Planning, monitoring and evaluation of the performance and cost-efficiency of sand storage dams in arid and semi-arid areas

Advanced technical training course for practitioners
Kitui, Kenya
3rd February 2017

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Acknowledgements and citation

- These training materials are based on innovative practical recommendations for the siting, monitoring and evaluation of sand storage dams which form part of the PhD research on March 2017 of Josep de Trincheria.

- These training materials are also based on know-how and experience of Erik Nissen-Petersen and his extensive work for more than 50 years on rural water supply in arid and semi-arid areas of sub-Saharan Africa with ASAL Consultants Ltd. To his efforts and insightful observations, we all practitioners who have learnt from his work, are most grateful.

- These materials should be cited as it follows:

De Trincheria, J. (2017). Planning, monitoring and evaluation of the performance and cost-efficiency of sand storage dams in arid and semi-arid areas. Advanced technical training course for practitioners on siting, design and construction of smart sand storage dams and their link with roadwater harvesting, Kitui, Kenya, 3rd February 2017. Roads for Water Consortium, MetaMeta, Wageningen, the Netherlands.

Goals

- To showcase practical recommendations to tap into naturally available alluvial water in seasonal sandy streams in the most cost-efficient manner.

- To showcase simple but robust monitoring and evaluation methods to select, site and design the most cost-efficient water option in seasonal sandy streams.

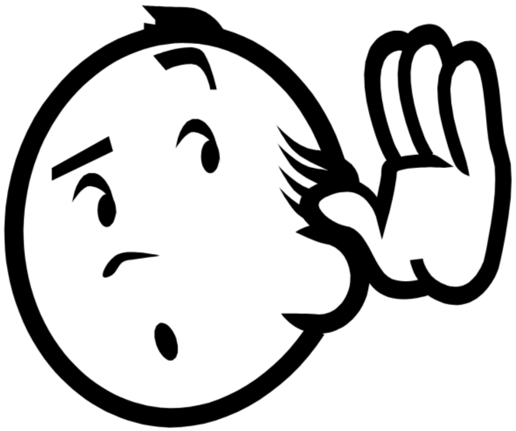
This presentation

1. Tapping into the natural alluvial capacity of the riverbed.
2. Structures for enlarging the natural capacity of the riverbed, if necessary.
3. Practical exercise.

If a sandy dry riverbed is able to yield enough water to meet local community needs, either in terms of numbers and/or uses, there is no need to build a subsurface dam or a sand storage dam!

→ **Always consider tapping into already available water in the riverbed with upgraded waterholes and different types of shallow wells connected to the reservoir**

Why?
How to know if this is the case?



Source: dianagabriel.com

It is possible to tap into this water with little investment

- Low investment and low effort, highest cost-efficiency, simplicity and robustness

- Funds available can be invested on pumping and conveyance systems to make the water available at the household and/or small-scale irrigation, **among others**!

- **BUT:** Need to be able to identify **where** this water is, **how much** there is and **if it is enough** to meet the needs of the beneficiaries

Nissen-Petersen, 2006. Water from Dry Riverbeds. How dry and sandy riverbeds can be turned into water sources by hand-dug wells, subsurface dams, weirs and sand storage dams. ASAL Consultants Limited for the Danish International Development Assistance: www.waterforaridland.com

Hussey, S. W. (2007). Water from sand rivers. Guidelines for abstraction. Water, Engineering and Development Centre (WEDC) Loughborough University of Technology.

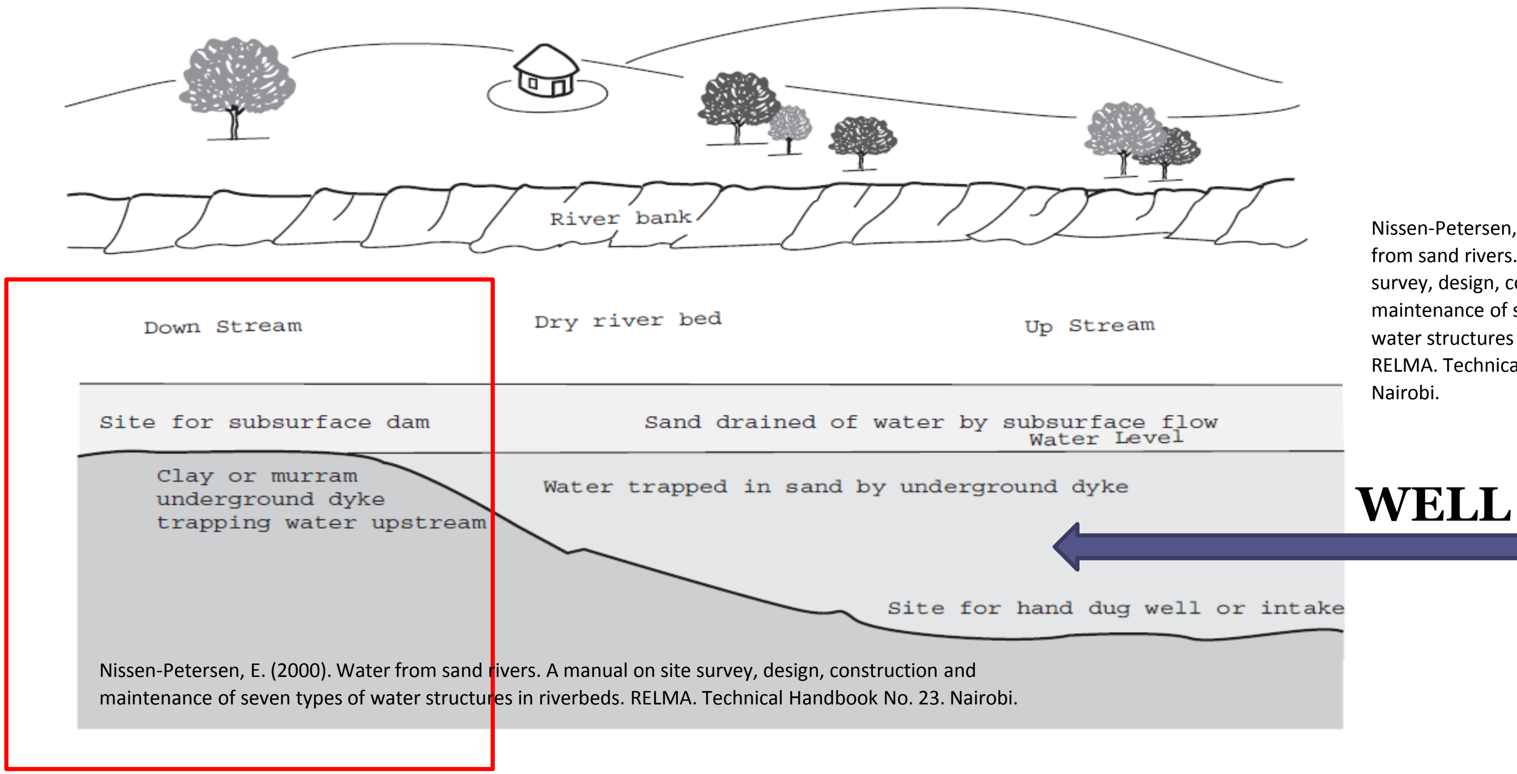
How to systematically do this?

