt by volume} = \frac{\textbf{Depth of sediment after 5mins. - Depth of sediment after 20 secs.}}{\textbf{Total depth of sediment}}$$

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

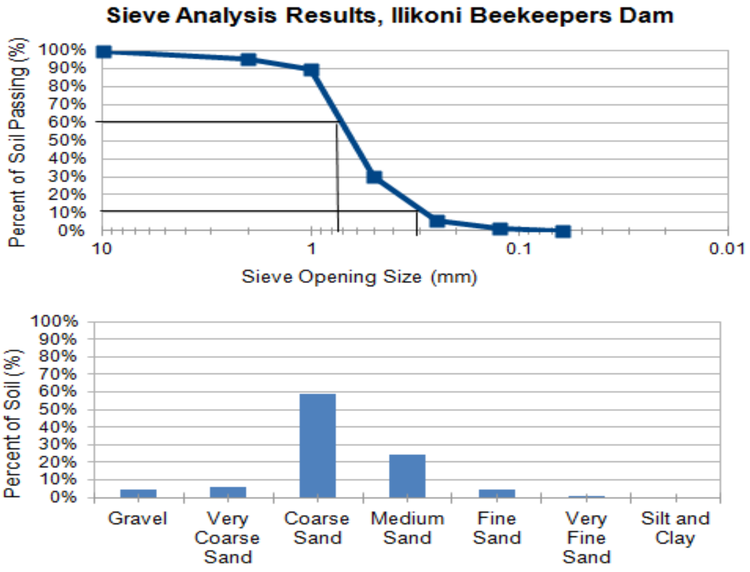
---

[121] Figure 2.5 modified from Dura, 1982 http://www.fao.org/docrep/field/003/E7171E/E7171E02.htm Further modified by Maddrell, S. 2017.

3.5.3 Dry sediment sieve test

All river sediments contain a mix of sediment types rather than a single uniform sediment – so a test to measure relative suitability for sand dam is more complex. One step towards this goal is to understand the mix of sediment types and their relative presence in a sediment to give it a 'net suitability' for sand dams. By sieving the sediment, it is possible to know the size and distribution of the particles. See below for an example analysis at a site on the Kambu River, Kibwezi District, Kenya.

There is a range of sediment testing equipment on the market. The author advises that a higher quality, mechanical shaker sieve to get a sufficient level of accuracy. Dry sediment is passed through a stack of sieves, each sieve corresponding to the international classification of particle size (ISO 14688). The weight of the sediment for each class is measured and its percentage of the total sediment weight calculated. 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. D10 is the diameter for which 10% of the sediment (by weight) is finer. D10 is also called the effective size and is used to estimate permeability. D60 is the diameter for which 60% of the sediment by weight is finer and the uniformity coefficient (Cu), which equals D60/D10, 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 for a sand dam.[122]



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

Warning: It is also critical to note that sediment tests should be done for a fixed volume of sediment as it is the quantity of silt and clay for a given volume that influences porosity and drainable porosity rather than the % weight in a fixed weight of sediment. The reason why this is important is that different volumes of sediment will have different densities and therefore weights (a sediment full of gravel and silt for example, compared to coarse sand). Without this, any rule determining the maximum % of silt or clay using the above method will be meaningless as the results will be inaccurate, misleading and incomparable.

Note 1: The author and Excellent Development started its sediment testing using a simple Keck shaker, which measures very low volumes of sediment using manual shaking and therefore has a low level of accuracy, especially in measuring relative silt/clay levels (because of their very low density), which are critical to *permeability* and *drainable porosity*. Whilst this low-cost method helped gain an insight into differing sediments, the method is not accurate enough to gain a sufficient level of knowledge, especially for the very fine sands, silts and clays, and more sophisticated equipment is strongly advised.

Note 2: It is recommended to use equipment that can test a higher volume of sediment, thereby giving more accurate differentiable results, especially for the low quantities of very fine sands, silt and clay that may exist in a river sediment.

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[122] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013

3.5.4 A test for sediment porosity & drainable porosity

Porosity is the amount of water a sediment will hold – and the drainable porosity is a measure of the abstractable water from a sediment, particularly key for sand dams that create their own perched aquifer or integrate into the water table of an unconfined aquifer. For a sand dam a minimum of 25% drainable porosity is recommended.

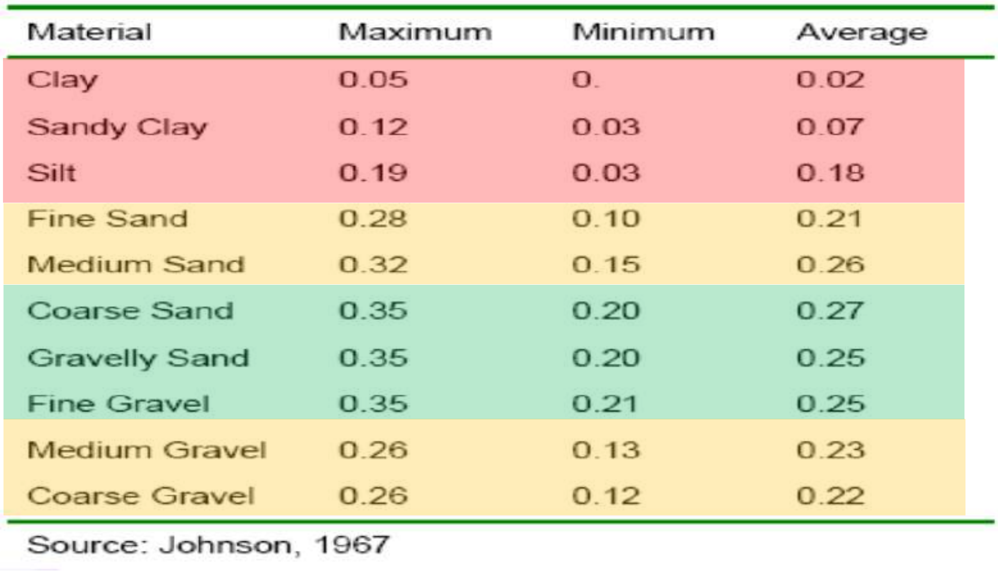
- **Fill a container of known volume (5-20 litres are preferable for accuracy) with a sample of dry river sediment,**
- **Saturate sample with water and measure volume of water added:**

***Porosity* (%) = Volume of water added ÷ Volume of sediment**

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

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

The table below[123] shows the range of specific yield (drainable porosity) values for different sediments, marked up with their red/yellow/green suitability. It is worth reiterating, that at greater detail level, sediments have a *porosity* and *drainable porosity* range and that sediments are almost always a mix of sediments when also the *uniformity coefficient* becomes important in terms of its influence on *drainable porosity*. Therefore, testing is the only way to establish the actual values.



Material	Maximum	Minimum	Average
Clay	0.05	0.	0.02
Sandy Clay	0.12	0.03	0.07
Silt	0.19	0.03	0.18
Fine Sand	0.28	0.10	0.21
Medium Sand	0.32	0.15	0.26
Coarse Sand	0.35	0.20	0.27
Gravelly Sand	0.35	0.20	0.25
Fine Gravel	0.35	0.21	0.25
Medium Gravel	0.26	0.13	0.23
Coarse Gravel	0.26	0.12	0.22

Source: Johnson, 1967

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[123] Johnson, 1967. Accessed from http://waterinfotech.com/Grwater/physical%20properties.pdf Colour-coding by Maddrell, S. 2017.

3.6 Sand dam hydrological functions

Traditionally, sand dams have been built where there is a confining layer of rock or clay close to the surface (referred to as a 'perched aquifer') to enable abstraction from horizontal abstraction pipes, scoop holes or, more recently, shallow wells. This could be a perched aquifer or an unconfined aquifer close to the surface. Alternatively, or also, sand dams are built in areas where the water table is close to the ground surface whereby the sand dam recharges the unconfined aquifer and supplements what is already a water supply for local communities. Excellent Development's experience in Rajasthan, India has demonstrated that sand dams have massively impacted* the recharging of unconfined aquifers at much deeper levels and (almost certainly) confined aquifers. Therefore, it seems that a process described by Hofkes and Visscher (1986)[124] as "Artificial Groundwater Recharge" can positively impact much deeper unconfined and confined aquifers than previously believed. The author contends that this is, potentially, a 'game changer' in terms of the technical feasibility and applicability of sand dams on a wider basis. This certainly should impact the choices of abstraction methods for sand dams and during feasibility studies ensure a greater understanding of the hydrology is understood.

***Rajasthan groundwater recharge:** A sand dam (6 metre sub-surface and 0.9 metre above-surface) was built in Thumba ka Goliya, Jalore, Rajasthan, India in partnership with the Jal Bhagirathi Foundation (JBF) in 2013. The sand dam has had enormous impact on the ground water levels and output from both private and government tube wells both in terms of volume and salinity.

Output from government tube wells has increased by 50% and water availability increased from several hours to 24 hours per day[125]. The impacts originally affected tube wells for 23 farmers but be 2015 it was realised that 109 private tube wells in the area were positively impacted. Water levels reported by local farmers in the tube wells previously were 75 metres deep but reduced to 60 metres by 2015 and were only 45 metres deep in 2016[126].

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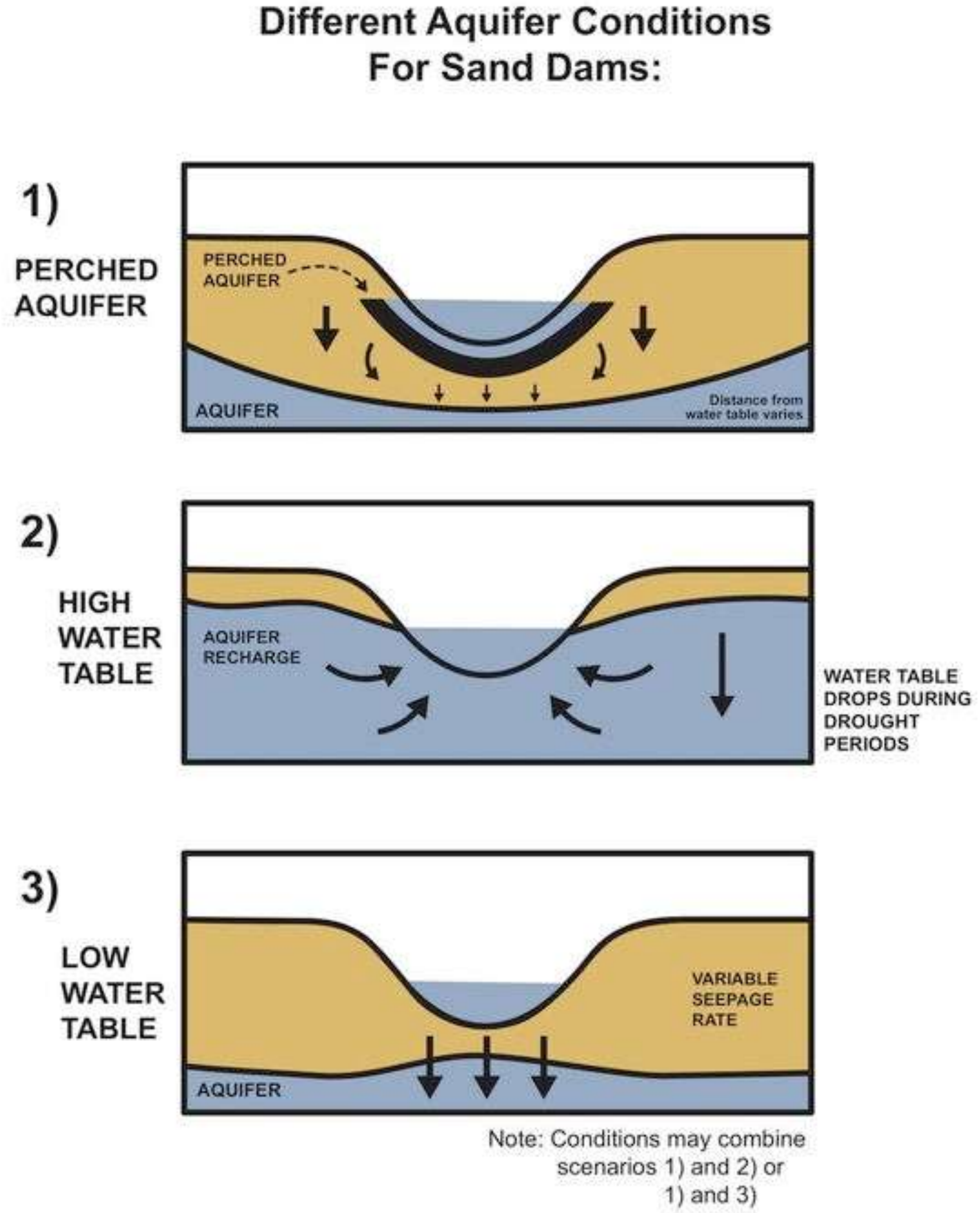
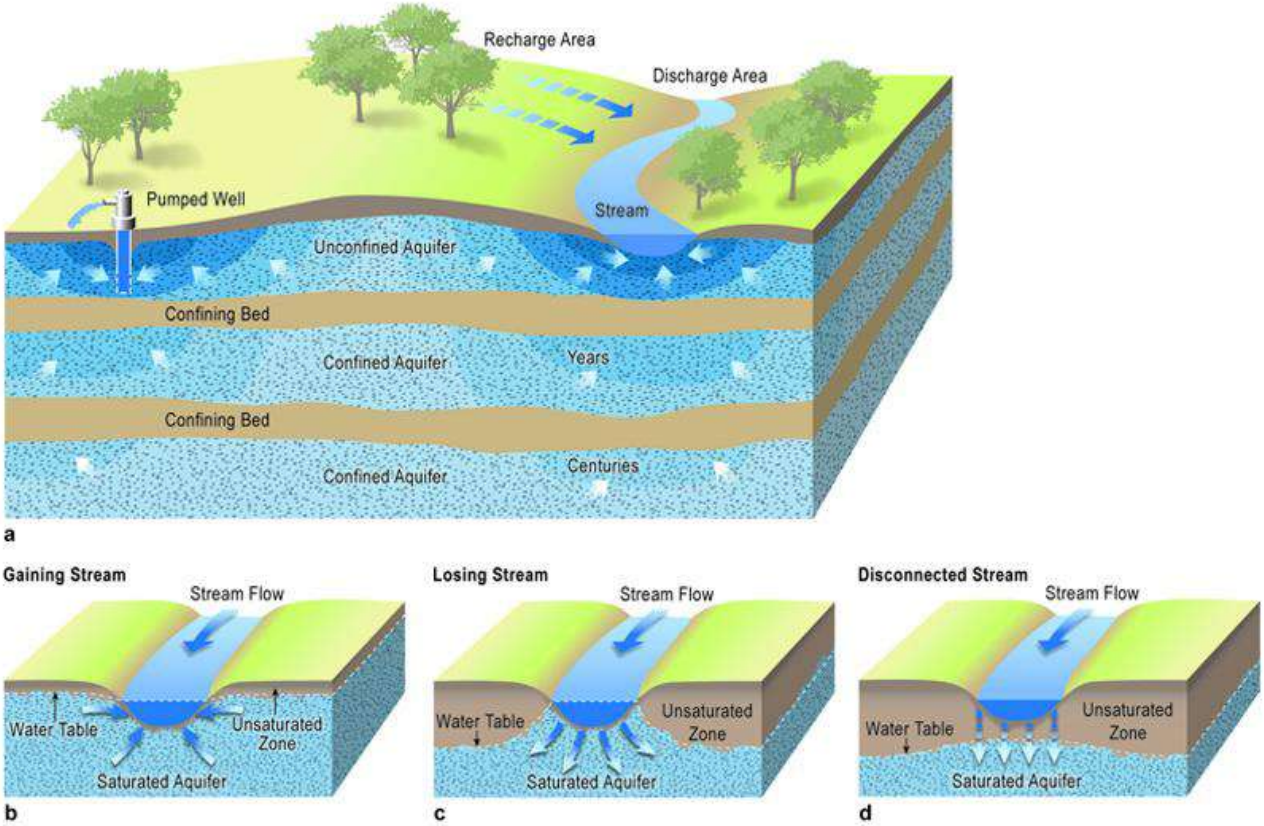
[124] Hofkes, E.H. and Visscher, J.T., 1986. Ibid.

[125] Interviews carried out on visit by Simon Maddrell to Rajasthan, December 2015.

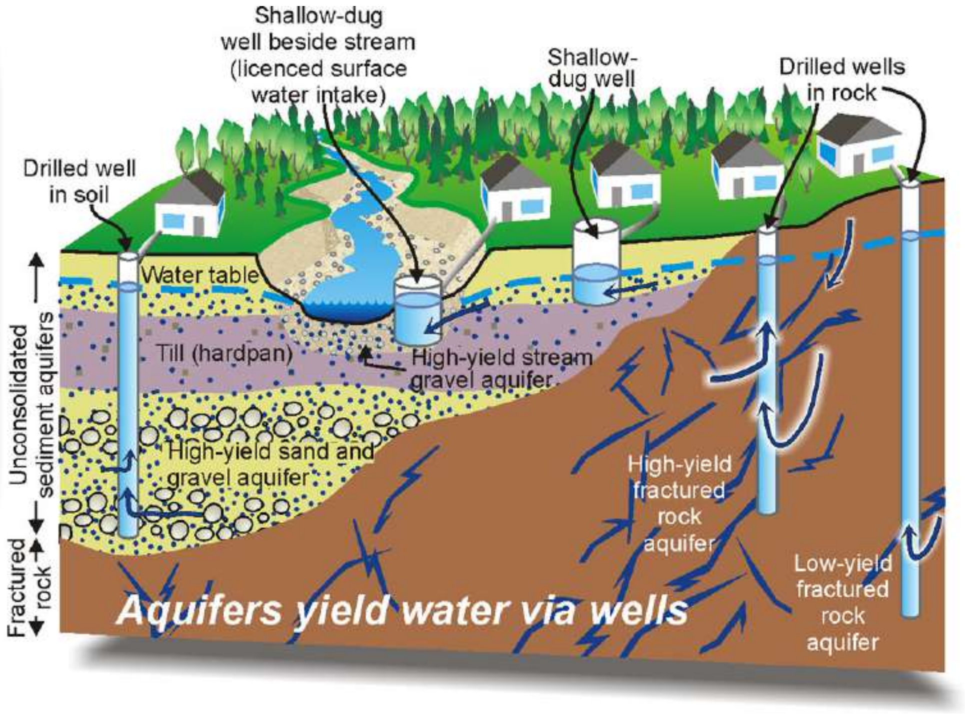
[126] Interviews carried out on visit by Simon Maddrell to Rajasthan, December 2016.

The graphic below shows differing aquifer conditions that sand dams can be utilised in and how they may recharge aquifers. In fact, sand dams occur, and can be built, in areas that combine scenario 1) and 2) and scenario 1) and 3). There are times for example, when a sand dam is not just built on a rock bar – but at the downstream end of a rock base that can serve as a ‘storage container’ and thereby be abstracted using scoop holes or infiltration galleries. Where the water table remains deeper, shallow wells can access the recharged aquifer. Depending on the permeability of the containing beds between uncontained aquifers and contained aquifers, lower aquifers can be recharged (as seems to be the case in Rajasthan).





The graphics above[127] and below[128] show differing aquifer conditions and the different well abstraction methods available to sand dam sites depending on sediment. soil and rock permeability.



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[127] http://www.watereducation.org/aquapedia/aquifers

[128] http://www.cgenarchive.org/bowen-island-underground.html

Chapter 4: Sand Dam Technology Transfer

4.1 Technology and Product Transfer

All technologies and products need, at minimum, ‘applying’ to new contexts – otherwise they will either underperform or fail, more likely the latter. In some cases, the technology or product needs ‘adapting’ to avoid failure (or perhaps even something else connected to the product’s success like legal regulations) because the contextual differences are so great that significant modification in design, function, or even purpose, is needed. “Copy and paste” rarely works with technology transfers and never brings optimum results.

Considering your mobile phone illustrates both ‘application’ and ‘adaptation’ and the importance of focussing more broadly than the actual product itself. Can you understand the language that the phone uses? Mobile phone screens and their manuals, are *adapted* with the language utilised in your market – and often other languages can be downloaded to customise your product to your needs. Can you plug your phone into your power supply to charge it? In this regard, the phone is the same the world over – but it was the phone charger accessory that is *adapted* to local power sockets and voltages.

A great example of ‘adaptation’ is the M^{c}Donald’s India menu (http://www.mcdonaldsindia.com/products.html) whereby one of the world leaders in standardisation removed all their beef and pork products, added both spice and Indian-style vegetarian options, like *aloo* and *paneer*, whilst keeping their chicken and fish burgers. This, of course, might sound obvious but it is not always as obvious as one might think.

To avoid product and technology transfer failure, the approach needs to appreciate that the ‘devil is in the detail’. Arguably, the best example is Coca Cola’s Dasani bottled water brand in the UK[129], which subsequently meant the cancellation of its launch in France and Germany despite Dasani being the largest selling water bottle brand in the USA[130]. Firstly, Coca Cola under-estimated the UK market response to the fact that Dasani was in fact treated tap water and not the spring water the UK market was used to. Whilst this was reported weeks earlier in the trade magazine, The Grocer, it was immediately picked up by the UK press after the launch in 2004. The tabloid press also picked up on the uncanny resemblance to a 1992 episode of the leading UK sitcom ‘Only Fools and Horses’ where the main protagonist Del Boy sold bottled ‘Peckham Water’ from the tap. Coca Cola were treating tap water from down the road in Sidcup. Whilst Dasani was reeling on the ropes from the bad publicity and response, three weeks later it suffered a knockout blow from which it never recovered in Europe. Unfortunately, the combination of the Sidcup water, their filtration process and the adding of minerals resulted in bromate, a potential carcinogenic, reaching levels twice that allowed by the UK’s Food Standards Agency[131]. In five weeks, Dasani had come and gone from the UK market costing Coca Cola millions of dollars then and ever since. How significant Coca Cola under-estimating the risk of the UK public’s social and cultural response to ‘treated tap water’ was is uncertain. After all, it is still proudly and effectively marketed as tap water around the world, “we start with the local water supply, which is then filtered by reverse osmosis to remove impurities. The purified water is then enhanced with a special blend of minerals”[132] But certainly, the failure to comply with UK legal standards should have been avoided and caused not only the withdrawal of half a million bottles of water from the market but the withdrawal of Coca Cola from the UK water market for many years.

Sometimes a product simply won’t work in a different context. As discussed in Chapter 2.5.2, culvert bridge technology transferred to rural roads in drylands has been almost entirely disastrous and continues to be so. It is a great example of a technology transfer that simply does not work most of the time (and is much more expensive in terms of repair and maintenance even when it does). The point here is that when transferring a technology or product one must be open to the fact that it might simply not work. The same can sometimes be said about sand dams (as discussed at length in Chapter 3). However, sand dam technology, even where it can technically work, will always need to be ‘applied’ or ‘adapted’ to effectively and efficiently meet its purpose.

The following section shares how Excellent has adapted corporate product delivery processes to assess and, if feasible, manage the transfer of sand dam technology to new areas.

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[129] http://news.bbc.co.uk/1/hi/business/3809539.stm

[130] https://www.statista.com/statistics/188312/top-bottled-still-water-brands-in-the-united-states/

[131] https://www.theguardian.com/uk/2004/mar/19/foodanddrink

[132] http://www.dasani.com/water

4.2 Programme Delivery Process

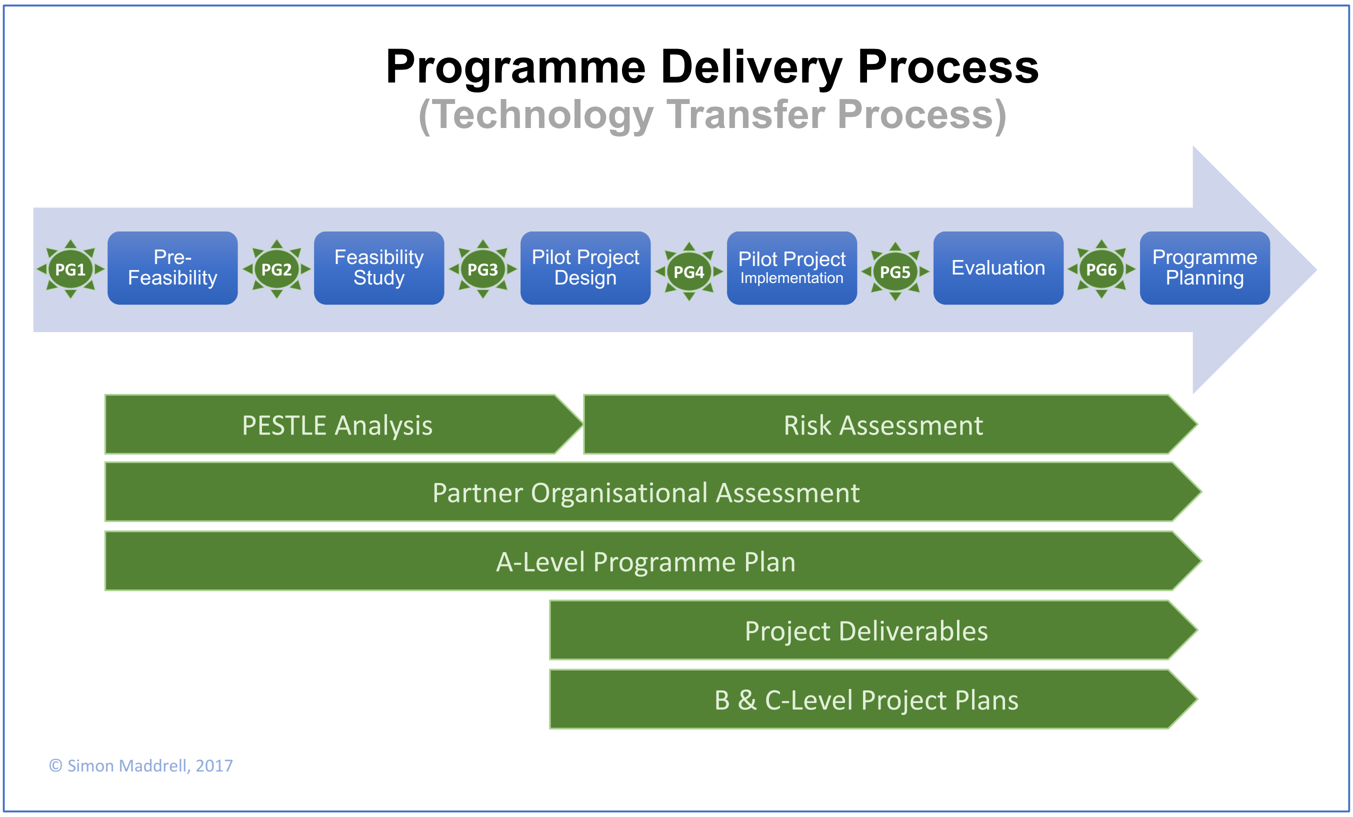
The author has adapted corporate product delivery and change programme approaches to develop a Programme Delivery Process (Technology Transfer Process) to define a process to ensure a step-by-step approach is taken to the possible delivery of a new sand dam programme in a different context. This establishes a strong governance and management of the investment of time and resources and assessment of risk as a programme progresses. This is managed by senior management Phase Gate Reviews to approve programme progression and manage the resolution of key issues.

Principles:

- **Most projects fail because of "what you don't know" NOT because of "what you do know";**
- **As soon as you establish the technical feasibility of sand dams it immediately becomes the least of your problems.**
- **Remember "it's not about the dam" [It's about the 'Purpose' NOT just the 'Output']**

Practices:

- **Start with the community stakeholders: current state, needs and priorities; [All stakeholder groups need to be considered, including the silent ones.]**
- **Think things through, all the way through; [The devil is in the detail, often in disguise.]**
- **Plan, plan, plan and monitor; [There's more to 'building a dam' than delivering materials and labour; There's more to plan than just 'building a dam']**



Note: A PESTLE Analysis assesses both the macro- and micro-geographical factors that may impact the technology transfer: Political, Economic, Social, Technical, Legal and Environmental

Phase Gate 1: Pilot Programme Proposal

Stage 1: Pre-feasibility Study. If necessary, desk-based only assessment of strategic alignment, technical suitability, implementing organisation suitability, financial do-ability of proposed programme.

Phase Gate 2: Pilot Project Assessment

Stage 2: Feasibility Study. PESTLE analysis including technical feasibility of sand dams and other options; more in depth organisational assessment; A-level project plan.

Phase Gate 3: Pilot Project Initiation

Stage 3: Pilot Project Design. More detailed PESTLE and organisational assessments, project deliverables, B & C-level project plans, risk assessment.

Phase Gate 4: Pilot Project Go/No-Go

Stage 4: Pilot Project Implementation. Implement project, close out phase gate actions, monitor progress of deliverables, manage risks.

Phase Gate 5: Pilot Project Review

Stage 5: Evaluation. Updated organisational and risk assessments; evaluation of pilot project purpose, assess need for another pilot versus progress to programme initiation.

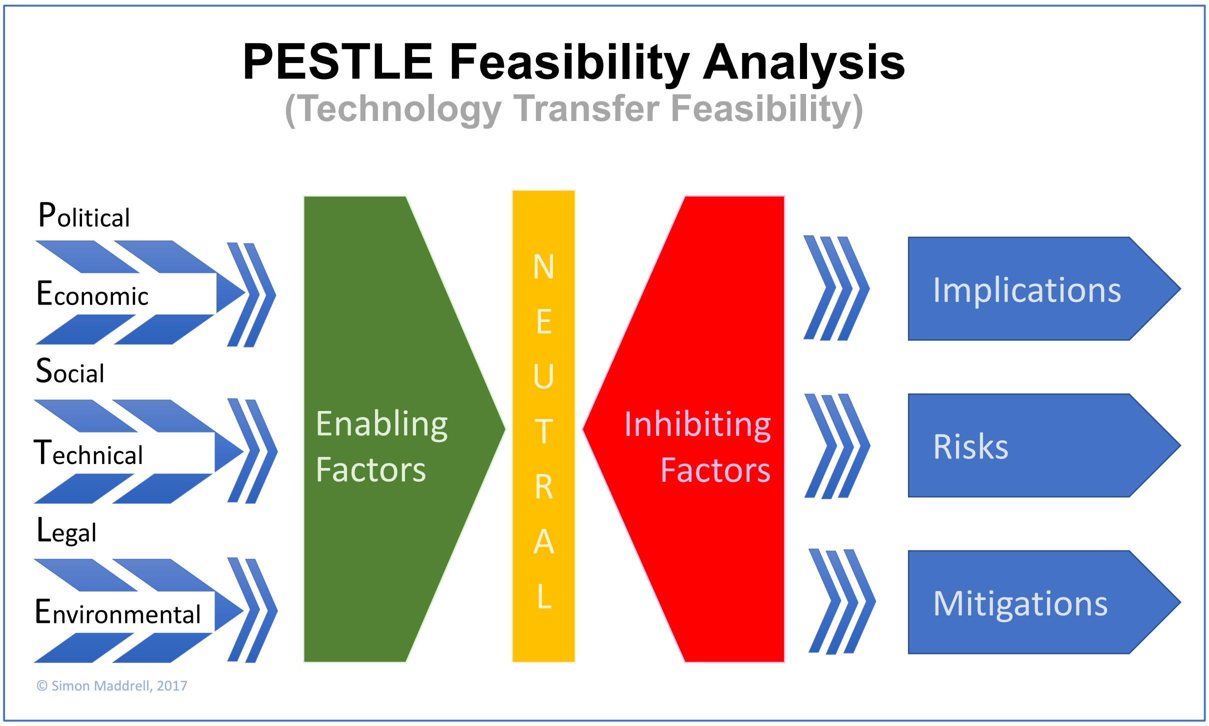
Phase Gate 6: Programme Initiation

Stage 6: Future Programme Planning. Define project plans and objectives for programme start up.

For the purposes of this manual, we will focus specifically on describing the PESTLE analysis, which is technology specific whilst the other elements are generic to programme delivery and often already incorporated into an organisations governance and management structure.

4.3 PESTLE Feasibility Analysis

The author has adapted PESTLE analysis, a corporate approach to market analysis and business strategies, to both assess the feasibility of transferring sand dam technology and to inform the design of both pilots and programmes. Using the checklist, the new context that is being considered is analysed for factors that either inhibit, enable and/or are neutral in terms of the planned technology transfer. Assuming feasibility is established, then from a project planning and design perspective, implications and possible mitigations are understood and planned to be resolved. At the same time the risk in terms of impact and likelihood is assessed. The PESTLE analysis framework assesses both the macro- and micro-geographical factors that may impact the technology transfer: Political, Economic, Social, Technical, Legal and Environmental. Using an evolving checklist of questions an overall assessment is made to help manage the progression through programme phase gates. Below is a summary of the questions considered, including examples or where inhibiting factors have been identified and resolved in some of Excellent Development's programmes.



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4.3.1 Political (& Institutional) Factors

- Existing social community (civil society) structures and organisations
- Legal status of community-level structures /organisations
- Linkages between tribal/cultural; civil society; local, regional and central governmental structures
- Political stability (national & local)
- NGOs & CBOs regulatory framework (international and national)
- National and local government support for rural development (water, environment and agriculture)
- Donor funds availability
- Other key stakeholders:
    - Other NGOs
    - NGO networks
    - UN agencies
    - Commercial or industry e.g. mining, large scale agriculture
    - Politicians
- Security environment

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, the local authority co-ordinates and authorises development activities. This includes the approval of technology choices (some of which, like hand pumps, are defined at national level). International and local NGO plans must align with and contribute to local development plans. Wider consultation and engagement is required in this situation and may conflict with community needs or priorities.

4.3.2 Economic Factors

- HDI (or another poverty index) Nationally & Regionally
- Beneficiary Livelihoods & Incomes
- SDG 6.1. Drinking Water
  - Accessibility
  - Availability
  - Quality
- SDG 6.5. Water Resource Management
- SDG 6.6. Eco-Systems
- Economic Growth & Stability (National & Regional)
- Inflation & Material price stability
- Exchange Rates
- Infrastructure esp. Roads, Telecoms,

Northern Rangelands, Kenya: The counties of Laikipia, Isiolo, Samburu and Marsabit are unusual in that there are 19 community conservancies supported by an umbrella organisation, the Northern Rangelands Trust; six private conservancies and parcels of private land with a mixed economy mainly of tourism, wildlife conservation and pastoralism. Community conservancies control their own geography with comparatively minimal political and governmental support or interference, although this has increased since devolution to County Governments in 2013. Development requires engagement with a wider range of stakeholders and potentially conflicting livelihoods and ethnicity, with their being ten tribal communities in the region.

4.3.3 Social

- Tribal and inter-tribal factors and/or issues
- Traditions and customs
  - gender roles
  - water collection methods
  - communal working
- Livelihood types e.g. agricultural, agro-pastoral, pastoral, nomadic, hunter/gatherer
- Education & Languages

Multiple communities in Rajasthan, India: Whilst some villages in Rajasthan are single caste, others include three castes plus other communities or ethnicities such as Muslims and Travellers. This means that more complex needs analysis is required especially as water collection traditions and customs may also differ requiring additional sources and/or abstraction methods.

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 for the common good is viewed with suspicion in many areas, especially in areas where the current ruling party, FRELIMO, is less supported.

4.3.4 Technical

- Technical Skills availability
  - Non-skilled labour availability
  - Generic building skills availability
  - Sand dam building skills availability
  - Dam design skills availability
  - Sand dam design skills availability

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

- Technical Feasibility of sand dam technology
  - Area of sufficiently seasonal rivers
  - Area of sufficiently sandy river sediments
  - Accessibility of bedrock
  - Existing water sources & effectiveness
- Availability, cost and quality of materials
  - Cement
  - Steel & barbed wire
  - Timber (shuttering)
  - Rocks
  - Sand & sand quality
  - Water
  - Hand pumps & spares
  - Piping, taps, ball cocks etc.
  - Tools and/or machinery.

Availability of timber in Zimbabwe & Rajasthan, India: The lack of availability and high cost of timber suitable for formwork has meant that steel shuttering used for building walls and pillars in the building industry have been adapted to form the dam formwork. Due to the forces exerted on the sheets, stronger binding wire was essential to maintain the integrity of the shuttering.

4.3.5 Legal

- Land Ownership
- Legal requirements for building sand dams & using hand pumps etc.
- Dam ownership and/or management
- Access rights to dams for building & collection
- Commercial or Government Land Development Plans
- Water rights law & pricing regulations
- Sand Harvesting Practice and Regulations
- Statutory Law Enforceability
- Impact of Customary Law

Land ownership in Mozambique: Some factors can be both inhibiting and enabling. In Mozambique, most land is state owned. As a result, individual farmers have little incentive to, or experience of, planting trees, terracing land on 'their' farms. Shifting agriculture and 'slash and burn' clearance of land is common place. This is an inhibiting factor to promoting soil and water conservation 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 as well as universal access to the dam.

4.3.6 Environmental

- Climate & agro-ecological zone
- Soil & Water Conservation
- Geology
  - rock, soil & river sediment types
  - surface rock
- Rainfall
  - modality
  - range/period
  - annual mm
- Rainfall seasonality: seasonal, monthly and daily variability
- River flow variability & river gradients
- Hydrology: water table depth incl. seasonal variability
- Sand dam siltation risks
- Water contamination issues & risks:
  - salinity, fluoride, arsenic, other chemical pollution

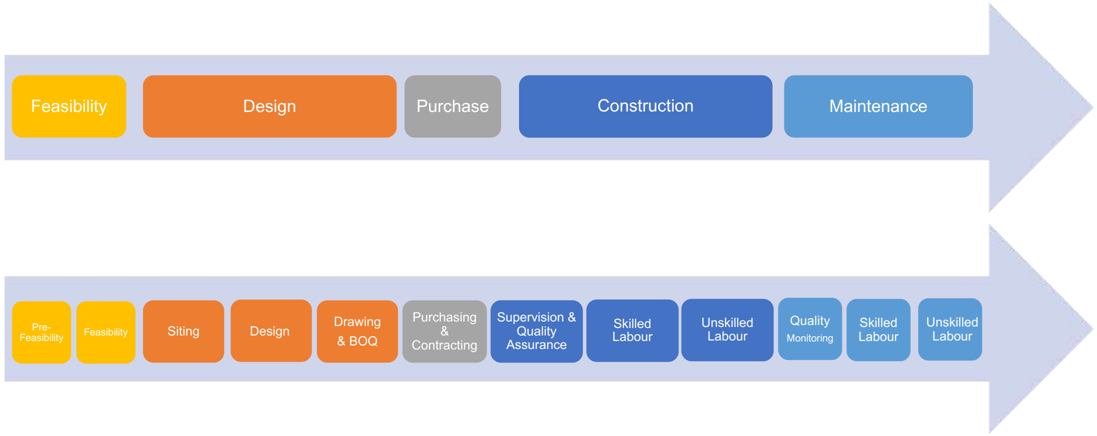
Rainfall in Zimbabwe: The rainfall seasonality in Zimbabwe is not as extreme as in Ukambani, Kenya. The unimodal rain season lasts for four months and many seasonal rivers flow with less intensity and at low levels for most that time. Consequently, there is high risk of dam siltation and sand dams are often designed to end-point size but with the spillway completed in stages of approx. 50-100cm at a time.

Salinity in Rajasthan, India: In many areas of Rajasthan, the ground water is saline and sand dams have been able to recharge (and dilute) ground water – reducing salinity to levels that make it both potable and suitable for growing a wide range of previously ungrown fruits and vegetables.

4.4 Technical Capability Analysis & Development

Usually the biggest barrier to building sand dams – especially scaling-up the technology – is the technical capacity to establish feasibility, site, design and construct sand dams. However, each of the steps of this process has different levels of complexity and uniqueness to sand dams, meaning they have different levels of difficulty in building the technical capacity whilst transitioning from a pilot to a programme.

Clearly there will be a gap in training, skills, knowledge and experience of staff – and this will vary according to the amount of experience the implementing organisation has in areas such as Community engagement, building programmes, masonry, non-sand dam designing, water engineering, masonry, technical drawing, etc.



Technical Competencies for Building Sand Dams
Technical Steps: Roles & Activities

Just as important as the "What?" it is important to ensure that it is not just the direct technical staff who are trained, but also the community engagement and project management staff. The critical need for community knowledge of how rivers flow to be successful in building sand dams makes this an even more important point. However, this is also because, "You can't manage what you don't understand"[133]. To be truly effective and efficient, understanding needs to develop into competence – a state along the journey to expertise.

According to the UK Health & Safety Executive, *"Competence can be described as the combination of training, skills, experience and knowledge that a person has and their ability to apply them to perform a task safely. Other factors, such as attitude and physical ability, can also affect someone's competence."* [134]

To be sustainable, technical capability needs to reach expertise level. The difference between competence and expertise is that **competence** is the quality or state of being able or suitable for a general role while **expertise** is great skill or knowledge in a certain field(s)[135].

