Water from Dry Riverbeds

How dry and sandy riverbeds can be turned into water sources by hand-dug wells, subsurface dams, weirs and sand dams

Women drawing water from an unlined waterhole in a sandy riverbed.

Water being drawn from a hand-dug well on a riverbank upstream of a subsurface dam.

A weir constructed across Talek river in Maasai Mara was extended to be a sand dam to provide domestic water for a tourist camp. The lush vegetation seen upstream is due to the weir having raised the water table in the riverbanks.

Erik Nissen-Petersen
for
Danish International Development Assistance (Danida)
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A small riverbed with a subsurface dam built of soil
is flooded with rainwater run-off at Kibwezi, Kenya.

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Acronyms

ASAL = Arid and Semi-arid Land
ASALCON = ASAL Consultants Ltd.
BADC = Belgium Assisted Development Council
BQ = Bill of Quantity
cm = Centimetres
CONCERN = A British Non-governmental Organization
cu = Cubic metres
Danida = Danish International Development Agency
DRC = Danish Refugee Council
g = gauge
GL = Ground level
Hardcore = Crushed stones
ILO = International Labour Organization
ITDG = Intermediate Technology Development Group
Km = Kilometre
KVA = Kilo Volts Amphere
Ksh = Kenya Shilling equal to US$ 72.00
KW = Kilo Watt
KWSP = Kenya Water and Sanitation Programme
m = Metre
mm = Millimetre
m^2 = Square metre
m^3 = Cubic metre
Max. = Maximum
MoA = Ministry of Agriculture
MoWI = Ministry of Water and Irrigation
NGO = Non-governmental Organization
PVC = Poly Venyl Conduits
RELMA = Regional Land Management Unit
RWSS = Rural Water and Sanitation Programme
SearNet = South East Africa Rainwater Network
Sida = Swedish International Development Agency
UNDP = United Nations Development Programme
UPVC = Ultra Poly Venyl Conduits
Y8 = 8 mm twisted iron bar
Y10 = 10 mm twisted iron bar
WL = Water level

FOREWORD

In dry land areas of Kenya, episodic shortages of water are quite common. In many areas, women have to spend days traveling long distances with donkeys and camels looking for water. Where the distances are too long, the people have been compelled to move with their livestock to the water sources. Due to the long distances covered searching for water, affected local people have had very limited productive time especially that devoted to agriculture and livestock production. Experiences in dry land areas have showed that when the water source is harnessed and conserved through watering points, local people and women in particular have more time to concentrate in other household chores and income generating activities.

At present in most of Kenya, local people are compelled to live close to permanent water sources; agricultural activities are scattered and localized in transitional agro-climatic zones. Thus it is pertinent that the supply of water for domestic, livestock and supplemental irrigation uses be considered a top priority in managing hydrological and agricultural droughts in dry land areas. This supply should be followed by a well planned distribution network of watering points which will meet the water requirements for various uses and minimize environmental degradation due to overgrazing or deforestation. Any development or rehabilitation of water supply schemes should aim to ensure reliable and adequate water supply and sanitation.

The socio-economic consequences of inadequate water supply in dry land areas of Kenya are costly and manifest themselves in low labor productivity, poor enrollment of children in schools, and livestock mortality due to drought and famine. Thus inadequate water supply ultimately decreases per capita water demand, and crop and livestock productivity. Consequently, water shortages reduce household water requirements, household food and water security and incomes. The low incomes propagate the vicious cycle of poverty and famine that must be overcome among affected rural communities.

The development of appropriate and affordable community water supply systems calls for innovative rain and runoff water management technologies for domestic, livestock, and supplemental irrigation uses. Some of the technologies that have proven to be effective and sustainable in water resource development and management in dry land areas include: runoff regulation and storage techniques (e.g. gully head dams, hafirs or waterpans, micro dams, ground catchments (djabias), roof catchments, underground water storage tanks (shui jiaos), barkads, and macro and micro catchment systems; and ground water sources such as hand dug wells, shallow drilled wells, infiltration galleries of sand storage dams, and piped water from springs.