1. Identify a suitable catchment ✓
2. Identify a suitable riverbed ✓
3. Locate underground reservoirs and dykes
4. Evaluate sand storage capacity, water yield, supply and cost-efficiency, water needs of beneficiaries
5. Select the most cost-efficient, simple and robust intervention

Note: We will not discuss steps 1 and 2 have already been implemented by the attendants of the course in cooperation with Kitui‘s SEKU University.

Natural storage of shallow groundwater in sandy dry riverbeds

For a riverbed to naturally supply water there must always be situated a natural underground dike which prevent water from seeping downstream through the sand and forms a natural underground reservoir



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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.

This is the reason why in some sections there is water during the dry season, poor rainfall years and droughts, which are usually central water points for local communities

Where is this water?

Quick and simple yet accurate methods to locate shallow groundwater and underground dykes

How to find suitable sections in the riverbed?

1. Location and types of water indicating trees
2. Location of waterholes and hand-dug wells
3. Location and types of rocks and boulders
4. Coarseness of sand sediments
5. No calcrete
6. Avoid building in bends of the river

Nissen-Petersen, 2006. Water from Dry Riverbeds. How dry and sandy riverbeds can be turned into water sources by hand-dug wells, subsurface dams, weirs and sand storage dams. ASAL Consultants Limited for the Danish International Development Assistance: www.waterforaridland.com

How to locate underground reservoirs and dykes

- A combination of 3 quick and simple methods:
  - 1) Waterholes with water during dry periods
  - 2) Natural indicators, especially, water-indicating trees
  - 3) 1-day probing of the width and depth of sand sediments in the riverbed

Nissen-Petersen, 2006. Water from Dry Riverbeds. How dry and sandy riverbeds can be turned into water sources by hand-dug wells, subsurface dams, weirs and sand storage dams. ASAL Consultants Limited for the Danish International Development Assistance: www.waterforaridland.com

Waterholes in the riverbed during the dry season

- Waterholes that yield water during the dry season indicate the presence of shallow groundwater.
- The length of time and water used for the beneficiaries give a first indication of the yield capacity of the riverbed.

Nissen-Petersen, E. (2013). Subsurface dams for water storage in dry riverbeds. ASAL Consultants Ltd., Kenya.

Natural indicators of shallow GW

1. The most successful natural indicator of good-quality ground water at shallow depth so far identified is *Acacia robusta* (Munina).

   Where this tree is found and supported by topographical indicators, ground water can be obtained at depths of less than 10 m.

2. *Acacia gerrardii* (Muthithiu), *Acacia xanthophloea* (Mulela), and *Fikus sur (*Mukuyu*)* are all useful indicators of ground water at shallow depth and their presence in conjunction with *A. robusta* (Munina) confirms a good site.

3. Absence of termite mounds.

4. Green cover during the dry season.

Woodhouse, Melvin. "Natural indicators of shallow ground water in Kibwezi division–Kenya." *Journal of the East Africa Natural History Society and National Museum* 81.197 (1991): 1-13.

Other water-indicating trees (Phreatophytes)

Botanical name	Kiswahili	Kikamba	Depth to water
Cyperus rotundus		Kiindiu	3 m to 7 m
Vangueria tomentosa	Muiru	Kikomoa	5 m to 10 m
Grewia spp	Itiliku	Itiliku	7 m to 10 m
Markhamia lutea	Muu	Chyoo	8 m to 15 m
Hyphaene compressa	Kikoko	Ilala	9 m to 15 m
Borassus aethiopum	Mvumo	Kyatha	9 m to 15 m
Ficus vasta	Mombu	Mumbu	9 m to 15 m
Ficus natalensis	Muumo	Muumo	9 m to 15 m
Ficus sycomorus	Mkuyu	Mukuyu	9 m to 15 m
Kigelia Africana	Mvungunya	Muatini	9 m to 20 m
Newtonia hildebranditi	Mganga	Mukami	9 m to 20 m
Acacia elatior	Mgunga	Munina	9 m to 20 m

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Geophysical survey at the site level

1-day field survey to measure depth and width of sand sediments of the specific section (500m-1,000 m) of the riverbed where the groundwater dam is to be built →

1. To tap into the natural capacity of the riverbed in a cost-efficient manner:
   - The spillway should be built at the shallowest point where there is an underground dyke.
   - The maximum depth of sand should be located downstream of the spillway.