There are no short-cuts to **expertise**, which requires both vast experience and the self-awareness that one is always learning. The author, Malcolm Gladwell discusses this in his book "Outliers"[136] that quotes neurologist Daniel Levitin, *"ten thousand hours of practice is required to achieve the level of mastery associated with being a world-class expert – in anything".* However, it is worth acknowledging that there is a difference between regional and worldwide sand dam expertise i.e. it is much quicker and easier to gain regional expertise within certain parameters vs. the ability to apply and adapt the technology in new regions. Also, Josh Kaufman in 2013 promoted a theory, in a TEDTalk[137] and a book[138], that **competence** can be achieved with 20 hours of practise and this would be a good minimum starting point, especially in the design of the training programmes and secondment assignments. It is important to note though, that this headline-grabbing 20 hours means ***twenty hours of practise*** and not twenty hours in a classroom or reading a manual, i.e. ***twenty hours of practically siting and designing sand dams.***

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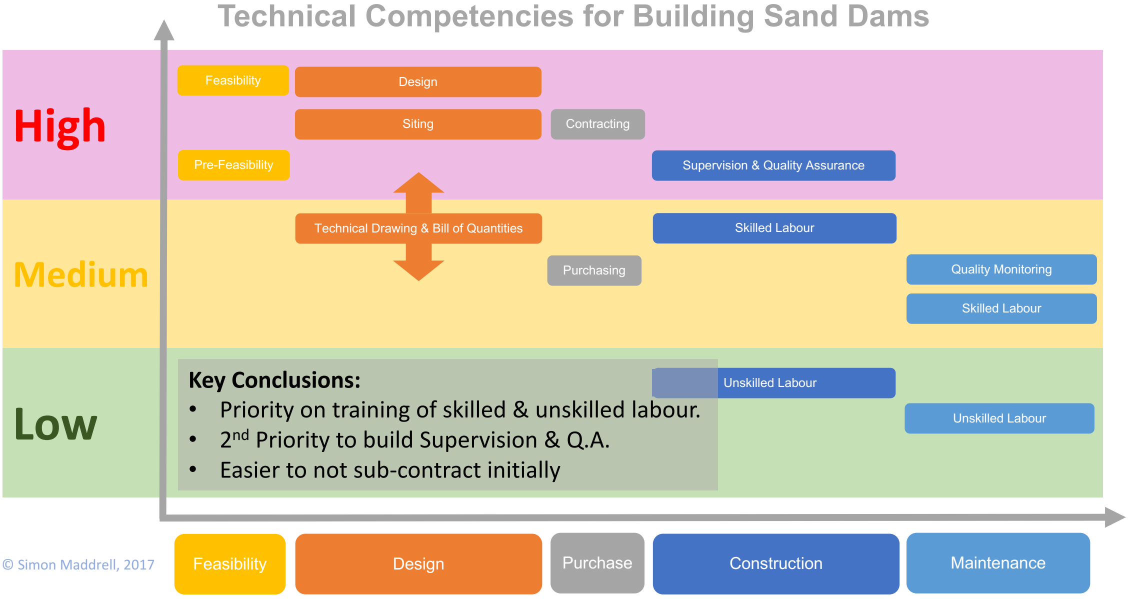
[133] Quote from Graeme Jones, Finance Director, Mikar Holdings Group Ltd., 1990. [Recalled by Simon Maddrell & Stephen Owen]
[134] http://www.hse.gov.uk/competence/what-is-competence.htm
[135] http://wikidiff.com/competence/expertise
[136] Outliers: The Story of Success Malcolm Gladwell. Published by Allen Lane, 2008. p. 40
[137] Josh Kaufman. The first 20 hours -- how to learn anything | TEDxCSU. https://youtu.be/5MgBikgcWnY
[138] https://first20hours.com/

What follows is a methodology of breaking down the range of competencies required to master "the art and science of building sand dams", understanding their relative complexity and assess the training, skills and experience gaps. This includes the assessment of potential risks and opportunities for outsourcing and utilising technology.

The level of training and experience required for each activity varies, meaning that building skills in construction unskilled labour is the easiest first step, followed by skilled labour and then supervision and quality assurance. This is because rubble stone masonry skills are more widely available than sand dam skills *per se* and the specifics to sand dams are most easily taught.

Level & Complexity of Skills, Training & Experience Required

Technical Competencies for Building Sand Dams



Key Conclusions:
- Priority on training of skilled & unskilled labour.
- 2nd Priority to build Supervision & Q.A.
- Easier to not sub-contract initially

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Having said that, developing the capacity and capability to improve training should be a priority. Currently, the author provides consultancy services to organisations wishing to assess feasibility of sand dams and to run pilot projects. In partnership with Excellent, ASDF offer week-long learning visits to support both introducing sand dams to senior people and the training of practitioners in sand dam technology. ASDF have also offered 'secondments' for siting, design and construction staff to learn 'on the job' albeit in a non-structured fashion. There are pre-existing versions of a Sand Dam Manual from Excellent (also in French and Portuguese) and other organisations of varying quality[139]. The Kenyan Government specifically highlights Excellent Development[140] in their manual for small dams[141]. The author is not aware of other specific sand dam training programmes in existence although The Rain Foundation[142] support have produced a sand dam manual[143] and provide regional rainwater harvesting (RWH) training and have also supported WaterAid[144] with sand dams in Burkina Faso. There are also significant sand dam resources provided by AFRHINET[145] and Roads for Water[146].

Whilst Excellent Development and ASDF have supported more organisations than anyone else to build sand dams (nine countries and four areas of Kenya) they recognise the need to improve the provision of training as well as the materials provided to support this. Strategically, this needs to be addressed all the way back in universities and technical training institutions that lack reference to sand dams. Excellent has, in the UK, successfully introduced sand dam educational resources[147] to primary and secondary education, the World Development WJEC AS/A Level recommends it as a case study[148] It is also promoted by The Geographical Association[149] as well as at St. Mary's University[150] teacher training.

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[139] http://www.sswm.info/content/sand-dams-and-subsurface-dams

[140] Ministry of Environment, Water and Natural Resources, Kenya, 2015. Practice Manual for Small Dams, Pans and Other Water Conservation Structures in Kenya http://design-of-small-dams.appspot.com/

[141] http://smalldamsguidelines.water.go.ke/useful_downloads/pdf/PRACTICE_MANUAL_FOR_SMALL_DAMS_PANS_AND_OTHER_WATER_CONSERVATION_STRUCTURES_IN_KENYA. pdf

[142] https://www.ircwash.org/sites/default/files/Nijhof-2010-Rainwater.pdf

[143] RAIN, A practical guide to sand dam implementation (2.0), 2011. http://www.bebuffered.com/downloads/PracticalGuidetoSandDamImplementation_April_2011.pdf

[144] http://www.wateraid.org/news/news/tackling-drought-in-west-africa-training-communities-to-be-water-experts

[145] http://afrhinet.eu/materials/finish/35-international-dissemination-event-in-kenya/39-josep-and-petersen-afrhinet.html

[146] http://roadsforwater.org/wp-content/uploads/2015/07/Sand-storage-dams-Design-and-Construction.pdf

[147] http://www.excellentdevelopment.com/resources/development-education

[148] http://www.wjec.co.uk/uploads/publications/18559.pdf?language_id=1 [Page 3]

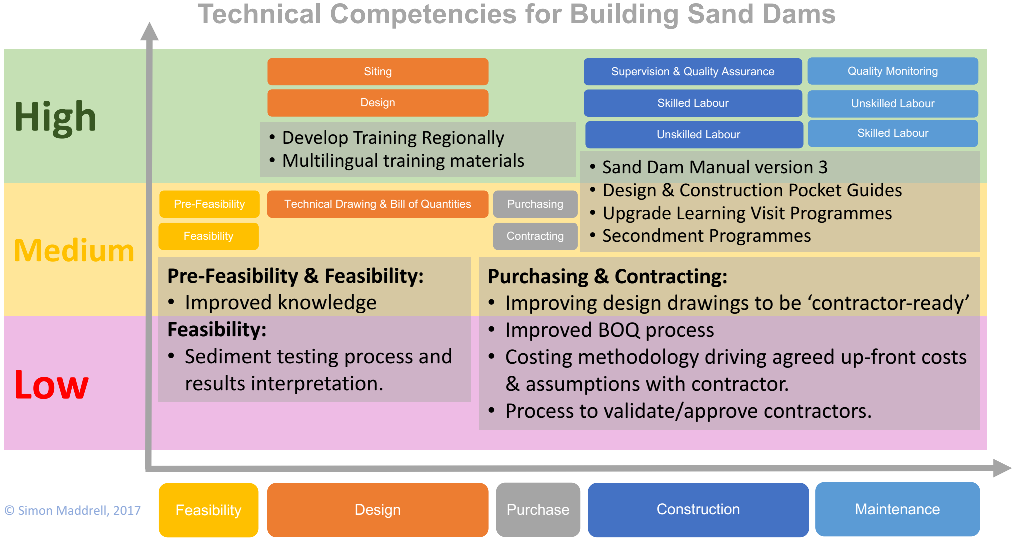
[149] http://geography.org.uk/resources/photosforenquiry/imagesofkenya/constructingasanddam/

[150] www.geography.org.uk/download/GA_Conf08Cook.ppt

However, more practically, sand dam training needs to improve for practitioners with a form of accreditation only being an important consideration in the medium term – the priority, however, needs to be to improve the quality of training available and the capacity to deliver it. In the author's view, starting with accreditation is a mistake; the priority should be to improve training and evaluate its effectiveness, to build a clear picture of what is required to create a meaningful accreditation process. A positive first step would be to enable, in training programmes, at least twenty hours of practice in sand dam siting and design.

Training Priorities: Improved Skills, Knowledge & Experience

Technical Competencies for Building Sand Dams



Training for capability high priorities – "What?"

- **Pre-feasibility:** Improved knowledge of the pre-requisites of sand dams
- **Feasibility:** Standardized sediment testing process and results interpretation.
- **Siting, Design & Construction:** These skills have still not been established outside a few organizations.
- **Drawings:** The current standard of drawings used by ASDF is suitable for insourced construction but can cause serious issues for outsourced contracting. Dam designs do not reference the onsite pegs or markings and there is no single reference point (*datum*), against which the other measurements on the drawing are made, which is critical when the design reference points often get removed during excavation.

Training for capability high priorities – "How?"

- It is hoped that this new version of the Excellent Development Sand Dam Manual will help to support significant improvement in knowledge and skills.
- There is an intent to develop from this manual practitioner guides for siting, design and construction that can be used as 'pocket book guides' for field staff.
- There is an intent to improve the learning visit awareness and training programmes – more strongly differentiated between different stakeholders such as decision-makers, project managers, engineers, community workers etc.
- It is also hoped, by the author at least, to implement the opportunity for short-term secondee programmes for designers and skilled labour to build practical knowledge, expertise and skills, but more critically experience in sand dams.

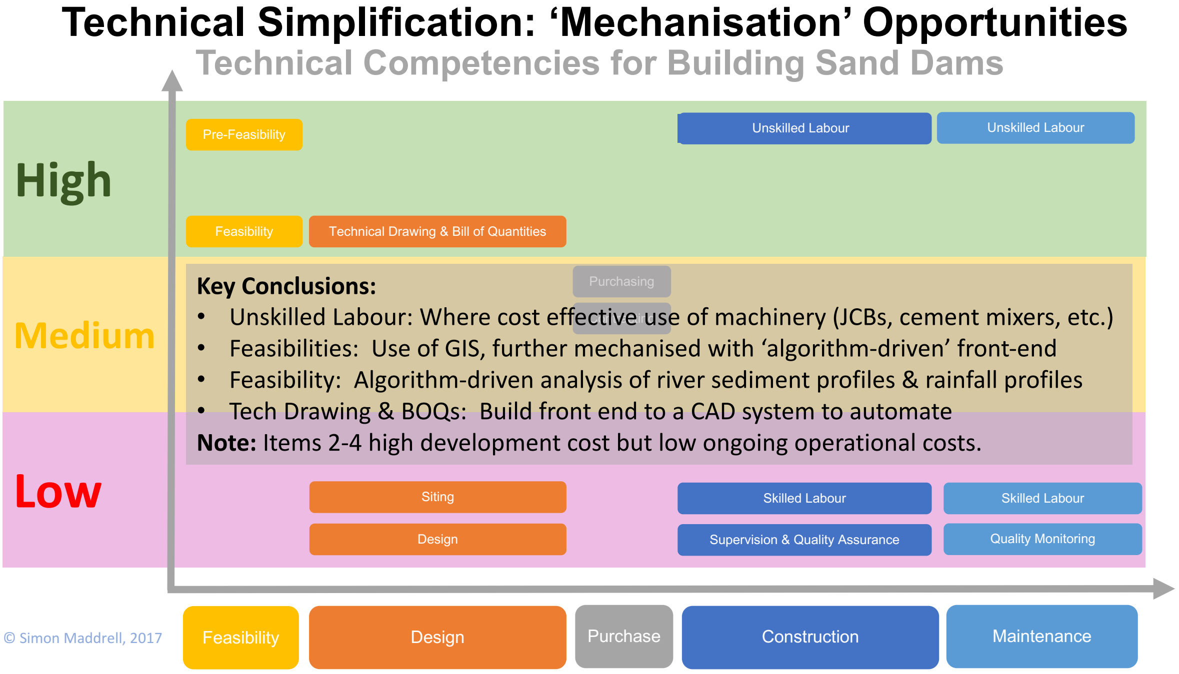
Training capacity high priorities

- There is a need to develop more centres of excellence in sand dam technology geographically (e.g. Francophile & Arabic Sahel & West Africa; Middle East [e.g. Palestine, Jordan]; South America [Brazil, Bolivia or Paraguay]; Central & Southern India [e.g. Tamil Nadu, Maharashtra];
- There is a need to increase the capacity to provide support including regionally and in different contexts.
- The intent is to provide multilingual training materials (biggest priorities are French, Hindi, Portuguese).

Subcontracting

- Subcontracting capability development is dependent on the high priorities detailed above but there is a need to:
- Develop the business processes and contracting rules to manage this relationship
- Introduce a methodology to validate and approve contractors, moving towards an accreditation process.

Another method to reduce the technical barriers to scalability of sand dam technology is to simplify the technical skills required through mechanization, automation or systemization of some processes. Whilst some of these would require both research to establish empirical data and relatively high system and software development, ongoing operational and maintenance costs would be relatively low. There is certainly enormous opportunity at institutional of dryland government level to build on the work the author and Excellent Development did with UNDP and the Government of Swaziland in terms of sand dam feasibility and implementation.


Technical Simplification: 'Mechanisation' Opportunities

Technical Competencies for Building Sand Dams

Key Conclusions:
- Unskilled Labour: Where cost effective use of machinery (JCBs, cement mixers, etc.)
- Feasibilities: Use of GIS, further mechanised with 'algorithm-driven' front-end
- Feasibility: Algorithm-driven analysis of river sediment profiles & rainfall profiles
- Tech Drawing & BOQs: Build front end to a CAD system to automate

Note: Items 2-4 high development cost but low ongoing operational costs.

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Here is a summary of the key opportunities:

- **Unskilled Labour:** Where cost effective use of machinery (JCBs, cement mixers, drills, etc.) can be very helpful if used with caution (e.g. cement must not be poured into the shuttering except for the first layer; cement vibrators to remove air pockets are a disaster because there should not be enough spaces between rocks to utilise one and when used in a sand dam cause the cement, sand and water to separate).
- **Technical Drawings:** The current standard of drawings used by ASDF is suitable for insourced construction but can cause serious issues for outsourced contracting. A front-end to a standard CAD programme would enable sand dam drawings to be done at a professional quality sufficient to act as part of a subcontracting contract.
- **Bill of Quantities (BOQs):** If more dimensions were captured at design stage (e.g. width of steel placement, test pits for bedrock) it would be possible to develop a 'model calculator' to quantify the materials required for a sand dam. This would improve the accuracy of especially if the model included factor scores to compensate for things such as rock sizes, sand type and moisture content.
- **Feasibility:** The use of GIS discussed in Chapter 3, could be further systemized with an 'algorithm-driven' front-end that converted the features data (e.g. soil types, rock types, seasonality etc.) into 'Red/Yellow/Green' maps showing the relative suitability for sand dams.
- **Feasibility:** Based on research of the suitable and unsuitable sediment types for sand dams, an algorithm-driven analysis of river sediment profile data could equally provide 'Red/Yellow/Green' maps showing the relative suitability for sand dams; a *'Sediment Index'* if you will.
- **Feasibility:** Similarly, an algorithm-driven analysis of rainfall data to create a Seasonality Index[151] or something even more sophisticated (discussed and explained in Chapter 3) linking it again to 'Red/Yellow/Green' maps showing the relative suitability for sand dams.

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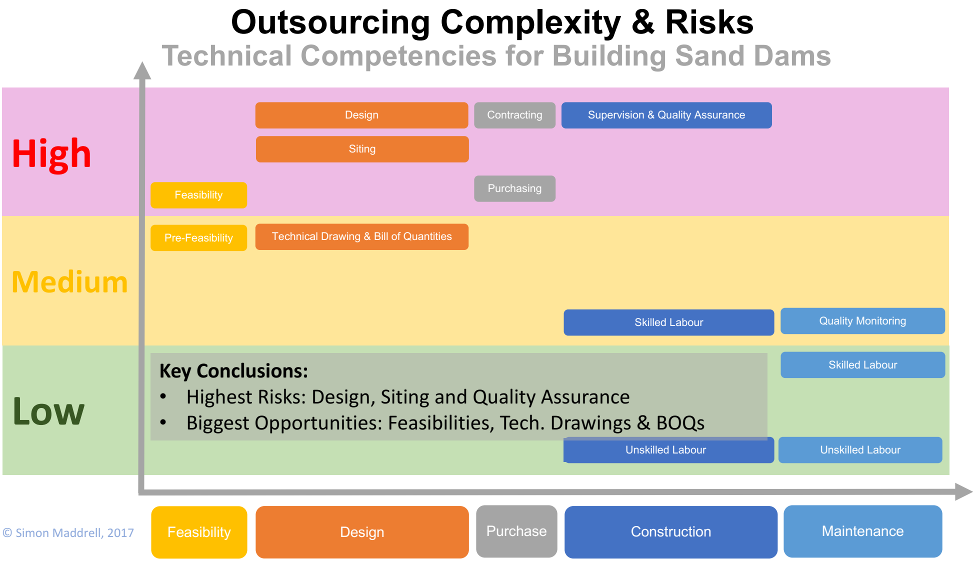
[151] https://www.researchgate.net/publication/243936748_Rainfall_seasonality_description_spatial_patterns_and_change_through_time_British_Isles_Africa

In terms of outsourcing, if communities are contributing cash, rather than their own labour the priority areas are the same in terms of skilled and unskilled labour. However, it is vital that the implementing agency maintains strict and close supervision and quality assurance and does not outsource this locally. In the short-term, during training, it can be provided by experts in sand dams but this competence must be developed in-house. This is explained in more detail in the construction and procurement chapters but the quality of sand dam construction is hidden underground in the foundations and behind the plastering.



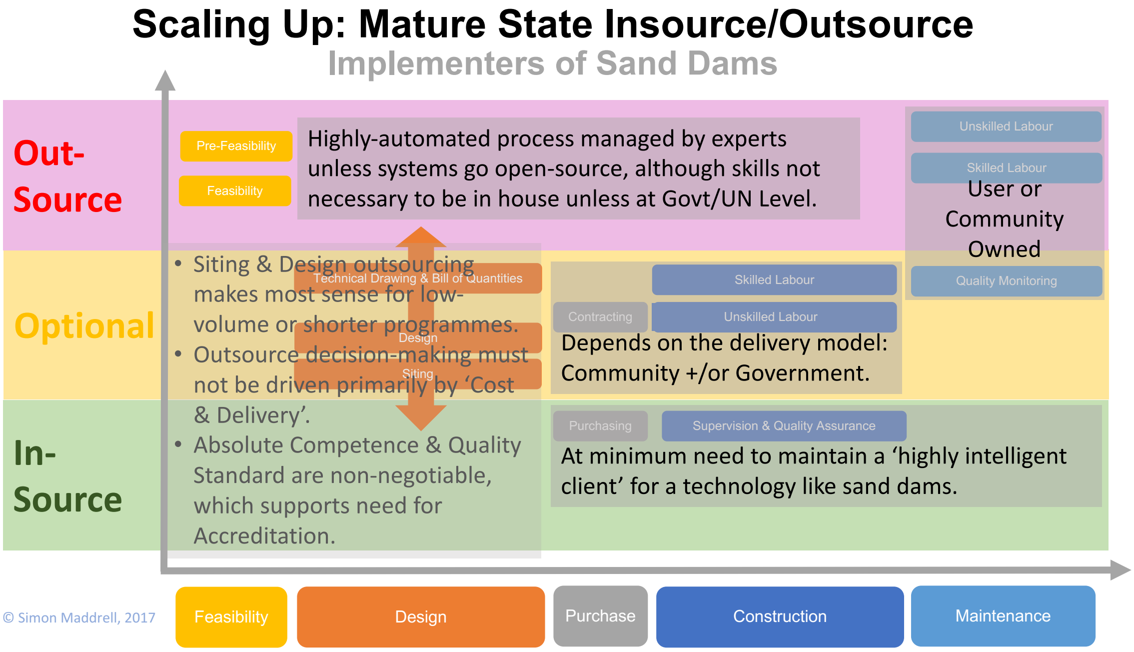
Outsourcing Complexity & Risks

Technical Competencies for Building Sand Dams

Key Conclusions:
- Highest Risks: Design, Siting and Quality Assurance
- Biggest Opportunities: Feasibilities, Tech. Drawings & BOQs

A mature 'outsourced model' especially for regional and national government programmes may look like the diagram below. **Care must be taken with outsourcing siting, design and construction**. In the author's extensive experience, Kenya is scattered with hundreds of failed sand dams built to outsourced contractors by regional or national government programmes – designs may or may not have been done by government engineers. India has a similar record with *anicut* (open water) check dams. Again, in the author's experience, both countries have a prolific record of failed (vented or culverted) rural road crossings although this is primarily due to design failures.

To reiterate, the nature of sand dam technology and the construction process, it is vital to maintain in-house at minimum a 'highly intelligent client' with onsite quality monitoring and ability to review designs critically.



Scaling Up: Mature State Insource/Outsource

Implementers of Sand Dams

Highly-automated process managed by experts unless systems go open-source, although skills not necessary to be in house unless at Govt/UN Level.

User or Community Owned

- Siting & Design outsourcing makes most sense for low-volume or shorter programmes.
- Outsource decision-making must not be driven primarily by 'Cost & Delivery'.
- Absolute Competence & Quality Standard are non-negotiable, which supports need for Accreditation.

Depends on the delivery model: Community +/or Government.

At minimum need to maintain a 'highly intelligent client' for a technology like sand dams.

Chapter 5: Community Engagement & Ownership

5.1 Community Engagement & Ownership

The intent of this chapter is to emphasise the philosophy and principle of community engagement in building sand dams even when this is part of a more 'top down' approach from regional government building dams or sand dam road crossings. The local population are a critical component of the design process as it is their knowledge and experience that provide the information to build a sustainable sand dam. Most sand dams in the world have been built through civil society organisations and, in this instance, community ownership is vital to enable sustainability. Emphasis here is on community ownership – not merely 'consultation' or 'participation' but actual ownership of decision-making from the beginning, which manifests itself in all statutory construction authorisations and water management permits being registered with the community's civil society (or land-owning) organisation not the partner NGO.

Communities need to be engaged to establish needs and priorities, which then serve to inform sand dam locations and abstraction methods required – if indeed a sand dam is the most appropriate solution to addressing their needs. To reiterate, it is also community knowledge of how rivers flow that are a critical component of sand dam design.

In Kenya communities participate in the building of dams and the dams are registered to the civil society organisation right from the beginning i.e. permit to build and then certificate of ownership/management after completion. See Chapter 8.1 for more on formal community agreements and government authorisations. Government led initiatives do not need to preclude community participation and sand dams are very appropriate to the type of programme initiated by the World Bank in Ethiopia. The Third Productive Safety Nets Program[152] aim is "to reduce household vulnerability, improve resilience to shocks and promote sustainable community development in food insecure areas of rural Ethiopia". One component is safety net grants that provide cash and in-kind transfers to chronically food insecure households through labour intensive public works for able-bodied households (and direct support to labour-poor households). The World Economic Forum emphasises the similarities to the principles and practices adopted by Excellent Development and its partners: "The response starts at the very beginning. The community committees, comprised of both men and women, select the assets and tools to be used in public works projects. Women's participation in this decision-making process ensures their views are not only considered but also that their needs are taken into account".[153]

The SDG Water & Sanitation target 6.b also emphasises this need[154]: "Support and strengthen the participation of local communities in improving water and sanitation management". The importance and success of this approach has been demonstrated by ASDF in an external evaluation of their work[155]:

"The supported SHGs have achieved much more than participating in the construction of sand dams... They have not only maximised the benefits from the improved and sustainable water supplies, but have gone on to improve agricultural production, nutrition and income within their communities."

"What is being experienced by individual community members is an increase in the sense of being able to initiate and complete tasks and initiatives previously considered beyond them."

The report noted *"the rigorous and principled stance that ASDF takes in insisting that members take full ownership and responsibility for investing in their own development."*

"Through the contribution of members complete 'ownership' of the developments are assured."

An example application form to register a Self-Help Group with the Government of Kenya is attached in Appendix 1.4.

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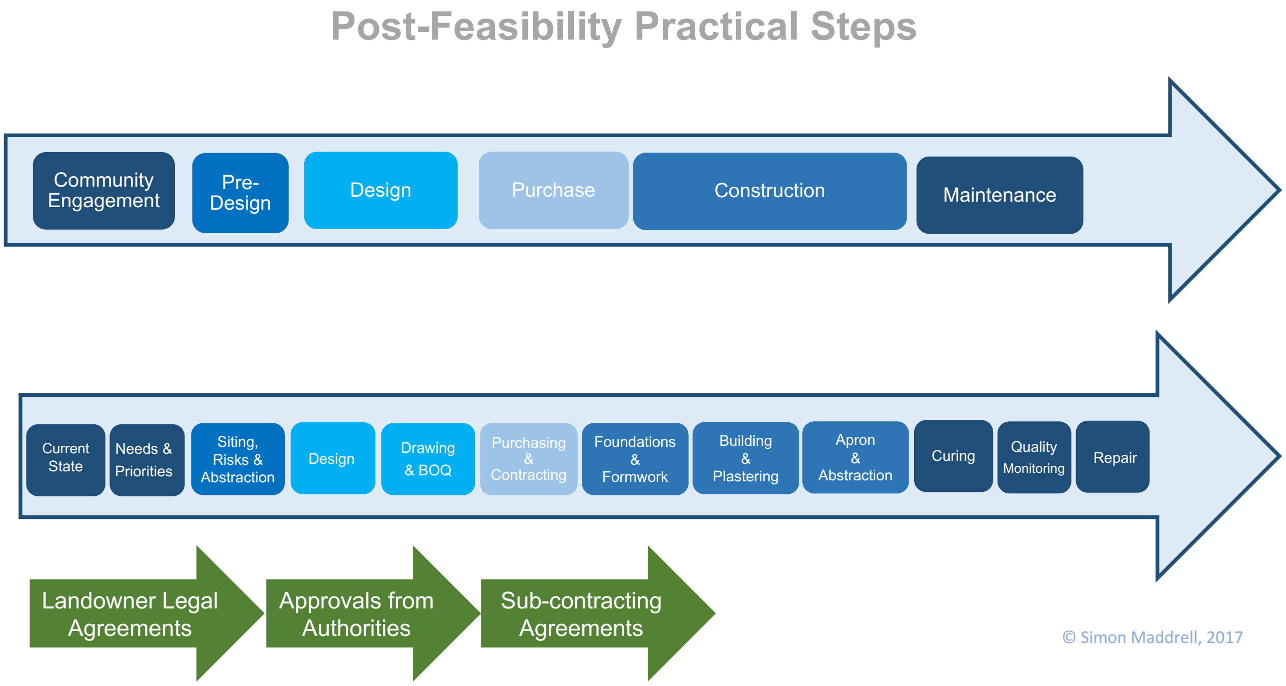
[152] http://projects.worldbank.org/P113220/productive-safety-net-apl-iii?lang=en
[153] https://www.weforum.org/agenda/2015/06/how-a-safety-net-programme-in-ethiopia-is-helping-tackle-gender-inequality/
[154] http://www.unwater.org/sdgs/indicators-and-monitoring/en/
[155] External evaluation 'Excellent Development/ASDF DfID/UK Aid Global Poverty Action Fund (GPAF) programme 2013-16' Sept. 2016.

The following five chapters map out the stages post-feasibility in delivering sand dam technology from community engagement all the way through to operations and maintenance. This can be understood in relation to the diagram below, which also introduces the concept of building sand dams as an art and a science (explained in detail in Chapter 7)**:**

At the initial stage the following guidelines/checklist for the information to be collected and the discussions to be had with the community (ensuring that the right range of stakeholders are engaged) before even visiting any possible sand dam sites:



Population Summary: *[Civil society group, village and sub-location populations to identify beneficiaries.]*

Livelihood Summary *[What are the livelihood means of the beneficiary communities e.g. Rain-fed agriculture, irrigated agriculture, livestock & type, shepherding, other occupations etc.]*

Community and Land Tenure Summary *[including area mix of private and government land and numerical mix of landowners vs tenants vs landless.]*

Current Public and Private Water Sources *[e.g. Tube wells, shallow wells (open or hand pumps), pipelines, dams, ponds earth dams, etc.]*

Community Water Challenges: *[including availability for people, livestock & agriculture, water quality & salinity, costs, conflicts of water sources, access, use, etc.]*

Community Water Needs *[including who, what, where and what for?]*

Community Water Priorities *[including who, what, where and what for?]*

Possible/Proposed Sand Dam Structures: *[Establish likely opportunities to site sand dams if applicable.*]

Other RWH Opportunities: *[e.g. Personal or community tanks, ponds, earth dams, rock catchments, wells etc.]*

Possible/Proposed Project Description *[Describe the interventions proposed and their purpose.]*

Next steps summary *[including further investigations, engagement with other stakeholders etc.]*

Chapter 6: Sand Dam Pre-Design Activities

We have now reached the stage prior to designing sand dams, having completed these steps:

- **Feasibility Assessment** has identified a region or area of technical and social feasibility;
- **Community Engagement** has identified the current water situation in terms of availability, accessibility and quality as well as the needs and priorities of the relevant stakeholder groups.
- Resolved any non-directly related sand dam issues with the community e.g. wider community consultation, local government consultations, governance, user agreements etc.

Since the 2013 incarnation of this manual, this chapter has been expanded and re-ordered for several reasons. Firstly, it is now clear that the complex inter-relationship between potentially multi-use water needs & priorities and those that can be delivered by specific dams requires water abstraction design options to be the next step after, and over-lapping with, community engagement. Furthermore, in addition to identifying potential sand dam sites alongside the community, experience of the varying geographies and climates where sand dams are now being implemented has helped to establish that a clearer picture of siltation risks (see Chapters 3.3.1 and 3.3.2 for context) is vital to be established alongside siting, prior to their prioritisation with the community, as well as before the next step of design.

Consequently, this chapter has now five sections covering the areas discussed above:

- Water Abstraction Options: Needs, usages & suitability
- Water Abstraction: Intake & Output Mechanisms
- Sand Dam Siting
- Establishing Siltation Risks
- Finalising Water Abstraction Options

6.1 Water Abstraction Options: Needs, usages & suitability

The range of abstraction technologies and their specific design options and differences are very complex, especially in the way that these different elements overlap in three dimensions, rather like a Rubik's Cube. Therefore, firstly they will be explained by looking at 'water abstraction' by its required functions and then from different perspectives to help establish a full picture:

The Three Functions of Water Abstraction:

- **Intake Mechanism:** What is the mechanism by which water is first captured?
    - Seepage
    - Infiltration: Horizontal gallery/system
    - Infiltration: Vertical gallery/system
- **Access Systems:** What system then holds and/or transmits the water?
    - Scoop hole
    - Tank and/or Pipe
    - Shallow Well
    - Well Point (Sunk)
    - Tube Well (Drilled)
- **Output Mechanism:** How is the water finally abstracted/collected?
    - By hand
    - Tap
    - Animal trough
    - Hand pump
    - Diesel/electric/solar pump

However, prior to getting more technical and specific about water abstraction technologies and options, it is vital to return to the community and their needs and priorities and understand their relationship with the possible sand dam types, sediment types and the abstraction technology options.

Sand Dam Water Abstraction Technologies	Usage Capability vs. Needs & Priorities					Type of Sand Dam			Sediment Type	
✓ = Recommended x = Not Recommended	People Drinking Water	People Other Domestic	Livestock	Irrigation	Wildlife	Perched Aquifer ^	Shallow Groundwater Recharge	Only Deep Groundwater Recharge	Finer Sandy Sediment	Coarser Sandy Sediment
Scoop holes	x	✓	✓	✓	✓	✓	x	x	x	✓
Tank with pipe & tap using infiltration gallery	✓	✓	✓	✓	x	✓	x	x	✓*	✓
Tap with pipe through dam using infiltration gallery	✓	✓	✓	x	x	✓	x	x	✓*	✓
Tap and animal trough using infiltration gallery & pipework	✓	✓	✓	x	✓*	✓	x	x	✓*	✓
Shallow well with hand-pump	✓	✓	x	x	x	✓	✓	x	x	✓
Shallow well with hand-pump plus infiltration galleries	✓	✓	x	x	x	✓	✓	x	✓*	✓
Shallow well with hand-pump & separated animal trough	✓	✓	✓	x	x	✓	✓	x	✓*	✓
Rowa hand pump & animal trough	✓	✓	✓	x	x	✓	✓	x	x	✓
Rowa hand pump & animal trough with enhanced infiltration	✓	✓	✓	x	x	✓	✓	x	✓	✓
Tube well	✓§	✓	✓§	✓§	x	✓§	✓§	✓	✓	✓

✓* Due to slow flow rate an enhanced infiltration gallery is required

✓* Note special measures to enhance elephant-proofing

✓§ Note risks with saline, fluoride or arsenic groundwater

^ i.e. where water is stored behind the dam (see Ch. 3.6)

✓§ All dams will recharge deeper groundwater to an extent

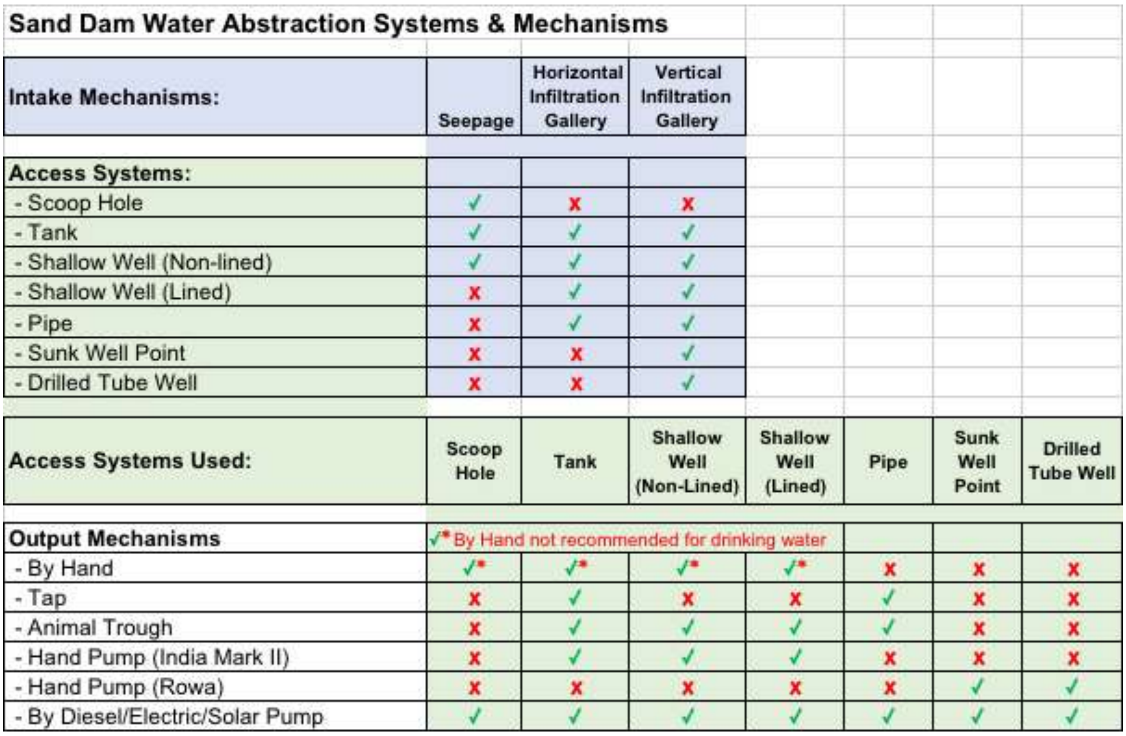
The community needs and priorities, which may vary by geography (e.g. in community conservancies the user needs vary greatly by geography between people, livestock and wildlife), help to inform the process of siting possible sand dams because certain abstraction technologies require not just certain 'sand dam types' and 'sediment types' but topography or soil types. For example, animal troughs need a protected spot with the ability for gravity-feed; shallow wells need a soil/rock type that can be dug; and, dams with low spillways will not abstract large amounts of water from horizontal infiltration galleries for taps and animal troughs. Additionally, shallow wells, Rowa hand pumps and tube wells abstract water from a deeper point in the riverbed.

Returning to the technical aspects of abstraction technology options, here is a reminder of the abstraction functions:

The Three Functions of Water Abstraction:

- **Intake Mechanism:** What is the mechanism by which water is first captured?
- **Access Systems:** What system then holds and/or transmits the water?
- **Output Mechanism:** How is the water finally abstracted/collected?

Each of the functional options relate to each other, some work together and some don't, leaving you with ways to get water (*output mechanisms*) that will only work with certain ways to hold and/or transmit the water (*access systems*) and certain ways to initially capture the water (*intake mechanisms*). This is a summary of those interactions:



Sand Dam Water Abstraction Systems & Mechanisms

Intake Mechanisms:	Seepage	Horizontal Infiltration Gallery	Vertical Infiltration Gallery
Access Systems:			
- Scoop Hole	✓	x	x
- Tank	✓	✓	✓
- Shallow Well (Non-lined)	✓	✓	✓
- Shallow Well (Lined)	x	✓	✓
- Pipe	x	✓	✓
- Sunk Well Point	x	x	✓
- Drilled Tube Well	x	x	✓

Access Systems Used:	Scoop Hole	Tank	Shallow Well (Non-Lined)	Shallow Well (Lined)	Pipe	Sunk Well Point	Drilled Tube Well
Output Mechanisms	✓* By Hand not recommended for drinking water						
- By Hand	✓*	✓*	✓*	✓*	x	x	x
- Tap	x	✓	x	x	✓	x	x
- Animal Trough	x	✓	✓	✓	✓	x	x
- Hand Pump (India Mark II)	x	✓	✓	✓	x	x	x
- Hand Pump (Rowa)	x	x	x	x	x	✓	✓
- By Diesel/Electric/Solar Pump	✓	✓	✓	✓	✓	✓	✓

6.2 Water Abstraction: Intake & Output Mechanisms

The range of abstraction technologies are complex, especially in the way that different mechanisms and systems overlap. To simplify, they will be explained by looking at '*intake & output mechanisms*' and their relationship to each other. These will then be related to the '*access systems'*, which hold and/or transmit water to the final abstraction point.

6.2.1 Intake Mechanisms

An intake mechanism is a way to capture water from a saturated sediment into a system to either transmit and/or abstract the water elsewhere. The purpose of an intake mechanism is to create a sufficient yield and yield rate (how quickly it transports water). Yield rate is determined by the *drainable porosity* (see Chapters 3.3.2 and 3.5.4) of the surrounding rock or sediment and the surface area of the mechanism. In designing any water abstraction system, the *intake mechanism* needs to achieve an infiltration rate equal to, or higher, than the maximum abstraction rate required at any given time. Higher abstraction rates are required to support irrigation and livestock[§], although storage systems like an animal trough act as a buffer.

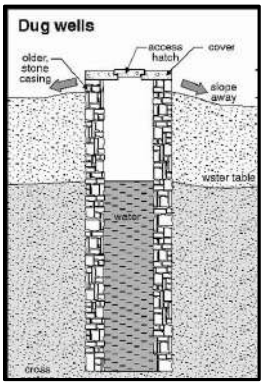
[§] Irrigation by pump requires an abstraction rate, equal to or higher than pump rate (or a sufficient buffer to allow the pump to run for a sufficient time. Livestock have higher daily needs than people and usually consume that once every 1-2 days in herds – so the refill rate and/or capacity of the animal trough needs to match those needs.

Water can be captured into a system in three, not necessarily mutually exclusive, ways:

- **Seepage**
- **Horizontal infiltration galleries**
- **Vertical infiltration galleries**

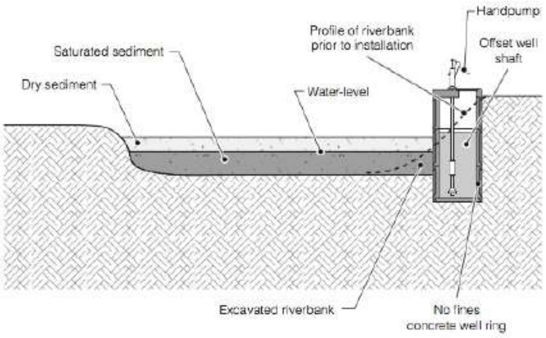
6.2.1.1 Seepage

Seepage, for the purposes of this manual, is the slow flow of water through rock, soil or sediment. It is a mechanism applicable to scoop holes dug in seasonal river sediments and deeper hand-dug shallow wells, which are usually dug into riverbanks adjacent to sand dams (see below left[156] and bottom right[157]).



Traditionally, people have collected water from sand rivers using simple holes scooped into the sand (see photo above centre of SE Kenya). Where the hole is used for domestic purposes, Acacia and thorns are often used to keep livestock out of the hole. 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 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 (see photo above right from Rajasthan, India). The diagram shown right[158] shows a hand-dug well adjacent to a sand dam with water seeping into the well through the caisson concrete ring walls.



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[156] Copyright www.CarsonDunlop.com https://www.pinterest.co.uk/pin/26951297741044035/
[157] Hussey, S. Water from Sand Rivers, WEDC, 2007. Page 45.
[158] Hussey, S. Water from Sand Rivers, WEDC, 2007. Page 45.