Water from dry riverbeds as a hands on manual provides the requisite insights and information on how surface runoff that is released into seasonal rivers as flash floods can be harnessed and abstracted through appropriate technologies such as hand dug wells, weirs and sand storage dams (sand and subsurface dams).

This hands-on handbook begins with a historical perspective/background information on sandy riverbeds as reservoirs of good quality water and then goes on to look into the survey and design considerations required before constructing hand dug wells, weirs and sand storage dams (sand and subsurface dams). This manual has also addressed the concern over when to develop these water sources by giving the suitable seasons for surveys and construction works. The latter information is important because experiences from emergency relief operations in the arid lands of Kenya (i.e. Turkana) have showed that the construction of sand storage dams in times of drought cannot provide the badly needed water to water deficit areas. Instead, these dams should be developed with a view to being recharged during the rainy season and utilized in subsequent dry spells.

Another major contribution by this handbook to the development of water from dry and sandy riverbeds is that of providing the necessary details on design, bills of quantities and costs, construction and maintenance procedures of the three water supply systems namely hand dug wells, weirs and sand storage dams. Alongside this, this handbook gives the costs and capacities of pumps, generator sets and pump houses as well as the calculations and costs of water conveyance and distribution systems.

Indeed the information provided by this handbook will be of immense use to recently established (under the new Ministry of Water and Irrigation) water resource development and management institutions in Kenya such as the Water Resources Management Authority (WRMA), the Water Services Trust Fund (WSTF), the Regional Water Services Boards, and the grassroots based Water Resources Users Associations (WRUAs).

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Chapter 1. Riverbeds

1.1 Types of riverbeds

Dry riverbeds are sandy and seasonal water courses that transport run-off rainwater from catchment areas, also called watersheds, into rivers or swamps once or a few times in a year.

Dry riverbeds are also called ***ephemeral streambeds, seasonal water courses*** or ***sand rivers***. In Kenya they are called ***luggah*** and in Arabic ***wadi.***

Most of the rainwater being transported downstream in riverbeds appears as ***flash-floods*** that can be several metres high, and that thunder downstream with the sound of a steam locomotive.

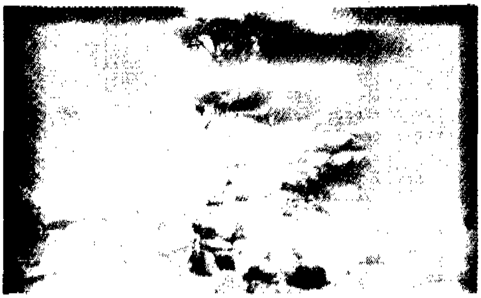
Flash-floods can uproot trees and other vegetation growing on riverbanks and fields. Homes, villages and towns may also be flooded and people, livestock, buildings and bridges washed away by the muddy maelstroms of flash-floods.

Riverbeds may be classified into 4 classes of potential water sources as follows:

1) The most potential riverbeds have hilly and stony catchments that produce coarse sand where up to 350 litres of water can be extracted from1 cu.m. of sand, i.e.an extraction of rate of 35%.

2) Gullies originating from stony hills have a potential for sand dams consisting of medium coarse sand where 250 litres of water can be extracted from 1 cu.m. of sand, i.e. an extraction rate of 25%.

3) Riverbeds having catchments of flat farmland usually contain fine textured sand, that can only yield a maximum of 100 litres of water from 1 cu.m. of sand, i.e. an extraction rate of 10%.



4) Stony riverbeds containing boulders and fractured rocks have the lowest potential for water extraction due to seepage caused by the boulders and fractured rocks. This seepage is, however, beneficial for replenishment of boreholes situated on riverbanks.

1.2 Water storage in sand

Sand consists of small stone particles that originate from stones and rocks being broken down by the effects of sunshine, rains and temperature variations.

Voids, which are empty spaces, are always found between sand particles. When dry riverbeds are flooded by rains and flash-floods, the air in the voids is pressed out by the water because it is heavier than air.

When a dry riverbed is being flooded, it looks as if the riverbed is boiling as tens of thousands of air bubbles are being pressed out of the sand. This process is known as saturation.

Fine textured sand has tiny voids that get saturated slowly with water. Only about 10% of water can be extracted from the volume of fine sand.