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1. To disregard specific sites with low potential before the implementation takes place (seepage, evaporation, siltation)

→ Optimise performance, cost-efficiency and benefit to local communities

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Probing

- The most simple method to survey the riverbed is to hammer iron rods of 2-4 m (14-16 mm) into the ground
- Along 500 m – 1,000 m
- Sub-sections of intervals of 20 or 10 m
- Measurement of the depth of sand and water at least once in the middle of the sub-section
- Need to measure other variables

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Other variables to record

Probing Data Sheet (m). Location: Mwiwe riverbed Date: 20/11/04

Probing number	Distance between probings	Width of riverbed	Depth to water	Depth of sand	Type of sand	Floor under the sand	Height of river banks Left / Right	Items seen on the banks
1	0	20.80	No water	0.50	Medium	Clay	1.50 / 1.80	Wingo
2	20.00	24.20	No water	0.25	Fine	Clay	1.30 / 1.60	
3	20.00	28.20	No water	0.28	Medium	Clay	1.30 / 1.70	Waterhole
4	20.00	25.50	No water	0.32	Medium	Clay	1.42 / 1.84	Pawpaw
5	20.00	23.40	No water	0.45	Coarse	Clay	1.30 / 1.65	
6	20.00	30.50	No water	0.85	Coarse	Rock	1.32 / 1.45	Acacia tree
7	20.00	29.50	No water	0.76	Murram	Soft rock	1.32 / 1.50	Rock
8	20.00	33.00	No water	1.00	Coarse	Clay	1.97 / 1.55	Waterhole
9	20.00	23.62	0.20	1.25	Medium	Clay	0.70 / 1.25	Fig tree
10	20.00	23.62	No water	0.50	Medium	Clay	2.25 / 1.67	Tele. Pole
11	20.00	29.60	0.10	1.00	Medium	Clay	0.70 / 1.35	Road
12	20.00	32.90	No water	0.59	Medium	Clay	0.97 / 1.80	Mukengeka
13	20.00	25.70	No water	0.55	Medium	Clay	1.33 / 1.76	Kiindiu
14	20.00	20.00	2.00	3.00	Medium	Clay	1.50 / 1.68	Waterholes
15	20.00	17.00	No water	0.75	Medium	Clay	1.32 / 1.56	Fence post
16	20.00	26.00	0.10	1.25	Coarse	Clay	1.85 / 1.60	Orange tree
17	20.00	22.69	No water	0.93	Coarse	Clay	1.00 / 1.45	Orange tree
18	20.00	18.40	No water	0.50	Medium	Clay	1.20 / 1.53	Munina
19	20.00	17.50	No water	0.50	Coarse	Clay	1.20 / 1.65	Fence post
20	20.00	20.00	0.50	1.75	Coarse	Clay	1.46 / 1.58	Mwangi
21	20.00	29.00	0.60	1.75	Coarse	Clay	1.75 / 1.67	Fig tree
22	22.00	30.00	No water	0.88	Coarse	Clay	1.13 / 1.58	Musewa
23	22.00	26.00	No water	0.45	Coarse	Clay	1.20 / 1.45	Kiindiu

1. Gradient of the riverbed
2. Texture of sand
3. Floor under the sand
4. Height of the riverbanks
5. Items seen on the banks

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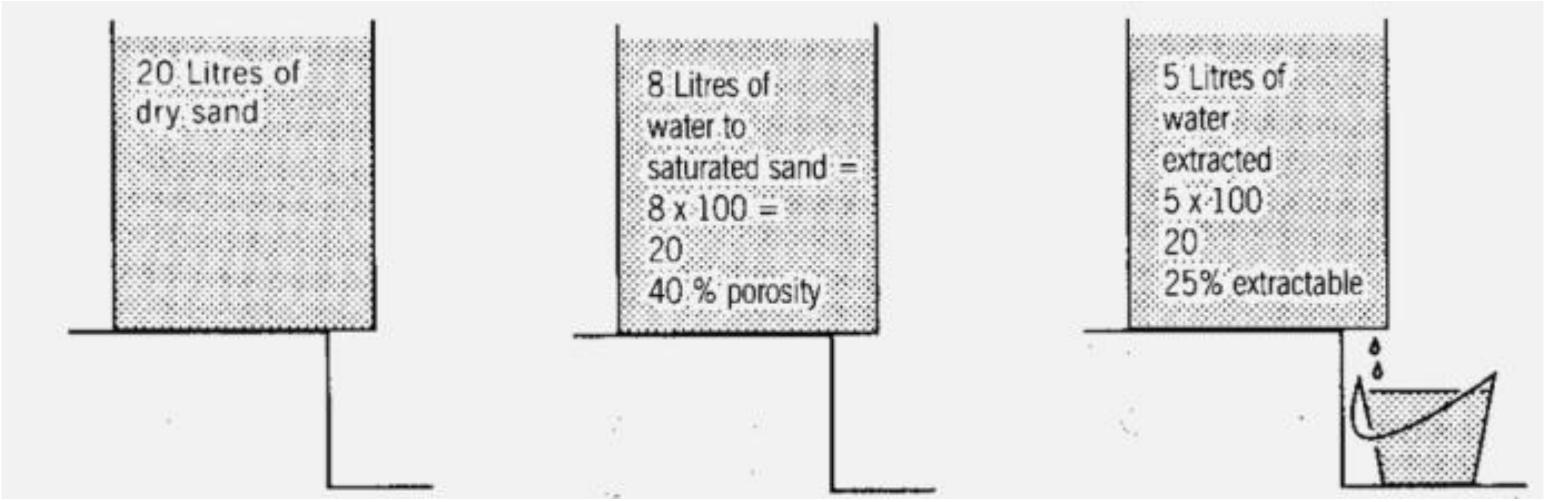
Specific yield of sand