6.2.1.2 Horizontal Infiltration Gallery/Mechanism

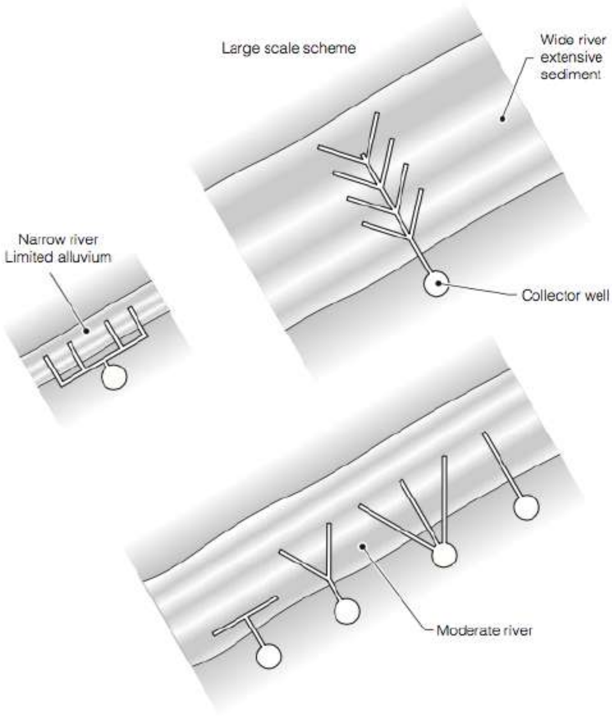
These systems can feed into the *Access Systems* of:

- **Pipe or Tank**
- **Shallow well**
  - **Lined (caisson):** If lined with non-porous material then 100% reliant on horizontal infiltration systems.
  - **Unlined:** Provides additional water to the well than seepage does.

An infiltration gallery, in the photo below, is a horizontal pipe or network of pipes, usually plastic, with slots or holes drilled into the top two thirds. It is placed in the riverbed following construction and covered with an increasing grade of gravel and stones and finally covered with coarse sand to maximise the surface area of infiltration and minimise blockage by silt or clay.

Obviously, the length of the piping and the area that the infiltration gallery covers will influence the yield of water (reducing the infiltration into the aquifer); and yield rate of water (by transmitting more at a time). The infiltration gallery is either connected to a tank built into the dam wall; a pipe running through the dam; or a shallow well in the riverbank. The additional benefit of infiltration galleries is that the water is filtered clean as it passes through the sand.

Methods to maximise the yield and yield rate:



- Lay in the deepest part of the aquifer behind the dam
- Lay on a slight gradient to carry water to a tank or sump at the base of an off-take well.
- Overlay with a layer of small stones, gravel, medium stones and then covered with coarse sand.
- Lay in a branched or herringbone network across the riverbed to maximise the surface area covered and hence the yield and yield rate (as in diagram right[159]).
- The finer the riverbed sediments (i.e. the lower *drainable porosity*) the greater diameter pipe and/or total length of pipework should be used to achieve the same yield and yield rate of higher *drainable porosity* sediments.

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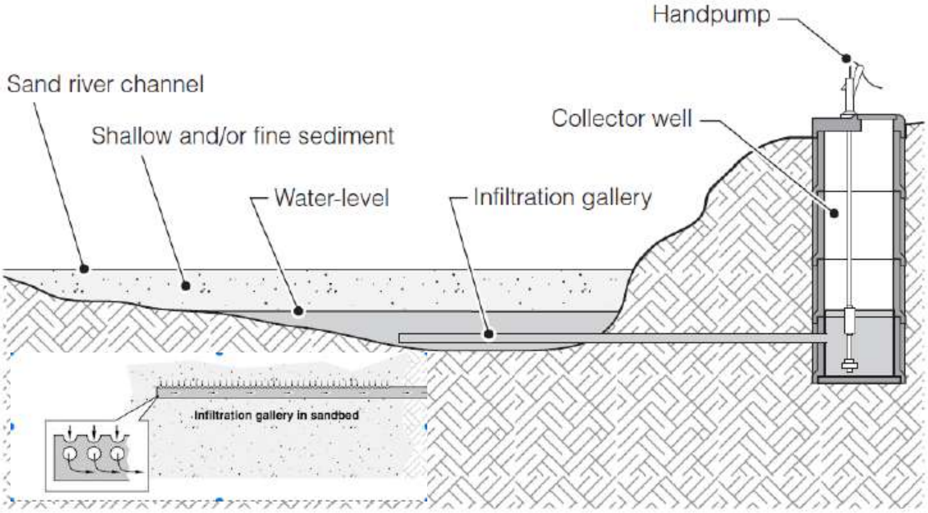
[159] Hussey, S. Water from Sand Rivers, WEDC, 2007. Figure 4.9.

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 the diagram and photo below left in the next sub-chapter). 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.   The diagram below shows a horizontal infiltration gallery feeding a shallow well[160].

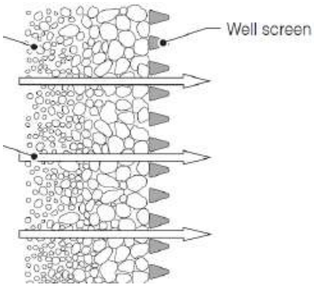


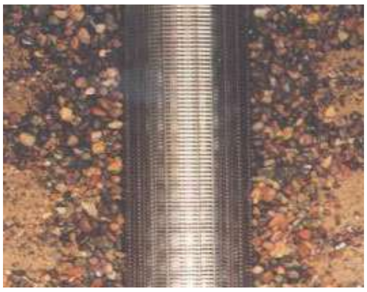
6.2.1.3 Vertical Infiltration Mechanism/System

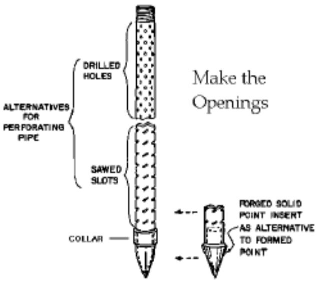
A vertical infiltration gallery can be achieved in the following two main ways:

1. Drilled/sunk well point with well screen	Tube Wells and Rowa Hand Pumps
2. Enhanced well point/submerged tank/shallow well	Tube Wells, Pumps: Rowa, Hand or Mechanical; and Taps

The vertical systems are usually circular with an increasing diameter, depending on both the nature of the sediment it is installed in and the yield rate required from the system, as well as the output mechanism e.g. tap, pump, hand pump, Rowa hand pump. A well point is driven or drilled into the sediment down to the water table (or perched aquifer level) and for sediments with good drainable porosity a natural filter will be formed around the well screen (see drawing below left[161]). The photo below left is typical of a tube well screen[162]. Photo below right is Dabane Trust's Rowa Hand Pump well point/screen that is driven directly into the sandy river sediment, although other methods of piping can be used as shown in the diagram below right[163].







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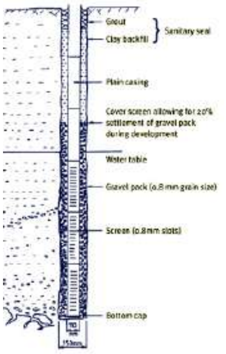
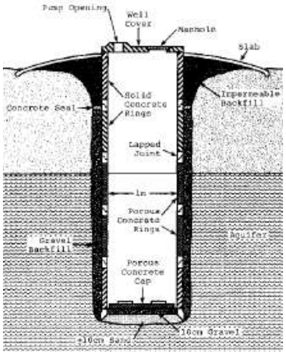
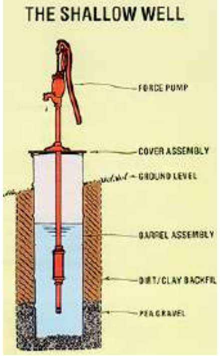
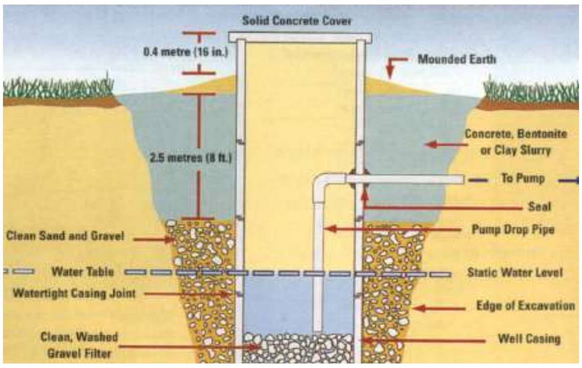
[160] Hussey, S. Water from Sand Rivers, WEDC, 2007. From figures 4.2 and 4.5.
[161] Hussey, S. Water from Sand Rivers, WEDC, 2007. Figure 4.1
[162] Driscoll F. G., Photo 4.1 in Hussey, S. Water from Sand Rivers, WEDC, 2007.
[163] Dungan, F. An Inexpensive, Do-It-Yourself, Small Diameter Water Well, 2007. http://www.fdungan.com/well.htm

If the sediment is not of sufficient drainable porosity an extra wide casing can be installed around the well point to increase the infiltration volume and rate. The diagram below left shows how a wider diameter area can be created by adding gravel around the submerged PVC pipe well screen[164] or using much wider porous no-fines concrete rings (known as caisson) with additional gravel backfill to further increase the infiltration from the aquifer[165]. This is also applicable to a shallow well[166] or submerged tank[167] that may be wider than 1m diameter with an enhanced vertical infiltration system of gravel to replace or supplement a horizontal one.









6.2.2 Output Mechanisms

Here are a brief description and photographs of the varied output options:

6.2.2.1 Tap

Horizontal infiltration system

- **Pipe & Tap:** Photo right is showing a tap from an infiltration system in Machakos, Kenya. (Copyright Polly Braden, 2009).

6.2.2.2 Tank

Horizontal infiltration system

- **Pipe & Tap**: photo immediate right from Makueni, Kenya.
- **Pump**: photo far right is of an underground tank and pump in Rajasthan, India; photo below is a tank built into the dam wall in Makueni, Kenya.

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[164] Tube wells and boreholes, Capital Engineering Corporation. http://capitalengineering.in/services4.htm
[165] Water and Sanitation Technologies: A trainer's manual. Peace Corps, 1985. http://www.nzdl.org/
[166] Adams, A. Digging a Shallow Well. Mother Earth News. Sept./Oct. 1981. http://www.motherearthnews.com/diy/shallow-well-zmaz81sozraw
[167] http://www.crystalflow.com/wp-content/uploads/2011/01/boredwelldiagram.jpg

6.2.2.3 Animal Trough

Animal troughs can be connected to pipework from the dam and they are very commonly used linked to a Rowa hand pump, but less commonly piped from a shallow well hand pump platform.

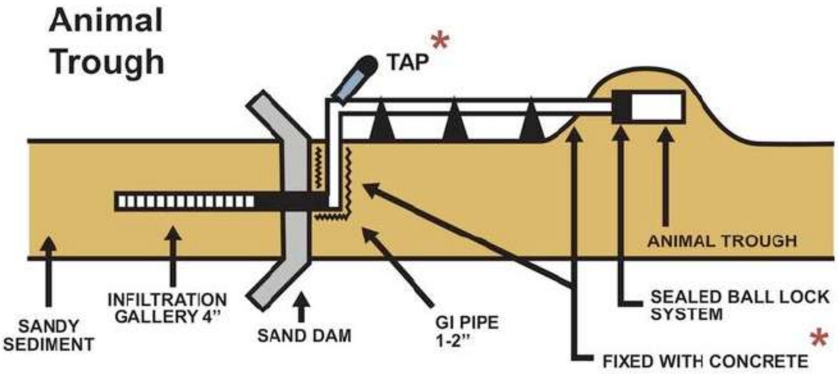
Horizontal infiltration system

Pipe: The horizontal infiltration system should be connected to an animal trough using strong GI (galvanised iron) pipe:

- Use at least 1" (preferably 2") GI pipe sealed in concrete in the centre of the river bed immediately below the dam.
- Take the pipework then down the river bank to a sheltered point for the animal trough
- A T-junction and tap is best to be separated for domestic water abstraction.
- Do not take the pipework diagonally across the riverbed or it will break and be washed away.
- The animal trough is best to be managed with a ball-cock system for automatic refilling.
- Do not use ball-cock systems and make the system more secure if the trough cannot be communally-managed.

Elephant-proofing: If the animal troughs are to be accessible by elephants, extra actions **MUST** be taken to reduce the chances that they will damage and/or destroy the system:

- The animal trough **MUST** be cleaned and washed out every 1-2 days to keep the water fresh.
- **DO NOT** separate the human water point from the animal trough system as the elephant will notice the fresher, cleaner water point.
- You **MUST** cover the whole length of the GI piping with concrete or the elephants will break the pipes.
- In summary, assume that elephants as discerning and ingenious as humans about water quality.



* SEE NOTES ON "ELEPHANT - PROOFING"

Vertical infiltration system

Rowa hand pump: A Rowa hand pump can also have an animal trough attached – please see Chapter 6.2.2.6.

6.2.2.4 Shallow Well

A shallow hand dug well should be located for good access in a place protected from heavy river flow. A shallow well connected to a sand dam will typically be 3 to 6 metres deep, due to a maximum height of 7.6 metres for a suction pump[168]. The well should be excavated at the same time as, or shortly after, the sand dam is built. An infiltration gallery may also be connected to a well in the adjacent riverbank. If fitted with a hand pump the water quality will be very much improved. Links to more information on the construction of shallow wells can be found in Chapters 11.3.2.

Types of Shallow Wells:

Shallow well	open	bucket	seepage
Shallow well	unlined	hand pump	seepage
Shallow well	lined (caisson)	hand pump	vertical infiltration
Shallow well	lined	hand pump	horizontal & vertical infiltration

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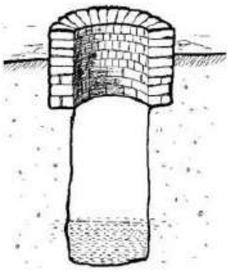
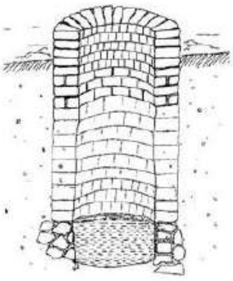
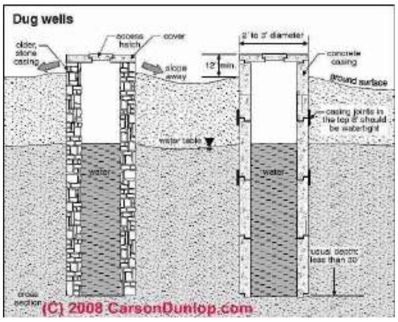
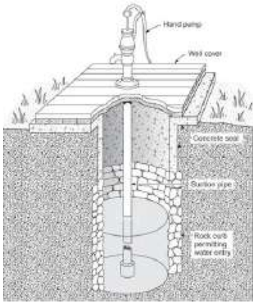
[168] http://blog.tuhorse.us/2012/07/definition-of-deep-well-and-shallow.html

Illustrative diagrams of shallow wells left,[169] centre[170] and right:[171]









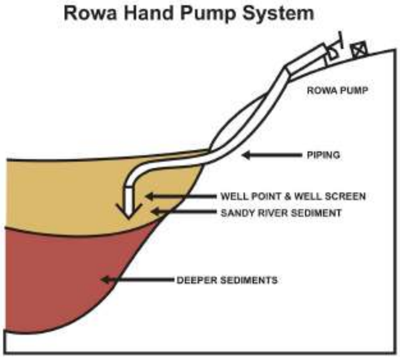
6.2.2.5 Hand Pump – India Mark II

The India Mark II Pump is a robust conventional lever action hand pump. It is designed for heavy-duty use, serving communities of 300 persons. The maximum recommended lift is 50m. The India Mark II is a public domain pump defined by Indian Standards and RWSN specifications. The India Mark II pump is not corrosion resistant.[172]

The photo to the right is of an India Mark II hand pump in Makueni, Kenya with an attached animal trough.

More technical information on hand pumps is available from Akvopedia[173].

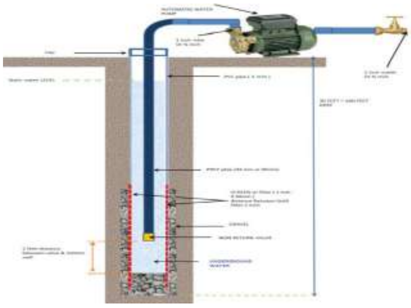
6.2.2.6 Hand Pump - Rowa



A well point driven into the sandy riverbed using a suction tube and rower mechanism to draw the water stored in the river sediment. For fine sediments, additional infiltration can be dug around the well point using gravel and/or cassion concrete tubes (see Chapter 6.2.1).

Below left photo of Dabane Trust's Rowa Pump with overflow system to a separate animal trough. Additional two photos courtesy of Dabane, show the original system and bottom left the newer design of a steel frame for the pump which is being developed.

6.2.2.7 Tube Well



A tube well is a type of water well in which a long 100–200 millimetres (4–8") wide stainless steel tube or pipe is bored into an underground aquifer. The lower end is fitted with a strainer, and a pump lifts water for irrigation. The required depth of the well depends on the depth of the water table[174]. Image to the right is an example of a tube well with attached pump[175].

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[169] https://www.amshaafrica.org/component/content/article/48-programs/123-getting-groundwater-safe-wells-and-waterholes.html

[170] Copyright www.CarsonDunlop.com 2008. https://inspectapedia.com/water/Hand_Dug_Wells.php

[171] McKinney, D.C. Well Development and Efficiency Groundwater Hydraulics. http://images.slideplayer.com/32/9811329/slides/slide_3.jpg

[172] http://www.rural-water-supply.net/en/implementation/handpump-overview/139-india-mark-ii

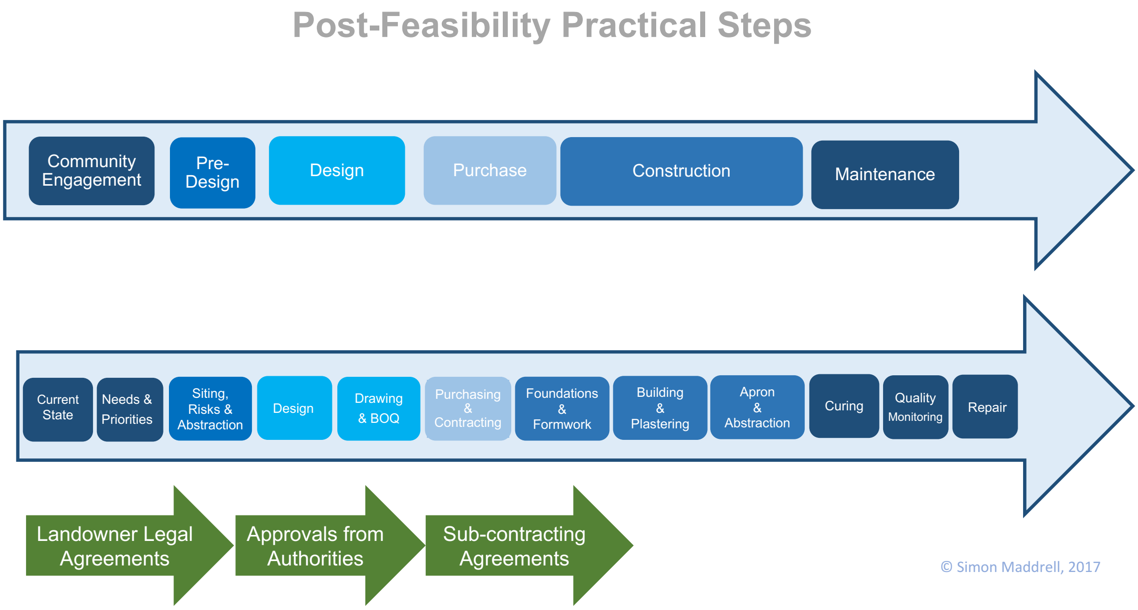
[173] http://akvopedia.org/wiki/India_Mark_2_and_3

[174] https://en.wikipedia.org/wiki/Tube_well#Sand.2Fgravel_packing

[175] Mounika Swathi, A. Tube Wells: Cavity Type, 2015. https://image.slidesharecdn.com/tubewell

6.3 Siting of Sand Dams

This chapter covers the approach to specific siting of sand dams once a regional and/or catchment level feasibility has taken place, and emphasises the continued importance of community involvement in siting decision-making. The chapter will cover reviewing the technical factors for good sand dam sites, the socio-economic factors to be considered and the prioritisation of identified sites.


Post-Feasibility Practical Steps

© Simon Maddrell, 2017

6.3.1 Assumptions

This chapter assumes that community engagement (Chapter 5.1) and catchment-level feasibility have been completed establishing that the three technical pre-conditions exist (see below and Chapter 3.1).

1. **Sand dams must be sited on a sufficiently seasonal river**
2. **The seasonal river must have a sufficiently sandy sediment**
3. **Sand dams must be sited where there is accessible bedrock.**

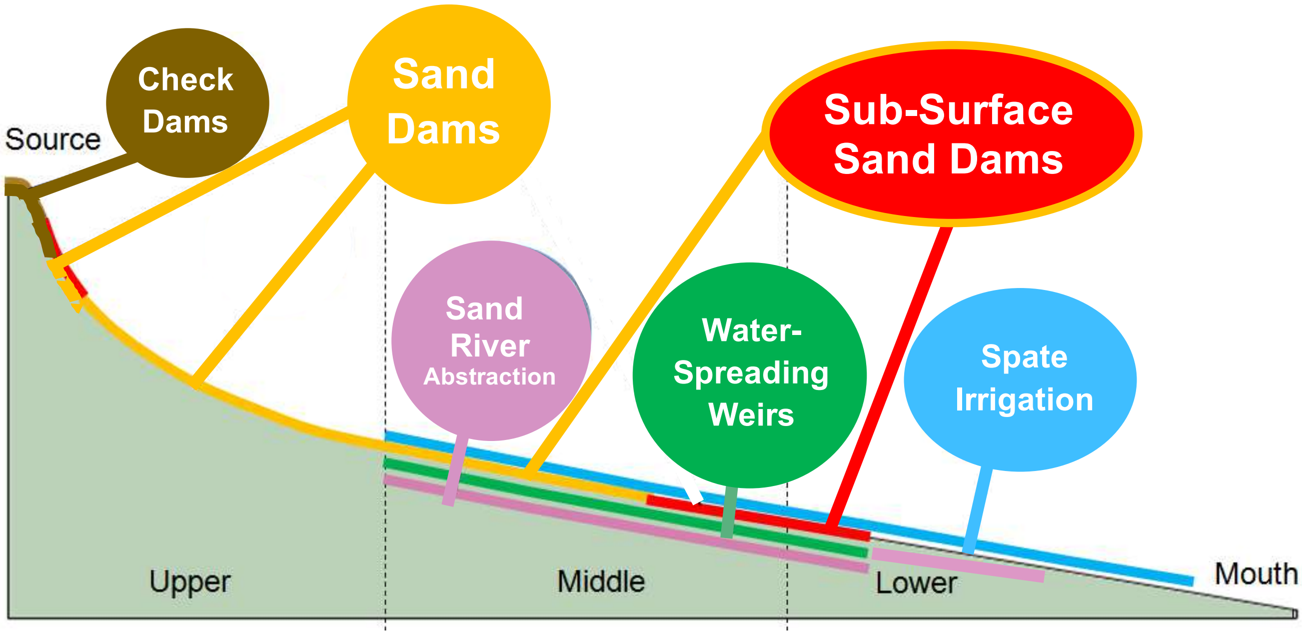
Notwithstanding, however, that rivers within a region or catchment will have different characteristics that may require specific sediment testing, for example, or a review of the seasonality of river flow.

6.3.2 Principles & Philosophy

It is critical to maintain the involvement of the community to ensure community ownership by seeking their guidance and utilising their knowledge. It is important to have both senior representatives of the civil society organisation you are engaged with plus community members with intimate and long-standing knowledge of the rainfall patterns, river flow and usage of water in the area.

6.3.3 Technical factors

Prior to the critical task of walking up and down seasonal rivers, it can be more time-efficient and effective to do some ‘desktop prioritisation’. Where sand dams are common, like SE Kenya, community members usually identify great sites all on their own and, usually, the challenge becomes solely about prioritisation of sites rather than discounting a site for technical reasons. However, where experience is low, there is a risk of being sent on a ‘wild goose chase’ wasting significant amount of time visiting unsuitable sites. Google Earth can be very useful to identify sandy rivers of suitable size and gradient as well as existence of bedrock with potential river sections discussed with the community in advance of a field visit. As a further guide to aid desktop research the river catchment profile below shows where sand dams are most likely to be appropriate and where other technologies may be more appropriate, the latter is discussed more in Chapter 11:



Long profile of river channel showing in-channel water harvesting technologies[176]

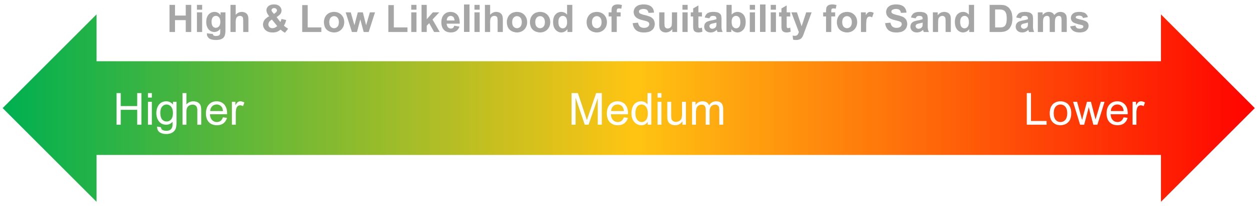
Sand dams are most commonly found in the upper and middle courses of the rivers in the transition between hills and plains. The velocity of flow is important, fast flows carrying a large amount of sediment (very seasonal river flows) will fill a sand dam quickly with coarse sand and gravel (flushing out fine sand and silt) although fast-flowing rivers with little sediment transport are unsuitable (high up a river catchment). Very slow river flows (caused either by being in a lower catchment or due to low volume and seasonality of rainfall) will cause most sediments – including fine silts and clays – which prevent abstractability of water. As rivers join in the lower catchments and base-flow increases, the larger rivers often, but not always, flow for more of the year (semi-perennial and therefore not suitable) and gradually become perennial. In summary, the distance from the source of the river and how far a potential site is down the river catchment influences the seasonality of river flows and the transport of sediments (see graphs below).

The technical factors of sand dam location suitability can be split into categories of water availability; river characteristics; and bedrock characteristics:

6.3.3.1 Water Availability

Indicators of Suitable Sand Dam Sites: Water Availability

High & Low Likelihood of Suitability for Sand Dams



Higher		Lower
Yes	Sand Harvesting	None
Yes	Scoop Holes (Human and/or Wildlife)	None
Yes	Shallow Wells Nearby	None
Yes	Bedrock Bar Across River	No
Yes	Vegetation/Key Tree Species Present	No

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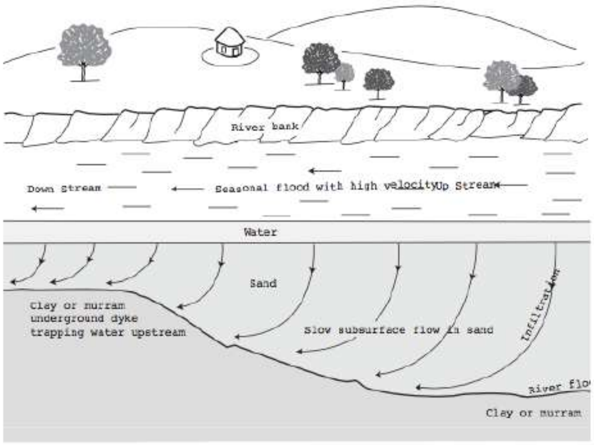
[176] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013 [Amended by Maddrell, S.R., 2017]

Water Availability: The overall purpose of sand dam siting is to establish locations in seasonal rivers that hold (or could hold) high levels of abstractable water i.e. hold water in the river sediment. Whilst rivers generally, or mostly, have a smooth even gradient, the underlying clay, murram or rock does not follow the river gradient in parallel (see the picture opposite from 'Water from Sand Rivers'[177]). Therefore, there are certain parts of the river that hold more water naturally underground already. If combined with rock near to the surface further downstream (causing a natural dyke) this is an ideal location for a sand dam – especially if utilising a shallow well or a Rowa hand pump abstraction technology that can access this deeper water in addition to the extra water stored by the sand dam.



Sand Harvesting: Whilst evidence of sand harvesting is a risk (discussed in Chapter 10.3.1), it proves that the river sediment is of, or near to, building sand quality. Such 'sharp sand' has a high *drainable porosity* i.e. water is easily abstracted from the sediment. As assessment of sediment suitability is discussed in Chapter 3.3.2 with field tests discussed in Chapter 3.5 it will not be repeated here. However, it goes without saying that a prime pre-requisite of a good sand dam site is suitable river sediment.

Scoop Holes: If it is common practice by the community to dig scoop holes (or there is evidence of elephants doing the same) then this demonstrates that water is being held in the sand. Establishing from the community where in the river these scoop holes last the longest in a river is a great place to start as it indicates an underground dyke is present. Note: There may be cultural reasons why water isn't collected from scoop holes or the practice may have faded out over the years in preference to bore holes or other sources of water. Therefore, do not treat a lack of evidence of scoop holes as a sign of unsuitability.

Shallow Wells Nearby: Nearby hand-dug shallow wells (the community will certainly be able to tell you deep they are and how the water levels change during the year) also indicate that accessible water is stored within the river. Again, these places should be investigated for suitable sand dam sites as dams often enhance shallow wells in terms of yield and the length of time water is available during the drought periods.

Bedrock bar across the river: This is also a sign of an underground dyke and can be an ideal place for a dam especially because the costs will be lower and construction easier with surface bedrock.

Vegetation and/or Key Tree Species: The type of vegetation, especially trees and shrubs, on the river banks or nearby is also an indicator of water being held in the river at certain depths. Nearby farmers may be growing, in adjacent flood plains, thirsty plants like bananas again indicating either water levels are high at this point or that a farmer is irrigating by pumping water from the river.

Botanical name	*Kamba name	Swahili name	Depth to Water (m)
Cyperus rotundus	Kiindiu		3 to 7
Vangueria tomentosa	Kikomoa	Muiru	5 to 10
Delonix elata	Mwangi		5 to 10
Grewia	Itiliku	Itiliku	7 to 10
Markhamia hildebranditi	Chyoo	Muu	8 to 15
Hyphaene thebacia	Ilala	Kikoko	9 to 15
Borassus flabellierfer	Kyatha	Mvumo	9 to 15
Ficus walkefieldii	Mombu		9 to 15
Ficus natalensis	Muumo	Muumo	9 to 15
Ficus mallatocapra	Mukuyu	Mkuyu	9 to 15
gelia aethiopica	Muatini	Mvungunya	9 to 20
Piptadenia hildebranditi	Mukami	Mganga	9 to 20
Acacia Seyal	Munina	Mgunga	9 to 20

Note: *Kamba is the local Buntu language of Ukambani (The counties of Machakos, Makueni and Kitui) south-east of Nairobi, Kenya.

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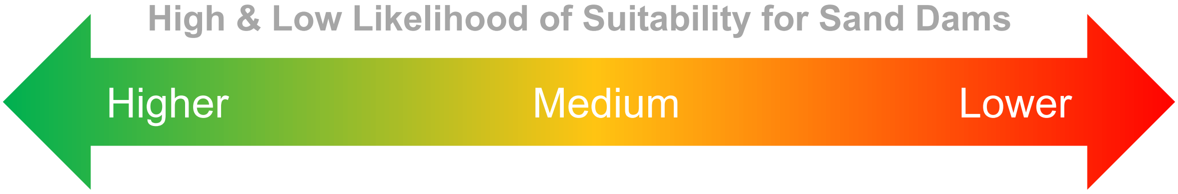
[177] Nissen-Petersen, E. 2000. Water from Sand Rivers. Nairobi: Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida), 2000. Figure 2, p. 6.

Nissen-Petersen[178] identified key tree species in SE Kenya that indicate the storage of water below the ground and the relative depths that water could be accessible (even in the drought periods). In different dryland regions, the local community will undoubtedly know the vegetation and trees that indicate water availability – especially pastoral and nomadic communities – thereby reiterating the importance of community involvement in sand dam siting.

6.3.3.2 River Characteristics

Indicators of Suitable Sand Dam Sites: River Characteristics

High & Low Likelihood of Suitability for Sand Dams



10-50 metres	Width of River	<10m. or >50m.
0.9% to 6.25%	Slope of River	>6.25% or <0.9%
Yes/>1m	Distinct Riverbanks	None/Very Low
Large	Catchment Size Upstream	Small
Yes	Narrower Point in River	No
Yes	User Accessibility	No
No	Upstream Impacts on Roads etc.	Yes

River Characteristics: There are certain river characteristics that denote suitability for sand dams but they are exceptions (narrow gorges are often perfect places for a sand dam) and some 'rules of thumb' are based on most cost-effective options because of course a sand dam can be built over 100 metres long if sufficient and appropriate resources are available.

Width of River: For total cost and practical construction reasons, most sand dams are built in locations in rivers 10-50 metres wide. It is unlikely that a dam in a location less than 10 metres wide will give a sufficient source of water to be worthy of the investment. The exceptions to this are locations in rivers where there is a rocky gorge where a very low cost, easy to design sand dam can be built. Such places often have river basins wider than the rest of the river course meaning they also provide larger storage of water than other locations in the river. Sometimes they also provide the opportunity to build a dam higher than in other locations, even if in two to three stages. Sand dams in narrower rivers (sometimes called check dams) may also be used as part of a wider water resource management (WRM) catchment plan and to reduce siltation risks for the larger dams. Rivers wider than 50 metres will often contain too fine sediments and insufficient riverbanks for sand dams. Such rivers are less likely to be seasonal rivers although climate change is meaning that larger and larger rivers are transitioning from perennial or semi-perennial to seasonal. However, there are sand dam location opportunities in rivers wider than 50 metres, which would probably require machinery to complete in a timely enough fashion.

Slope of River:

General River Course: In Ukambani, Kenya 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%[179]. River gradients that are too steep mean that the catchment will be much smaller and therefore water storage relatively much lower. Gradients that are too shallow tend to have less seasonal river flows, less sediment carry and lower riverbanks, making them unsuitable. A laboratory scale model study[180] concluded that the appropriate slope range for sand dams is 0.9% to 6.25%.

Gradient at specific points: Looking at the diagram below, river gradients that are steep at certain points in the river mean that the catchment will be much smaller and therefore water storage lower unless extra expense is invested in building a taller dam, i.e. if built at the point of *Option B* rather the point of *Option A*.

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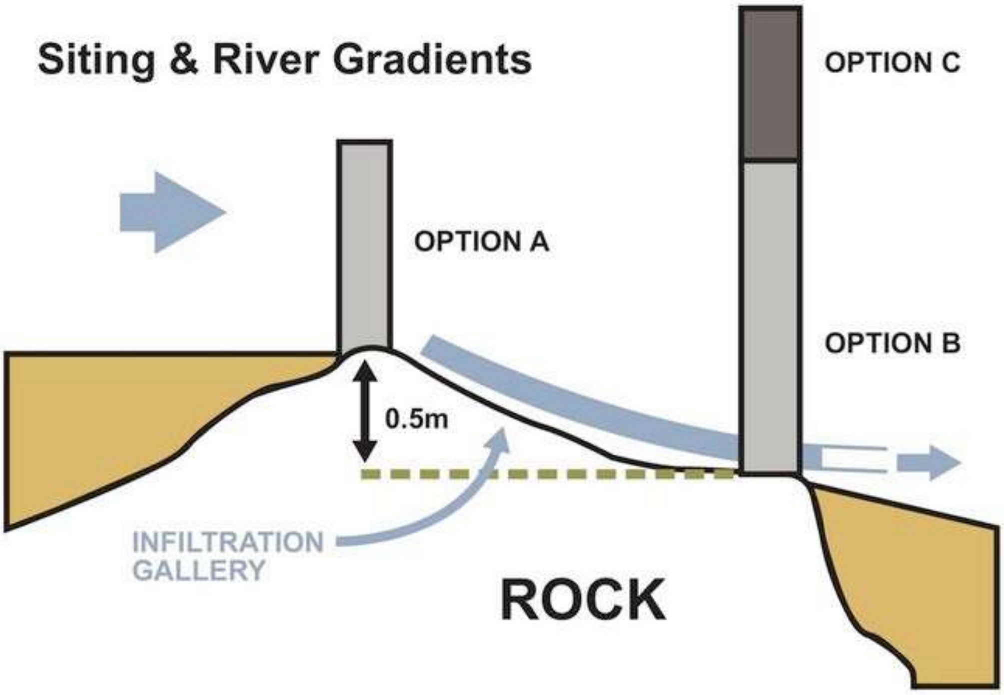
[178] Nissen-Petersen, E. 2000. Water from Sand Rivers. Nairobi: Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida), 2000. Table 1, p. 8.

[179] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013

[180] INVESTIGATING THE EFFECT OF STEP HEIGHT INCREMENT, CHANNEL SLOPE, AND FLOW RATE ON SPECIFIC YIELD OF SAND DAMS. George M Ochieng', Fred A O Otieno, Stanley M Shitote, and Cox C W Sitters

However, a potential site might have a steep gradient for a short distance but the river banks further downstream may mean that a dam can be built to a greater height (*Option C*) than the *Option A* further upstream and therefore provide greater volume of storage. Furthermore, the 'impermeable basin' of rock created with *Option B* and especially *Option C* can create a more efficient infiltration system to either a tap or animal trough, whilst upstream a shallow well may also be replenished by the dam.



The author has designed several dams using *Option C* in preference to *Option A* – a good example being Kirjan Bhoja in Rajasthan with JBF (see both the diagram above and the photos above and right). In this case *Option A* was rejected because it would need much wider wing walls to achieve the same height above *Point A* than *Option C* would because of the topography at *Point C* and the bank on the right-hand side looking upstream (see photo right), compared to the flood plain at *Point A* (see above right). Similarly, there was an impermeable rock 'basin' to collect water that would otherwise be inaccessible to be used by people or livestock. Shallow wells nearby (including in the photo above) would also be replenished as it currently didn't provide water all-year around.

Distinct Riverbanks: In siting sand dams, one is looking for a location where the maximum height spillway can be built as efficiently and effectively as possible. Rivers with higher riverbanks enable higher dams to be built with greater storage capacity. Without distinct riverbanks, the spillway would either need to be very low and/or the wing walls very wide to enable the capture and storage of water above the current river level. Indeed, it may be impossible to build a spillway above river-level. However, where the potential site is a sub-surface dam and there is a dam wall to be built 2-6 metres below current river level down to bedrock, riverbanks aren't required. Obviously, in this instance either the dam is recharging a deep water-table and/or the abstraction methods need to be tube wells, shallow wells or Rowa hand pumps to reach the water stored or replenished by the dam.

Catchment Size Upstream and/or Narrower Point in River: Finding a location where the river width upstream is larger than average will mean more water will be captured and stored. Whilst it is easier to design a dam on straighter stretches of river, bends in rivers often offer a wider catchment possibility – especially where the bend is caused by a significant rock outcrop. In this case, the river is often narrower too making a dam more cost efficient. In fact, even on straighter stretches of river rock outcrops often cause the river to go narrower, especially when the rock is across the river or even created a gorge. In addition, it is worth looking for sites that are just downstream of where two rivers join as a dam here can create a double benefit by storing water up both river courses. However, care should be taken in siting a dam too close (less than 50-100 metres) to the point they conjoin as it could cause the river or rivers to divert.

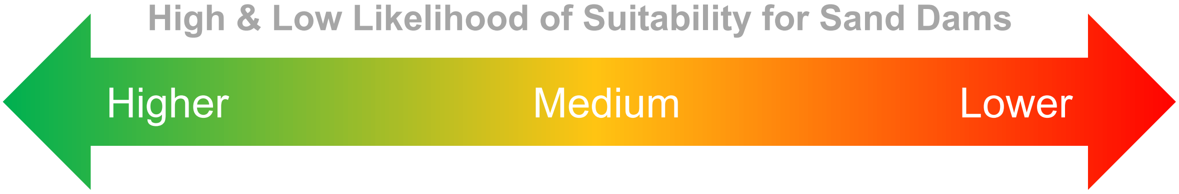
User Accessibility: The location of a sand dam needs to enable access for users (people, livestock and/or wildlife) from whatever abstraction technologies are planned. In addition to thinking of the physical environment barriers such as river banks, vegetation, rock faces etc. it is worth noting the possible legal barriers because of land ownership, which again the community will have the detailed knowledge of. Land ownership is discussed more in Chapters 4.3.5 and 8.1.1.

Upstream Impacts on Roads etc.: In siting a sand dam it is important to have in mind the likely height of the spillway so that the implications of higher riverbed for the distance of the *throwback* of the dam can be considered. For example, there may be a point upstream that may cause the river to be diverted or there may be a road bridge or drift that would be severely affected and may need further legal (rather than just community) permissions to allow the dam.

6.3.3.3 Bedrock Characteristics

Indicators of Suitable Sand Dam Sites: Bedrock Characteristics

High & Low Likelihood of Suitability for Sand Dams



Across Riverbed	Riverbed Bedrock	None
Both Sides	Riverbank Bedrock	One Side/None
0-4 metres	Depth to Bedrock	>6 metres
Granite/Limestone	Bedrock Type	Shale/Gravel
Solid	Bedrock Condition	Vertical Fractures
None	Salt-type Rocks	Calcrete/Rock Salt

Bedrock Characteristics: Suitable and accessible bedrock is a key factor discussed in the sand dam feasibility chapter (see Chapters 3.3.3 and 3.4.3.2). Whilst there is no intent to repeat the fundamentals of this pre-requisite, it is worth considering some of the same factors but through the lens of finding a suitable specific location for a sand dam. As discussed earlier in Chapter 6.3.3.1, locations where there is surface bedrock across the river and up the banks are the ideal place for a sand dam. The costs and risks of failure are lower; and the design and construction is more straightforward.

Visible Bedrock: Finding locations where there is visible bedrock provides an essential foundation for a sand dam and often also means there is already a natural underground dyke, which a sand dam would enhance. Ideal locations are either a narrow rock gorge or a site where there is bedrock across the riverbed surface and the banks of the river. The most important and therefore priority rock characteristic is that it is on the surface of the main river channel. Solid rock is preferred as rocks with vertical fissures will probably allow the water in the dam to drain away. However, this is less of a problem if the sand dam intent is to replenish the deeper water table and use tube wells for abstraction.