Coarse textured sand has larger voids and is therefore saturated much quicker than fine sand. The volume of water that can be extracted from coarse sand is about 35% of the volume of sand.

Silt and sand extractability was tested and classified as follows:

	Silt	Fine sand	Medium sand	Coarse sand
Size mm	<0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 5.0
Saturation	38%	40%	41%	45%
Water-extraction	5%	19%	25%	35%

Therefore, much more water can be extracted from riverbeds containing coarse sand than from riverbeds with fine textured sand.

No water can be extracted from riverbeds containing silt, such as in sand dams whose spillways were built in stages higher than 30 cm.

Water storage in sand has several advantages, such as:

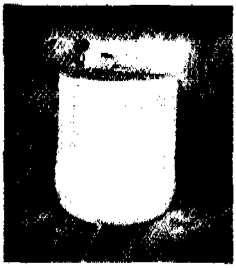
1) Evaporation losses are reduced gradually to zero when the water level is 60 cm or more below the sand surface.

2) Livestock and other animals cannot contaminate the water reservoir because it is hidden under a surface of dry sand.

3) Mosquitoes, and insects that carry water-borne diseases, cannot breed in underground water reservoirs. Frogs, snakes and other unpleasant reptiles and animals are also unable to live in, and to and pollute, water reservoirs in sand.

Sand testing

The porosity and extractable capacity of sand are found by saturating 20 litres of sand with a measured volume of water.



The water is then drained out of the container and measured by removing a plug from the bottom of the container.

1.3 Water in riverbeds

Since time immemorial, riverbeds have provided water for people and animals. During extreme droughts, when all other water sources have dried up, water can still be found in riverbeds.

Elephants, ant-eaters and some other wild animals have a special sense by which they can locate such places where water is found in riverbeds.

Some rural people and most well-diggers know that water can only be found at certain places in riverbeds. They can also give a rough estimate on how deep they have to dig before reaching the water-table.

Their knowledge is based on the fact that certain species of trees and vegetation must have roots reaching down and into the water-table in order to survive droughts. This traditional information is compiled in the table below.

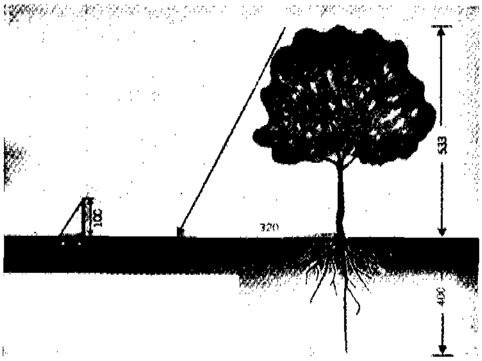
Water-indicating vegetation

Botanical name	Kiswahili & Kikamba names	Depth to water-level
Cyperus rotundus	Kiindiu	3 m to 7 m
Vangueria tomentosa	Muiru Kikomoa	5 m to 10 m
Delonix elata	Mwangi	5 m to 10 m
Grewia	Itiliku Itiliku	7 m to 10 m
Markhamia hildebranditi	Muu Chyoo	8 m to 15 m
Hyphaene thebacia	Kikoko Ilala	9 m to 15 m
Borassus flabellierfer	Mvumo Kyatha	9 m to 15 m
Ficus walkefieldii	Mombu	9 m to 15 m
Ficus natalensis	Muumo Muumo	9 m to 15 m
Ficus malatocapra	Mkuyu Mukuyu	9 m to 15 m
Gelia aethiopica	Mvungunya Muatini	9 m to 20 m
Piptadenia hildebranditi	Mganga Mukami	9 m to 20 m
Acacia seyal	Mgunga Munini	9 m to 20 m

Since the above mentioned trees must have their tap root in the water table, the depth of a water-table can be found by knowing the depth of the tree?s tap root.

A rule of thumb states that the tap root of a tree has a depth equal to about of the height of the tree.
The height of a tree can be found by measuring the length of the shadow the tree is casting on the ground and comparing it with the length of the shadow of a stick 100 centimeters long.

The two measurements should be taken in the sunshine of early morning or late afternoon when the shadows are longest.