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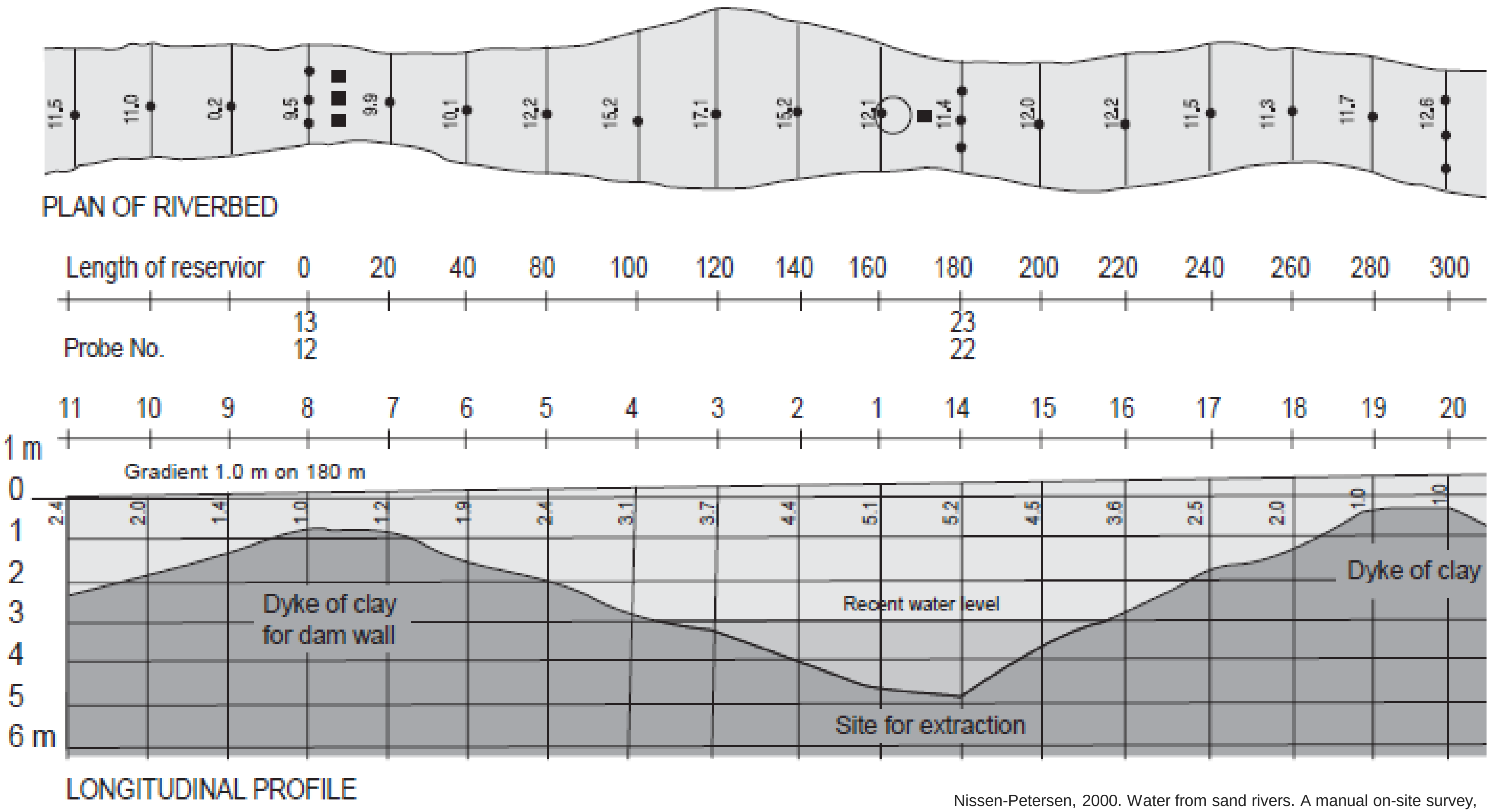
The specific yield is given by:

$$n = Y_S / V_S$$

where YS is the volume of drained water (L) and VS is the volume of sand (L)

Longitudinal profile and plan



Nissen-Petersen, 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.

Hydrological evaluation of the reservoir

- To evaluate if the water yield of the sand reservoir can meet the water needs of the beneficiaries
- To identify the most cost-efficient option to implement
  - Waterholes and/or hand-dug wells
  - Pumping and conveyance systems
  - Subsurface dams
  - Sand storage dams

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Simple and quick method to estimate sand storage capacity and water yield

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

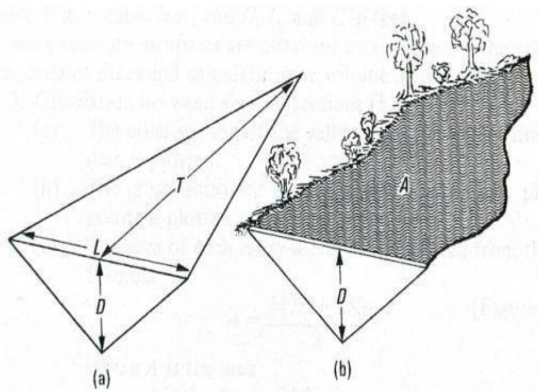

Figure 5.1. Estimating the storage capacity of a reservoir.

Storage capacity

1. An approximate estimate of the capacity is

$$Q = \frac{L \times T \times D}{6},$$

where Q is the capacity in cubic metres,
L is the length of the dam wall in metres at full supply level,
D is the maximum depth in metres, and
T is the throwback in metres.

This assumes that the basin is a pyramid whose base is the dam wall

Hudson, N. (1975). Field engineering for agricultural development. Clarendon Press, Oxford, UK.

For example:

25% of water can be extracted from 5,000 m^3 sand = 1,250 m^3 water

5% of water can be extracted from 5,000 m^3 sand = 250 m^3 water

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A more accurate method to estimate sand storage capacity and water yield

Sand storage capacity of each section

- General equation to estimate the capacity of a water reservoir:

$$C_P = K * D * W * T$$

  - where C_P is the reservoir capacity (m^3), K is a constant to reflect the geometrical shape of a reservoir, D and W are the depth and width of each section (m), respectively, and T is the length of the probing section (m).