Depth to Bedrock: The best sand dam sites are usually where there is surface bedrock. However, sand dams can be built where the bedrock is accessible within 4-6 metres of the surface of the riverbed. If there is no visible bedrock it may be necessary to dig test pits (or use a hand augur) to estimate the depth of bedrock. This is especially true when there is no visible bedrock in the actual river as this is the area of biggest risk of failure for a sand dam because it is where the main river flow is. Sometimes upon excavation, it is found that the bedrock does not follow the assumed profile, but instead dips down sharply and deeply. It is not cost-effective to dig down more than 6 metres and even then, only over a small portion of the riverbed, where there is a narrow fissure or crack between two rock outcrops. Understanding the depth to bedrock can mean that the dam is not possible but it certainly should be a consideration when prioritising potential sites due to relative cost.

(Note: There is an exception to the bedrock rule, which is explained in Chapters 9.3 and 9.15.1.)

Bedrock types: Granite and limestone type rocks are the most favourable. Calcrete or rock salt is usually a whitish rock that livestock lick for their salt content. Where bedrock contains calcrete, there is a risk that these salts will leach into the water and cause salinity of the stored water, albeit that sand dams usually reduce the level of salinity compared to nearby wells or scoop holes because of sand filtration. This may not make it suitable for drinking however. Saline water, depending on the levels, can however be used for other domestic purposes, irrigation and especially for livestock or wildlife.

6.3.4 Socio-Economic Impact Factors

In addition to the technical factors, other socio-economic factors should be considered. An example of assessing socio-economic factors at the macro-level in Swaziland is discussed in Chapter 3.4.5. However, this is also important at a site level.

Other costs: For a potential site are there other big land management investments required and/or possible to ensure the dam is effective and, for example, protected from siltation? Apart from the usual three rows of terracing that are dug for 150 metres each side of the upstream riverbanks there may need to be other investments in check dams, gulley filling, cut-offs etc. that are required to ensure the dam does not fill with silt or get sand and silt lenses.

Comparison to other options: When deciding on the suitability of a site (as opposed to relative priority) it is important to consider the relative cost/benefit versus other water solution options that may exist. For example, if the main priority is water for livestock there may be an ideal earth dam opportunity. The topography may mean that a rock catchment would be a better solution or the amount of water already stored in the river means that only a sand abstraction system is needed. Other water solutions are described in Chapter 11.1.

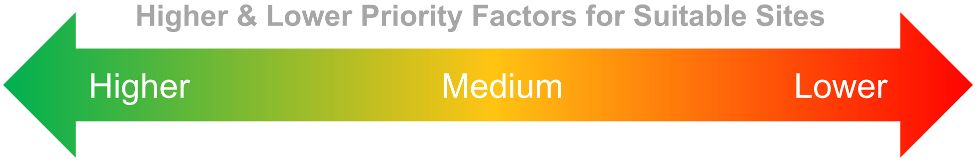
Other nearby sources: It may be that a suitable site is very close to another or other water sources meaning that there is not a need for a dam, although this may be more of a factor to consider in prioritisation of different potential dam sites.

6.3.5 Prioritisation of Suitable Sites

Especially when identifying locations for sand dams in very suitable regions it is usual to identify more sites than the community wants or needs or that funding is available and it is therefore necessary to prioritise sites. There are several factors that should be considered by the community in making decisions about priority, which may also be limited by the implementing organisation due to, for example, NGO policies, donor criteria etc. The relative importance of each factor is of course not fixed and is down to the community needs and priorities as well as any restrictions there may be on funding or the funding criteria. Prioritisation may also be important at a higher macro-level rather than just comparing a list of dams with each other. For example, with the Lekurruki Conservation Trust in Laikipia, Kenya, a plan for the whole community ranch was developed including areas where only capped springs and RWH tanks were suitable. The community needs and priorities were complex covering areas such as border conflict reduction, grazing zones, wildlife zones, schools and Trust HQ needs etc. Not only was the sequencing of build important but it was important to establish sites that met all these water needs and abstraction requirements geographically rather than just choosing the best seventeen sand dam sites out of a list of almost thirty potential locations. This was carried out over five years and, of course, the plans and priorities evolved over time as the community learnt more and the impacts of the dams were better understood. At a more simplistic level, here is a checklist of the factors that should be considered in the prioritisation of sites alongside the community although, of course, individual circumstances may define that there are others too.

Factors for Prioritisation of Suitable Sand Dam Sites:

Higher & Lower Priority Factors for Suitable Sites



Higher	Relative Cost/Benefit	Lower
Nearby	Availability of Materials	Low or None
Higher	Water Storage & Likely Yield	Lower
Lower & Shorter	Time & Distance for Users	Higher & Longer
High	Suitability to Meet Community Needs	Low
High	Suitability for Desired Abstraction	Low
No	‘Overlap’ with Another Site	Yes
Yes	Preferred Building Sequence	No

Relative Cost/Benefit including Water Storage and Likely Yield: Dam capacity, water storage and yield was discussed in detail in Chapter 2.8 and assessing the ‘value for money’ of sand dams was discussed in detail in Chapter 2.9. Obviously, every sand dam will have a different cost/benefit depending on its location. Especially when there are limited funds it is worth considering the relative cost benefits and potential total yields from each of the dams.

Availability of Materials: Different locations will have differing availability of the water, sand and rocks required for building the dam, which has implications on the cost and community participation. Also, is it going to be possible to gain access to deliver the cement, steel and shuttering to the site without too significant cost implications?

Time & Distance for Users: Different potential sites may be closer or further away from the users, meaning that a so-called ‘better’ site may be less of a priority than a site that saves the community the most time – a massively under-rated benefit of sand dams.

Suitability to meet the community needs & priorities: Again, different locations will contribute differently to the community’s needs and priorities around what they need water for and where. Again, a technically ‘better dam’ may not meet the needs of users as well as another dam in a different location.

Suitability for Desired Abstraction: In a similar way to the above point, each sand dam will have different opportunities in terms of the abstraction methods that can be used with them. It is important to assess the abstraction methodologies available against the community needs and priorities.

Preferred building sequence: When several dams are planned in the same river catchment the sequence of building them can be important, especially in terms of siltation risk. In general, for dams less than 1 km apart, it is better to build the dam downstream first to reduce the time it takes for dams to fill with sand and reduce the siltation risk. Consequently, it is also better not to build dams nearby each other in the same season unless the spillway heights are built in stages.

‘Overlap’ with another site: Sometimes building on all potential dam sites will mean that dams ‘overlap’ meaning that one dam would cover or partially cover a dam upstream with sand making both less cost-effective or even unnecessary. In this case, a choice needs to be made between one dam or another.

6.4 Finalising Water Abstraction Options

Having started with an understanding of the community needs and options and establishing the potential types of sand dams, river sediment types, plus the topography and other features of the potential sites; it is now possible to return to those needs & priorities and draft a proposal for the possible suitable abstraction options for the community to consider prior to design – especially where there may be different opportunities with the different sites available. Different sites, of course, will have other advantages and disadvantages in terms of cost and potential yields etc.

Sand Dam Water Abstraction Technologies	Usage Capability vs. Needs & Priorities					Type of Sand Dam			Sediment Type	
✓ = Recommended ✗ = Not Recommended	People Drinking Water	People Other Domestic	Livestock	Irrigation	Wildlife	Perched Aquifer ^	Shallow Groundwater Recharge	Only Deep Groundwater Recharge	Finer Sandy Sediment	Coarser Sandy Sediment
Scoop holes	✗	✓	✓	✓	✓	✓	✗	✗	✗	✓
Tank with pipe & tap using infiltration gallery	✓	✓	✓	✓	✗	✓	✗	✗	✓*	✓
Tap with pipe through dam using infiltration gallery	✓	✓	✓	✗	✗	✓	✗	✗	✓*	✓
Tap and animal trough using infiltration gallery & pipework	✓	✓	✓	✗	✓*	✓	✗	✗	✓*	✓
Shallow well with hand-pump	✓	✓	✗	✗	✗	✓	✓	✗	✗	✓
Shallow well with hand-pump plus infiltration galleries	✓	✓	✗	✗	✗	✓	✓	✗	✓*	✓
Shallow well with hand-pump & separated animal trough	✓	✓	✓	✗	✗	✓	✓	✗	✓*	✓
Rowa hand pump & animal trough	✓	✓	✓	✗	✗	✓	✓	✗	✗	✓
Rowa hand pump & animal trough with enhanced infiltration	✓	✓	✓	✗	✗	✓	✓	✗	✓	✓
Tube well	✓§	✓	✓§	✓§	✗	✓§	✓§	✓	✓	✓

✓* Due to slow flow rate an enhanced infiltration gallery is required

✓* Note special measures to enhance elephant-proofing

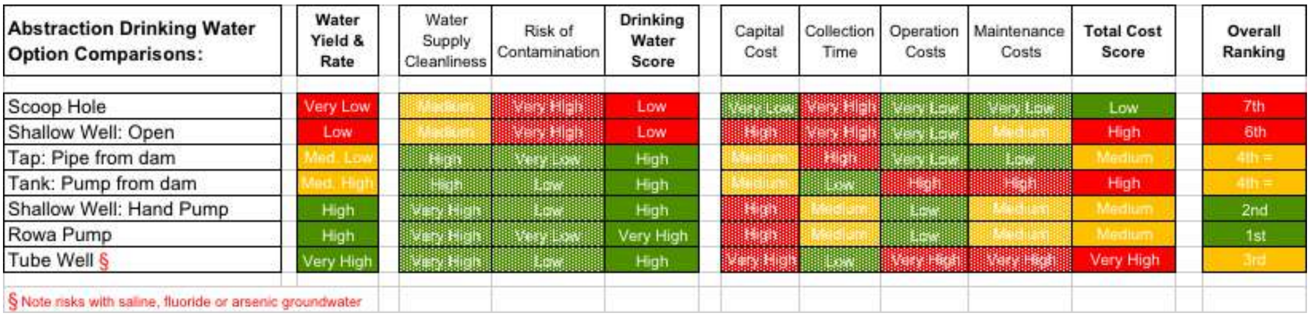
✓§ Note risks with saline, fluoride or arsenic groundwater

^ i.e. where water is stored behind the dam (see Ch. 3.6)

✓§ All dams will recharge deeper groundwater to an extent

Directly related to these choices are also how each technology option performs, particularly in relation to drinking water use if that is a priority; and in relationship to yield and yield rate capability (also related to desired use such as irrigation or high livestock supply) as well as the costs: capital, operational costs and ongoing maintenance & repair costs. This may also influence the decisions that the community make over the options available.

Relative comparisons of abstraction technologies for drinking water suitability and costs are mapped out below:



Abstraction Drinking Water Option Comparisons:	Water Yield & Rate	Water Supply Cleanliness	Risk of Contamination	Drinking Water Score	Capital Cost	Collection Time	Operation Costs	Maintenance Costs	Total Cost Score	Overall Ranking
Scoop Hole	Very Low	Medium	Very High	Low	Very Low	Very High	Very Low	Very Low	Low	7th
Shallow Well: Open	Low	Medium	Very High	Low	High	Very High	Very Low	Medium	High	6th
Tap: Pipe from dam	Med. Low	High	Very Low	High	Medium	High	Very Low	Low	Medium	4th =
Tank: Pump from dam	Med. High	High	Low	High	Medium	Low	High	High	High	4th =
Shallow Well: Hand Pump	High	Very High	Low	High	High	Medium	Low	Medium	Medium	2nd
Rowa Pump	High	Very High	Very Low	Very High	High	Medium	Low	Medium	Medium	1st
Tube Well §	Very High	Very High	Low	High	Very High	Low	Very High	Very High	Very High	3rd

§ Note risks with saline, fluoride or arsenic groundwater

The costs of different options – especially the operation & maintenance costs – often have a strong influence on the final community choices. It is critical that the community has process capability and/or willingness to manage the ongoing financial and operational activities. The 'best' abstraction solution failing is a worse option than choosing the second or third 'best' one that will work sustainably in the long-term. The best answer is the one that works for the community once you've gone.

The costs for implementing abstraction technologies obviously vary but an indication of the average additional labour and material costs are as follows:

Water Abstraction Technology Costs:

Tap with pipe & infiltration gallery	$ 350
Tank with pipe & infiltration gallery	$ 650
Animal trough with infiltration gallery & pipework	$ 1,100
Shallow well & hand-pump	$ 1,500
Shallow well & hand-pump with infiltration gallery	$ 1,800
Rowa hand pump & animal trough	$ 1,600

Chapter 7: Designing Sand Dams

Designing sand dams is not a straight-forward task. It is unusual in that there is insufficient data (and insufficient research-driven rules) to design dams by measurement and calculation. Sand dams are, technically speaking, overflow gravity dams constructed with steel-reinforced rubble stone masonry, of which there are several fundamental principles that must be followed.

This chapter covers:

- **Laying out the common causes of failure;**
- **Detailing the scientific principles and rules for overflow gravity dams that need to be followed;**
- **Explaining the golden rules of design;**
- **Mapping out a step-by-step process for designing sand dams.**

7.1 Common Causes of Failure for Gravity Dams

A gravity dam may fail in following modes[181]: (See Chapter 7.3 for more details on mitigations.)

1. **Overturning** of dam about the toe – mitigated by the weight of the dam and the shape of the dam including a 'toe'
2. **Sliding** of the dam – mitigated by the weight of the dam to increase friction and steel bars drilled into the rock base.
3. **Compression** by crushing – mitigated by the fact that cement has high compressive strength if cured correctly.
4. **Tension** by development of tensile forces which results in cracking of the dam – mitigated by increasing the tensile strength with barbed wire tied between the steel reinforcements horizontally across the dam.
5. **Seepage** (>33% cause of failure for earth dams) if too high will cause the dam to undercut and/or wash away due to the increased uplift pressure[182] – mitigated by ensuring the dam is keyed into the bedrock at least 1.5 m wider than the flood width of the river; also by ensuring the construction of the dam does not allow water to pass through cracks or air pockets.

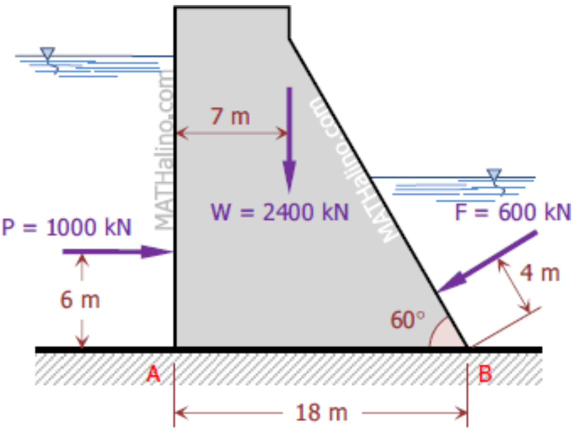
7.2 Additional Causes of Failure for Sand Dams

Additionally, a sand dam [broad-crested, contracted rectangular weir] may also fail in following modes:

6. **Bypassing**: the river changes course around the dam – mitigated by correct positioning of spillways and width of wing walls.
7. **Undercutting** the dam causing it to fall over – mitigated by the correct positioning of a sufficiently strong apron.
8. **Under-flow**: water passes underneath the foundation – mitigated by ensuring the dam is built on bedrock (with a good seal) for a sufficient width of the dam to avoid water seeping, then eventually flowing, underneath the dam.
9. **Siltation**: the dam fully, or partially, fills with silt or clay possibly causing it to fail completely – mitigated by building phased spillway heights each season.

7.3 Principles & Rules of Overflow Gravity Dams

Technically speaking, sand dams are overflow gravity dams, constructed with steel-reinforced rubble stone masonry.



- Gravity dams utilize the weight of the construction material alone to resist the horizontal and uplift pressures: (see diagram right)[183]
  - Pressure of water (and later when full of sediment for sand dams) pushing against the dam wall;
  - Also for sand dams the 'wave pressure' caused by the river (and floating objects) when seasonal rains flow and whilst the dam is filling with water and sediment.
- Hence, gravity dams must be built on a sound rock base so it transfers all the forces to the foundation.
- Lateral movement or slippage of a sand dam is further reduced by using steel bars drilled into the rock base.
- The weight of the dam prevents toppling, enhanced by the 'toe' of the dam (see diagram below left[184]).

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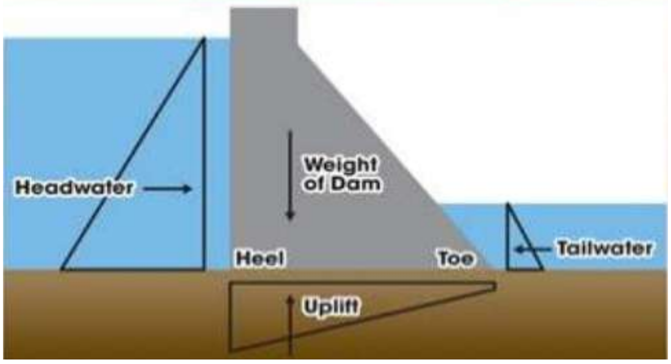
[181] Shaik, Naazo. Gravity Dams: Causes of failure for gravity dams, 2016. https://theconstructor.org/water-resources/failure-of-gravity-dam-types-causes-modes/11787/
[182] https://www.slideshare.net/gauravhtandon1/earthen-dams
[183] http://www.mathalino.com/tag/reviewer/gravity-dam Copyright 2017 © Romel Verterra
[184] https://www.slideshare.net/gauravhtandon1/gravity-dam

7.3.1 Dam Thickness versus Height



There are four major static forces exerted on a gravity dam (see diagram above right[185]) and a myriad of very complicated ways to calculate the required thickness of a gravity dam in relationship to its height e.g. hydraulic pressure, hydrodynamic pressure, silt pressure, water pressure and wave pressure; including many complicated cross-sectional shapes of gravity dams[186].

In 1913, George Holmes Moore wrote in Engineering News, “In possibly no other branch of dam design is the amplification of the unessential so marked as here, for the ‘theoretic profile’ and the ‘hyperbolic-curve’ nonsense [of some gravity dam design methods] heaped upon what might be termed the gravity section is astounding indeed. Pages, chapters, even volumes are devoted to a discussion of gravity profiles which depart but negligibly from a simple basic section.” He added, that gravity dam designs were “merely variations of a simple triangle, a triangle whose base is two-thirds of its height” [187]. Consequently, relatively empirical methods of design (based on Moore’s “two-three triangle”) are sufficient to meet any real engineering needs.[188] For example, the Roosevelt Dam, using a whole range of calculations concluded that for its height of 280 feet it needed to be 184 feet thick; the two-thirds method would make that thickness 186.7 feet[189] which is 1.5% different.

This leaves us emboldened with a set of very simple calculations and assumptions, backed up with empirical evidence:

Golden Calculation: Dam Base Thickness§ = $^2/_3$rds Height

§ Dam Base Thickness is at the original river level. The foundation extends to the base rock at the same thickness.

Using Moore’s “two-three triangle” principle, and the simplified shapes shown above, the base thickness reduces at a 60° angle (i.e. 30cm for every 1m height) up to a minimum thickness at the central spillway crest:

Golden Calculation: Dam Thickness§ reduces by 30cm# for every 1m of Height

§ Dam Thickness has a minimum of 1.2-1.5m depending on the size of the river.

 # Dam Thickness up to the [finally planned] central spillway level has a minimum thickness of 0.9m.

Because sand dams are relatively low height gravity dams, there Is a need to set minimum foundation and base thickness of 1.5m to maintain the integrity of the engineering principles behind the calculations. Experience tells us that for sand dams ≤2m high this can vary according to the size of the river, judged as less than 6-9m depending on flow rate/strength (e.g. a 6m gorge would be treated as a larger river):

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[185] Gregory S. Paxson, David B. Campbell, Michael C. Canino, and Mark E. Landis. Dam Safety: Stability and Rehabilitation of "Smaller" Gravity Dams. *2011*. http://www.hydroworld.com/articles/hr/print/volume-30/issue-6/articles/dam-safety-stability-and-rehabilitation-of-smaller-gravity-dams.html

[186] Mishra, Gopal. FORCES ACTING ON A DAM STRUCTURE, 2010. https://theconstructor.org/water-resources/forces-acting-on-a-dam-structure/5251/

[187] Moore, George Holmes, “Neglected First Principles of Masonry Dam Design”. Engineering News 70 (Nov. 4, 1913) pp 442-5

[188] Jackson, Donald C., Dams. Routledge, 1998. https://books.google.co.uk/books p. 36.

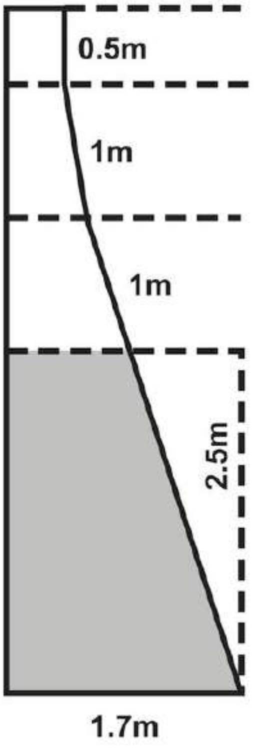
[189] Jackson, Donald C., Dams. Routledge, 1998. https://books.google.co.uk/books p. 39.

Golden Assumption: Minimum Dam Base Thickness is 1.5m[§]

[§] For dams ≤2m spillway height in smaller rivers of <6-9m the minimum dam base thickness is 1.2m.

These rules can be translated into a table of calculated foundation & base thicknesses and main spillway crest thicknesses for differing heights (the diagram right is an example cross-section for a 2.5m high dam with 2.5m of spillways). It is recommended to round up calculations to the nearest 10cm to give 'process-capable' measurements to the dam builders:

Sand Dam Thickness vs. Height Rules: Larger River										
Larger River	> 6-9m riverbed width depending on flow strength									
Foundation = $^{2}/_{3}{}^{rds}$ Central Spillway Height										
Foundation Minimum	1.5	Reduces at 0.3m/m								
Spillway Crest Minimum	0.9	Reduces at 0.3m/m								
Height Central Spillway (m)	**1.0**	**1.3**	**1.5**	**1.8**	**2.0**	**2.5**	**2.7**	**3.0**	**3.5**	**4.0**
Base Thickness (m)	1.5	1.5	1.5	1.5	1.5	1.7	1.8	2.0	2.3	2.6
Spillway Crest Thickness (m)	1.2	1.1	1.1	1.0	0.9	0.9	1.0	1.1	1.3	1.4



Sand Dam Thickness vs. Height Rules: Smaller River										
Smaller River	< 6-9m riverbed width depending on flow strength									
Foundation = $^{2}/_{3}{}^{rds}$ Central Spillway Height										
Foundation Minimum	1.2	Reduces at 0.3m/m				*n.b.* Dimensions unaltered >2m Height				
Spillway Crest Minimum	0.9	Reduces at 0.3m/m								
Height Central Spillway (m)	**1.0**	**1.3**	**1.5**	**1.8**	**2.0**	**2.5**	**2.7**	**3.0**	**3.5**	**4.0**
Base Thickness (m)	1.2	1.2	1.2	1.2	1.3	1.7	1.8	2.0	2.3	2.6
Spillway Crest Thickness (m)	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.1	1.3	1.4

Dam Wing Thicknesses above Spillway Height:

Again, using Moore's "two-three triangle" principle, from the spillway height, the base thickness reduces at a 60° angle (i.e. 30cm for every 1m height) up to a minimum thickness at dam wing crests of 0.4m:

Golden Calculation: Dam Wing Thickness[§] reduces by 30cm[#] for every 1m of Height

[§] Upwards from the spillway height thickness

[#] Dam Thickness up to the [finally planned] central spillway level has a minimum thickness of 0.9m.

As can be seen in the full tables below, a logical pattern of crest heights is created, with a uniform set of crest heights for smaller river dams ≤2m high. Again, it is recommended to round up calculations to the nearest 10cm to give 'process-capable' measurements to the dam builders:

Sand Dam Thickness vs. Height Rules: Larger River

Larger River **> 6-9m riverbed width depending on flow strength**

Foundation = $^{2}/_{3}{}^{rds}$ Central Spillway Height

Foundation Minimum	**1.5**	**Reduces at 0.3m/m**
Spillway Crest Minimum	**0.9**	**Reduces at 0.3m/m**
Wing Crest Minimum	**0.4**	

Height Central Spillway (m)	**1.0**	**1.3**	**1.5**	**1.8**	**2.0**	**2.5**	**2.7**	**3.0**	**3.5**	**4.0**
Base Thickness (m)	1.5	1.5	1.5	1.5	1.5	1.7	1.8	2.0	2.3	2.6
Spillway Crest Thickness (m)	1.2	1.1	1.1	1.0	0.9	0.9	1.0	1.1	1.3	1.4
Wing Crest Thickness (depending on total depth of wings)										
1m wings depth	0.9	0.8	0.8	0.7	0.6	0.6	0.7	0.8	1.0	1.1
1.5m wings depth	0.8	0.7	0.6	0.5	0.5	0.5	0.5	0.6	0.8	1.0
2m wings depth	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.5	0.7	0.8
2.5m wings depth	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
3m wings depth	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5

Sand Dam Thickness vs. Height Rules: Smaller River

Smaller River **< 6-9m riverbed width depending on flow strength**

Foundation = $^{2}/_{3}{}^{rds}$ Central Spillway Height

Foundation Minimum	**1.2**	**Reduces at 0.3m/m**
Spillway Crest Minimum	**0.9**	**Reduces at 0.3m/m**
Wing Crest Minimum	**0.4**	

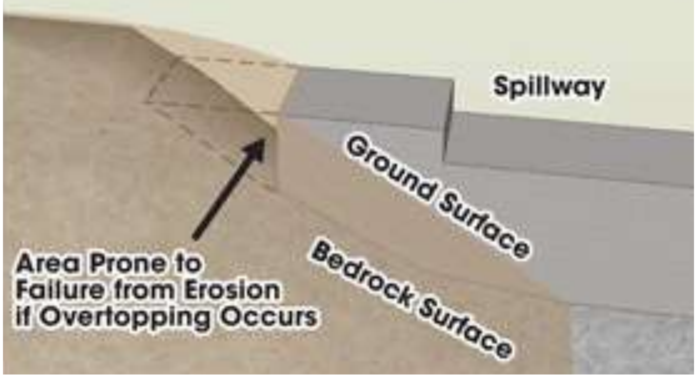
n.b. **Dimensions unaltered >2m Height**

Height Central Spillway (m)	**1.0**	**1.3**	**1.5**	**1.8**	**2.0**	**2.5**	**2.7**	**3.0**	**3.5**	**4.0**
Base Thickness (m)	1.2	1.2	1.2	1.2	1.3	1.7	1.8	2.0	2.3	2.6
Spillway Crest Thickness (m)	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.1	1.3	1.4
Wing Crest Thickness (depending on total depth of wings)										
1m wings depth	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.8	1.0	1.1
1.5m wings depth	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.8	1.0
2m wings depth	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7	0.8
2.5m wings depth	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
3m wings depth	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5

7.3.2 Wing Walls

Overflow gravity dams require wing walls (shown in the diagram right) built into the valley sides wider than the spillways in order prevent the river from diverting around the dam. If wing walls overflow or overtop, there is potential for erosion and failure of the wing, resulting in a potential dam failure or loss of reservoir[#].

There is a rule around how this is preferably done with several exceptions to the rule in given circumstances:[190]



Rule: Wing walls should be built down to bedrock[§] for the full width of the sand dam.

[#] If the full width of the wings is built on <u>surface rock</u>, then limited overtopping will not cause damage to the dam.

<u>If, in designing the dam you are certain that the dam will not be overtopped:</u>

[§] >10m from the widest spillway, the wing walls can be dug and built >1m into compacted sub-soil rather than bedrock.

[§] >20m from the widest spillway, the wing walls can then be extended with compacted sub-soil and rocks.

7.3.3 Wing Thickness into the Valley Sides

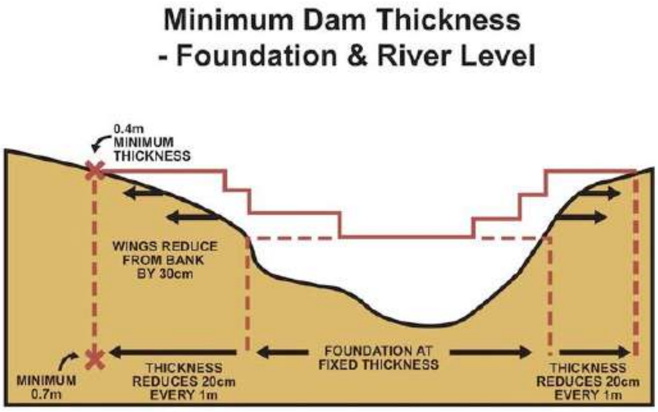
Once a wing wall is built into the valley sides the forces on it change dramatically whereby the downstream horizontal force is in virtual[§] equilibrium with the upstream horizontal forces. Consequently, the thickness of the dam walls can begin to reduce in thickness without reducing their effective strength, especially when also the walls embedded in the banks are not subject to the dynamic forces of water and/or wave flow of the river[§]. **Note:** [§] There will be some difference between the forces when the valley sides upstream are saturated with water but the downstream valley sides are not.

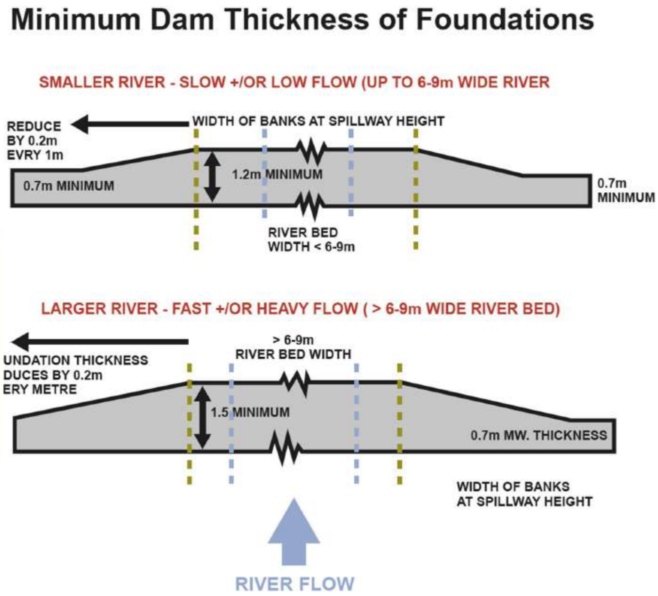
Golden Calculation: Dam Wing Thickness[§] reduces by 20cm[#] for every 1m of Width

[§] Once dam wings are embedded into the valley sides; maintain the same wing thickness whilst 'underground'.

[#] Dam Thickness, up to both ends of the dam, has a <u>minimum thickness of 0.7m</u>.

These rules are shown below in diagrams of foundation & base thicknesses reducing into the valley sides:





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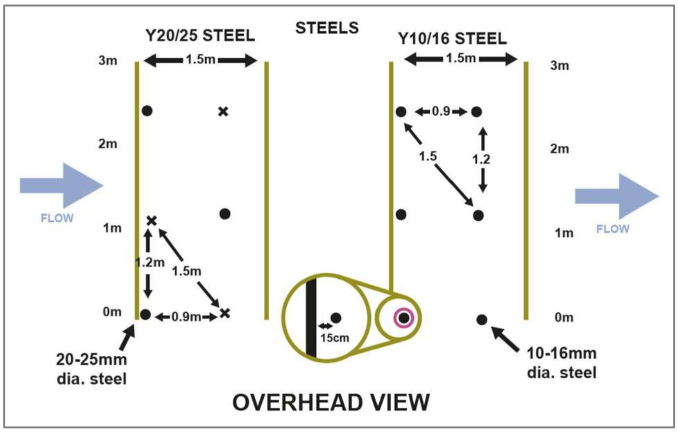
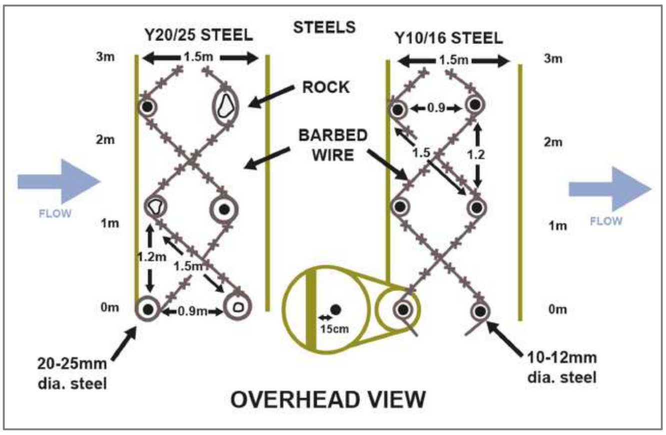
[190] *Gregory S. Paxson, David B. Campbell, Michael C. Canino, and Mark E. Landis*. Dam Safety: Stability and Rehabilitation of "Smaller" Gravity Dams. 2011. *ibid.*

7.3.4 Tensile Strength: Steel 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 and barbed wire reinforcement increases the tensile strength and reduces the risk of slippage.

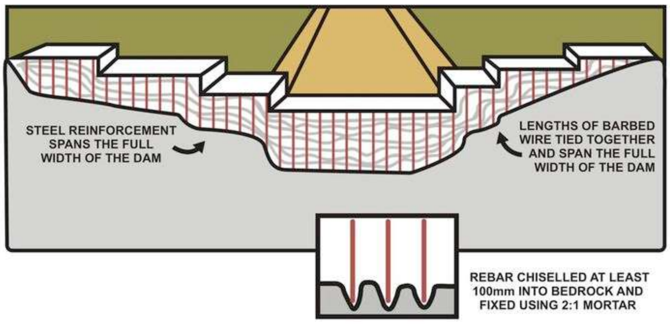
A 3-4-5 (30°-60°-90°) triangle system "is in moment equilibrium due to a concurrent force system"[191] and therefore highly suitable for the construction of sand dams, which seek to be an immovable object. The steels are laid out in a triangle shape 1.5m apart diagonally (and 0.9m apart across the dam width when using lower strength Y10/16 steels).

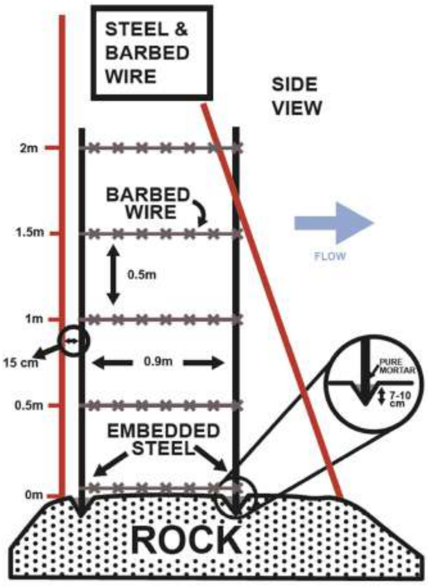




- **Steel reinforcement bars embedded vertically in the bedrock to prevent the dam from slipping (lateral movement) by increasing friction.**
- **Steel bars are fixed vertically in 10-15cm deep holes chiselled or drilled into the bedrock using a 2:1 mortar.**
- **The bars are spaced in a 3:4:5 ratio triangular formation diagonally every 1.5 m across the full length of the foundation (every 1.2m length).**

The Placement of Steel Reinforcement Bars and Barbed Wire





- **The barbed wire strung across the dam in a helix-shape and firmly anchored at each end of the dam.**
- **This is done at the foundation level of the dam and at every 50cm increase in height afterwards. This increases the tensile strength of the dam (a weakness of cement mortar) and thereby reduces the chance of cracking.**
- **The bars are placed 15cm in from the sides of the formwork and are cut to length so that they extend from the bedrock to 5cm below the top of the dam, so they can be covered in cement to prevent corrosion.**

7.3.5 Principles of Concrete & Rubble Stone Masonry

The principles of concrete and stone-masonry are also critical to a successful sand dam but are more applicable to construction than dimensional design; they are discussed in detail in the Chapter 9.5.

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[191] Luebkeman, Chris H., 1997. http://web.mit.edu/4.441/1_exprobs/1_exprob_7/1_exprob_71.html

7.4 Two Golden Rules of Sand Dam Design

There are two fundamental Golden Rules of Design for a sand dam, whereby every single design decision is either related to one or both at the same time. Whilst there may be a few detailed exceptions to these rules, it is an understanding of, and adherence to, these rules that are the key to success.

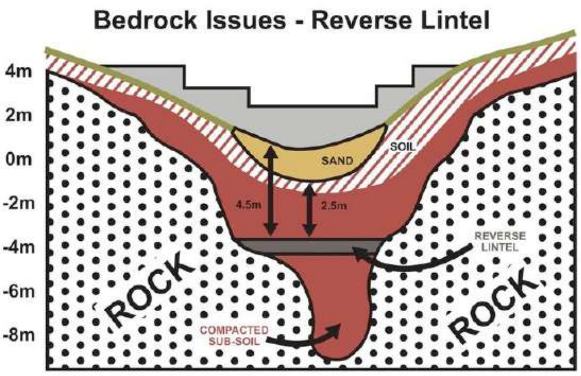
1. **A sand dam must be built on bedrock to create a water-tight seal across the valley.**
2. **A sand dam must not change a river's course, thereby allowing it to flow as before.**

Note 1:

Sand dams must be built on sites with accessible bedrock (within 4-6m of the surface of the riverbed).
This is because, the dam needs to withstand the downward forces on the dam, which is mostly its weight. Otherwise the dam wall will sink causing it to crack. The river will then immediately, or eventually, flow through the dam causing complete failure.
Therefore, the sand dam should be built onto bedrock at least 1.5m wider than the annual flood width of the river.
Also, to be effective, the sand dam needs to create a near water-tight seal across the valley to:

- **ensure that water does not flow directly underneath or around the dam, thereby either under-cutting the dam and causing complete failure;**
- **maximise ground water recharge; and**
- **hold water behind the dam.**
- Albeit, of course, there will always be some very small seepages of water through underground fissures in the rocks or slow underground movement around, or even deep underneath, the dam.

Where, after 4-6m depth, there is still no bedrock *all the way* across the river channel it may still be possible to build an effective sand dam. If there is impermeable, compacted sub-soil at this depth a 'reverse lintel' can be constructed from steel and concrete, but this must be at a depth of least 1.5m into the compacted sub-soil (see diagram above). It is preferable that this is laid onto bedrock both sides of the dam or at least one side to reduce the chance of the dam subsiding and cracking.



If there is **no bedrock at all** this is highly risky especially for a dam that is built more than a metre above river level because the weight of the dam can cause the dam to sink and crack. If this is done the compacted sub-soil **must** be very solid and the lintel **must** be built across the full width of the dam and as deep as possible into the compacted sub-soil to avoid subsidence.
Failure to build on bedrock (or a suitably placed reverse lintel) will cause the dam to sink and crack.

Note 2:

There are several reasons for Golden Rule No. 2 (not changing the river's course & allowing it to flow as before):

- **The spillway and wing widths need to ensure the river continues to follow its original path, rather than diverting it;**
- **The positioning of the spillways and wings must be angled to ensure the river does not change direction;**
- **The total spillway and wing heights must not allow the river to overtop the dam[#];**
- **The spillway widths must not 'spread' the river causing erosion due to too wide flow up & downstream of the dam;**
- **The central spillway height and/or spillway widths must not confine the flow of the river too much, causing siltation.**

[#] If the full width of the wings is built on surface rock, then limited overtopping will not cause damage to the dam.

7.5 Understanding River 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, 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.

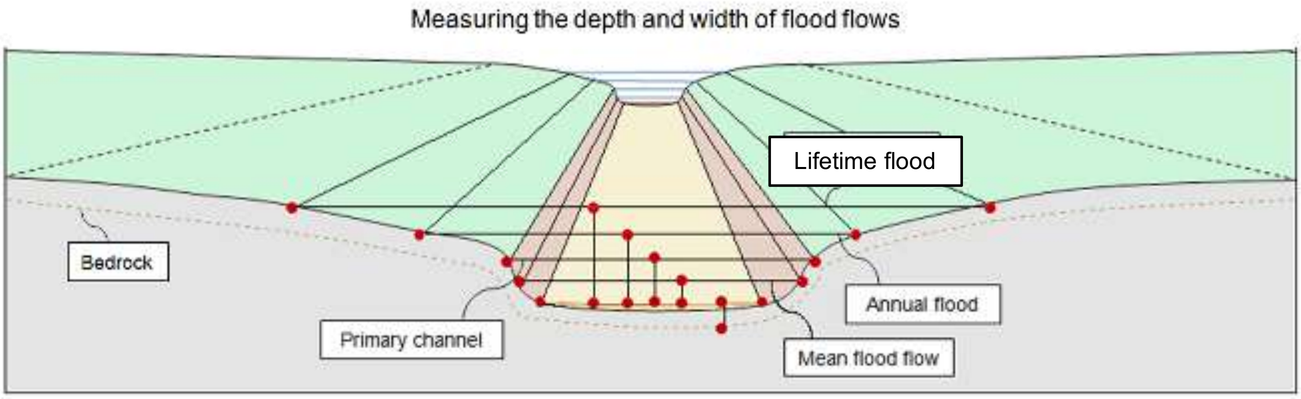
At the potential dam site and at other points upstream and downstream of the site, ask people to identify the points on both banks that correspond to the flood levels shown in figure overleaf and mark these points. Choose people, especially elders, who live near the river and who have a detailed knowledge 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 below. 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?