For example: If the stick? shadow is 80 cm long, the ratio is: 80/100 = 0.8.
If the tree?s shadow is 12 m long, then the tree is: 12 m x 5 / 4 = 15 m high and the tap root and water level is at:
15 m x = **11.25 m depth.**

1.4 Waterholes in riverbeds

The reason why some waterholes are perennial and others are not, lies under the sand, where it cannot be observed.

1) The floors under the sand in riverbeds can consist of soil, clay, murram, black cotton soil, boulders, fractured rocks or solid rock bars.

2) Where floors consist of permeable (water-leaking) material, such as sandy soil, fractured rocks or large boulders, water will seep into the underground through the floor. This may be beneficial for deep boreholes but certainly not for extracting water from riverbeds.

3) If a floor consists of an impermeable (water-tight) texture, such as clay, clayey soil or murram, there is no leakage through the floor. Water can therefore be extracted from the riverbed, unless it has drained downstream and left the riverbed dry.

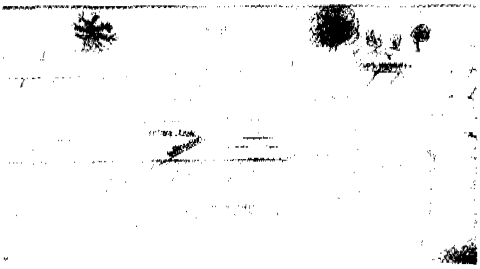
4) Riverbeds have downstream gradients because they function as drainage channels for rainwater run-off. Water in riverbeds is therefore always moving downstream, either on the surface or between the sand particles under the surface of riverbeds. Surface flow of water can easily be observed during floods but the subsurface flow can only be observed when water is scooped out of waterholes.

The reason why some riverbeds have water and others have not, lies in the floor under the sand in riverbeds with impermeable floors.

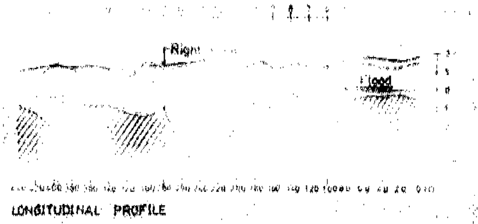
If riverbeds have impermeable floors but no water, it is because the water has been drained downstream by gravity.

If riverbeds with impermeable floors have water, then something must have stopped the water from being drained downstream. What could that be?

The answer is found by hammering iron rods into the sand of riverbeds at certain intervals. Such probing shows that most riverbeds have a floor under the sand that bulges up and down. These natural barriers, called dykes, give the answer.



Water is found in this waterhole because the dyke prevents the water seeping downwards in the voids between the sand in the riverbed.



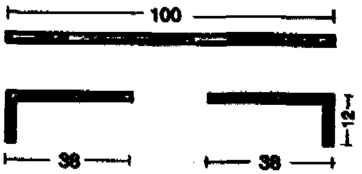
Where the floor bulges upwards it acts as an underground dyke that stops the underground flow of water, as seen on probing points no. 10, 13, 15, 19 and 23.

Where there are a depression in the floor it accumulates water, as seen on probing points no. 9, 14, 16 and 21.

These are subsurface water reservoirs in the sand, from where water can be extracted.

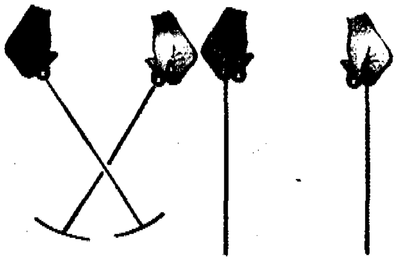
1.5 Dowsing

Gifted persons can use dowsing to locate underground water sources and underground dykes.



The tool consists of a 1m long brazing rod cut in two halves and each half having a 12 cm long handle.

The two dowsing rods are held loosely and pointing downwards so that they can swing freely. However, the hands must be held steady to allow gravity to pull the rods down while they are parallel.



Here is water. Here is no water.

When walking slowly over an unknown underground water source, the rods will swing inwards. The force of the pull indicates the depth and volume of water in the ground.