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Evaporation losses

- To take into account evaporation losses, an evaporation depth of 0.6 m (Hellwig, 1973) – 1.0 m (Wipplinger, 1958) should be taken into account. This means:

- D_E=D- [0.6-1.0] (m)
- C_{PE}= K * D_E * W * T (m3)

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Geometrical shape

K = 1.0

K = 1.6

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Total sand storage capacity

$$C_T = \sum C_{1 \text{ to } n}$$

$$C_T = C_{P1} + C_{P2} + C_{P3} + \ldots + C_{Pn}$$

- where C_T is the total reservoir capacity (m^3), C_P is the reservoir capacity of each probing point

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LEVELLING A RIVERBED

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Water yield of a sand dam

Y_A indicates the capacity of the reservoirs to yield water per year taking into account the volume of sand accumulated and the associated specific yield of the sand sediments. The formula is given by

$$Y_A = C_T \text{ x } n \text{ x } R$$

- where Y_A is the annual water yield of the sand reservoir (m^3/year) and R is a constant which reflects the number of rainy seasons in the study area.

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Seepage losses

To take into account seepage losses, the formula is given by

- $Y_S = Y \times Sp$
  - where Y_E is the yield after accounting seepage (m^3) and Sp is a conservative constant which aims to reflect minimum potential seepage losses (%).
- Sp= 10% (Stephens, 2010)

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Water supply capacity

- $S_S = Y_D / Co_D$
  - where S_S is the total number of households supplied by the groundwater dam during one dry season (households), Y_D is the effective water yield of the sand dam during that specific dry season (m^3) and Co_D the water needs per household during that specific dry season (m^3).
- Co_D is given by $Co_D = Co_H \times L_D$
  - where Co_H is the total consumption of one household per day (m^3/day) and L_D is the length of the dry season (days).

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Annualised construction costs

- $$AC_{\text{sand dam}} = CC_{\text{sand dam}} \times i \times \frac{(1+i)^n}{\{(1+i)^n - 1\}} + AOM_{\text{sand dam}} \quad (17)$$
  - where AC are the annualised costs (USD/year), CC are the capital costs of the sand dam (USD), i is the interest rate (%), n is the lifespan of the sand dam (years), and AOM are the annual operation and maintenance costs (USD).

- AOM=0
- i= 5% (Jafaar, 2014).
- N= 20 years (Batchelor et al., 2011).

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Cost-efficiency

- $$CE = \frac{\text{CC sand dam (EUR)}}{\text{Water Yield (m3) or Water Supply (households)}}$$

- $$ACE = \frac{\text{AC sand dam (EUR/year)}}{\text{Water Yield (m3)or Water Supply (households)}}$$

  - where CE is the capital cost-efficiency of the annual water yield (EUR/m^3) or supply capacity (EUR/household), and ACE is the annualised cost-efficiency of the annual water yield (EUR /m^3·year) or supply capacity (EUR /household·year).

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The probing and evaluation can be carried out during and after the construction so as to monitor and evaluate the performance and cost-efficiency

The second method is recommended to be used for the monitoring and evaluation exercise

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Selecting the most cost-efficient, simple and robust intervention on the riverbed

→ Structures for tapping into the natural water yield capacity of dry riverbeds

Upgraded waterholes and hand-dug wells

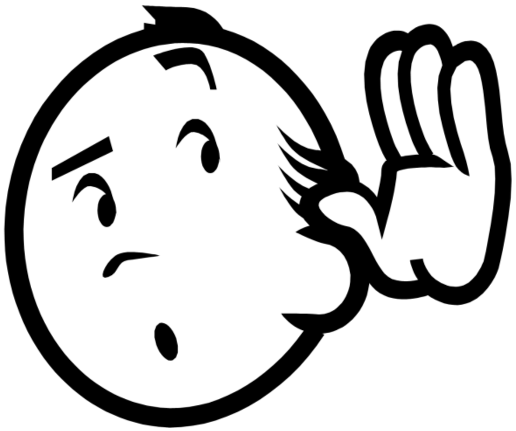
- More attention should be given to low-cost water projects incorporating upgraded waterholes, hand-dug wells and sub-surface dams.

- The investment can be used to upgrade waterholes and hand-dug wells → A pump, a water reservoir and a water kiosk.

Nissen-Petersen, 2006. Water from Dry Riverbeds. How dry and sandy riverbeds can be turned into water sources by hand-dug wells, subsurface dams, weirs and sand storage dams. ASAL Consultants Limited for the Danish International Development Assistance: www.waterforaridland.com

Structures for enlarging the water yield capacity of dry riverbeds: Subsurface dams and sand storage dams

Key Remark!