Flotsam carried by recent flood indicate peak flood level

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

The flood levels determine the position, width and height of the central and flood spillways. At the proposed site, record the frequency and duration of the floods shown in the diagram overleaf including:

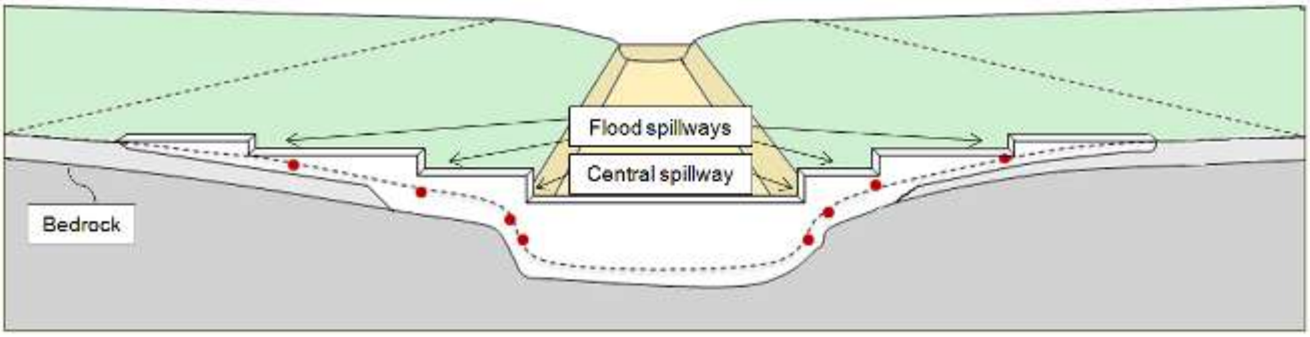
- The depth of bedrock or suitable foundation
- The width of the riverbed
- The width and depth of the mean or 'normal' flood flow defined as the average depth of flow when the river is flowing
- The width between the top of the riverbanks and their height above the riverbed
- The width and depth of the annual flood
- The width and depth of the 'lifetime' 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?



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.

7.6 Design Decisions & Process Order

This final section of the chapter goes step-by-step through the design of sand dams from siting to drawings; and the design of the ancillary infrastructure or measures that need to be taken. The section will refer to, rather than repeat, previous chapters or sections on siting, siltation risk, abstractions methods and soil & water conservation measures, but will place them in their logical sequence in the design process. For context, the two drawings below show a bird's eye view of an example site (below left) and a generic sand dam cross-sectional shape labelled with the terms being used.



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

7.6.1 Confirmation of Decisions made at Siting Stage (see Chapter 6.3):

- Positioning & angle of the dam spillway;
- Positioning & angle of the dam wings.

7.6.2 Main Design Steps (see Chapter 7.5):

- Height of the central spillway (above current river level);
- Width and position of the central spillway and height of the spillway step;
- Width, height and positioning of flood spillway(s);
- Width and placement of apron (if required).

7.6.3 Measurements & Calculations, leading up to the Drawings (See 7.6.2.2):

7.6.4 Siltation Risk & Actions:

- Planning phased build of spillways, if required.

7.6.5 Design Method(s) of Abstraction (see Chapter 6.2 and 6.4):

- Design, measurement & positioning of infiltration galleries;
- Specification & positioning of hand pump(s);
- Positioning of taps &/or animal troughs including measurement of pipework.

7.6.6 Design of Soil & Water Conservation Measures:

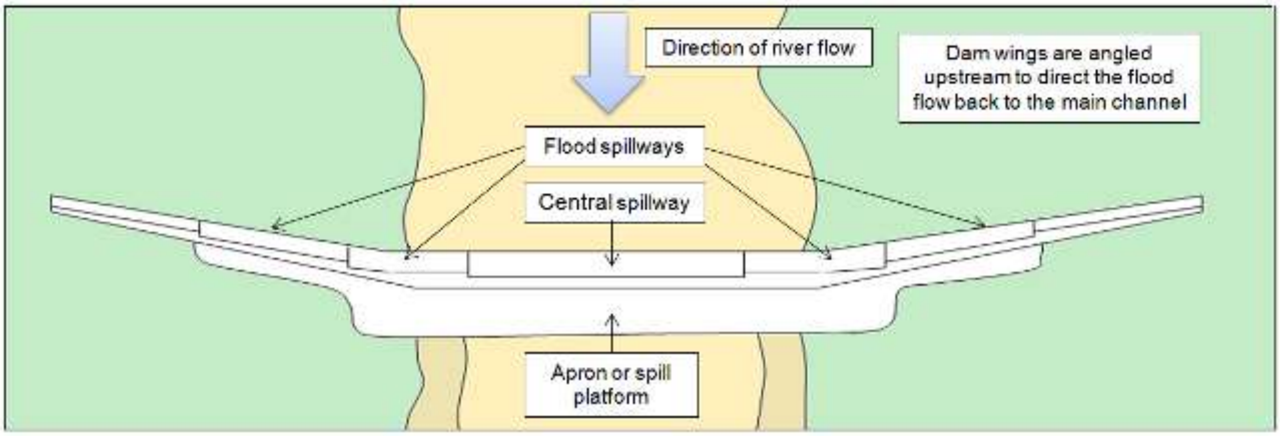
- Riverbank protection measures;
- Measuring & layout of contour terracing;
- Measuring & layout of cut-off ditches, if any;
- Planning gulley reclamation plan.

7.6.1 Positioning of the Dam & Wings

Confirmation of decisions made at siting stage (see Chapter 6.3):

- Positioning & angle of the dam spillway;
- Positioning & angle of the dam wings;
- Exceptions. Dam bent in the middle

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



Dam wings angled upstream

7.6.1.1 Common Error A: Dam spillway not built perpendicular to flow

Best case negative impacts:

- Water is pushed around the dam causing erosion upstream and downstream of the dam

Worst case negative impacts:

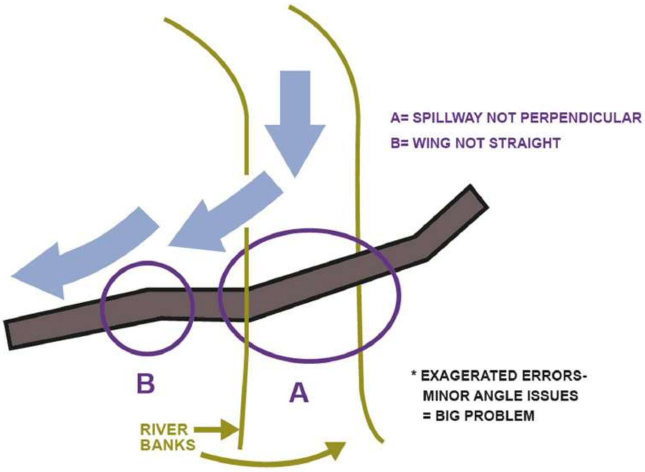
- **River completely changes direction around the dam, causing complete failure**

Mitigation:

- Take care on river bends and where the outside river bank is rock because the river will 'bounce' off the outer side and try and flow the other direction.

Avoidance:

- **Ensure the dam spillway is designed perpendicular to the main flow.**



7.6.1.2 Common Error B: Wings not designed straight

Best case negative impacts:

- Water is pushed around the dam causing erosion upstream and downstream of the dam

Worst case negative impacts:

- **River completely changes direction around the dam, causing complete failure**

Mitigation:

- Wing walks are often built or designed on an angle to keep river flowing over the spillways which makes it easier to not build that section of the dam wall perfectly straight, which causes the flow to 'split' pushing the river outwards.

Avoidance:

- **Always set a build line when setting formwork and when plastering the dam on upstream side**

7.6.1.3 Exceptions to a perpendicular spillway

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. To bring the flow back towards the central spillway, the downstream wing is angled upstream as shown in the photos below.

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

7.6.2 Main Design Steps[192]

7.6.2.1 Height of the central spillway

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 while 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 to capture sufficient water and sediment to be worthwhile unless the main purpose is aquifer recharge and there is significant below river-level depth to the dam.

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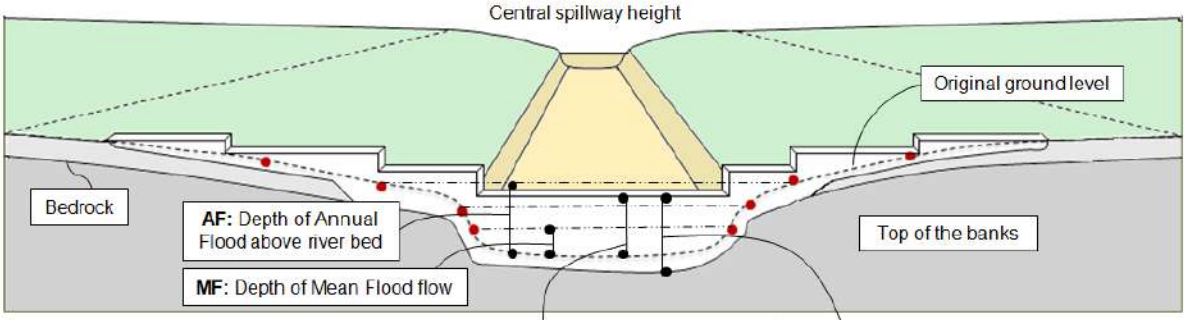
[192] This has been edited by Maddrell, S. from the original appearing in Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013.



Height of central spillway above the original river bed is > MF and < MF + 2/3 (AF-MF)

Worked example: If MF is 0.5 m and AF is 2 m, the minimum height of central spillway above the original river bed is 0.5 m and the maximum is is 0.5 + 2/3 (2 - 0.5) = 1.5 m

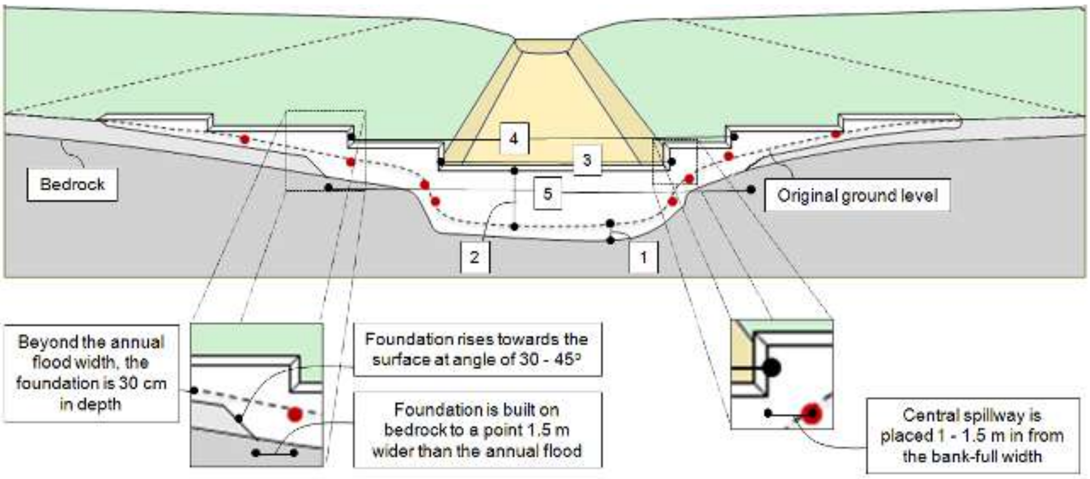
Central spillway is > 1.5 m above bedrock, the minimum sediment depth for the dam to be worthwhile

Central spillway height

7.6.2.2 Width and position of the central spillway and height of the 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.

From the diagrams below, 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. 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.**



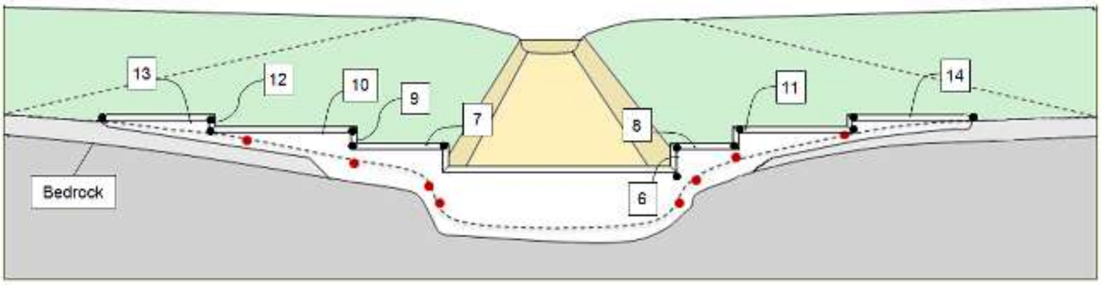
Beyond the annual flood width, the foundation is 30 cm in depth

Foundation rises towards the surface at angle of 30 - 45°

Foundation is built on bedrock to a point 1.5 m wider than the annual flood

Central spillway is placed 1 - 1.5 m in from the bank-full width

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)

7.6.2.3 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 or, in the case that it 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) 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 exceed 1 metre.**

7.6.2.4 Width and placement of 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.

7.6.3 Design Drawings

Measurements & calculations, leading up to the drawings (See Appendix 1.3 and 1.5):

7.6.4 Siltation Risk & Actions

Sand dams built in the wrong place or designed incorrectly will silt up, rather than fill with sufficiently sandy sediment and sufficiently abstractable water. This was discussed at length in the chapter on sand dam feasibility (specifically Chapter 3.3.1 on seasonality, Chapter 3.3.2 on sediments and Chapter 3.5 on testing river sediments). The time required for a dam to fill with sediment is a good indicator of siltation risk. 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[193] recommend that to avoid siltation:

1. The spillway should always be raised in small incremental steps (approx. 30-40 cm)
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, however, this is an oversimplification:

- Firstly, if the original river sediment has high silt content, the dam sediment will also have high silt content (regardless of spillway height or catchment size).
- Secondly, if the original river sediment is sand, the risk of siltation varies with spillway height, catchment size, slope and rainfall as explained below.

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 shallower 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.

Having established a siltation risk, the first thing to do is ensure that, if there is not a positive score for the conservation of the land in the dam catchment that this is addressed as a very significant mitigation of siltation risk. If this is already done or planned then considering a phased approach to the construction of the spillway should be reviewed.

In 90% of the cases a dam should be designed to its maximum height and then, if necessary, a phased plan for the height of the spillway should be included in the design (with the full height and width of wings being planned to be built at the first stage). In 10% of cases, one may believe there is a *possibility* of a further extension, but there may be doubts or uncertainties of how the river or sediments may react. In which case, the conservative design should be built and an extension assessed after the dam

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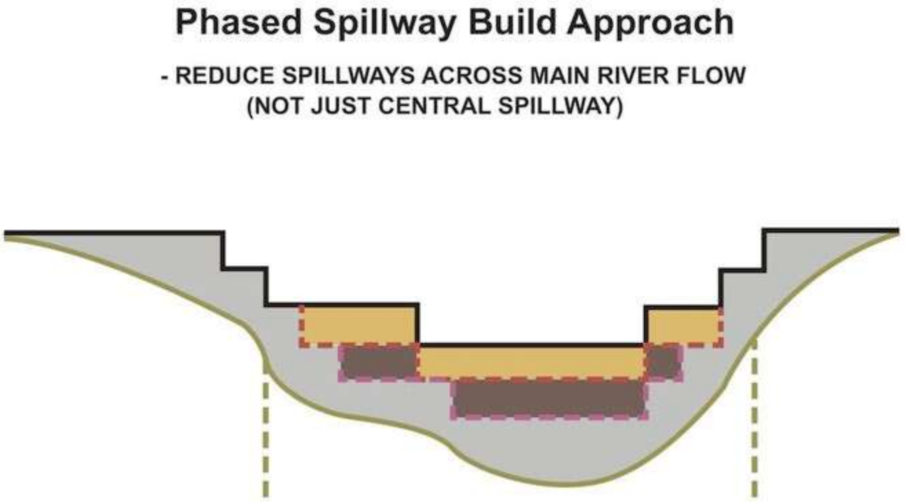
[193] Nissen-Petersen, 2011, Sand dams or silt traps, Sand dams or silt traps? [Link]

has filled completely with sediment. It is advised, against conventional wisdom, to reduce the spillways across the main river channel rather than just the central spillway which, ironically, is likely to cause increased erosion and/or deposition of silt. The diagram below shows an example three-phase build of spillways.



With very high siltation risk, building a sub-surface dam only should be considered, especially if there is a need to dig down some metres to bedrock and there is a plan for sub-surface abstraction like a shallow well, Rowa hand pump or tube well.

7.6.5 Abstraction Designs

Design method(s) of abstraction method (see Chapter 6.2 and 6.4):

- Design, measurement & positioning of infiltration galleries;
- Specification & positioning of hand pump(s);
- Positioning of taps &/or animal troughs including measurement of pipework.

7.6.6 Soil & Water Conservation Measures

The incursion of soil and water in the catchment immediately upstream from a sand dam may be prevented by the existing vegetation and/or land management or by utilising the following SLM techniques,[194] which also enhance dam performance:

- **Gulley Reclamation**
- **Terracing Valley Slopes**
- **Valley-side Vegetation**
- **Riverbank Stabilisation**

The photo right shows a dam in Lekurruki Conservancy built where existing vegetation protected the dam from siltation.

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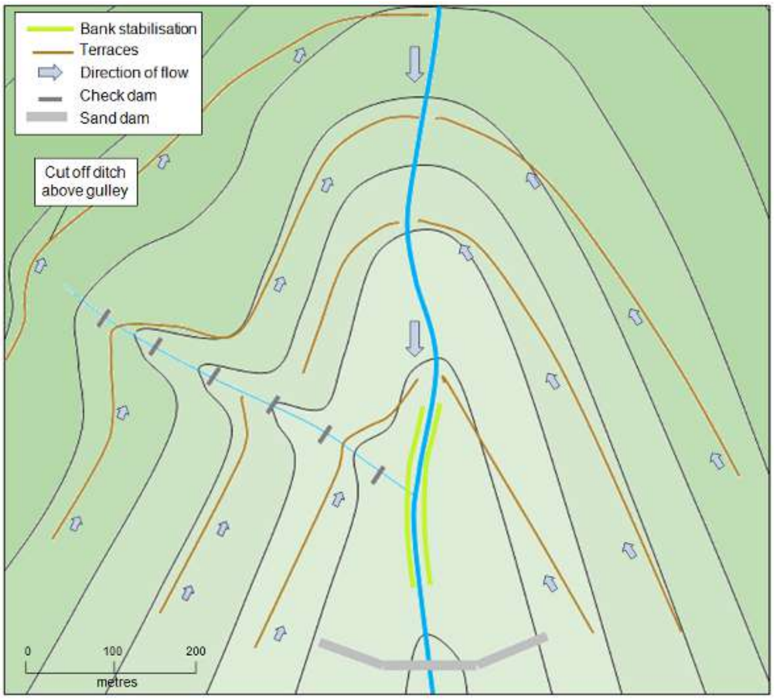
[194] This has been edited and significantly enhanced by Maddrell, S. from the original appearing in Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013.



The goal should be to prevent any water entering the river for at least 150 metres upstream from the sand dam through infiltration with any excess channelled upstream (see diagram right). The importance of this is dependent on the risk of erosion, bringing soils, silt and clays into the dam catchment.

In general, the steeper and longer a slope is, the faster water runs off it, and the greater potential there is for erosion. But there are many other factors determining the level of run-off and erosion when exposed to storm water runoff. In some landscapes, extremely steep slopes can be observed with dense vegetation and little or no erosion, while other locations with more moderate slopes develop into barren gullies. Other factors include rainfall volume and seasonality, soil type, vegetation types as well as the condition of the land above the valley sides[195].

7.6.6.1 Gulley Reclamation

Gullies near to the sand dam catchment, especially those within 20 metres of the dam (upstream and downstream), are the biggest threat to siltation. However, gullies close to the dam may also undermine the foundations of the dam wings or create a point lower than the spillways outside of the dam, all of which can cause failure of the dam. Footpaths or cattle paths around the end of the wings can have the same affect and should be protected.

Gullies should be reclaimed by some, or all, of these initiatives:

- Improving land management above the gulley to reduce runoff into it.
- Digging a cut-off contour trench (1m wide x 1-2m deep depending on gulley size) above the head of the gulley to reduce runoff entering the gulley.
- Filling the gulley with live planting such as sisal, or pegging in barriers made of branches, stone gabions or bags filled with soil. In very large gullies, mini-dams can also be built, they should be dug into the gulley sides with a central spillway. For deeper gullies, as the gulley silts up, the barriers can be progressively raised.
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7.6.6.2 Terracing Valley Slopes

Contour terracing (or trenching) valley slopes reduces soil deposition into the catchment upstream of the dam by increasing the infiltration of rainfall run-off water. Terracing land has been very common in the steeper topographies of Machakos, Kenya since the 1930s, as brilliantly and famously documented in the book, “More People, Less Erosion” [196]. This achievement is often referred to as the “Machakos Miracle” and is used as a case study in UK secondary school Geography syllabus.[197]

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[195] http://homeguides.sfgate.com/slope-area-affects-runoff-87453.html

[196] MORE PEOPLE, LESS EROSION Environmental Recovery in Kenya. TIFFEN, M., MORTIMORE, M., GICHUKI, F. Kenya Edition, ACTS Press/ODI 1994. Online PDF available at: https://www.odi.org/publications/3497-more-people-less-erosion

[197] https://www.tes.com/teaching-resource/ks3-year-8-ecosystems-8-the-machakos-miracle-11459594

It is important to note, however, that there can be highly significant run-off on land of only 5% gradient and existing terracing is much less common in lower gradient areas. On the valley sides, or land above the valley, with less than a 5% gradient stones lines[198 & 199] or bunds[200] are very common soil and water conservation initiatives. Sustainable land management (SLM) in the upper catchment also increases the yield of the dam due to increased infiltration 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 are dug.

Fanya juu ['throw-it-upwards'] terracing is the most effective as illustrated by a brilliant video from Access Agriculture.[201] To protect sand dams the terracing should be three lines of trenches at least 1 metre deep by 1.5 metres wide (up to 2m x 2m) and at least 150 metres long should be dug from the dam going upstream and follow the contours of the riverbanks. To protect sand dams even more, a small upstream gradient and mini-bunds should be implemented so that any non-infiltrated excess water flow enters the river at least 150 metres upstream of the dam. The photo above left shows small bunds within the terrace to enable more water to infiltrate into the land. The exact length, number and spacing of terraces is dependent on the slope and how well the land has already been conserved, if at all, immediately around the dam catchment and its vulnerability to erosion.

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[198] Video available at Access Agriculture https://www.accessagriculture.org/stone-lines
[199] Video available at Access Agriculture https://www.accessagriculture.org/slm01-stone-lines
[200] Video available at Access Agriculture https://www.accessagriculture.org/contour-bunds
[201] Video available at Access Agriculture https://www.accessagriculture.org/slm02-fanya-juu-terraces

7.6.6.3 Valley-side Vegetation

Increasing the vegetation on valley sides will also increase infiltration of rainwater run-off and reduce soil erosion. In addition to crops growing in terraced land, grass strips[202] and agroforestry[203] can also be grown either along the banks of terraces or directly on the slopes, depending on steepness and other factors, to achieve significant soil and water conservation and protection of the sand dam from siltation. Apart from the direct benefits of the crops, plants or trees involved, the additional infiltration of rainwater into the valley sides also slowly recharges the dam over the dry season. Soil fertility is also protected with the reduced soil erosion.

As part of the virtuous circle of soil and water conservation that sand dams can create, tree nurseries are often developed alongside a dam so that seedlings can be propagated during the dry season and planted when it rains. A tree nursery below a dam is photographed below left and trees and banana plants on terraces are pictured below right.

7.6.6.4 Riverbank Stabilisation

Seasonal river valleys have clearly defined channels. During flood, the river flows outside and above this channel, usually causing erosion, especially whilst a dam is filling with sediment. Also, the construction of a dam will cause the river to flow above its banks more often. If the banks are not already protected with vegetation, the banks can be planted with trees and grasses such as Vetiver and Napier. Riverbanks can also be protected by ensuring that the spillways are situated 1 metre inside the banks to reduce erosion (see Chapter 7 on design).

Incorrectly situated spillways may accelerate erosion both upstream and downstream of the dam. The banks should be protected whenever there is a risk of erosion. If the banks are rocky, protection is less critical. Banks that are mainly soil, especially unconsolidated soil or where erosion is already visible, need protecting. Bank protection is particularly important if the central spillway is higher than the riverbanks. Unless the banks are very well protected, the spillway should initially be lower than, or level with, the top of the riverbanks to prevent it collapsing into the dam catchment and causing siltation.

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[202] Video available at Access Agriculture https://www.accessagriculture.org/grass-strips-against-soil-erosion
[203] Video available at Access Agriculture https://www.accessagriculture.org/slm03-grevillea-agroforestry

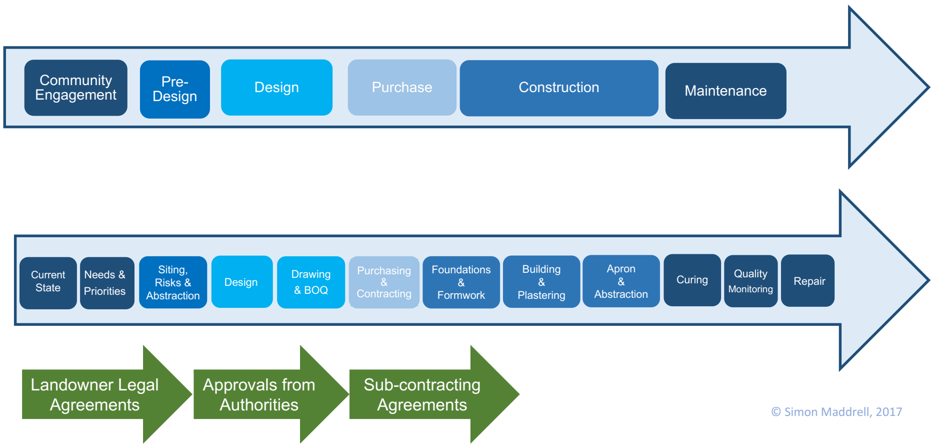
There are a significant number of additional and successful RWH, land management and soil and water conservation techniques proven and documented by many organisations and databases. See Chapter 11.3 for a list of resources.

Chapter 8: Pre-construction activities

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

- Agreements & Approvals.
- Bill of Materials (BOMs).
- Calculating Bill of Quantities (BOQs).
- Project Planning.
- Procurement and Contracting.

Post-Feasibility Practical Steps



8.1 Agreements & Approvals

Depending on the location of the dam and the method of construction, certain agreements and authorisations may be required to allow the dam to be built and its purpose maximised after construction. How this can help with the management of risks, such as large-scale water and sand abstraction, is discussed more in Chapter 10.3. The types of agreements are:

- Landowner Construction & Access Agreement.
- Community Participation Agreements.
- Government Agency/Agencies Authorisation.

8.1.1 Landowner Construction & Access Agreement

In most countries, rivers and riverbeds are owned by the government (typically 108ft or 30m either side of the centre of the river – or the centre of a seasonal river bed) usually meaning that some form of government approval is needed. However, most sand dam construction extends outside of this area and requires greater access during construction, never mind the ongoing community access afterwards. Depending on land ownership either landowner or local government permission may be needed to meet the construction and access needs.

Land ownership examples by country:

- Kenya: Most of rural community land is individually privately owned, with the exceptions being Community Conservancies in Northern Kenya, which are owned by the local community, divided into what are legally known as Group Ranches.
- Zimbabwe, Mozambique and Ethiopia: All rural community land is government owned and controlled.
- Swaziland: Rural Communities tend to live on Swazi National Land (Government-owned) unless they are resident on privately owned plantations (most likely sugar cane). There is also Crown Land reserved solely for the King and his interests.
- Rajasthan, India: There is a consistent mix of private land and government-owned land. Unlike in Kenya, the local NGO JBF avoids building on private land due to the great difficulty in getting access agreements that will be sustained.

Where the land is government-owned permission is usually just required by the local government. However, where there are also agencies that manage and control water resources on a regional catchment basis, additional more complex authorisation is required for the technology, the siting and the design of the river structure (see Chapter 8.1.3).

In south east Kenya, the NGO ASDF ensure that a legal agreement is signed between the self-help group (SHG) owning the management of the dam (NOT the implementing NGO) and the local land-owner(s). This is witnessed by an independent person e.g. ASDF, the local administrative Chief or a lawyer. This agreement also covers a commitment to control over-use of the water and sand harvesting. An example agreement is in Appendix 1.2: Landowner Permission & Access Agreement

8.1.2 Community Participation Agreements

Where sand dams are built in partnership with the community it is important to establish and agree the exact contribution that the community will make towards the delivery of the sand dam. This may cover the provision of materials, labour and/or cash towards the overall costs and is often between 20-40% of the total materials and labour costs.

Some examples are:

- ASDF insist that the community SHGs agree to collect all the sand and stones (which are usually readily available nearby) and water (which often isn't) as well as to contribute their unskilled and semi-skilled labour required to construct the dam and other activities, for example:
  - Terracing, in advance, the sides of the river valleys where sand dams are to be constructed.
  - Collecting sufficient stones, water, and sand towards the construction of the sand dam(s) in advance.
  - Putting in place the necessary agreements with the relevant land owners to allow the construction of a sand dam and to allow access to the sand dam to abstract water.
  - Applying and receiving the sand dam registration with relevant authorities (see Chapter 8.1.3).

  Dabane Trust in Zimbabwe and CCM in Mozambique have a similar model in terms of community labour contribution.
- Excellent Development working in the Northern Rangelands have a similar model but because the partner organisation is the whole community conservancy it is not feasible for 2-10,000 people (or even 300-1,500 family representatives) living over a wide area to all work on a dam. Instead the Group Ranch/Community Conservancy, as its contribution, pays people in their own community to carry out the tasks outlined in the ASDF summary above.
- In Rajasthan, India the local NGO JBF has a different model again with their community groups (Jal Sabah). Construction is mechanised, supported by JCBs and cement mixers, so there is a need to get civil contractors to carry out the work. The community *Jal Sabah* (with varying individual contributions depending on their economic conditions) contribute a total of 20% of the materials and construction costs. The civil contractor will usually employ the unskilled labour from the local community.

8.1.3 Government Agency/Agencies Authorisation

The legal authorisation process for sand dams and shallow wells differs widely from country to country. For example, only local government body authorisation is required for sand dams in Rajasthan, Mozambique and Zimbabwe. However, in Zimbabwe and Uganda the hand-pump technologies allowed is very strictly controlled. Swaziland has five river basin authorities but is only just developing the detailed processes to control water resource and river structures, including sand dams.

Kenya, in contrast has evolved significantly over the last twenty years with such controls under one national body with very detailed controls for every water resource intervention. Authorisation from the Water Resources Management Authority in Kenya is required before developing any water resource. This includes surface water (rivers, springs, land run-off) structures that divert, abstract, or store water including in-stream works like sand dams; and groundwater systems like shallow wells and boreholes. This consists of having the technical design approved prior to construction but may also involve site visits and assessments [See Appendix 1.3: Example Government Agency Authorisation Forms and example design submission]. Initially, permission to construct is granted and upon satisfactory construction, a water permit is issued to the applying body, which gives them the rights to manage the water resource.

In the opinion of the author, it is crucial that the registering organisation is formally the local community (via, for example, a registered civil society organisation rather than an ad hoc group created solely for that purpose). The reason for this is that ownership (from the beginning rather than after some "hand-over ceremony") is critical to ensure that sand dams and any associated abstraction technologies are managed sustainably and able to be protected from exploitation of sand or water harvesting as well as any ongoing preventative maintenance or repair. The water permit recognises the group's rights to abstract water for different specified uses and enables the group to use statutory law to manage the water resource including control of water abstraction and sand harvesting, which is discussed more in Chapter 10.3.

8.2 Bill of Materials (BOM)

Below is the Bill of Materials & Tools required for the dams built by ASDF.

Sand dam materials	**Units**
Grade 42.5 Portland Cement	1 x 50kg bag
Twisted Iron Bars: Y20[§] (20mm); 40ft Std. grade	1 x length (12m or 40 feet)
Barbed Wire (12.5 gauge)	1 x length of 250m each
Nails 2.5" & 4"	1 x kg
Builder's (Sharp & Clean) Sand	1 x tonne.
Stones (> 600mm)	per tonne
Ballast mix (mixture of smaller stones: 20-30mm)	per tonne
Timber for shuttering[#]	
Timber Cypress (6" x 1" or 150mm x 25mm)	1 x foot
Timber Cypress (4" x 2" or 100mm x 50mm)	1 x foot
Tools	
Hacksaw blades	each
Hard sweeping brush	each
Wire brush	each
Grease	kg
Wheelbarrow	each
Metal shovels	each
Metal buckets	each
Hacksaw & high-speed blades	each
Stone breaking claw bars	each
Masons claw bars	each
Plastic drums (200 litre)	each
Sledgehammer (8lb)	each
Digging pick axe	each
Notes: " = inches; ft = feet; lb = Imperial pound	

[§] Standard bars are Y20 (20mm diameter) or Y25 if not available. Thinner Y10 to Y16 bars (10-16mm diameter) may be used, but in this case, place bars opposite each other 0.9m apart and 1.5m diagonally apart (i.e. twice as many iron bars).

[#] See Chapter 9.5.1 for other formwork options.

For the abstraction systems, they are custom designed and more susceptible to local standards and material availability. As the sand dam infiltration systems are uncommon, here follows a BOM for the infiltration systems installed behind the dams after construction:

Infiltration System	
PVC pipes class B4"	each
PVC pipes class D2"	each
GI Pipe 1"	each
uPVC Reducing socket from 4" to 2"	each
PVC Tee 4"	each
PVC Bend 4"	each
Reducing Bush 2" x 1"	each
PVC Valve Socket 2"	each
GI Socket 2"	each
GI Bend 1"	each
GI Socket 1"	each
Gate Valve 1"	each
Barrel Nipple 1"	each
GI pipe 2"	each
GI Bend 2"	each
GI Union socket 1"	each
Water Meter 1"	each
Ball valve	each
Stones (>300mm)	tonne
Ballast mix (mixture of smaller stones - 20mm to 30mm)	tonne
Thread Tape	each
Tangit	1 x 500ml pot

8.3 Calculating Bill of Quantities (BOQ)

8.3.1 Principles and approach

The BOQ can be estimated from a sufficiently detailed drawing and dimensions (see Chapter 7) but it is important to understand that unless the full excavation of foundations has been done, the BOQ is an estimate rather than an exact calculation. Organisations that are building several dams over a period tend to procure and deliver an extra 10% materials contingency and then measure exact usage of purchased materials (for donor reporting purposes) as they can transfer any surplus materials to the next dam site. Chapter 2.6 shows the average materials and direct labour costs of sand dams built by ASDF, which vary between around $5,000 to $20,000.

In this case, the approach is as follows:

- Calculate the total volume of the dam wall and use ratios to calculate the mortar and rock requirements.
- Use the total width of the dam and the various heights to calculate the steel requirements.
- Shuttering/formwork and tools have a life greater than one dam so whilst the total amounts need to be procured to enable the dam to be built, for costing purposes their life is spread across several dams.

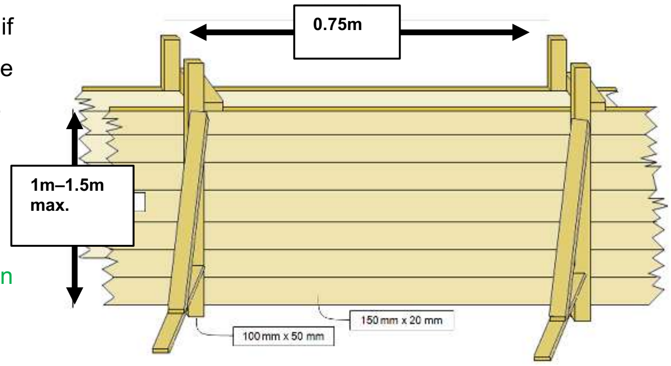
8.3.2 Estimating cement, sand & water (mortar) and rock requirements

Based on the experience and construction process (described in Chapter 9) of ASDF, the following rules and average assumptions have been established:

- **From the drawings calculate the total volume of the dam wall including assumed foundation depths (V m^3)**
- **Mortar:**
  - 3.5 bags of cement are required for every cubic metre of dam volume **[Cement Bags (B) = V ÷ 3.5]**
  - By volume the ratio of sand to cement is 4:1 and 1 bag of cement is 32 litres. **[Sand volume (S m^3) = B x 32 x 4]**
  - 50 litres water required for each bag of cement **[Water volume (W m^3) = B x 50]. (Lower if the sand is wet).**
- **Rocks and stones:**
  - Mortar is 45% of dam volume and volume of rocks are 55%. **[Rock volume (R m^3) = V x 55%]**
- **Mortar & Rocks: The smaller the sizes of rocks the greater the mortar % and lower the rock % which will significantly increase the cost of the dam. The same is true if rocks are not placed properly in the dam (see Chapter 9.12.1).**
- **Additional Water:** Additional water is required for curing the cement (4 litres per bag) and an additional 10% for cleaning tools and washing rocks. **[Additional Water (AW m^3) = B x 4 x 110%]**

8.3.3 Calculating steel and timber requirements

The minimum amount of timber shuttering is the amount that can be filled with one day's work. For efficiency purposes, and because they build 50+ dams per year, ASDF tend to procure enough shuttering to cover the whole width of the foundations. This is also because it produces a stronger dam if construction is completed in 1-1.5m horizontal layers across the dam each day. The timber to be delivered can easily be estimated using the total width of the dam and the desired height of either 1m or 1.5m of shuttering. The maximum height for lower strength timber is 1m with supports then every 50cm. For guidance, the average quantities used are mapped out on the next page.

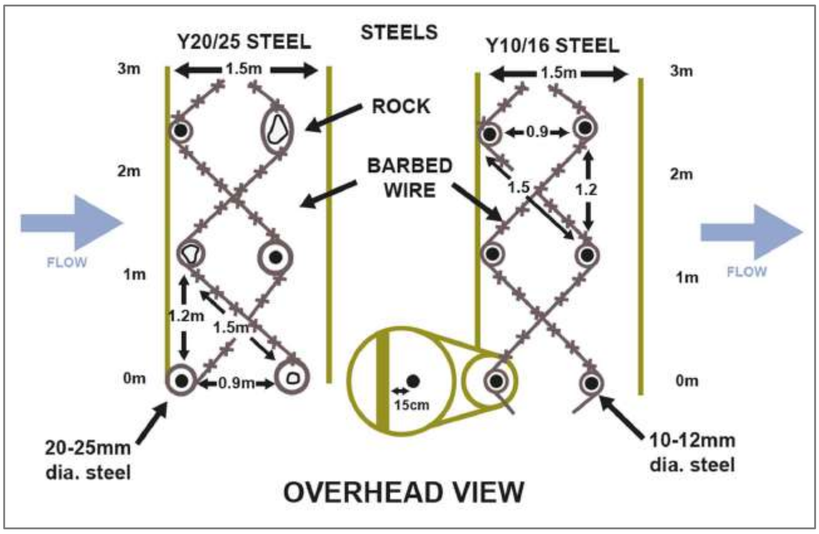


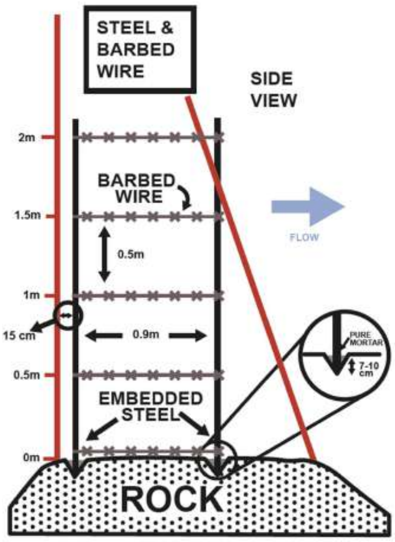
Timber and steel quantities	Assumed life (in # of dams)	Average Dam
Timber boards[#] (150 mm x 25 mm x 12 metre lengths)	3	35 lengths
Timber supports[#] (100 mm x 50 mm x 12 metre lengths)	3	30 lengths
Nails 2.5" & 4" (kg)	1	30kg
Y20[§] (20 mm diameter) twisted steel bar x 12 m	1	7 bars
25kg 12.5 gauge barbed wire (approx. 250 m length)	1	5

Table 1: Timber and steel quantities

[#] **Timber:** With ASDF, the formwork is made up of horizontal 6 metre lengths of 150mm x 20mm cypress wood planks, supported by vertical 100mm x 50mm supports placed at a maximum every 0.75 metre, although the quality of timber boards determines the spacing of supports and the height of the shuttering, which should be a minimum of 1m. There are alternatives of steel sheet formwork or stone-masonry formwork discussed further in Chapter 9.5.1.

[§] Standard bars are Y20 (20mm diameter) or Y25 if not available. Thinner Y10 or Y16 bars (10-16mm diameter) may be used but the bars are placed opposite each other every 1.2m along the dam **(i.e. twice the quantity of iron bars).**





Steel and barbed wire estimations are based on the total width of the dam:

- Total width of the dam from the drawing **(TW m^3)**
- **Y20 Steels (12m long):** placed one every 1.2m width over average **Height of foundation and spillway (H m)**.
  - **Number of Steel Lengths = (TW ÷ 1.2 x H) ÷ 12**
  - Same quantity for Y25 steels and **double quantity for Y10/Y16.**
- **Barbed wire (250m length rolls):**
  - Each layer uses 2 x 1.5m length for every 1.2m width of the dam **[Each Layer Length (m) = (TW ÷ 1.2 x 1.5) x 2]**
  - Layers every 0.5m in height, starting from base and finishing at spillway. **[Number of Layers = (H ÷ 0.5) + 1]**
  - **Number Barbed Wire Rolls = (Number of Layers x Each Layer Length) ÷ 250**

8.3.4 Tools and equipment requirements and costings

The minimum number of tools and equipment required for the building of an average dam are mapped out below. Where an organization is building multiple dams, the costs should be spread across their useful life. Below are the assumed lives used by ASDF in their costings.