Although these traditional techniques are rather successful when applied by reliable persons, more precise data is required by professionals.

1.6 Evaluation of riverbeds

The most potential stretches of a riverbed are identified by walking in them together with the community members who have requested for assistance to improve their existing water source or to construct new ones in the riverbed.

First draw a sketch of the riverbed.

Then walk and dowse, if capable of that, in the riverbed while plotting the following information on the map:

1) Location and types of water-indicating trees and vegetation.

2) Location of water-holes and their depth to the water-table and quality of the water.

3) Location and types of rocks and boulders.

4) Location of calcrete, which is a salty whitish substance that turns water saline.

5) Coarseness of the sand.

6) Location of hand-dug wells, boreholes and weirs in the riverbed.

7) Names of houses, schools and road crossings near the riverbed.

After having compiled the information listed above, the community is informed of the various possibilities for improving their water supply. When an agreement is made with the community, a detailed survey with probing is implemented for the purpose of providing data for drawing designs and estimating the yield of water, and the cost of construction, operation and maintenance.

Chapter 2. Survey of riverbeds

2.1 Probing

When the most promising lengths of a riverbed have been identified during the evaluation walk, they are probed using probing rods hammered into the sand.

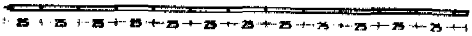
The probing data is used for:

1) Drawing a plan and profiles of the riverbed to identify the deepest place from which water should be extracted and the most shallow place where the wall for either a subsurface dam, a weir or a sand dam can be constructed.

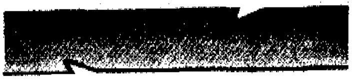
2) Estimating the volume of sand in the reservoir and the extractable volume of water from the sand.

3) Providing the required data for drawing the designs and estimating the costs of construction.

The tools required for simple surveys as follows:

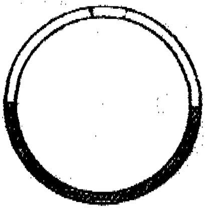


1) Probing rods made of 16 mm (5/8?) iron rods for measuring depths of sand.



Notches should be cut in the probing rods for every 25 cm to bring sand samples when the rods are pulled up.

2) A circular levelling tool made of a transparent hosepipe for measuring the gradients of riverbeds.



3) Two long tape measures, one hanging down vertically from the horizontal one, to measure width and depth of riverbeds.
4) A tripod ladder for hammering long probing rods into the sand.
5) A mason hammer.
6) A 20 litres jerrycan with water.
7) Half a dozen of transparent plastic bottles with water.
8) A knife and writing materials,
9) The ***Probing Data Sheets*** shown on the next page.

2.2 Probing of Mwiwe riverbed

Parts of the following contents are based on the actual implementation of the Mbitini and Kisasi Water Projects situated about 30 km south of Kitui township in Eastern Kenya.

The Mwiwe riverbed, which is the water source for the Mbitini project, was surveyed in November 2004. The survey started where the Wingo riverbed joins the Mwiwe riverbed. The procedure was as follows:

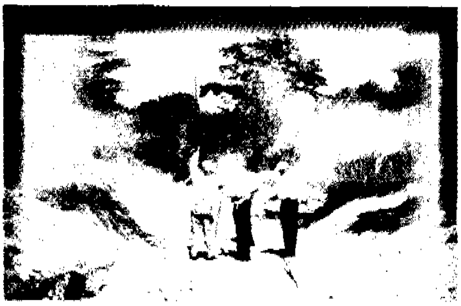
1) A probing rod was hammered down in the middle of the riverbed until it hit the floor under the sand with a dull sound. Then the level of the sand was marked on the rod and it was pulled straight up without twisting. The following data was noted on the data sheet:

1) The depth of water is measured from the tip of the rod to the water indication mark.
2) The depth of sand is measured from the marked sand level to the tip of the rod.
3) The coarseness of sand is seen in the notches of the rod.
4) The type of floor under the sand is seen at the tip of the rod.
5) The width of the sand in the riverbed is measured.
6) The height of the banks are measured with two long tape measures.
7) The presence of water-indicating vegetation, waterholes, roads, etc. is noted.
8) The next probing is measured at regular intervals, for example 20 metres.