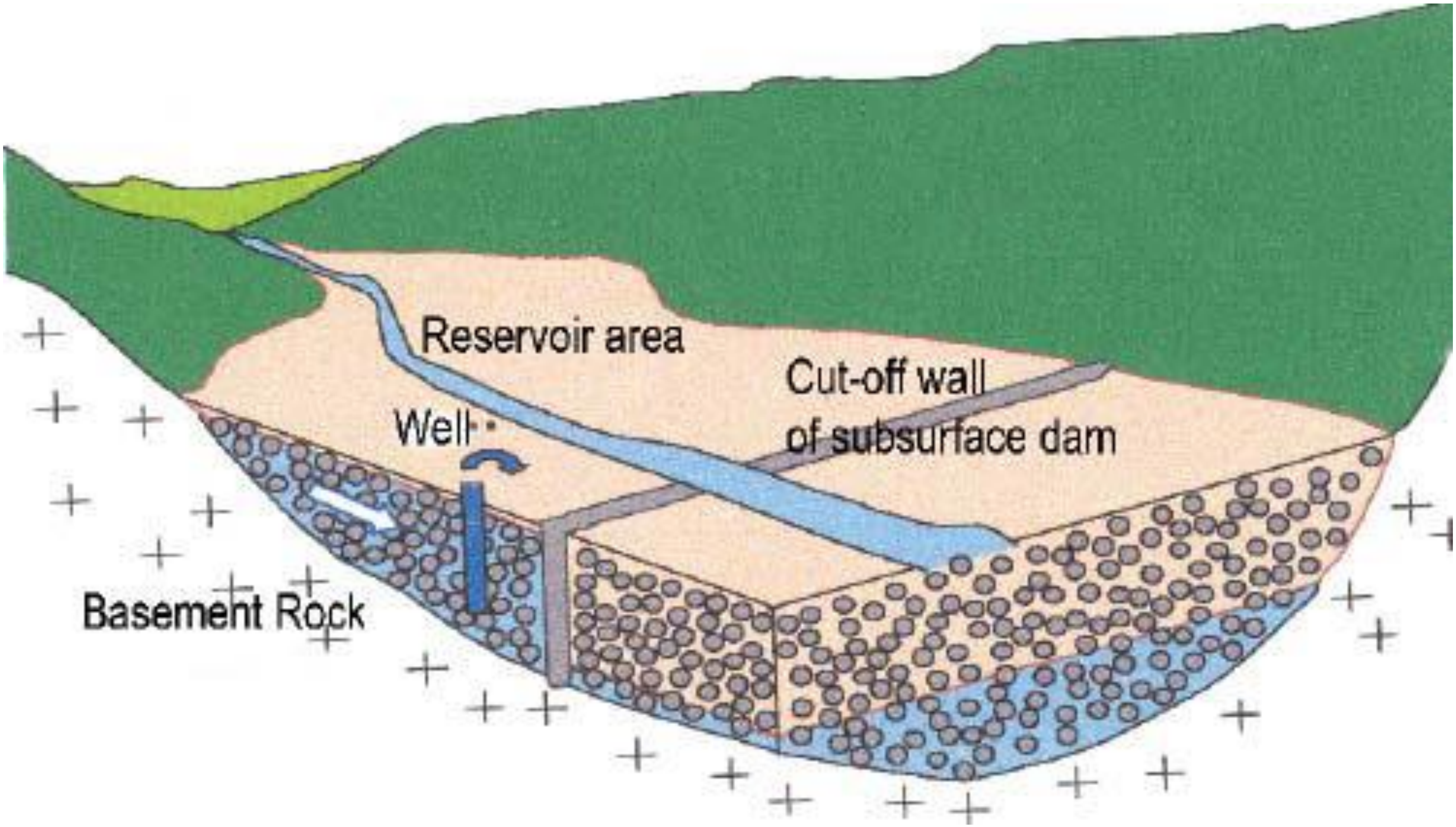
Source: dianagabriel.com

1. A subsurface dam should always be considered always before than a sand storage dam because of higher cost-efficiency, simplicity and robustness to erosion and siltation.

2. Only if the water yielded for a subsurface dam is not enough to meet the needs of the beneficiaries, a sand storage dam is the most cost-efficient option

Subsurface dams

Practical recommendations: Subsurface dams



Source: Vétérineaires sans Frointères (2006)

Practical recommendations: Subsurface dams

Practical recommendations: Subsurface dams

Practical advantages of subsurface dams

- Subsurface dams show inherent higher cost-efficiency and strategic advantages as compared to sand storage dams, provided the water yielded is enough to meet local communities:

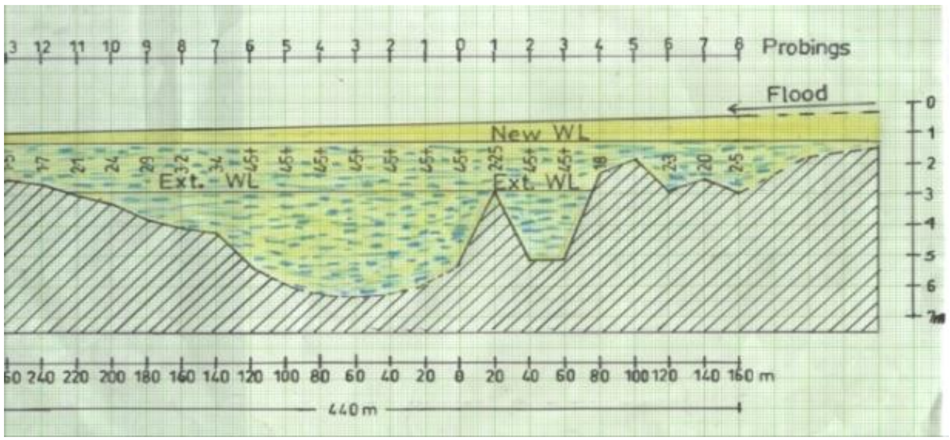
  1) No siltation
  2) No vulnerability to the erosion of floods: no wing walls, lower erosive forces, lower hydraulic pressure
  3) Higher lifespan
  4) No maintenance or repairs required.
  5) Lower capital investment because it will always require lower volumes of materials and can be built of clayey soil
  6) Natural deposited sand sediments produce reservoirs with higher specific yields (good levels of sorting and texture)
  7) They can always be built in 1-stage, i.e. faster and easier
  8) SDs can be implemented in low riverbanks because there is no need to build wing walls

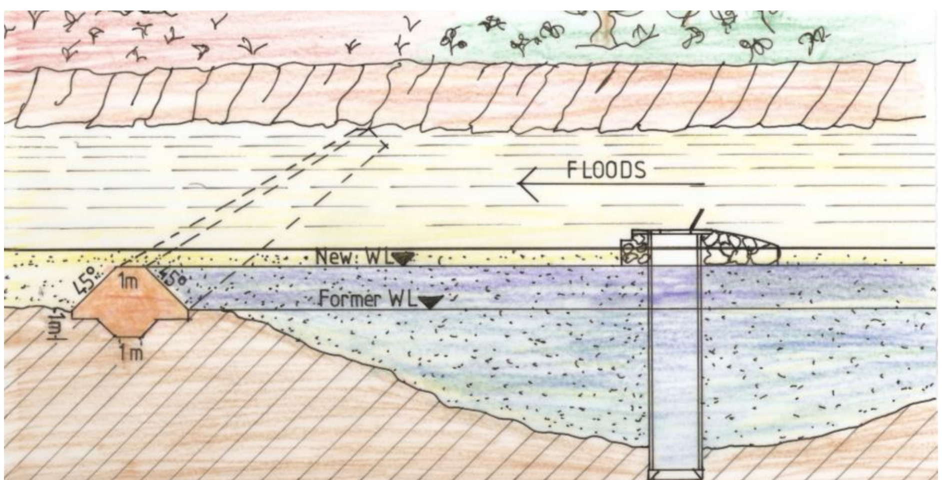
Adapted from Nissen-Petersen, E. (2013). Subsurface dams for water storage in dry riverbeds. ASAL Consultants Ltd., Kenya.