Tools & Equipment Requirements	Assumed life (in # of dams)	Quantity Average Dam
Wire brush	1	2
Hard broom	1	2
Wheelbarrows	6	6
Shovels	20	25
Metal buckets	6	6
Hacksaw	10	1
High-speed hacksaw blades	1	3
200 litre water drums	25	6
Large sledge hammers	20	4
Pick axes for excavation	6	6
Grease for tools (kg)	1	1
Claw bars (large)	10	4
Claw bars (medium)	20	2
Line level & 50m builders' line	6	2
Tape measures	6	3
Tapered probing rod >3 m	25	1

Tool requirements and usage rates

8.4 Project Planning

It is not the intent of this manual to teach programme or project planning or to provide definitive checklists of project deliverables. However, as with any project, there should be phased milestones, for example: design, quantification, authorisations, collection of materials, site planning, ordering and delivering materials etc. The schedule should include a critical path and appropriate elapse times so that, for example, the plan may define that the design is completed three months prior to construction to allow sufficient time to collect the materials and prepare the site – as well as getting the appropriate authorisations and agreements in place.

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

- Signed-off design & material estimates
- Signed legal agreements
- Traditional or cultural approvals
- Authorisation from government authorities
- Associated land management actions: e.g. Gulley reclamation and terracing completed
- Rocks and sand collected (if not purchased)

8.5 Procurement[204]

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

Timber formwork: Select harder seasoned woods such as aged cypress rather than green softwoods. Select mature, aged/seasoned timber, not fresh, green timber that has higher moisture content and is less effective due to being weaker and more flexible. Although more expensive, harder seasoned wood is more durable and cost-effective but selecting endangered species of timber is obviously strongly discouraged.

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 Y20 twisted steel bar and if only Y10 or Y16 is available for use, more care should be taken with both the quality of steel and maintaining its straightness during construction.

Tools: Similarly, cheap tools are usually a false economy. The tools that fail most frequently are shovels followed by wheel barrows. It is recommended to select the best value, most durable tools.

Cement: Ordinary Portland Cement (OPC Grade 42.5) is highly recommended. Cement quality will vary by 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% lower	30% lower	40% lower	50% lower

Due to the high storage cost and limited lifespan, cement is better to be purchased as required. It is rarely cost-effective to tender for cement in bulk unless direct from a manufacturer on a call-off basis. It is usually better to use multiple quotes from larger local suppliers and retain the flexibility to change suppliers if price, availability or quality change. There are very low margins on cement supply so it is often not worth going direct to the manufacturer and paying the additional transport costs. However, for organisations building a significant number of dams (or using large amounts of cement) it may be worth registering with the manufacturer as a distributor, which will give fairly significant discounts but will have minimum purchase quantities and may increase the 'last leg' transportation costs.

Value Added Tax (VAT): In countries such as Kenya, NGOs and AID agencies can gain exemption from paying VAT on materials purchased for 'charitable purposes' provided they follow a specific process[205]. The savings can be significant (e.g. VAT rate in Kenya is 16%) but the processes, on a pro-forma invoice basis rather than a VAT exemption certificate can make the logistics very difficult without timely approvals[206].

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[204] Edited from: Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013

[205] http://www.kra.go.ke/notices/noticevatremission280306.html

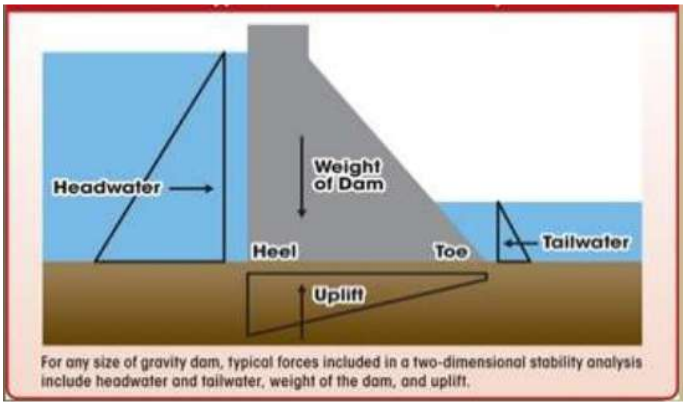
[206] http://www.logcluster.org/sites/default/files/attachments/wfp_ken_vat_exemption_procedures_-for-kenya_041231.pdf

Chapter 9: The construction of a sand dam

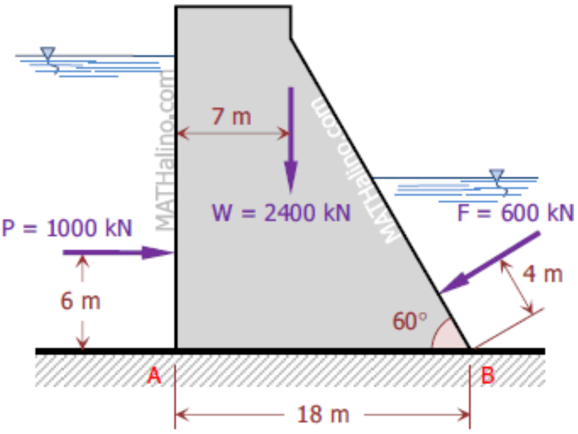
9.1 Principles and construction of rubble masonry gravity dams

Technically speaking, sand dams are [broad-crested, constricted rectangular weir] overflow gravity dams, constructed with steel-reinforced rubble stone masonry.

- Gravity dams utilize the weight of the construction material alone to resist the horizontal pressures whilst full and empty (see diagram below right)[207]:
- Pressure of water (and later sediment for sand dams) pushing against the dam wall
- Also for sand dams the 'wave pressure' caused by the river (and floating objects) when seasonal rains flow and whilst the dam is filling with water and sediment.
- Hence, gravity dams must be built on a sound rock base because it transfers all the forces to the foundation.
- Lateral movement or slippage of a sand dam is further reduced by using steel bars drilled into the rock base.
- Movement of the dam due to poor foundations or air pockets causing rubble to shift can cause the dam to crack.
- The dam is weakened if there are air pockets within it due to touching or badly placed rubble.
- The dam is heavier with the more rocks versus cement contained within it
- Too much cement in the dam can cause cracking especially if the cement is not cured effectively.
- The weight of the dam prevents toppling, enhanced by the 'toe' of the dam (see diagram below left[208])
- The tensile strength of the dam is increased by tying barbed wire across the dam at 50cm depth intervals.



For any size of gravity dam, typical forces included in a two-dimensional stability analysis include headwater and tailwater, weight of the dam, and uplift.



9.2 Major causes of failure of gravity dams

A sand dam may fail in following modes:

1. **Overturning** of dam about the toe – mitigated by the weight of the dam and the shape of the dam including a 'toe'
2. **Sliding** of the dam – mitigated by the weight of the dam to increase friction and steel bars drilled into the rock base
3. **Compression** by crushing – mitigated by the fact that cement has high compressive strength if cured correctly.
4. **Tension** by development of tensile forces which results in cracking of the dam – mitigated by increasing the tensile strength with barbed wire tied between the steel reinforcements horizontally across the dam.
5. **Seepage** (>33% cause of failure for earth dams) if too high will cause the dam to undercut and/or wash away due to the increased uplift pressure[209] – mitigated by ensuring the dam is keyed into the bedrock at least 1.5 m wider than the flood width of the river; also by ensuring the construction of the dam does not allow water to pass through cracks or air pockets.

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[207] http://www.mathalino.com/tag/reviewer/gravity-dam Copyright 2017 © Romel Verterra
[208] https://www.slideshare.net/gauravhtandon1/gravity-dam
[209] https://www.slideshare.net/gauravhtandon1/earthen-dams

9.3 Key Point: Construction includes an element of design

Construction includes an element of design because the design drawings usually only estimate the depth of foundations and this can therefore only be defined during construction. Digging the full foundations at this stage is an uncommon approach for a variety of reasons, including not starting significant works prior to community agreement and any statutory approvals required.

- **The foundation is the most fundamental aspect of a sand dam – if this is wrong the dam will fail.**
- **The dam MUST be built on bedrock (See Note* below)**
- **The dam MUST NOT be built to the ASSUMED foundation depth of the design – it needs to reach bedrock**.
- Test pits prior to design reduce the difference between the assumed depth of foundations and what is needed.
- **Therefore, strict supervision by an experienced dam designer/engineer/craftsman is vital – especially when sub-contracting the work**

Note*

Sand dams are normally built on sites with bedrock accessible within 4-6m of the surface of the riverbed.

This is because the dam needs to withstand the downward forces on the dam, which is mostly its weight. Otherwise the dam wall will sink causing it to crack. The river will then immediately, or eventually, flow through the dam causing complete failure.

Also, to be effective, the sand dam needs to create a near water tight seal across the valley to:

a) hold water behind the dam;

b) maximise ground water recharge behind the dam; and

c) ensure that water does not flow directly underneath or around the dam, thereby either under-cutting it or flowing around it.

Therefore, the sand dam should be built onto bedrock at least 1.5m wider than the flood width of the river.

However, there is an exception to this, which must be approved by a sand dam expert: Where, after 4-6m depth, there is still no bedrock *all the way* across the river channel it may still be possible to build an effective sand dam. If there is impermeable, compacted sub-soil at this depth a 'reverse lintel' can be constructed from steel and concrete, but this must be at a depth of least 1.5m into the compacted sub-soil. It is preferable that this is laid onto bedrock both sides of the dam or at least one side to reduce the chance of the dam subsiding and cracking.

If there is **no bedrock at all** this is highly risky especially for a dam that is built more than a metre above river level because the weight of the dam can cause the dam to sink and crack. If this is done the compacted sub-soil **must** be very solid and the lintel **must** be built across the full width of the dam and as deep as possible into the compacted sub-soil to avoid subsidence.

Failure to build on bedrock (or a suitably placed reverse lintel) will cause the dam to sink and crack.

9.4 Principles of steel reinforcement of gravity dams

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.

- **Steel reinforcement bars embedded vertically in the bedrock to prevent the dam from slipping (lateral movement) by increasing friction.**
- **The barbed wire strung across the dam in a helix-shape and firmly anchored at each end of the dam. This is done at the foundation level of the dam and at every 50cm increase in height afterwards. This increases the tensile strength of the dam (a weakness of cement mortar) and thereby reduces the chance of cracking.**

9.5 Principles of concrete and rubble stone-masonry construction

Rubble stone-masonry is rough, unhewn building stone set in mortar, but not laid in regular courses. It consists of using mortar (a mix of sand, cement and water) to bond together rocks of different sizes to construct a wall. For sand dams this method includes the steel reinforcement described above and the use of formwork (also known as shuttering).

9.5.1 Formwork

Formwork is used to hold the materials in place during construction and removed after 12 hours once the cement is cured sufficiently to allow the dam wall to stand freely without support. Formwork can be formed in various ways. Most of the sand dams we are aware of have been built using timber formwork.

Timber: Timber, used by ASDF and UDO NGOs in Kenya, is a very versatile method to fabricate formwork and can be re-used. The quality of timber boards determines the spacing of supports. In Kenya, the formwork is made up of horizontal 6 metre lengths of 150mm x 20mm cypress wood planks, supported by vertical 100mm x 50mm supports placed every 0.75 metre.

- The wooden shuttering can be reused and repaired.
- Timbers usually only last for 3-4 dams depending on the quality of wood (strength and moisture content from ageing).

Steel sheet formwork: In places where durable hardwood timber is either expensive and/or very difficult to source, sheets of steel bolted or strongly bound together have been used as formwork. The Dabane Trust in Zimbabwe and Jal Bhagirathi Foundation in Rajasthan use forms of steel shuttering to build sand dams.

- Higher cash investment to purchase or rent, which also varies depending on the type.
- Require tying together and can be more difficult to support if 100% metal.
- Purchase cost offset by the fact they will last much longer than timber shuttering with less repair and maintenance.

Stone-masonry formwork: SASOL, a Kenyan NGO based in Kitui have constructed over 500 dams using 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.

- The advantage of this method is that it does not require timber formwork.
- Experienced artisans are needed to fabricate the formwork.
- Each section of the constructed dam must be cured for long enough to withhold the forces of the rubble masonry inside the formwork (usually 12 hours).
- Extra steel reinforcement is needed on higher dams.
- Rocks touching each other and air pockets is more likely with this shuttering and extra care is critical.
- Because of this, dams built using stone formwork will take longer to build.

9.5.2 Rocks

A mix of different sized and shaped rocks is the best combination to be used to maximise strength e.g. the smaller stones filling the gaps between the larger rocks; long rocks enable the rocks to interlock between layers, larger rocks reduce the amount of mortar. Rocks should be hard (won't break by dropping onto hard rock or being hit with a hammer) – granite, quartz, sedimentary rocks are best. **Rocks should be a mix of 15-60cm diameter with some stones preferably up to 80-100cm long.**

- **When relatively smaller stones are available:** The depth of the mortar layers **must be reduced to 15-20cm** to prevent layers or lenses of mortar that weaken the dam. Even more emphasis needs to be put on the stones being placed **vertically over-lapping**. With smaller rocks, the ratio of mortar to rocks increases. The additional cement needed will increase the cost.
- **When rocks are uniform shapes and sizes:** rocks should be broken into different sizes.

9.5.3 Sand

Mortar will be stronger when coarse sand derived from crystalline rocks with sharp angular edges is used compared to finer, more rounded sand, hence often termed as "builders' 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 very fine sand, silt or clay. Organic matter should not be contained in it as this will reduce mortar strength also. If good quality sand is not available, to improve the quality of sand it can be sieved to remove organic matter and remove the finer sediments.

9.5.4 Cement

The sourcing and storage of cement is critical. Ordinary Portland cement (OPC) Grade 42.5 is highly recommended. Cement quality may still vary enormously by manufacturer however. 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 loses 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 %

It is essential cement is kept dry prior to use. If cement does get wet, it will harden and contain lumps and must not be used. With ASDF, most cement is delivered directly to the dam site immediately prior to construction, safeguarded by the community and used within 1-2 weeks of delivery. 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.

9.5.5 Mixing cement into mortar

The standard mortar mix is

- **In Kenya the ratios are practical i.e. bags of cement to level wheelbarrows*. The on-site ratio used is 1:3**
- **'By volume' this is a ratio of 1:4 (cement:sand).**
- **The exception is that the ratio must be changed to 1:2 (cement bags to level wheelbarrows of sand) when the foundation is water logged. By volume this is 1:3 (cement:sand)**

Note*:

In Kenya, sand is measured in standard wheel barrows, which contain approx. 40 litres of sand when level.

A 50 kg bag of cement has a volume of 32 litres.

9.5.5.1 Mixing

- 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.

- The mixing ratio is uniform on all parts of sand dam, from foundation to completion unless the foundation has water.
- Initially, sand and cement is dry mixed in batches of 20-30 bags of cement at a time.
- Then water is added (typically 25 litres of water for each 50 kg bag of cement) § and progressively mixed.
- The water and sand must be clean and free from silt, clay and organic matter.
- 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.
- 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 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. 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.

§ **Note:** A low water to cement ratio is the number one issue effecting concrete quality.[210] The lower the water/cement ratio the higher the compressive strength and the lower the permeability of the hardened concrete. The lower the permeability the greater the potential durability of the concrete[211]. Concrete hardens because of the chemical reaction between cement and water (known as *hydration*, this produces heat and is called the *heat of hydration*). For every pound (or kilogram or any unit of weight) of cement, about 0.35 pounds (or 0.35 kg or corresponding unit) of water is needed to fully complete hydration reactions.[212] However, a mix with a ratio of 0.35 may not mix thoroughly, and may not flow well enough to be placed. More water is therefore used than is technically necessary to react with cement. Water–cement ratios of 0.45 to 0.60 are more typically used[213]. For Ordinary Portland Cement 42.5 the recommended ratio is 0.5[214].

9.5.5.2 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.
- Curing means maintaining a relative humidity in the concrete of greater than 80 percent, a temperature greater than 50 degrees Fahrenheit,
- **90% of its final strength is reached within the first 4 weeks, so this period is most critical.**
- **If the mortar dries, 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.
- A layer of sand and/or a covering of cement bags, sacking or vegetation should be 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), the layer of the dam must be watered and the upstream and downstream sides splashed with water.**
- **Curing requires 4 litres of water per day for each bag of cement used.**

Strength of cement mortar depending on days of watering

Kept wet for 28 days	**100 %**
Kept wet for 7 days	**90 %**
Kept wet for 3 days	**80 %**
No wetting	**55 %**

Importance of curing.
Source: Portland Cement Association

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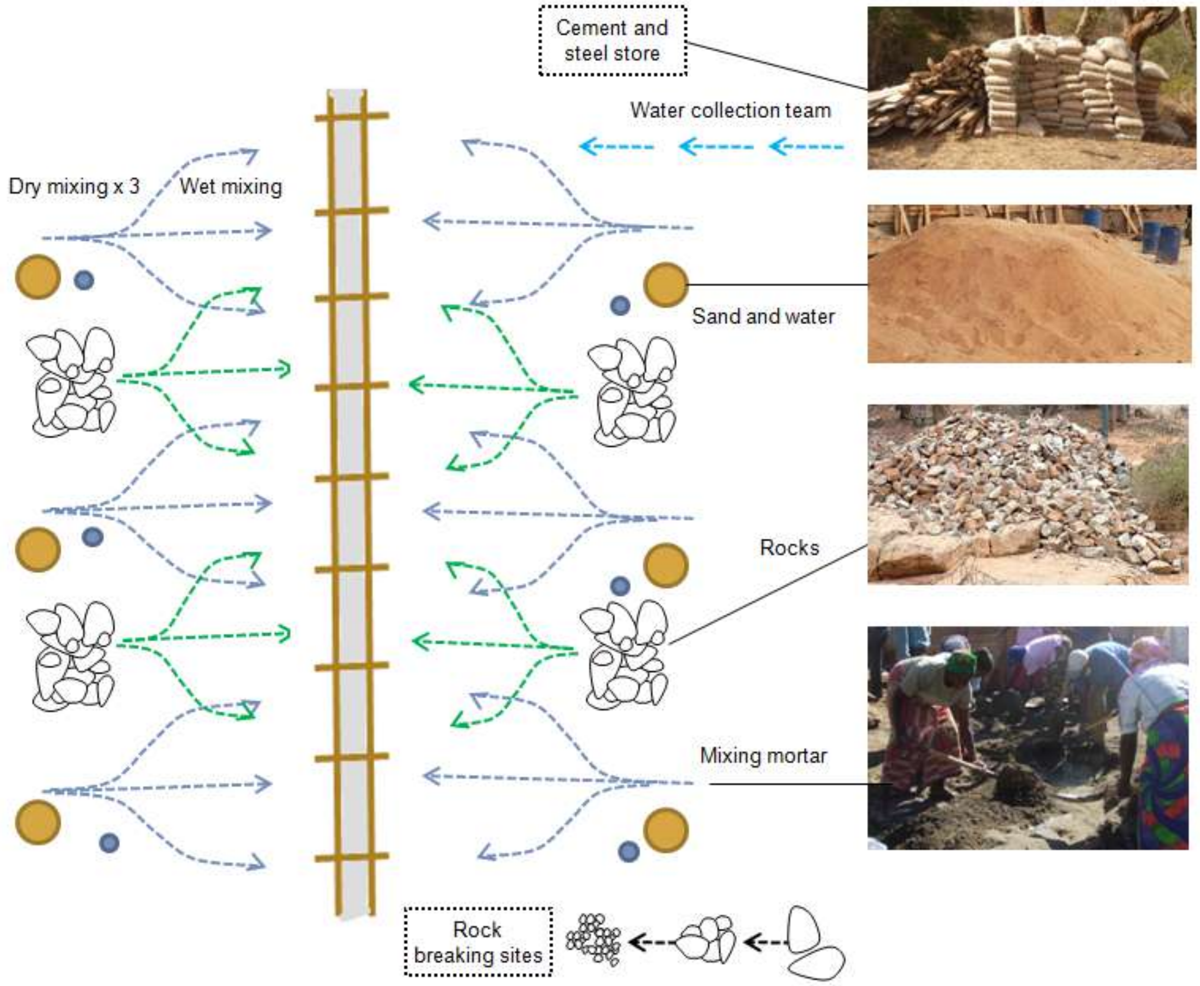
[210] https://www.concretenetwork.com/concrete/slabs/ratio.htm
[211] http://www.concrete.org.uk/fingertips-nuggets.asp?cmd=display&id=140
[212] *Somayaji, Shan (2001). Civil Engineering Materials. Upper Saddle River: Prentice Hall. p. 129. ISBN 0-13-083906-X.*
[213] https://en.wikipedia.org/wiki/Water%E2%80%93cement_ratio
[214] http://civil.emu.edu.tr/courses/civl284/8%20Mix%20design%20calculations.pdf

9.6 Site planning logistics



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 (ASDF)				
Prepare Foundations	Erect Formwork	Construction	Plastering	Watering/Curing Mortar
1–5 days	0.5-1 day	4-10 days	1 day	30 days
5-15 people	2-5 people	30-100 people	2-5 people	2-5 people

9.7 Excavation for foundations

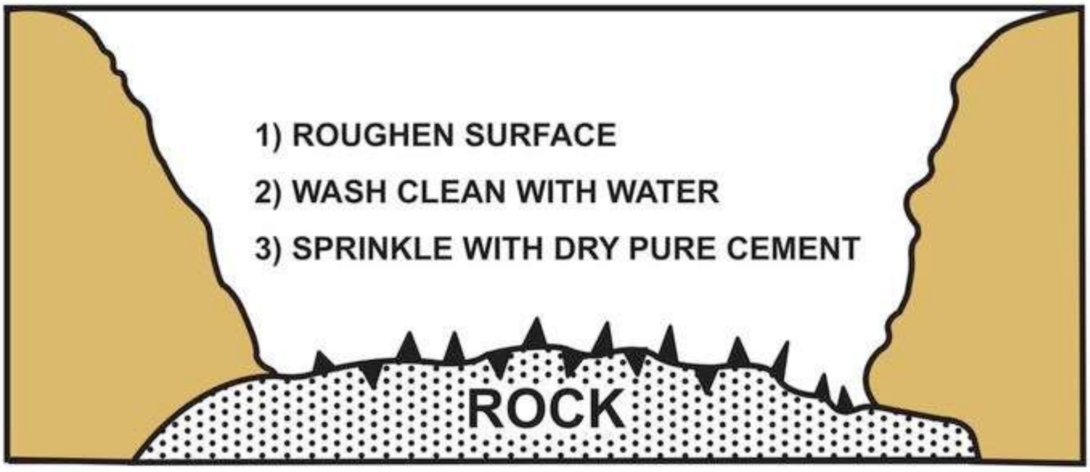
During design, the position of the dam is marked by pegs in the ground. Probing and test pits are sometimes used initially to estimate the position and depth of bedrock, but the full picture is only apparent once the foundation is fully excavated. Sometimes, there are deep fissures or sections where 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.

- **This will show on the design, but when the dam foundation goes into the banks the width of the foundation reduces as it moves away from the river channel at a rate of 0.3m less every 1m to a minimum of 0.4m.**
- **Do not therefore dig the trench into the banks too widely and waste time and materials**

9.8 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 washing away.

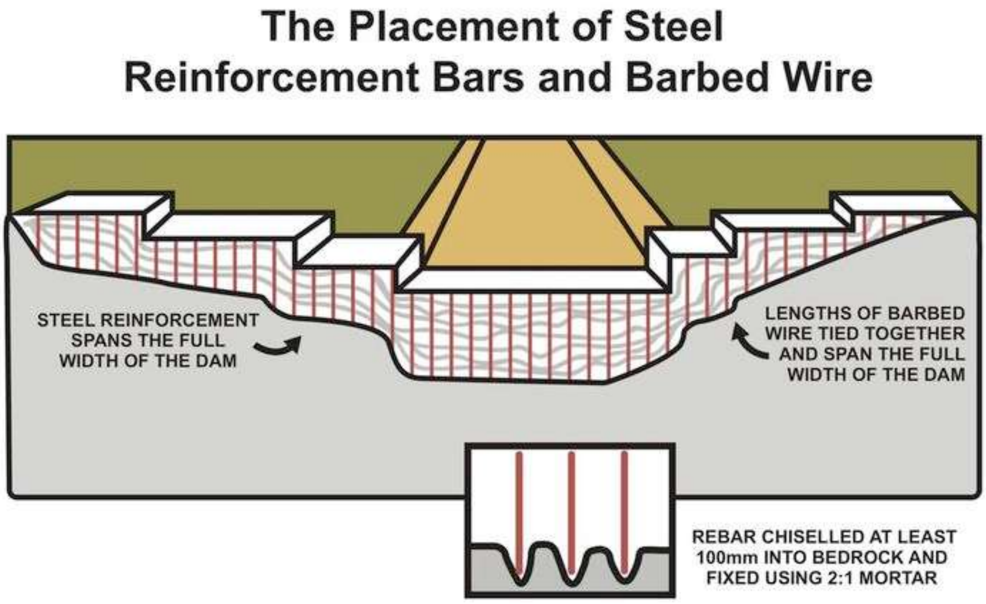
- Remove all sediment from any fissures and then wash out and seal with pure cement mortar.
- If the bedrock is at the surface, look for horizontal fissures that may extend above and below the dam. These fissures need to be filled with mortar or if the fissures are extensive, it may be necessary to prise 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
- After the rock is well cleaned sprinkle water on it and then sprinkle with dry cement (100% dry cement powder) on it to enable the bonding of the rock and the structure to keep it water tight and strong.



- 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 10-15cm deep and as close in diameter as possible to the 20 mm diameter steel bars. This is a long and arduous job in hard crystalline rock without machinery, but essential to prevent failure of the dam.

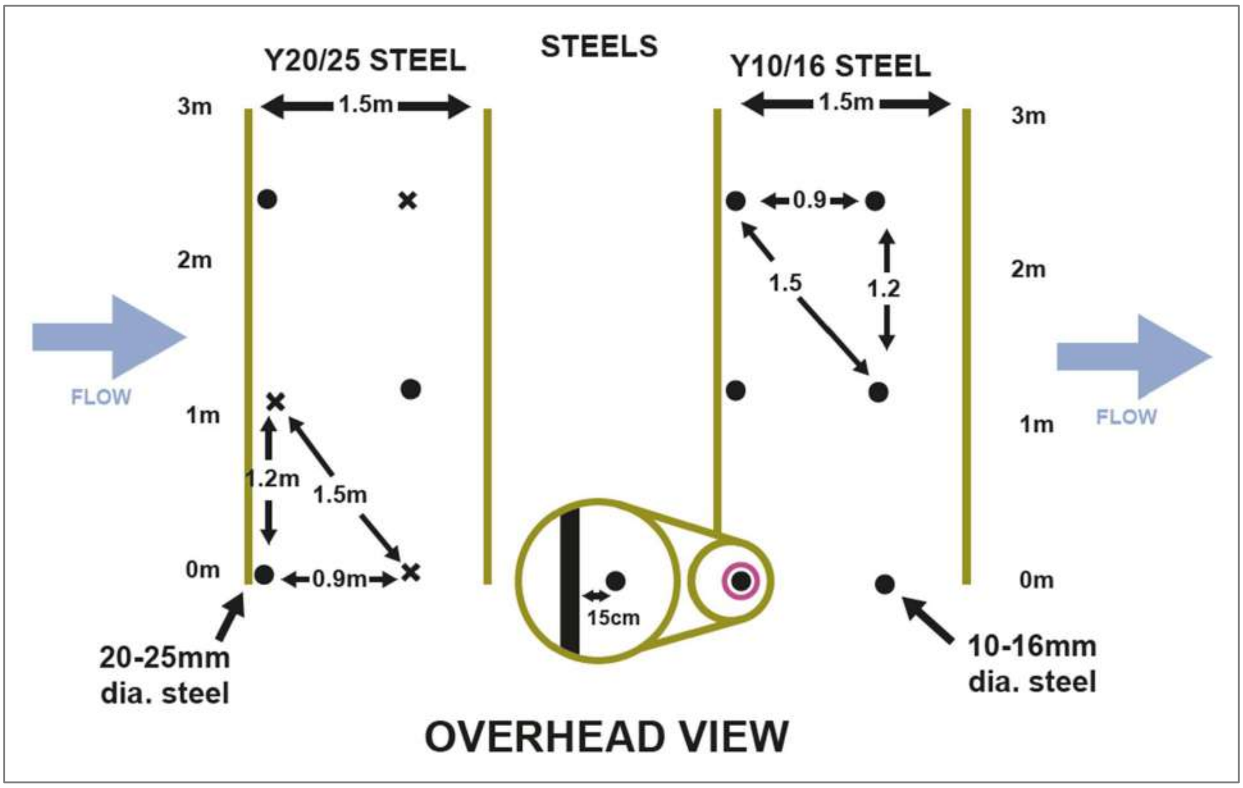
9.9 Placement of steel bars

- **Steel bars are fixed vertically in 10-15cm deep holes chiselled or drilled into the bedrock using a 2:1 mortar.**
- **The bars are spaced in a 3:4:5 ratio triangular formation diagonally every 1.5 m across the full length of the foundation (every 1.2m length)**.

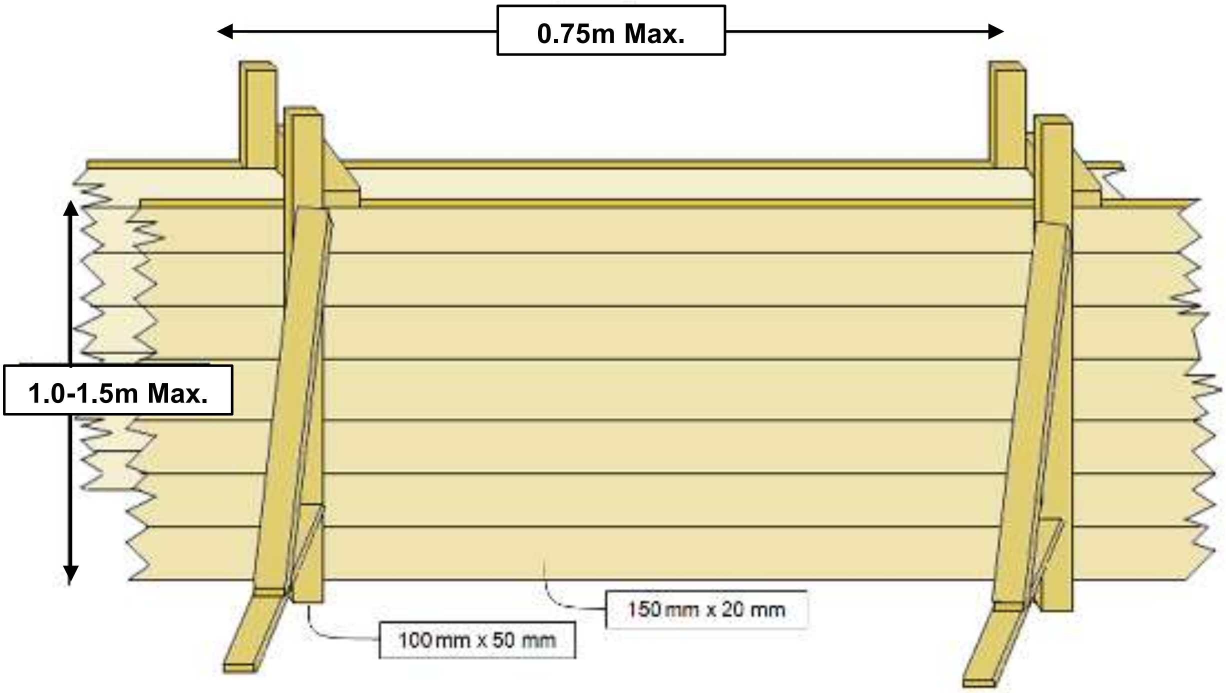


The placement of steel reinforcement bars and barbed wire

- **Standard bars are Y20 (20mm diameter) or Y25 if not available. Thinner Y10 to Y16 bars (10-16mm diameter) may be used, but in this case, place bars opposite each other 0.9m apart and 1.5 diagonally apart (i.e. twice as many iron bars).**
- **The bars are placed 15cm in from the sides of the formwork and are cut to length so that they extend from the bedrock to 5cm below the top of the dam, so they can be covered in cement to prevent corrosion.**

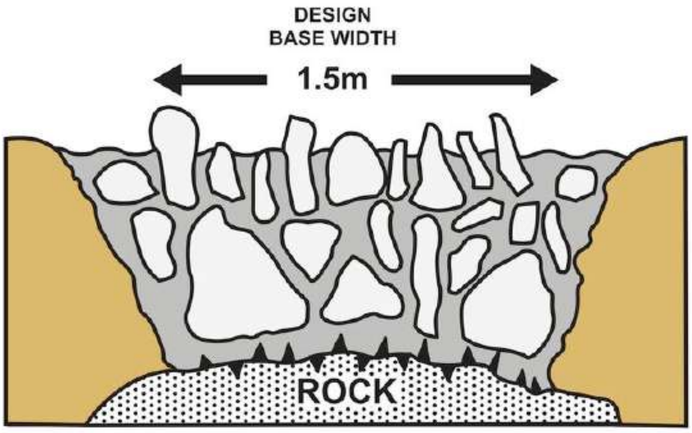


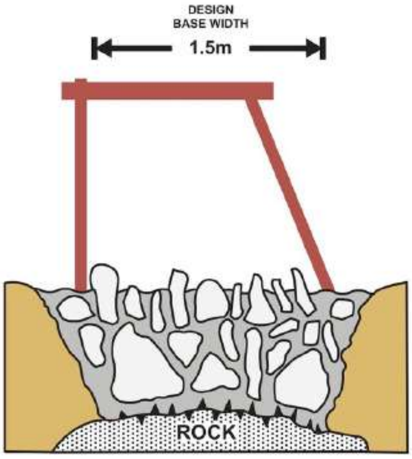
9.10 Formwork/shuttering

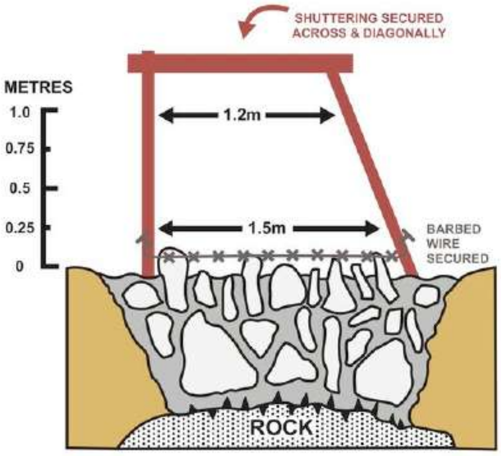


Setting out the formwork:

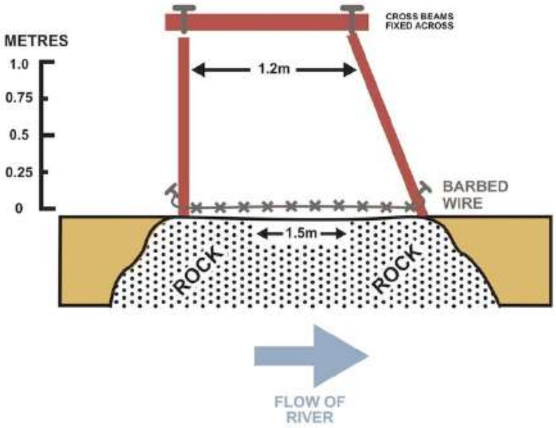
- The principle is to create a secure and strong enough ‘box’ to be filled with the rubble masonry
- The maximum height of formwork that is filled in one day is 1.0-1.5 m. For less strong timber the maximum is 1m.
- **Formwork MUST narrow by 0.3m for each 1m height to a minimum of 60cm thickness at the spillway height.**
- **Above spillway height the formwork narrows by 20cm for each 1m height up to a minimum of 40cm.**
- The upstream formwork is vertical and the downstream formwork has an inward slope.







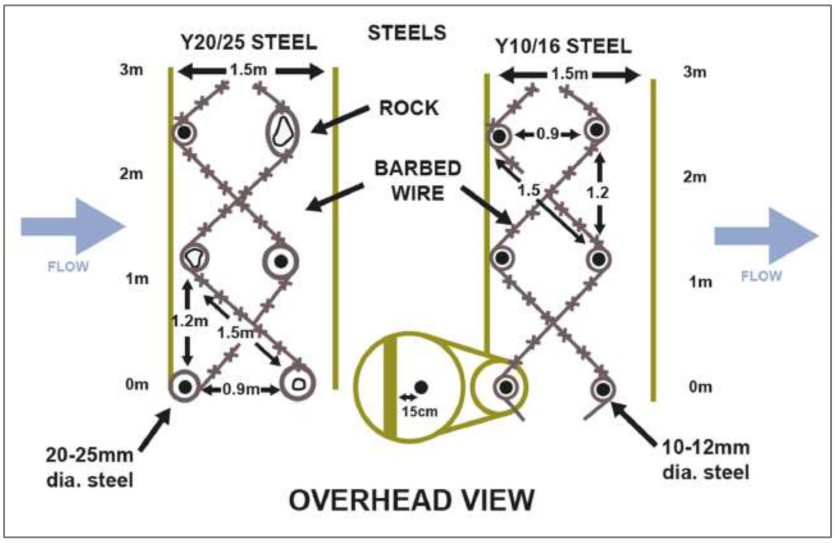
- **Formwork MUST be secured top and bottom otherwise it will spread once filled.**
    - **Barbed wire ties the two forms together at the base (and is left in the dam afterwards)**
    - **Wooden or metal supports secure the formwork at the top horizontally (diagonally and perpendicularly).**
- The formwork is removed and raised up the following day – when it will also require supporting from underneath
- Each time a new layer or section of stone-masonry is added to a previous hardened layer, there is a potential weak spot in the dam. Therefore, the dam should be built in the shortest time possible.
- **Build the dam across the full width of the dam to 1m height in one day to maintain maximum strength.**
- **This will show on the design, but when the dam foundation goes into the banks the width of the foundation reduces as it moves away from the river channel at a rate of 0.3m less every 1m to a minimum of 0.4m.**
- **Do not therefore dig the trench into the banks too wide and waste materials**

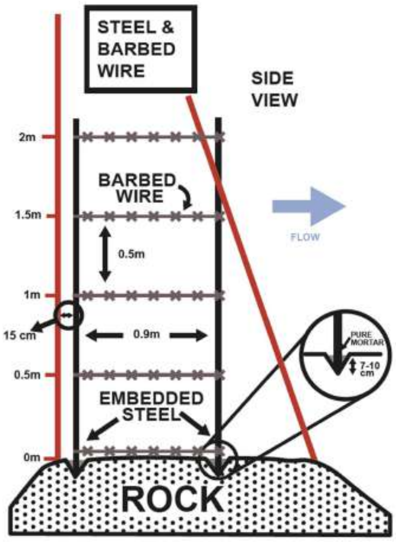


- When digging for bedrock the trench sides are used for the shuttering wherever possible
- Often in the riverbed the sediment is too soft to create a defined trench at the exact best width
- In this case ensure that you manage the placement of stones at the surface to enable the shuttering to be placed at the right distance apart to avoid high wastage of materials

9.11 Barbed wire reinforcement placement within the form work

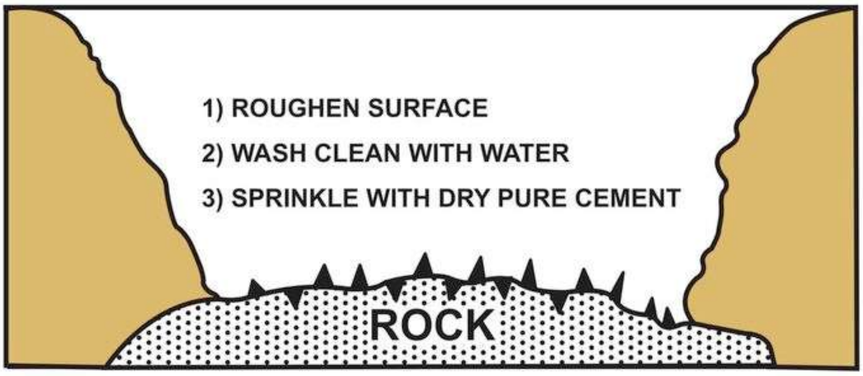
- Barbed wire is fixed across the dam in a helix shape every 50cm of height of the dam to increase tensile strength.
- Barbed wire is tightly wrapped around the steel bars (and rocks) and secured at each end of the dam.

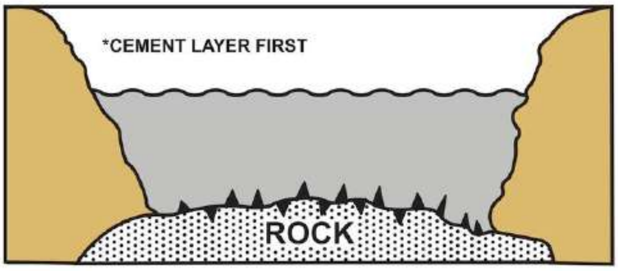


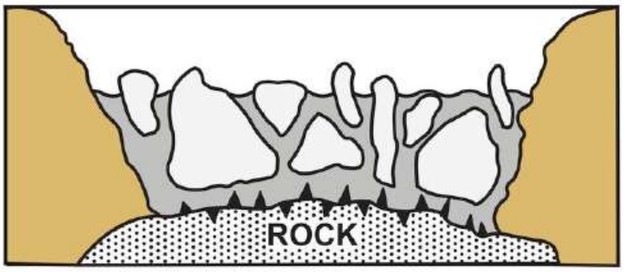


9.12 Rock and mortar placement within the form work

- Because this is a gravity dam as much rock and as little mortar should be used in the dam to maximise strength (which also minimises the costs as less cement is used).
- 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
- For below ground level larger rocks can be safely placed into position **onto the cement base**.
- When placing stones at, or just below, ground level it is preferable to use very large rocks (that may be too heavy to lift into the formwork later). In this case, the rocks can be moved into position onto the pre-prepared rock base that is already covered in cement.