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

2.3 Survey of Mwiwe riverbed



The heights and shape of the riverbanks were measured using two long tape measures, one hanging vertically down from the other which was drawn tightly between the top of the riverbanks.

The gradient of the riverbed was measured by a person standing at probing point No. 1 while sighting downstream using the two horizontal water levels in a circular hosepipe that was filled halfway with water.

Other persons were standing downstream at probing point No. 23 while holding a long pole vertically.

The horizontal sighting line in the circular leveling instrument hit the pole 0.8 metres above the level of the sand. The difference of 0.8 m in height between probing points No.1 and No. 23 being 440 metres apart, gives a gradient of: 0.8 / 440 m x 100 m = **0.18%.**

Sand test

Samples of dry sand were taken and filled in a 20 litres container for the purpose of measuring the porosity and the volume of water that can be extracted from the sand reservoir.

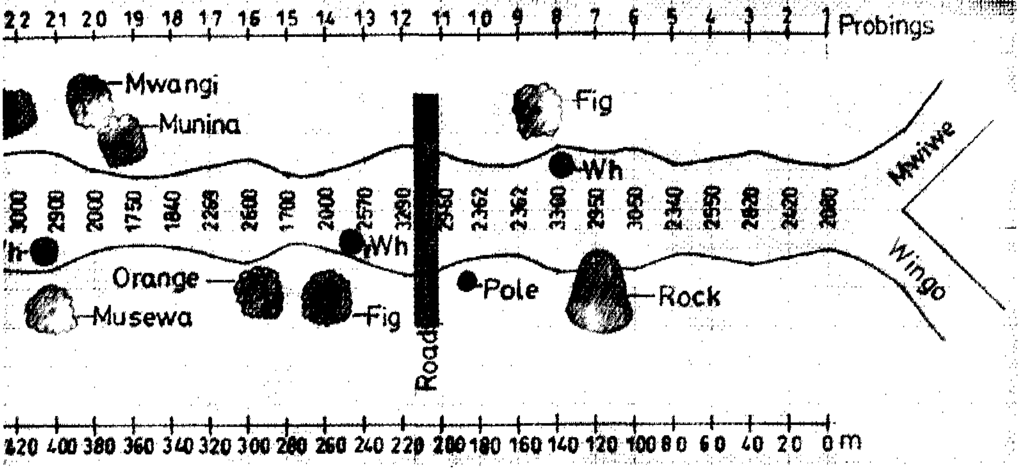
The saturation of the sand was reached after adding 8 litres of water, giving a saturation rage of 40% (8 / 20 x 100).

Then a small hole was made in the bottom of the container to drain the water out of the sand. In one hour, 5 litres of water was extracted from the sand. That gives an extractable capacity of 25% (5 / 20 x 100).

2.4 Plan and longitudinal profile of Mwiwe riverbed

A plan and a longitudinal profile was drawn according to the probing data on a sheet of A3 mm graph paper which is 40 cm long and 28 cm wide.

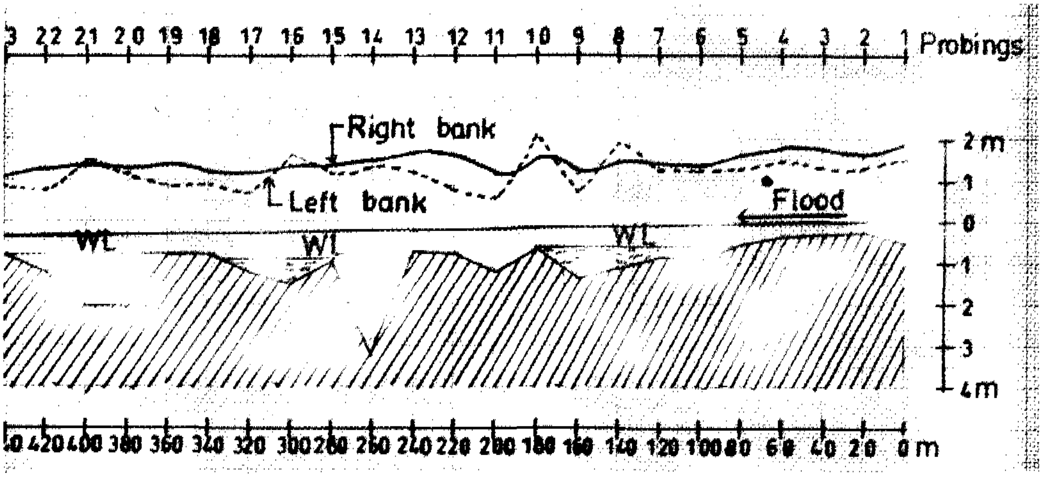
The horizontal measurements were drawn to a scale 1:2000, which means that the 440 metres length of the riverbed was drawn as 22 centimetres long and the 20 metre intervals between the probings were drawn as 1 centimetre long on the graph papers.