Practical recommendations: Subsurface dams

- (-) SSDs must be implemented where there are reservoirs with deep layers of sand
- (-) SSDs have a lower impact on the reduction of flood intensity and erosion → they do not reduce the gradient of the original riverbed
- (-) SSDs cannot be built at the head of the valley → SDs will have lower performance and cost-efficiency

Free storage capacity and lower costs by building on underground dykes





The longitudinal profile shows the underground dyke that traps water for the deepest point.

If a subsurface dam is built onto the dyke, it will raise the water to near the surface of the riverbed, thereby increasing the volume of water for the well

Minimum construction costs as the dyke provides a free part of the dam wall and de-watering is not required as water cannot stand on a dyke.

Nissen-Petersen, E. (2013). Subsurface dams for water storage in dry riverbeds. ASAL Consultants Ltd., Kenya.

Construction costs of a subsurface dam

Size of subsurface dam	Construction material	Ksh	US$
24 m long x 2.1 m high	Soil from a nearby riverbank	156,400	1,777
24 m long x 2.1 m high	Reinforced rubble stone masonry	771,075	8,762
24 m long x 2.1 m high	Reinforced concrete in timber shuttering	1,857,250	21,105
24 m long x 2.1 m high	Dam-liner (Geo-membrane)	192,510	2,188

Construction costs include survey, design, permits, construction materials and labour + 15% overhead.

Nissen-Petersen, E. (2013). Subsurface dams for water storage in dry riverbeds. ASAL Consultants Ltd., Kenya.

SOIL FOR BUILDING A DAM WALL

The dam wall should be built from the most clayey soil available near the site to reduce transport costs

The most clayey soil is determined by filling soil samples into bottomless plastic containers and saturating them with water

The soil sample having the slowest infiltration rate is the most clayey soil that can prevent water in the dam reservoir from seeping through the dam wall

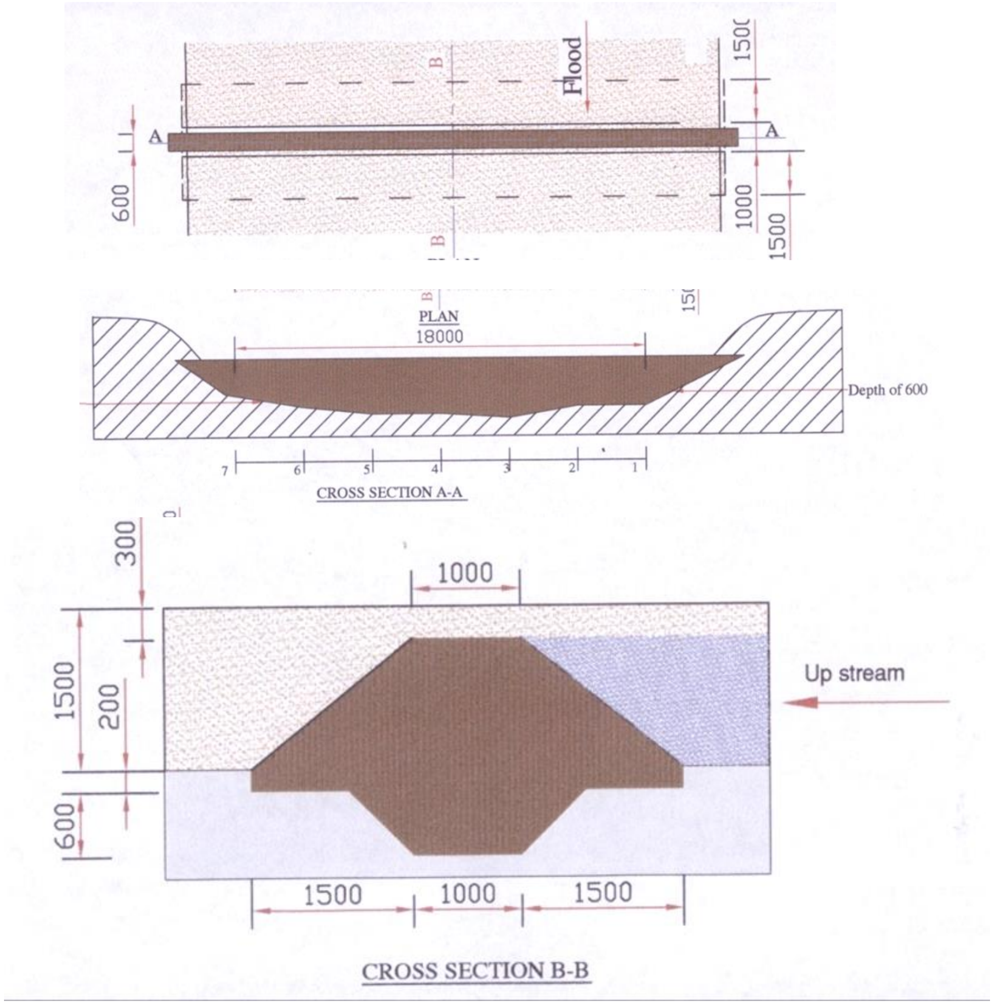
Nissen-Petersen, E. (2013). Subsurface dams for water storage in dry riverbeds. ASAL Consultants Ltd., Kenya.