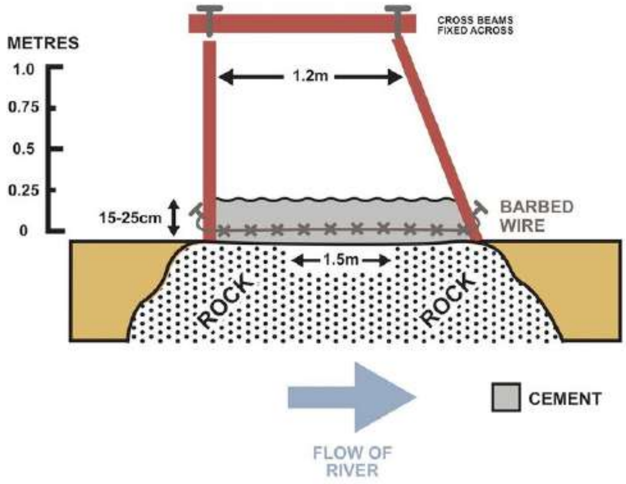


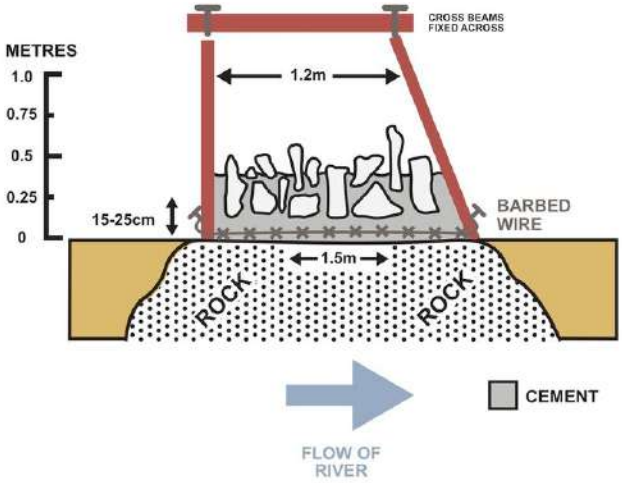




9.12.1 Filling of the formwork rules

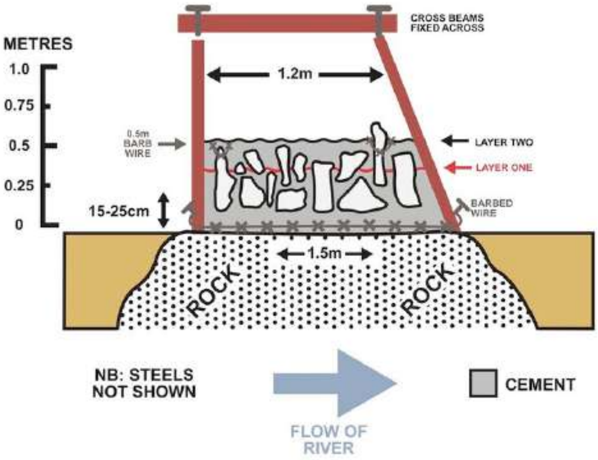
- **Mortar is placed only to a depth of 15-25cm at a time (depending on the sizes of stones available)**
- **The cement mixture needs to be wet enough for stones to sink the artisan is responsible for the placement of the stone and mortar in the dam and controlling how wet the mortar is.**
- **Technique is to PLACE ROCKS INTO THE CEMENT (not the other way around).**
- **Rocks are PLACED into the dam by hand (they must NOT be tipped into the formwork).**
- **The rocks MUST be clean (wash or remove soil with a wire brush).**
- **The rocks DO NOT TOUCH each other or the bedrock.**
- **The rocks are no closer than 7.5–10 cm from the formwork.**
- **There are NO air pockets in the formwork due to placement of stones or too dry cement.**
- **The rocks overlap each other vertically**
- **Mortar MUST be placed carefully in the dam by shovel or cement pans so as not to disturb the rocks, make them touch or create air pockets.**
- **DO NOT tip mortar into the dam on top of rocks.**

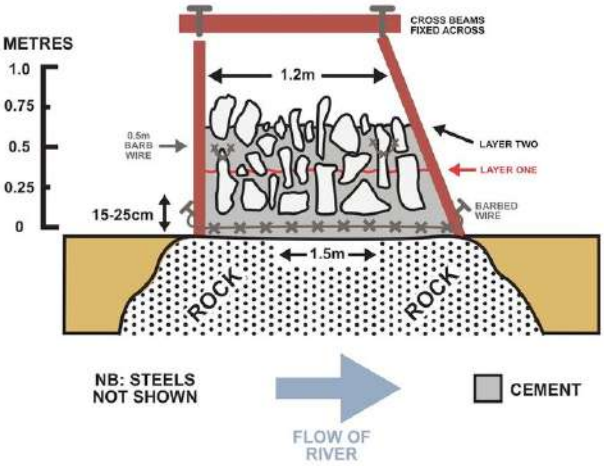




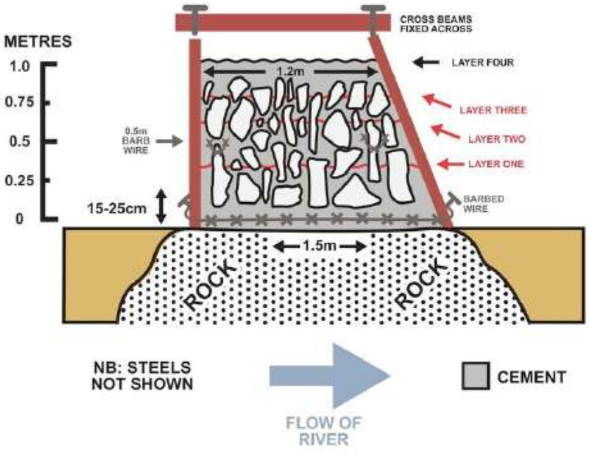
9.12.2 Filling the formwork process

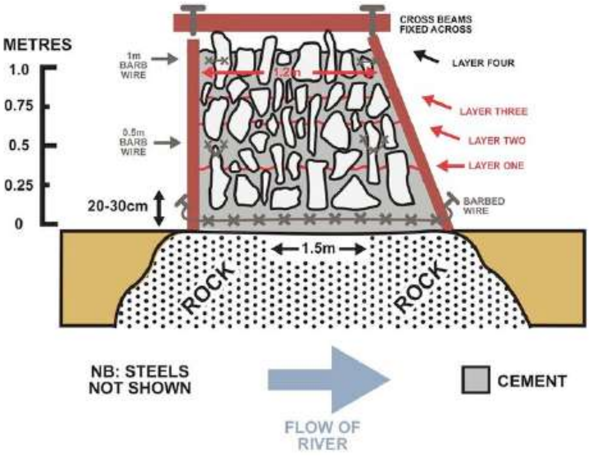
- Make sure the surface is clean by washing with water and sprinkle with pure dry cement
- YOU MUST fill the shuttering section with 20-30cm depth of mortar (depending on the relative sizes of stones that you have). This is to avoid having layers or lens of mortar with very few stones that will cause weakness.
- The bigger the biggest rocks the deeper the mortar is placed and vice versa. With relatively smaller rocks and/or few long rocks, 15-25cm depth would be the maximum depth required for each layer. Larger rocks (hard for one person to carry) would need 30cm.
- 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. **Typically, 25 litres of water are added for each 50 kg bag of cement, if the sand is dry**.



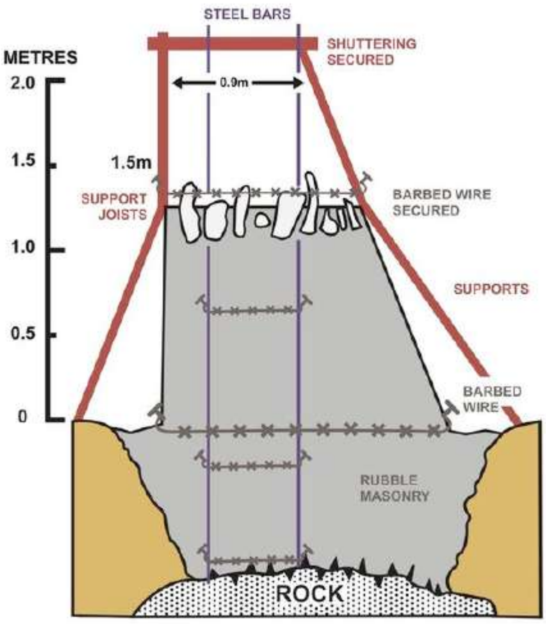


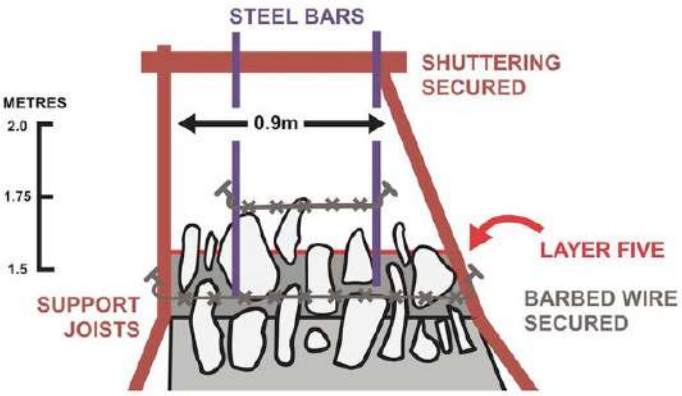
- The mortar must be workable and air pockets easily removed upon compaction. If a lot of water is driven to the surface during compaction, reduce the water content of the mortar.
- PLACE the rocks into the mortar (largest ones first, then filling the gaps with ever increasing smaller stones)
- Do not cover or sink all the rocks in cement at this stage
- Then fill again with same depth of mortar (you **must** have some longer or larger stones still not covered yet).
- PLACE stones in the gaps as before **(AGAIN MAKING SURE ROCKS DO NOT TOUCH)**
- Every 50cm depth barbed wire is zig-zagged between the steels and/or rocks and then tied on to the embedded steel at each end of the dam.
- Continue upwards with **VERTICALLY INTER-LOCKING** layers of rock.
- When completing a layer for the day ALWAYS leave plenty rocks protruding to provide a key for the next layer





- 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.
- Each day the dam should be built in horizontal layers of 1-1.5m high rather than vertical blocks.





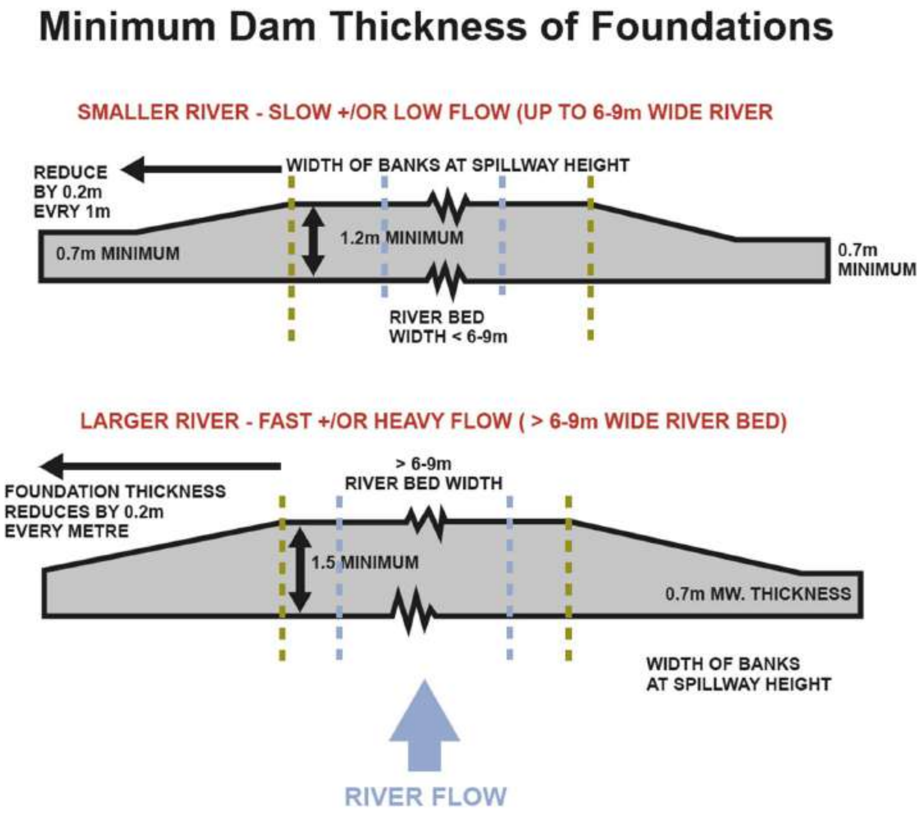
Reminder of reducing thickness with height:

- **Formwork must narrow by 0.3m for each 1m height to a minimum of 90cm thickness at the spillway.**
- **Above the spillway height the formwork narrows by 30cm for each 1m height up to a minimum of 40cm at the wing crests.**

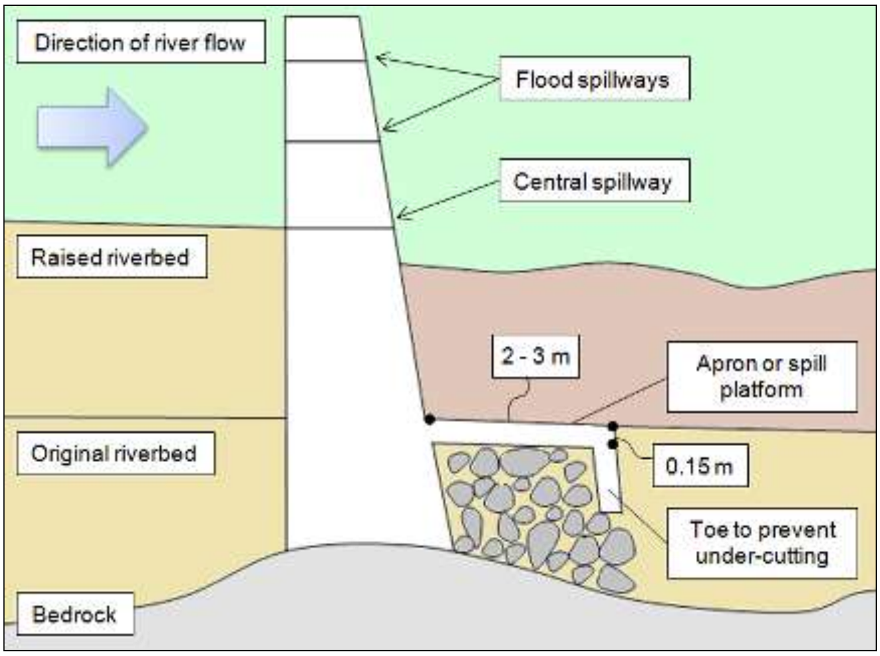
Reminder of reducing thickness of wings with width:

Whilst the design will detail the dimensions of the dam over its height and width, it is a useful reminder to remember that the dam should gradually reduce after the dam wall foundation goes into the banks of the river because the forces on the wall are more balanced due to soil being present upstream and downstream of the wall.

- **Beyond the riverbank width the formwork narrows by 20cm for each 1m width up to a minimum of 70cm.**



9.13 Apron construction



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 (see diagram above) that protects the base of the dam from being undercut (see photos below) and reduces erosion. This is only required if a natural rock apron does not already exist.
- 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.
- **The apron is slightly wider than the spillways and typically extends 2-3 m from the base of the dam**.
- Where the bedrock is less than 1m below the level of the apron, the foundation is made directly on top of the bedrock.
- If the bedrock is deeper than 1m and there is limited availability of rock, river sediment may be used to backfill the hole if it is well compacted. At 1m below the river surface a thick rock foundation is made on top of this sediment.
- **The apron is finished with a 15cm 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. Often, after maturity in a few years the sand backfills into the area of the apron, although it is unclear to the author as to why.

Examples of poorly constructed dam aprons

9.14 Post construction: Plastering the dam and curing the cement

9.14.1 Plastering

- **Plastering should only be necessary when there are errors in stone placement and to cover the barbed wires used to secure the formwork.**
- Shuttering/Formwork may be removed on the day after construction is completed.
- Cut the barbed wire that has been used to secure the formwork and ensure plastered over with cement.
- Check the levels of all the spillways to ensure they are flat and correct with plastering (and stones if required)
- If the central spillway is to be extended later DO NOT plaster the central spillway smooth.
- Check that opposite spillways are level and correct with plastering (and stones if required).
- Any holes, exposed rocks or reinforcement on the faces of the dam are **plastered with a minimum 5cm of mortar**.
- Any barbed wire or reinforced steel bars must be covered in cement to prevent corrosion of steel within the dam.
- **The upstream face is the most critical.**
- **The trenches dug into the riverbed or riverbanks are back filled after plastering**
  - Filling up trenches is **crucial upstream of the dam** – especially in the river bed to reduce or prevent any disproportionate forces being placed on the dam base when the river flows
  - If necessary, the soil/sediment should be wetted to aid compaction.
  - 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 and effectiveness.

9.14.2 Curing

- **Failure to enable the cement to cure by not keeping the mortar moist will reduce the strength of the dam.**
- **The sand dam should therefore be kept moist through protection and watering.**
- **This MUST happen both throughout the building process and for 30 days afterwards**
- In very strong heat and/or low humidity conditions the mortar should be covered with sand, empty cement bags, sacking or cut vegetation like banana leaves to reduce evaporation and keep the dam moist.
- **The top of the dam and the walls should be splashed with water three times per day for 21-28 days.**

9.15 Special circumstances

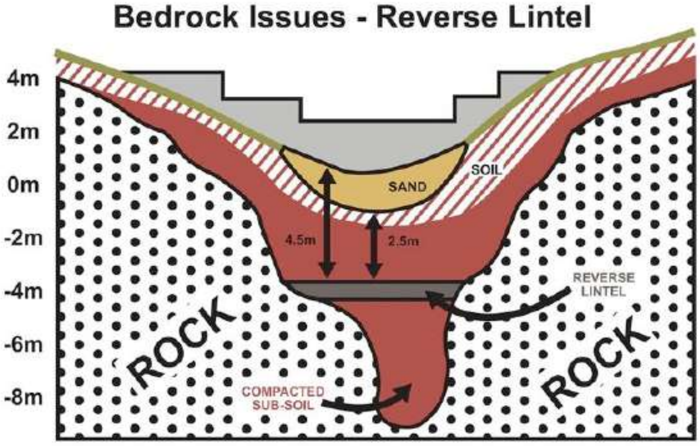
9.15.1 No accessible bedrock all the way across the river channel

Sand dams are usually built on sites with accessible bedrock (within 4-6m of the surface of the riverbed).
This is because, the dam needs to withstand the downward forces on the dam, which is mostly its weight. Otherwise the dam wall will sink causing it to crack. The river will then immediately, or eventually, flow through the dam causing complete failure. Also, to be effective, the sand dam needs to create a near water tight seal across the valley to:
a) ensure that the river does not flow directly underneath the dam, thereby causing complete failure;
b) hold water behind the dam for abstraction, and
c) maximise ground water recharge, especially during the rains or where there are underground river flows.
Therefore, the sand dam would normally be built onto bedrock at least 1.5m wider than the flood width of the river.

However, there is an exception to this, which must be approved by a sand dam expert:

- If, after 4-6m depth of digging, there is still no bedrock across the whole river channel it may still be possible to build an effective sand dam.
- **If there is impermeable, compacted sub-soil at this depth a 'reverse lintel' can be constructed from steel and concrete, but this must be at a depth of least 1.5m into the compacted sub-soil.**
- **The reverse lintel is a steel reinforced 'bar' across the dam designed to hold the weight of the dam:**

  - It must be built inside formwork the thickness of the planned foundation (minimum 1.5m) at a depth of 1m.
  - The reverse lintel is reinforced horizontally with steel reinforcement bars and barbed wire.
  - The vertical steel reinforcement bars are built into the lintel and tied to the horizontal steel bars.
- **The reverse lintel is built:**
  - **At minimum 4m deeper than the riverbed.**
  - **At least 1.5-metre-deep into the compacted sub-soil to absolutely minimise any water seepage.**
  - Ensure the reverse lintel is built on properly compacted subsoil and not on an intermediate permeable sub-soil.
  - The sub-soil must be heavily compacted, with a low permeability (test this if required).
- **It is best that the reverse lintel is laid onto bedrock both sides of the dam to eliminate subsidence.**
  - Preferably at least one side to minimise the chances of the dam subsiding and cracking (see diagram below).
  - If there is no bedrock at all there is a **VERY HIGH RISK** of subsidence and cracking. **If this risk is taken**, the reverse lintel **MUST be built across the full width of the dam** and as deep as possible into **very solid** compacted sub-soil to reduce the chances of subsidence.


Bedrock Issues - Reverse Lintel

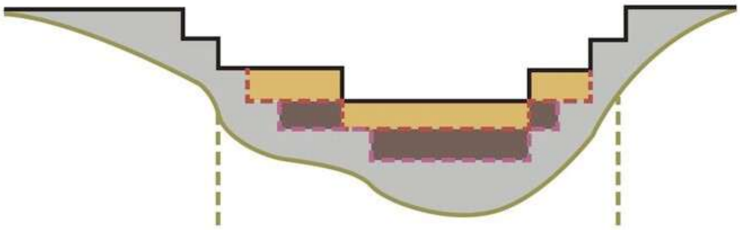
9.15.2 Building the central spillway in stages

Sometimes, because of the risk of siltation the design specifies building the dam in stages.

- It is **highly recommended** to complete all the dam to its finished height except the spillway heights within the main banks of the river.
- When completing the central spillway height for that stage **ALWAYS** leave plenty of rocks protruding from the surface to provide a key for the next layer of the spillway
- **DO NOT** plaster the central spillway smooth
- **DO NOT** leave the steels exposed – they need to be covered in cement to prevent corrosion and creating shock waves through the dam when hit by rocks during flood flows.
- **When starting the next layer proceed exactly as per starting a dam on rock foundations** (i.e. drill steels into the surface, roughen the surface, clean and wet the surface, sprinkle with dry cement).

Phased Spillway Build Approach

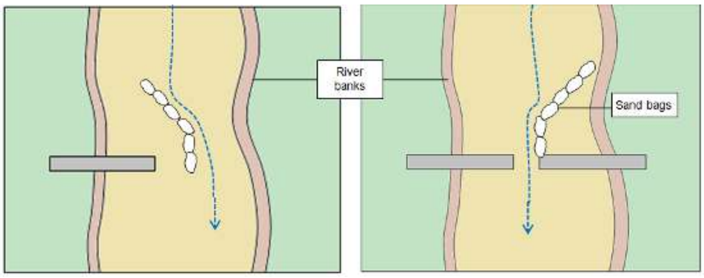
- REDUCE SPILLWAYS ACROSS MAIN RIVER FLOW
(NOT JUST CENTRAL SPILLWAY)



9.15.3 Water in the river during construction

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 uPVC pipe may be used to channel the flow through. The pipe is then filled in and sealed as the last step. See diagram below for one technique to manage building in flowing rivers.

The cement mix should be increased to 2:1 sand wheelbarrows to one bag of cement (i.e. 3:1 ratio by volume).



9.16 Common Construction Errors to Avoid

There are several common construction errors that can have dramatic, even catastrophic impacts. This re-emphasises the need for good quality control during the construction process, especially when construction is out-sourced. Beyond the obvious failure to follow measurements or losing the reference points on the drawing, there are a number of risks: when digging foundations short-cuts are very tempting – especially when they become ‘invisible’ fairly quickly; it is easy to be confused about levels with sloping banks – especially in asymmetrical valleys.

9.16.1 Common Error (Part 1 A): Dam not built on bedrock

Best case negative impacts:

- Seepage or leakage through the dam, slowly or quickly draining the dam
- Reduced recharge of groundwater

Worst case negative impacts:

- **Leakage gets more severe and the river flows underneath the dam causing complete failure**
- **Dam drops causing it to crack and the river flows through the dam causing complete failure**

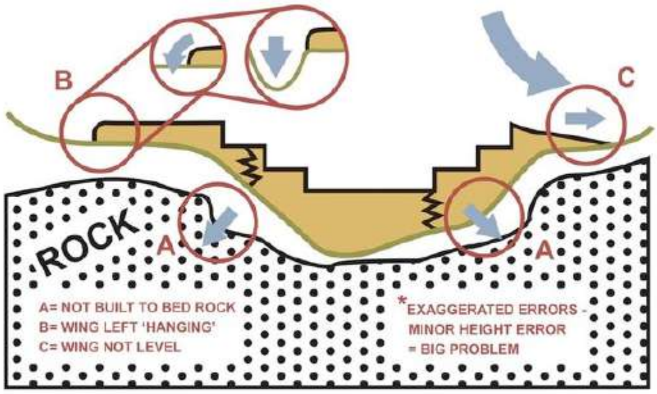
Mitigation:

- Close supervision of foundation excavation and laying of foundations
- Ensure all vertical and horizontal fissures are cleaned and filled

Avoidance:

- **Biggest risk and most common failure point is the area into the banks of the river (See Circles A)**
- **Ensure that excavation is to bedrock and that the rock surface is cleaned**

Common Construction Errors* Part 1



9.16.2 Common Error (Part 1 B): Wings not built into river banks (left ‘hanging’)

Best case negative impacts:

- Flood water flowing around the dam
- Wearing out of ground at the end of the dam

Worst case negative impacts:

- **Level of ground on outside of dam drops to below spillways**
- **River completely changes direction around the dam, causing complete failure**

Mitigation:

- Cover end of dam walls with brush or acacias to prevent people and livestock eroding the ground.
- Pile rocks and soil to extend the dam wall.

Avoidance:

- **Always built dam wing walls level into the ground**

9.16.3 Common Error (Part 1 C): Wing walls not built level

Best case negative impacts:

- Water is pushed around the dam causing erosion upstream and downstream of the dam

Worst case negative impacts:

- **River completely changes direction around the dam, causing complete failure**

Avoidance:

- **Always check the levels of wing walls with a line and spirit-level during construction.**

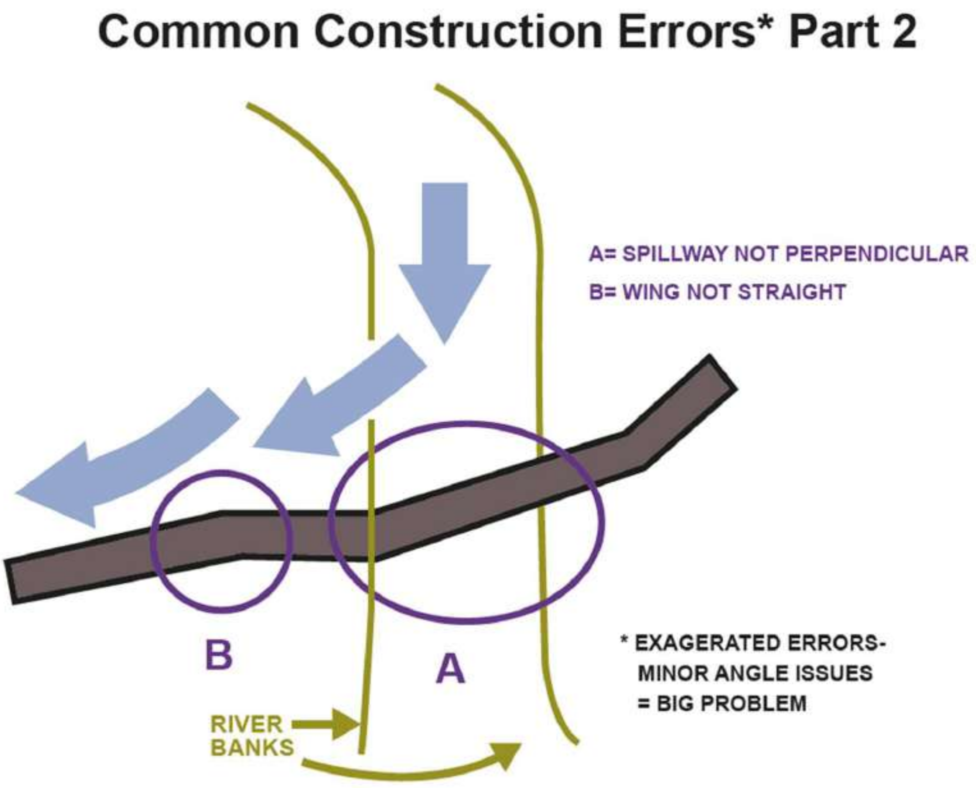
9.16.4 Common Error (Part 2 A): Dam spillway not built perpendicular to flow

Best case negative impacts:

- Water is pushed around the dam causing erosion upstream and downstream of the dam

Worst case negative impacts:

- **River completely changes direction around the dam, causing complete failure**



Mitigation:

- Take care on river bends and where the outside river bank is rock because the river will ‘bounce’ off the outer side and try and flow the other direction.

Avoidance:

- **Ensure the dam is built to where the designer pegged the spillway and wing positioning.**

9.16.5 Common Error (Part 2 B): Wing not built straight

Best case negative impacts:

- Water is pushed around the dam causing erosion upstream and downstream of the dam

Worst case negative impacts:

- **River completely changes direction around the dam, causing complete failure**

Mitigation:

- Wing walks are often built on an angle to keep river flowing over the spillways which makes it easier to not build that section of the dam wall perfectly straight, which causes the flow to ‘split’ pushing the river outwards.

Avoidance:

- **Always set a build line when setting formwork and when plastering the dam on upstream side**

9.16.6 Common Error (Part 3): Spillways not built level or are imbalanced

Best case negative impacts:

- River flow is pushed to one side causing erosion upstream and downstream of the dam
- causing erosion upstream and downstream of the dam

Worst case negative impacts:

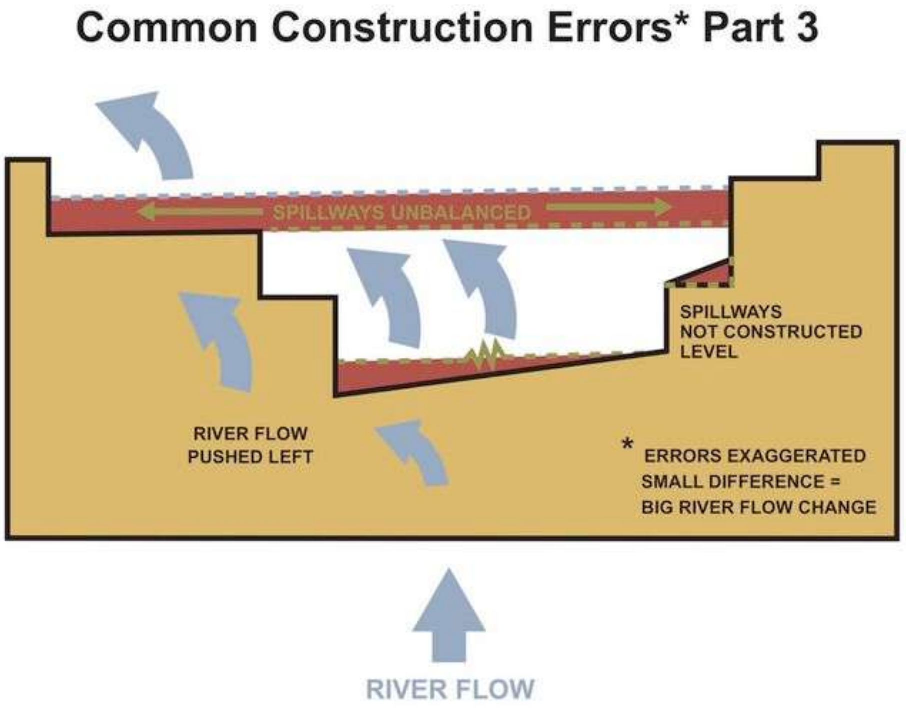
- **Water flows around the dam and river changes direction around the dam, causing complete failure**

Mitigation:

- After removal of formwork/shuttering measure the level of the spillway over its length and repair with cement
- After removal of formwork measure the levels of opposite spillways and level with cement if necessary

Avoidance:

- **Always utilise build lines during construction and check levels afterwards.**



9.17 Site safety

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

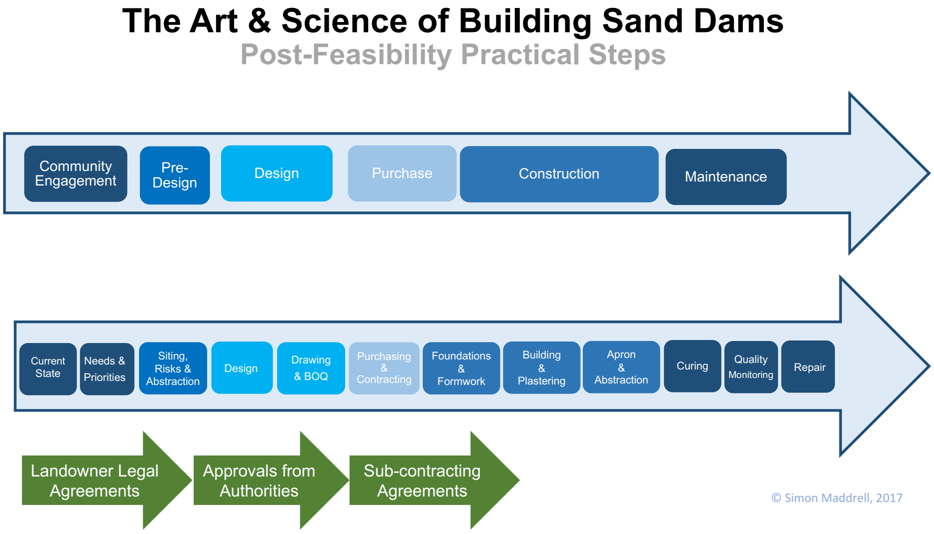
- Collapse of excavations in unstable sediments, the risk of this is higher the deeper you go [4-6m should be the absolute maximum] and the less consolidated the deeper river sediment is.
    - Any excavation in unconsolidated sediments deeper than 1-2 metres is highly dangerous. Unconsolidated sediment either side of the excavation must be removed to create a gentle slope or held back with shuttering or sand bags.
- Lift and crush injuries from handling, lifting or dropping heavy items
- Bites from snakes and stings from scorpions, particularly when disturbing rock piles
- Irritation of skin, lungs and eyes from handling cement.
    - Cement is an irritant to eyes and skin. When handling wet cement, it is advisable for gloves to be worn.
    - Always wash any cement off your skin – and do so immediately if any gets into your eyes.

Adequate risk measures should be put in place such as (but are not limited to):

- Site safety briefings for all workers including safe lifting, digging, use of shovels, etc.
- 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 a medical emergency

Chapter 10: Maintenance and management of sand dams[215]

Whilst a well-designed and constructed sand dam requires zero or minimal maintenance it is important to watch for signs of failure. Abstraction technologies such as hand pumps and animal troughs do require maintenance and repair and therefore need to be managed. This chapter also lays out the types of preventative maintenance or repairs that may be required and discusses the possible external threats and risks surrounding sand dams including large-scale abstraction of water or sand and the risks of conflict.



10.1 Warning signs of sand dam failure risk

Whilst sand dams rarely require minimal maintenance or repair, the community group should regularly inspect the dam for damage, especially after major rains and 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:

- **Soil erosion outside and/or around the wings** [Water flowing around the dam]
- **Erosion of riverbanks, especially downstream of the dam** [Water flowing over the highest wing of the dam]
- **Cracks in the wall and/or visible leakages** [e.g. by poor construction, insufficient curing, settlement of the dam]
- **Undercutting of apron** [inadequate apron or unusually large and heavy objects flowing over the dam]

10.2 Monitoring and preventative maintenance

10.2.1 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.

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[215] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013

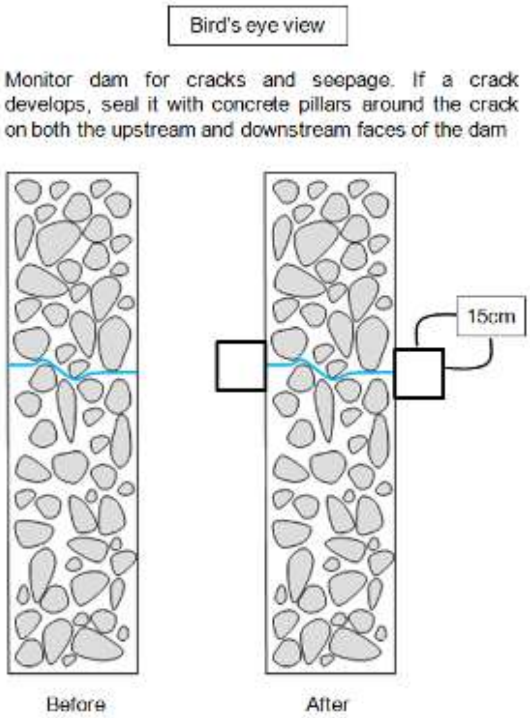
10.2.2 Monitoring bank erosion and changes in river course

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 either extending and/or raising the wings or altering the positioning of spillway(s) to control the position of the main flow of the river.

10.2.3 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. A tell-tale sign of leakage through the foundations can be seen upstream of the dam if the sand behind the dam and there is a deep funnel of sand covered in silt, which shows how water has seeped downwards rather than being held in the sand or going over the top of the dam [see two photos below].

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 (>5mm) a 15cm by 15cm concrete block is created around the crack or leak on both the upstream and downstream side of the dam, as shown in the diagrams below.

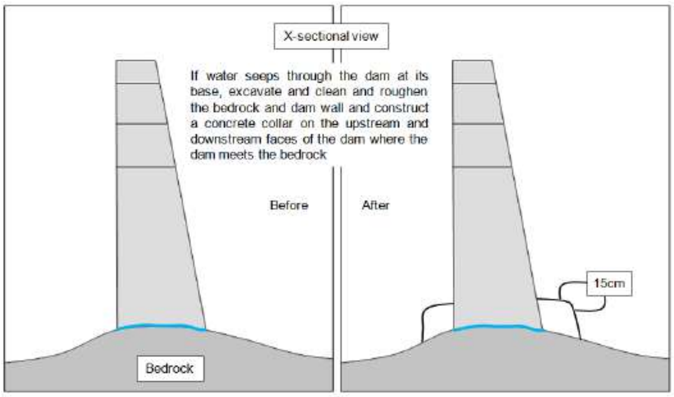


Bird's eye view

Monitor dam for cracks and seepage. If a crack develops, seal it with concrete pillars around the crack on both the upstream and downstream faces of the dam

10.2.4 Monitoring and preventative maintenance of apron and wings

Any damage to the apron or its foundation (as seen in below) 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.



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

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

10.2.5 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.

10.3 Sand dam management of risks

Effective management is essential maximise the benefits and for sustainability, whilst in some areas customary law is paramount in resolving water, land and grazing conflicts – especially in single tribe areas – formal ownership of managing the sand dam is usually also essential to preventing and/or mitigating the risks. Local usage agreements and government authorisation and registrations was discussed in Chapter 8.1.

10.3.1 Risks: Controlling large-scale abstraction of sand

Small-scale sand abstraction for domestic construction is not a problem, especially if deeper holes are refilled/smoothed out. However, large scale sand harvesting (usually by commercial contractors) reduces the sand and water levels in the river and increases bank erosion and must be controlled. In addition, large excavated holes left in the river bed will, after the next rains, almost certainly fill with silt rather than the sand needed for effective water retention and abstraction. Large-scale sand abstraction is most common at sites close to paved roads and nearer larger towns and cities. In Kenya and many other countries, commercial sand abstraction is only legal if a permit is obtained, but corruption and difficulty in effectively 'policing' rural areas can make this only a notional barrier, means the law is sporadically enforced, although there are more controls now with the institution of devolved County governments in Kenya. In Kenya, community groups (e.g. SHGs or Group Ranches) are better able to manage this problem if the dam is legally registered to them; legal agreements are in place with land owners and the importance of managing sand harvesting is recognised by the wider community.

10.3.2 Risks: 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.

10.3.3 Risks: managing livestock & wildlife access, usage and conflict

One risk is contamination of water from animals although due to the filtering nature of sand the risks are greater around shallow wells where water can be directly contaminated, especially where there is damage. However, in Ukambani, SE Kenya where mixed agriculture takes place, people often use Acacia thorns to keep livestock out of scoop-holes used by people and others ensure that animals take water downstream from the dam. In Zimbabwe, Dabane Trust's Rowa hand pump design separates animals from the pump output and often has an attached, but segregated, animal trough.

In the Community Conservancies in the Northern Rangelands, water is also needed for wildlife and elephants are clever enough to know that water dug from sand is cleaner than open water pools and of equivalent cleanliness to remote springs[216]. By digging scoop holes, or using ones dug by people, elephants also provide an open water source for other wildlife. To reduce human-wildlife conflict in Lekurruki Conservancy in the Northern Rangelands, sand dams have been built specifically for the benefit of elephants and other wildlife and great efforts are made to elephant-proof animal troughs. Of course, conflicts can also exist between neighbouring conservancies, especially between different tribal groups, over water and grazing access.

Customary law is often paramount in resolving water, land and grazing conflicts, especially in single tribe areas. Peaceful sharing of resources can be put under significant strain during extended droughts where access to water and/or pasture is limited for people, livestock and wildlife. This is especially true for pastoral, nomadic and/or multi-tribal areas where organisations like the Northern Rangelands Trust (ultimately controlled by the regional elders) who support community conservancies in that region of Kenya are helping to co-ordinate access bye-laws and often act as a broker peace.

10.3.4 Risks: 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

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[216] Eva M Ramey, Rob R Ramey, Laura M Brown, and Scott T Kelley. Desert-dwelling African elephants (Loxodonta africana) in Namibia dig wells to purify drinking water. Pachyderm No. 53 January–June 2013.
http://www.the-eis.com/data/literature/Desert_dwelling%20African%20elephants_Loxodonta%20africana_%20in%20Namibia%20dig%20wells%20to%20purify%20drinking%20water.pdf

- 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.

10.3.5 Risks: 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 that they have little or no operation and maintenance costs and significantly improve incomes through livestock watering, vegetable and tree nurseries etc. Consequently, 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 would 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.
- The governance and management of the system.

Chapter 11: Alternative water technologies in drylands

11.1 Introduction

This chapter is covers the alternative water technologies in drylands – both rivers and other rainwater harvesting. The previous incarnation of this manual described each technology in detail[217]. However, this version is briefly summarising the technologies and then referencing the experts or expert sources for more details. Other authors with their specific experience and knowledge can do more justice to the alternative technologies.

11.2 Water from Sand Rivers

There is a range of technologies that harvest, store and/or abstract water in drylands from seasonal sandy rivers. Figure 26 shows a version of how the suitability of sand river technologies changes within a catchment. The suggested limits to feasibility for each technology will vary from basin to basin according to its geography – and of course non-sandy rivers are only suitable for check dams. However, in general terms, lower in a catchment/basin, where slopes are shallower, structures such as sub-surface dams and water spreading weirs and spate irrigation 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 simply directly from the sand river is most likely to be appropriate. Sub-surface dams are more suitable for shallower river flows or rivers with little or no banks, although they are also a lower-cost, lower-yield option where sand dams are suitable.

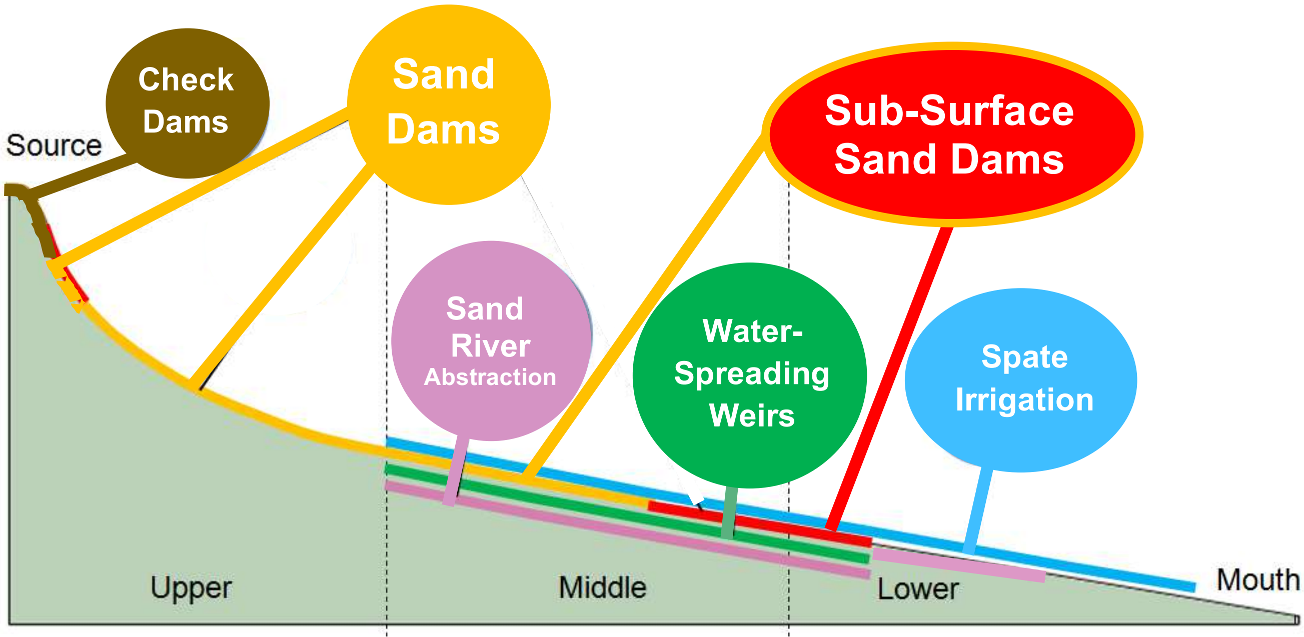

Figure 26: Long profile of river channel showing in-channel water harvesting technologies[218]

More detailed information from others with substantial experience is available from:

Water from Sand Rivers. Nissen-Petersen, E., RELMA and SIDA, 2000. Technical Handbook 23[219].

Water from Sand Rivers. Hussey, S. WEDC, 2007[220].

WOCAT Sustainable Land Management Database: https://qcat.wocat.net/en/wocat/

AFRHINET: http://afrhinet.eu/about-afrhinet.html

Akvopedia : http://akvopedia.org/wiki/Water_Portal_/_Rainwater_Harvesting_/_Groundwater_recharge

Appropedia Technology Database: http://www.appropedia.org/Portal:Water

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[217] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013. Chapter 10, p. 66-75.

[218] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013 [Amended by Maddrell, S.R., 2017]

[219] http://outputs.worldagroforestry.org/cgi-bin/koha/opac-detail.pl?biblionumber=35412

[220] http://wedc.lboro.ac.uk/resources/books/Water_From_Sand_Rivers_-_Complete.pdf

11.2.1 Check Dams[221]

A check dam[222] or trap dam[223] is a permeable barrier placed in the flow path of an ephemeral waterway such as a channel, stream, ditch, or spillway (these terms are used interchangeably throughout this page) to hinder flow and cause upstream pooling. They are suitable either in the higher reaches of a sandy river catchment – or all the way down to the lower reaches where the river sediment is not suitable for sand dams. This pooling of water increase infiltration of rainfall to groundwater and reduces effects of erosion while trapping transported sediments and preventing downstream transport. Check dams have been shown to be particularly effective in trapping sediments when placed in gullies in areas with severe land relief[224]. Check dams were used extensively in the rehabilitation of the Loess Plateau (a region of China the size of Belgium with very silty, clay fine sediment soils).[225] The Loess Plateau project has been extensively studied by John D. Lui including a great film 'Hope in a Changing Climate'[226].

11.2.2 Sub-surface Dams

Championed by Erik Nissen-Petersen (semi-retired from ASAL Consultants Ltd)[227] for the last forty years, sub-surface dams are effectively 'below ground-level' sand dams. The function of a subsurface dam is to stop water from seeping downstream in the sand of a riverbed. Water is thus trapped upstream of the dam wall and will increase the yield of a hand-dug well or intake situated there[228]. They are built only to the level of the original riverbed. Therefore, the riverbed sediment provides equal lateral support either side of the dam wall. Consequently, 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. Sub-surface dams are ideal where there are no discernible river banks and no accessible bedrock.

11.2.3 Sand River Abstraction

Sand rivers, especially downstream, often contain large volumes of unconsolidated sediment that retains water in the pore spaces. In a large river system, the supply of water in the sediment can last all year round. Such water retained within sand riverbeds has been used by arid-land dwellers for centuries and is an established and accepted practice. 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. The most experienced person and organisation is Stephen Hussey[229] from the Dabane Trust[230] who have installed over 450 sand abstraction systems and Rowa Hand Pumps since 1992 supplying a mix of domestic water and water for livestock and garden irrigation.

11.2.4 Water-spreading Weirs

Water-spreading weirs[231] are long barriers across seasonal rivers that spread flood flows and sediment from seasonal rivers onto the flood plains before flowing into the seasonal river channel. This water and sediment raises the water table and irrigates and fertilises the flood plains.

11.2.5 Spate Irrigation

Spate (or diversion irrigation)[232] 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.

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[221] http://akvopedia.org/wiki/Water_Portal_/_Rainwater_Harvesting_/_Groundwater_recharge_/_Check_dams_(gully_plugs)

[222] http://www.appropedia.org/Check_dam

[223] Baurne, G. "Trap-dams": Artificial Subsurface Storage of Water, 1984. https://www.researchgate.net/publication/245327618

[224] Xiang-Zhou, Xu. "Development of check-dam systems in gullies on the Loess Plateau, China." Sediment Laboratory, Department of Hydraulics and Hydropower Engineering, Tsinghua University, 2004.

[225] X. Z. Xu, H. W. Zhang, G. Q. Wang, S. C. Chen, W. Q. Dang. An experimental method to verify soil conservation by check dams on the Loess Plateau, China, Environmental Monitoring and Assessment, 2009, 159, 1-4, 293

[226] https://www.youtube.com/watch?v=bLdNhZ6kAzo

[227] http://www.waterforaridland.com/

[228] Water from Sand Rivers. Nissen-Petersen, E., RELMA and SIDA, 2000. Technical Handbook 23. p. 23.

[229] Hussey, S. Water from Sand Rivers. WEDC. 2007. http://wedc.lboro.ac.uk/resources/books/Water_From_Sand_Rivers_-_Complete.pdf

[230] http://www.dabane.org/

[231] https://www.giz.de/fachexpertise/downloads/giz2013-en-water-spreading-weirs.pdf

[232] http://spate-irrigation.org/what-is-spate-irrigation/

11.3 Other Rainwater Harvesting Solutions

There are a whole range of other non-river rain water harvesting (RWH) methodologies that can be used in combination with, or instead of, the seasonal sand river options, just as Jal Bhagirathi Foundation[233] in Rajasthan, India combine sand dams, Earth dams (*talabs*), pans/ponds (*nadi*) and underground tanks (*tankas*)[234]. Again, the internet is awash, so to speak, with videos, manuals and guides about rainwater harvesting but here follow the key organisations who have videos, a database and/or publications that demonstrate great work in this area. Each RWH solution or approach is only briefly explained, edited from previous version of this manual[235], with links to more resources on both RWH, WRM and SLM[236].

Access Agriculture: Sustainable Land Management	https://www.accessagriculture.org/category/
AFRHINET: Technical Sheets of Alternative RWH	http://afrhinet.eu/materials/
Akvopedia:	http://akvopedia.org/wiki/Water_Portal
Appropedia Technology Database:	http://www.appropedia.org/Portal:Water
ASAL Consultants Ltd. Kenya:	www.waterforaridland.com
Rain4Food/Rain Foundation:	http://www.rainfoundation.org/
Roads for Water:	http://roadsforwater.org/
WaterAid	http://www.wateraid.org/~/media/Publications/technology-notes-2011.pdf
WikiWater	http://www.wikiwater.fr/e8-construction-of-small-sub.html
WOCAT Sustainable Land Management Database:	https://qcat.wocat.net/en/wocat/

11.3.1 Water from Roads

As well as promoting sand dam road crossings, Roads for Water promote many of the below methodologies integrated with roads[237]. More language versions of this summary and other papers are also available[238]. Roads serve up a great opportunity to take opportunity of their greatest challenge, drainage, with the harvesting of rainwater as they serve very much like a rooftop, rock catchment or enabling more focussed land run off.

To quote Roads for Water, “Water is short in many places but roads are everywhere – and when it rains it is often along the roads that most water runs, as roads unknowingly either serve as a dyke or a drain. By ‘harvesting’ the water with these roads, water shortage can be overcome and climate change addressed. The potential to scale up the use of water with roads is enormous – especially with the on-going investment in road building globally – with every area having its own specific best solutions. At present, unfortunately the construction of roads often typically leads to local flooding, gully erosion, water logging, dust and sedimentation. Yet this can be turned around and roads and water, rather than being enemies, can be friends.”[239]

11.3.2 Shallow Wells

There are two main types of shallow wells, which of course can be used in combination with sand dams:

- Hand-dug, open wells with rope & bucket or hand-pump[240]
- 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.

Tube-wells are drilled down into the aquifer rather than excavated and are significantly narrower (10 - 20 cm) than hand dug wells. Tube-wells must be fitted with a hand or motorised pump. Hand-pumps typically suit wells that are

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[233] http://jalbhagirathi.org/Thematic-Areas
[234] http://jalbhagirathi.org/themes/upload/document/569720.pdf
[235] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013
[236] Pacey A and Cullis A, (1986), Rainwater Harvesting, IT Publications
[237] http://roadsforwater.org/wp-content/uploads/2016/01/Roads-for-water-brochure_final_EN.pdf
[238] http://roadsforwater.org/category/techniques/
[239] http://roadsforwater.org/
[240] Watt S B and Wood W E, (1977), Hand dug wells, IT Publications.

5 to 50 metres deep, but some hand-pumps can lift water more than 100 metres. Hand-pump yield varies according to the model and depth of the water table, but typically they serve the domestic needs of 300 people.

11.3.3 Ponds/Pans

Ponds/pans capture and store run-off in an open surface reservoir on gently sloping land. Earth ponds or pans, called *haffirs* in Arabic and *nadis* in Hindi, 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.

11.3.4 Earth Dams

Earth dams capture and store run-off in an open surface reservoir on gently sloping land. Earth dams, called *talabs* in Hindi, vary considerably in size but are much larger than ponds/pans. They can vary from 50 metres to over 300 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 the cheapest and simplest to site, design, construct and maintain.

Earth Dam, Kenya. Credit: UDO / EDK

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

11.3.5 Underground (Run-off) Tanks[241]

Lined, underground tanks (called *tankas* in Rajasthan) 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.

11.3.6 Roof Rainwater Harvesting Tanks

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 are best suited to permanent buildings with non-thatch roofs, where water consumption is low such as individual homes and schools. The NGO Africa Water Bank builds RWH tanks in Northern Kenya with their own roofing system. Additional resources on tanks are available from organisations listed in Chapter 11.3 as well as a manual on Ferro-cement tanks (Watt, 1978)[242].

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[241] Skinner B and Shaw R, WELL Technical Briefs, Buried and semi-submerged tanks, WEDC, UK. http://www.lboro.ac.uk/well/resources/technical-briefs/56-buried-and-semi-submerged-tanks.pdf

[242] Watt S B, Ferrocement Water Tanks and their construction, IT Publications, 1978.

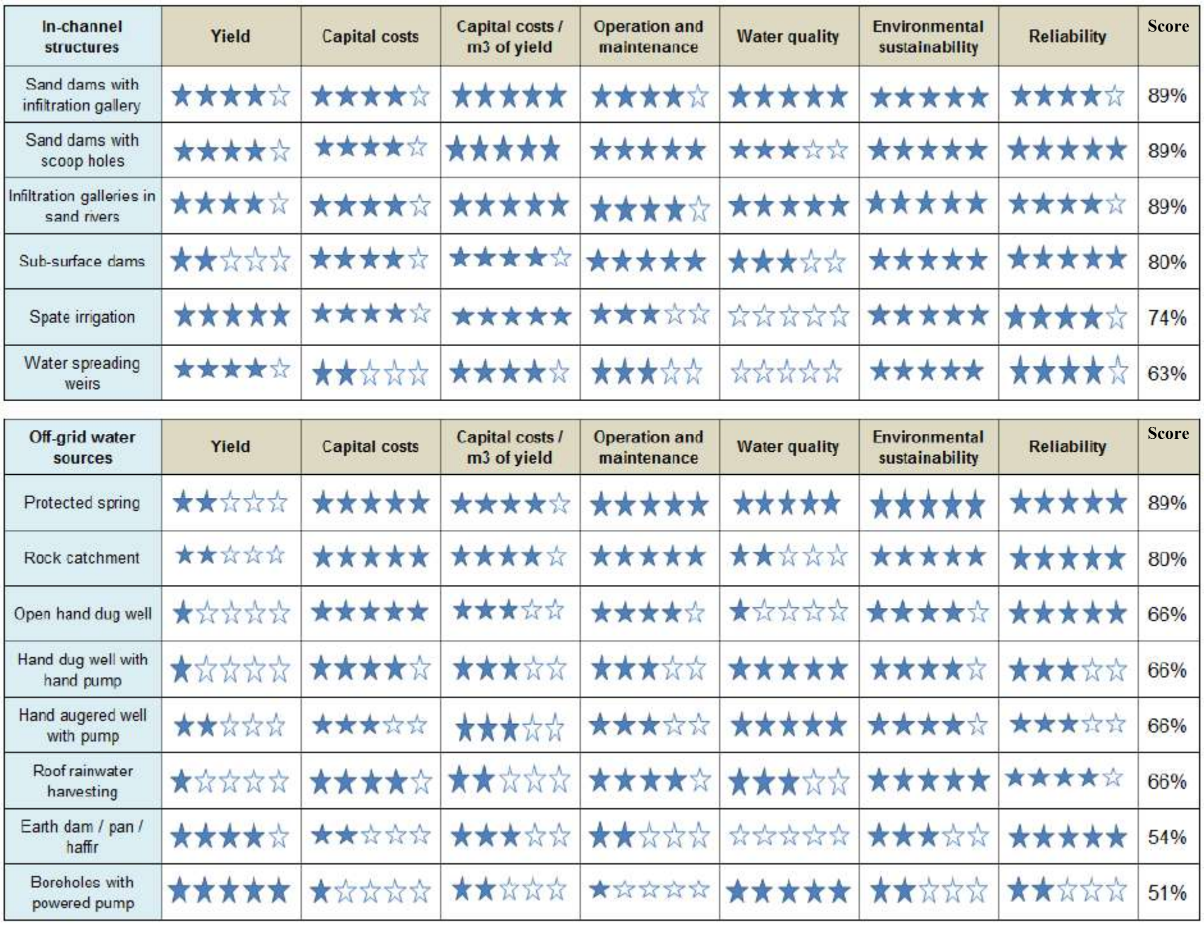
11.3.7 Rock Catchments

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.

Rock catchment and storage tanks

11.4 Comparison of Dryland Water Solutions

The table below 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 considers 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.



In-channel structures	Yield	Capital costs	Capital costs / m3 of yield	Operation and maintenance	Water quality	Environmental sustainability	Reliability	Score
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	Score
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%

Comparison of water supply technologies[243]

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[243] Maddrell, S., Neal, I., Building Sand Dams: A Practical Guide, 2013

Appendix 1: Example Legal Agreements

Appendix 1.1: SHG Sand Dam Materials & Construction Agreement[244]

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 ASDF, 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 ASDF KENYA REPRESENTATIVES:

1.) _____________________________ 2.) _____________________________

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

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[244] Africa Sand Dam Foundation, Kenya

Appendix 1.2: Landowner Permission & Access Agreement[245]

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: _______________________________

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[245] Africa Sand Dam Foundation, Kenya

Appendix 1.3: Example Government Agency Authorisation Forms[246]

The Chief Executive Officer,
Water Resources Management Authority,
P.O. Box 45250 – 00100
NAIROBI

Form: WRMA 001A
Catchment: _______________
WRMA ID: _______________
File: _______________

Water Resources Management Authority

APPLICATION FOR WATER PERMIT

(To be submitted in triplicate) *(Rules 23,24,71,72)*

Type of Water Use	**Surface Water**				**Groundwater**		**Effluent Discharge**	**Swamp Drainage**
	Diversion	**Abstraction**	**In-stream Works**	**Storage**	**Shallow well**	**Borehole**		
Tick Box								
Attach Form	**1B**	**1B**	**1B**	**1C**	**1D**	**1D**	**1E**	**1F**

PARTICULARS OF APPLICANT		**DETAILS**	
1. Full name of applicant(s) (In Block Letters)			
2. Category of Applicant - Individual, Group [Association, Society], Company, Institution			
3. ID Number of Applicant (Individual) or Certificate of Incorporation or Registration for Groups or Companies			
4. PIN Number (where available)			
Physical Address where water is to be used		**Contact Address of Applicant**	
5. L.R Number(s)		10. Box Number	
6. Village(s)/Ward(s)		11. Town	
7. Sub-location(s)		12. Post Code	
8. Location(s)		13. Telephone Contact (Landline)	
9. Division(s)		14. Telephone Contact (Mobile)	
10. District(s)		15. Email Contact	

WATER RESOURCE DETAILS

16. Name of Body of Water or Aquifer where water is to be diverted, abstracted or stored	
17. Is the point of abstraction or storage in a Protected Area or a Groundwater Conservation Area? (yes/no)	
18. Sub-catchment Number	
19. Class of Water Resource	▨
20. Name of Body of Water or Aquifer where effluent is to be discharged	
21. Sub-catchment Number (Effluent)	
22. Class of Water Resource (Effluent)	▨
23. Category of Application (Class of Permit)	▨
MIXING WATERS	
24. State the authorization(s) and permits already issued in respect of the water use on the land described in No. 4. (If NIL, state "Nil", if YES, list authorisation or permit numbers).	

Note: Shaded Areas to be filled in by WRMA Officials

Page 1

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[246] Water Resources Management Authority, Kenya (WRMA).

LAND	
25. Does applicant own all the land related to the permit application? Yes/No	
26. If No, have easement(s) been attached (Yes = 1, no = 0)	
27. Does application involve land located within or adjacent to a riparian, protected or groundwater conservation area? Yes/No	
28. Is proposed activity permitted within the riparian area, protected or groundwater conservation area? Yes/No	
OWNERSHIP OF WORKS	
29. Will the applicant own all the works related to the permit application?	
30. If No, have agreement(s) been obtained from owner(s) of all works and these agreements are adequate and are attached (Yes/no)	
SUPPLEMENT TO PERMIT/AUTHORISATION	
31. Is application made under Section 21 of WRMA Rules? Yes/No	
32. Provide Permit Number for Main Permit	

QUANTITY WATER REQUIRED

33. Brief Description of Project and Intended Use for Water				
Type of Water Use	**Groundwater (m^3/day)**	**Surface Water (m^3/day)**		
		River - Normal Condition	**River - Flood Condition**	**Lake**
34. Public				
35. Domestic				
36. Livestock				
37. Subsistence Irrigation				
38. Commercial Irrigation				
39. Industry/Commercial				
40. Hydropower				
41. Others				
42. Sub-total				
43. Quantity Returned				
44. Water Used (row 41-row 42)				
45. Effluent Discharge				

PERIOD OF CONSTRUCTION

46. State the estimated period of construction of the works (months)	
47. State the period for which the permit is required (year – maximum 5 years)	

The Chief Executive Officer,
Water Resources Management Authority,
P.O. Box 45250 – 00100
NAIROBI

Form: WRMA 001A
Catchment: ______________
WRMA ID: ______________
File: ______________

DESCRIPTION OF WATER USE

DOMESTIC

Population to be served (number of people)	
Basic Human Needs (m^3/day)	
Domestic Water Demand (m^3/day)	

LIVESTOCK

Type of Livestock	**Number of Animals**
Number of Grade Cattle	
Number of Local Cattle or donkeys	
Number of goats & sheep	
Number of camels	
Other	

PUBLIC PURPOSE

Supply Area (km^2)	
Population to be served	

SUBSISTENCE IRRIGATION –Water for Household Food Security

Number of connections	
Area per connection (ha)	
Total Irrigated Area (ha)	
Expected Rate of Water Use m^3/ha/day	
Total Expected Water Requirements (m^3/day)	

COMMERCIAL IRRIGATION

Type of Crop (hectares)	Type of Production System (Outdoor, GH, hydroponics)	Type of Irrigation Technology (overhead, micro-sprinkler, drip)	Expected Rate of Water Use m^3/ha/day	Total Expected Water Requirements (m^3/day)
TOTAL				

INDUSTRIAL

Number of Persons Employed			
Type of Industry (tick whichever is appropriate)			
Food Processing		Pulping (Coffee, sisal, sugar,)	
Horticultural Packaging		Tea	
Chemical Manufacturing		Bottling	
Tanning		Others (state type)	
Water Requirements			
Water required for Plant/Processing (m^3/day)			
Water required for Sanitation Facilities (m^3/day)			
Water required for other purposes (m^3/day)			
Total Water Requirements (m^3/day)			

POWER

Maximum static head (m)	
Expected Power Generated (KVa-hr) at Maximum Static Head	

OTHER USES

Fishponds (volume – m^3)	

The Chief Executive Officer,
Water Resources Management Authority,
P.O. Box 45250 – 00100
NAIROBI

Form: WRMA 001A
Catchment: ______________
WRMA ID: ______________
File: ______________

FEES SUBMITTED

Category A, B, C or D Application	**Fees for Examination of Application**
AMOUNT PAID	
Receipt Number	

ATTACHEMENTS	**Attached (Yes/No)**	**Comments/Remarks**
Form 1B		
Form 1C		
Form 1D		
Form 1E		
Form 1F		
Copy of Identification Documents		
Copy of Land Documents		
Copy of Agreements on Land Use		
Copy of Agreements on Use of Water Works		
Relevant Maps		
Copy of EIA License		
Site Assessment Report		
Technical Reports		
Hydrological Assessment Report		
Hydrogeological Survey Report		
Technical Design Report		
Dam Design Report		
Effluent Discharge Control Plan		
Soil and Water Conservation Plan		
Copy of Receipt for Payment		
WRUA Comment Form		

I agree to supply any further information which may be required by the Water Resources Management Authority.

SIGNATURE

Signature of Applicant or duly Authorised Agent	
Name	
Date of Application	

SIGNATURE OF WRMA OFFICIAL RECEIVING APPLICATION

Signature of WRMA Official	
Name	
Position	
Date Application Received	

The Chief Executive Officer,
Water Resources Management Authority,
P.O. Box 45250 – 00100
NAIROBI

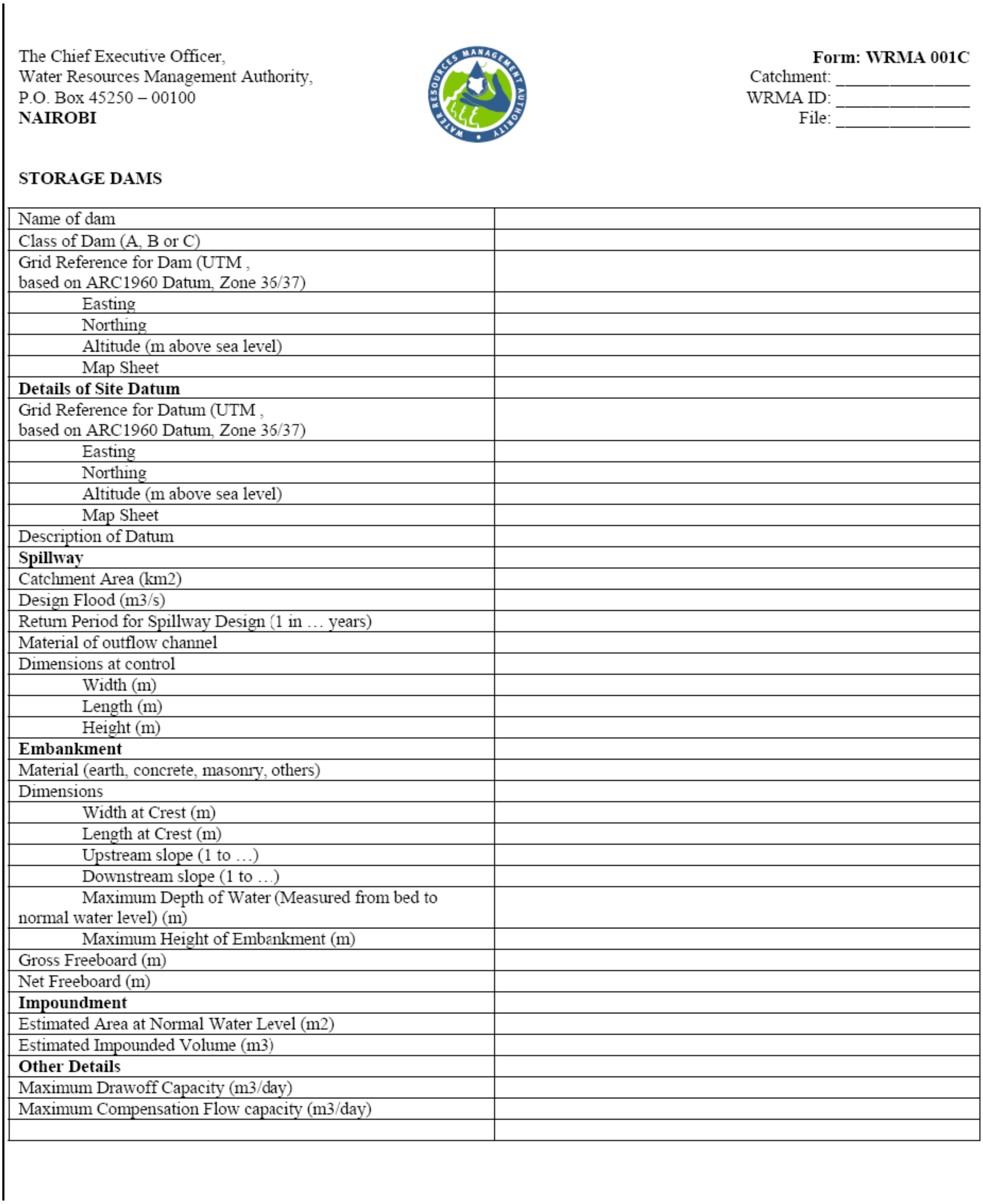
Form: WRMA 001A
Catchment: _______________
WRMA ID: _______________
File: _______________

OFFICIAL SECTION

(To be filled in by WRMA officials)

	Tick	Date	Officer
Submission			
WRUA advice received			
Recommended			
Rejected			
Conditional Recommendation			
CAAC advice received			
Recommended			
Rejected			
Conditional Recommendation			
WRMA National Office (Category D)			
Recommended			
Rejected			
Conditional Recommendation			
WRMA Regional Office			
Recommended			
Rejected			
Authorisation			
Issue of Authorisation			
Validity Period (months)			
Expiry			
Extension of Validity Period (months)			
Revised Expiry Date			
Inspection of Final Completion			
Date of Issue of Permit			
Date of Expiry of Permit			

WRMA Additional Form 1C for Storage Dams[247]



The Chief Executive Officer,
Water Resources Management Authority,
P.O. Box 45250 – 00100
NAIROBI

Form: WRMA 001C
Catchment: ________________
WRMA ID: ________________
File: ________________

STORAGE DAMS

Name of dam	
Class of Dam (A, B or C)	
Grid Reference for Dam (UTM , based on ARC1960 Datum, Zone 36/37)	
Easting	
Northing	
Altitude (m above sea level)	
Map Sheet	
Details of Site Datum	
Grid Reference for Datum (UTM , based on ARC1960 Datum, Zone 36/37)	
Easting	
Northing	
Altitude (m above sea level)	
Map Sheet	
Description of Datum	
Spillway	
Catchment Area (km2)	
Design Flood (m3/s)	
Return Period for Spillway Design (1 in … years)	
Material of outflow channel	
Dimensions at control	
Width (m)	
Length (m)	
Height (m)	
Embankment	
Material (earth, concrete, masonry, others)	
Dimensions	
Width at Crest (m)	
Length at Crest (m)	
Upstream slope (1 to …)	
Downstream slope (1 to …)	
Maximum Depth of Water (Measured from bed to normal water level) (m)	
Maximum Height of Embankment (m)	
Gross Freeboard (m)	
Net Freeboard (m)	
Impoundment	
Estimated Area at Normal Water Level (m2)	
Estimated Impounded Volume (m3)	
Other Details	
Maximum Drawoff Capacity (m3/day)	
Maximum Compensation Flow capacity (m3/day)	

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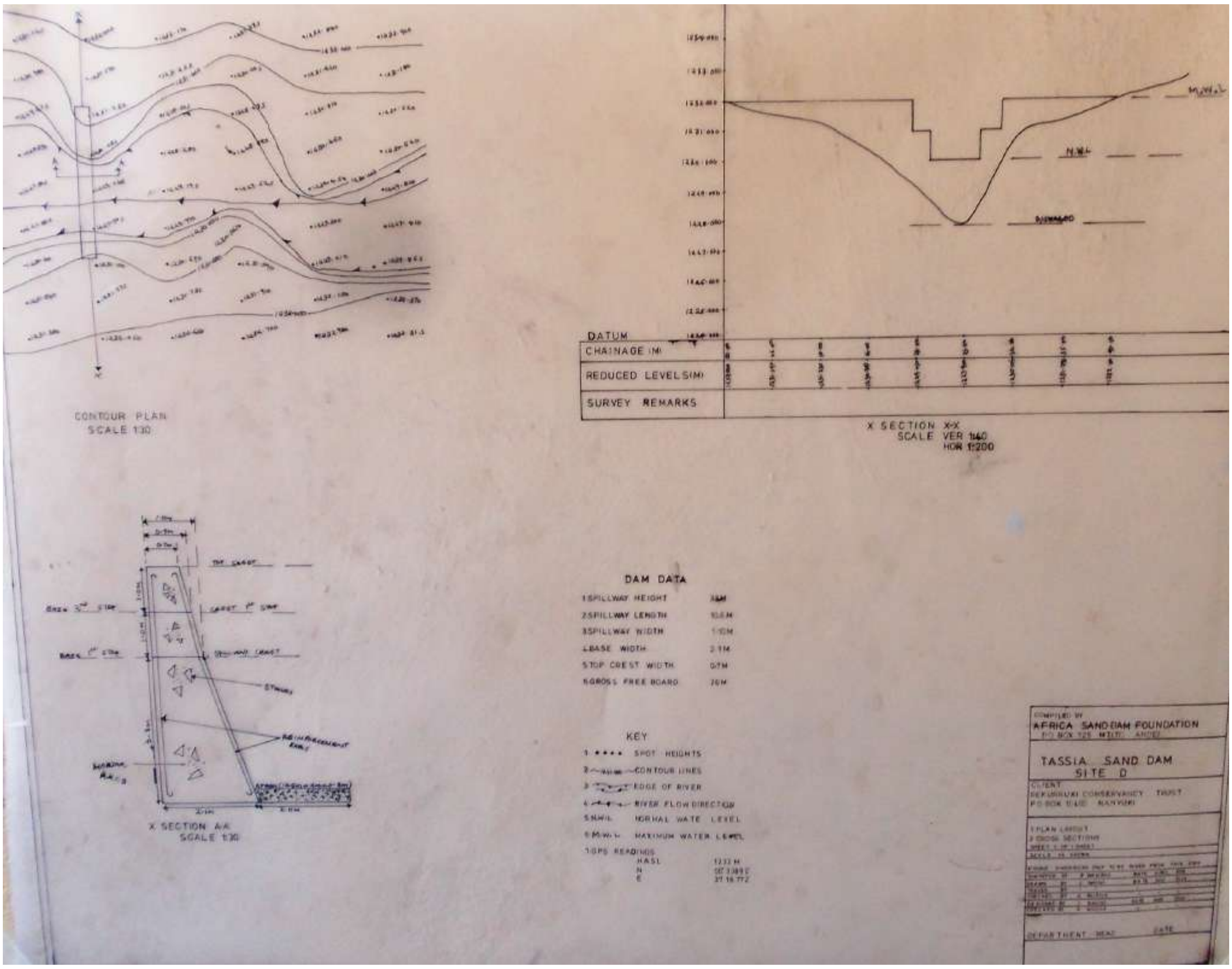
[247] Water Resources Management Authority, Kenya (WRMA).

Example Drawing Design for WRMA [248]



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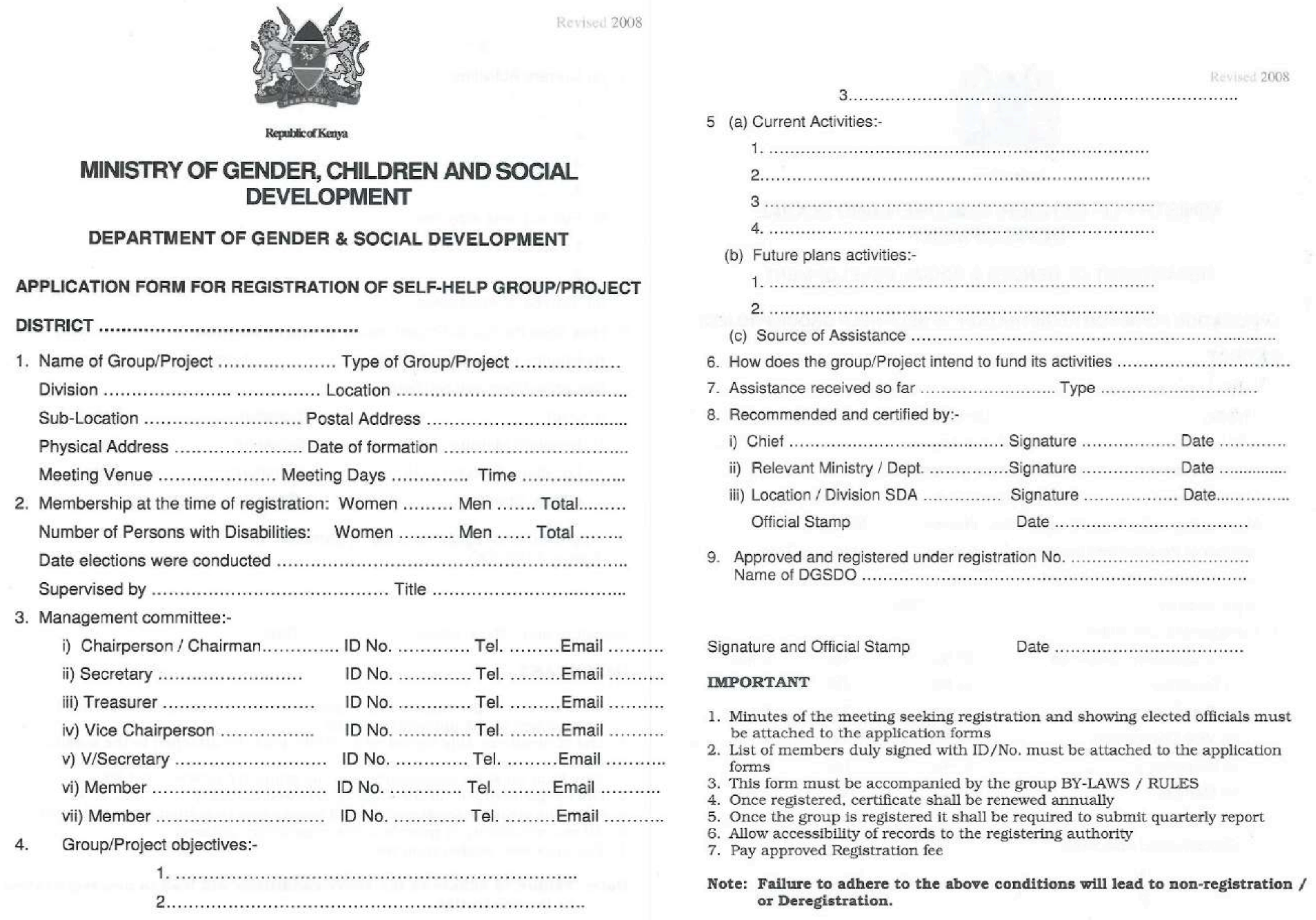
[248] ASDF Drawing for Lekurruki Conservancy Trust's WRMA Application, Kenya

Appendix 1.4: Registration application for a Self-Help Group 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 ....

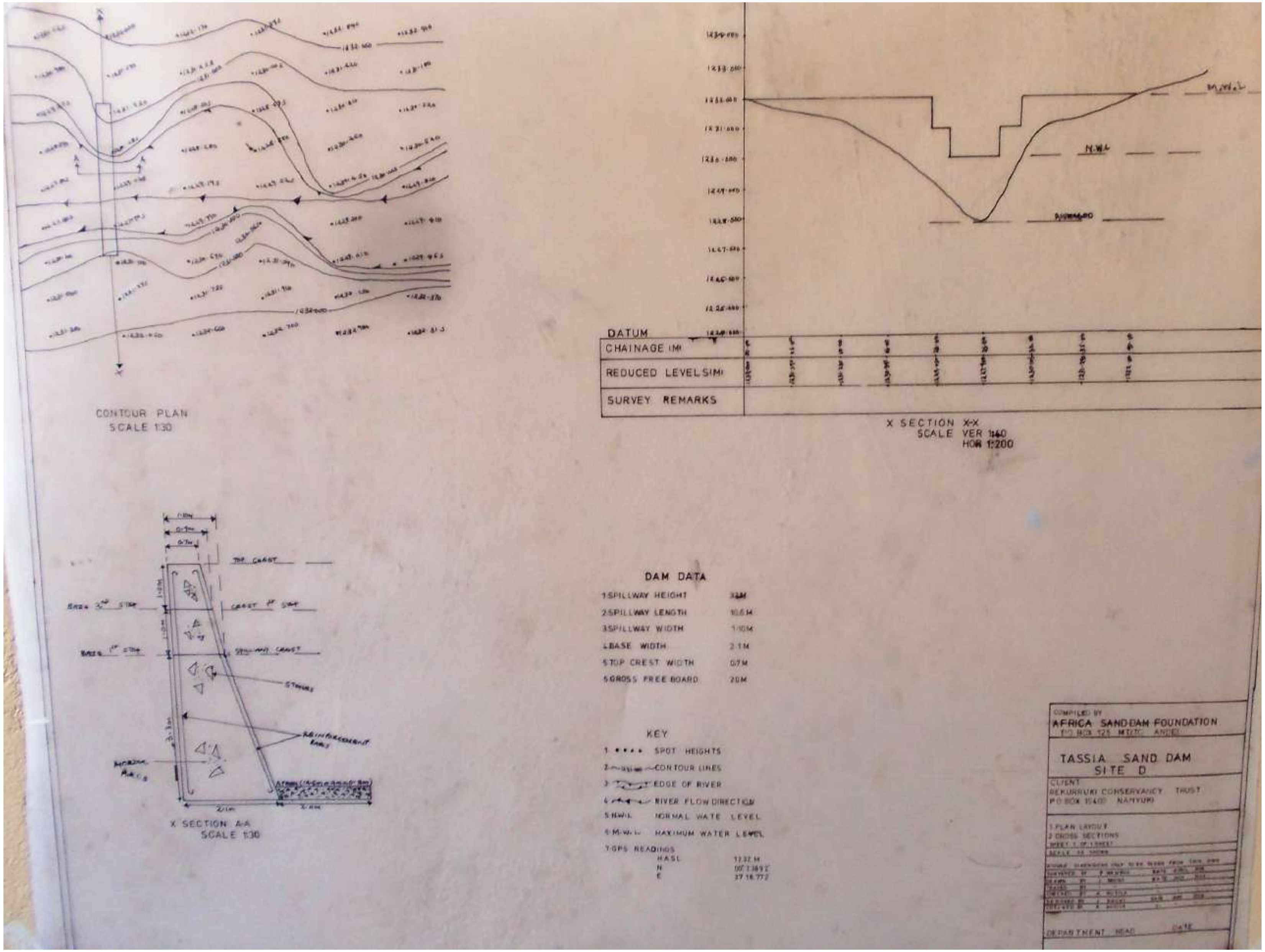
Signature and Official Stamp Date ....

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 1.5 Example Drawing Design Government Submission [249]



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[249] ASDF Drawing for Lekurruki Conservancy Trust's WRMA Application, Kenya

978-1-9997263-0-0