STANDARD DESIGN OF A SUBSURFACE DAM BUILT OF SOIL

Plan of a subsurface dam seen from above

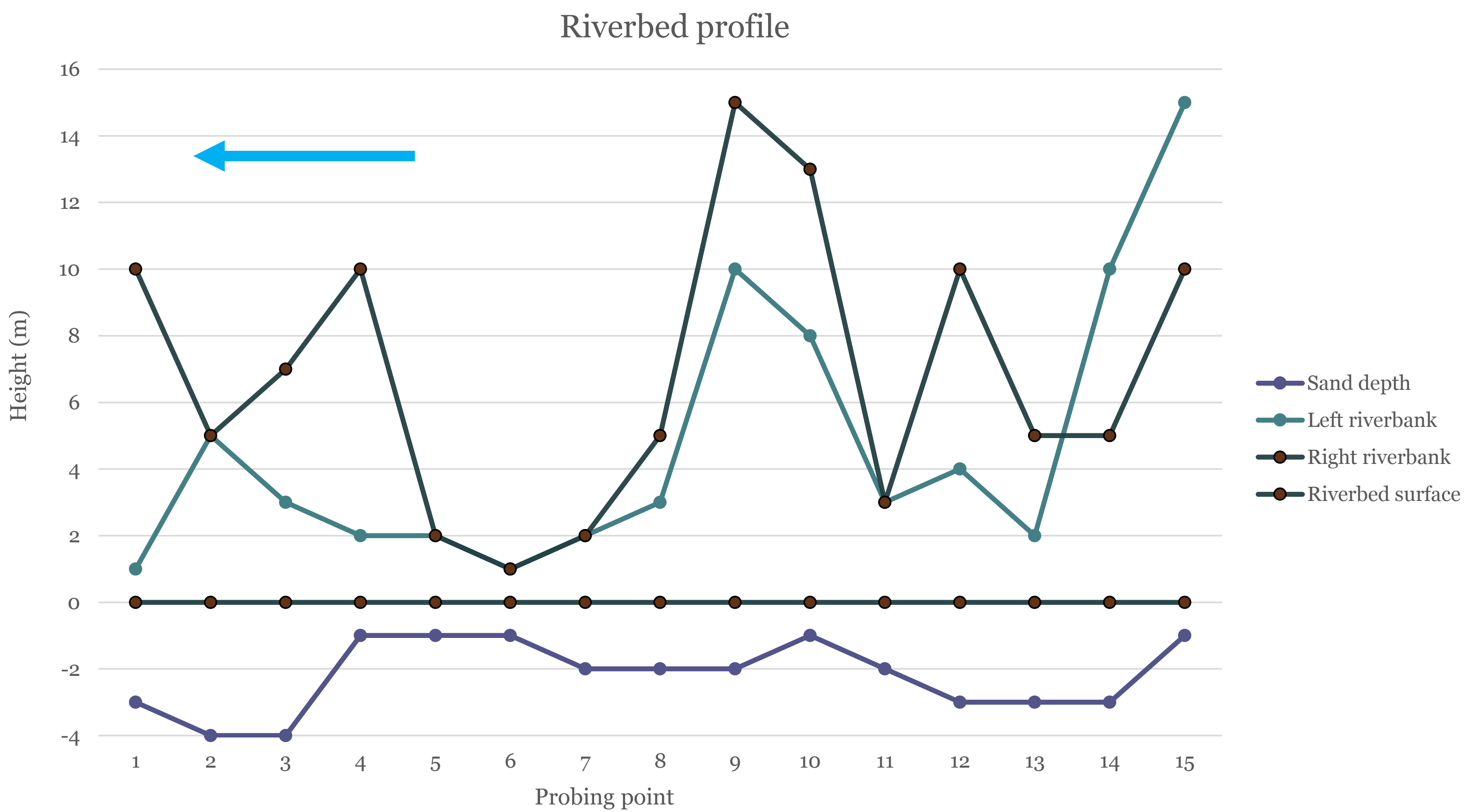
Longitudinal profile of the dam wall

Cross section of the dam wall. Note that the crest should be 0.6 m-1.0 m below the surface of the riverbed



Nissen-Petersen, E. (2013). Subsurface dams for water storage in dry riverbeds. ASAL Consultants Ltd., Kenya.

Practical exercise



1. Identify the best depression to sink a hand-dug well

2. Identify the best dyke to build a subsurface and a sand storage dam

Identifying the most cost-efficient structure to meet the needs of the local communities

Throwback	500	Yield	667
Width	20		
Natural depth	2		
Specific Yield	20%		
30 households	30	Needs	540
5 j/d	100		
6 months	180		

Throwback	500	Yield	667
Width	20		
Natural Depth	2		
Specific Yield	20%		
30 households	30	Needs	1080
10 j/d	200		
6 months	180		

Throwback	500	Yield	1333
Width	20		
Depth with a SSD	4		
Specific Yield	20%		

Throwback	500	Yield	2000
Width	20		
Depth with a SD 2 m	6,00		
Specific Yield	20%		
30 households	50	Needs	1800
10 j/d	200		
6 months	180		

Storage capacity

1. An approximate estimate of the capacity is

$$Q=\frac{L \times T \times D}{6},$$

where Q is the capacity in cubic metres,
L is the length of the dam wall in metres at full supply level,
D is the maximum depth in metres, and
T is the throwback in metres.
This assumes that the basin is a pyramid whose base is the dam wall

Further cooperation and research

We encourage implementing agencies to **contact us to scale up this research**!
→ Large-scale PME, restoring and rehabilitation programme on silted-up SDs.

Please, **send an email to:**

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Thank you for your attention!

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Planning, monitoring and evaluation of the performance and cost-efficiency of sand storage dams in arid and semi-arid areas

Advanced technical training course for practitioners
Kitui, Kenya
3rd February 2017

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