DOWNSTREAM UPSTREAM

Plan of Mwiwe riverbed.

The plan shows that the probed river has a length of 440 m and width varying from 17.5 m to 33.0 m. Water-indicating trees, e.g. Figs, Mwangi and Munina, grow along the riverbed. Waterholes having water 7 months after the last rains were located at probing point No. 10, 14 and 21 where the sand is deep. Water is trapped in the sand by downstream dykes at points No. 11, 18 and 23, as see on the longitudinal profile below.



DOWNSTREAM UPSTREAM

Longitudinal profile of Mwiwe riverbed.

The longitudinal profile on the former page shows that the sand is 3.0 m deep at point No. 14 and 1.75 m deep at point No. 21. Since both places are holding water 7 months after the last rain they are the best extraction points in that part of Mwiwe riverbed. The next phase in surveying the riverbed was to probe across at point No. 17 in order to learn of the volume of the depression and its water yielding capacity.

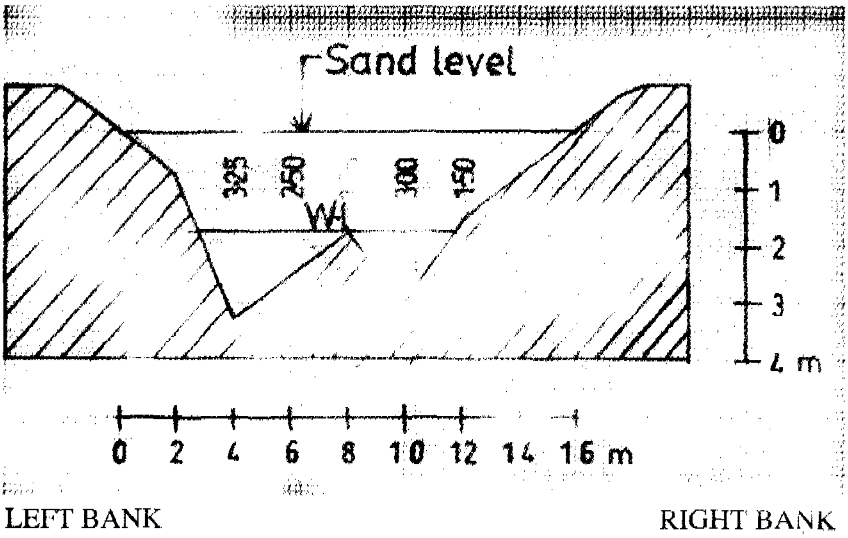
2.5 Cross profiles of Mwiwe riverbed

2.5.1 The most suitable site for Mwiwe extraction point

The riverbed was probed from bank to bank at 2 metre intervals at point No. 14. To confirm that point No. 14 was the deepest point, further probing was done both upstream and downstream from that point.

Probing data across the extraction point at No. 14 in Mwiwe riverbed

Probing No.	Distance between probings m	Depth of sand m	Type of sand	Type of floor under the sand
1	2	0.75	Coarse sand	Sandy clay
2	2	3.25	Coarse sand	Sand
3	2	2.50	Coarse sand	Sandy clay
4	2	1.75	Coarse sand	Sandy clay
5	2	3.00	Coarse sand	Sand
6	2	1.50	Coarse sand	Sand
7	2	0.75	Coarse sand	Sandy clay
8	2	NIL	Coarse sand	Sandy clay

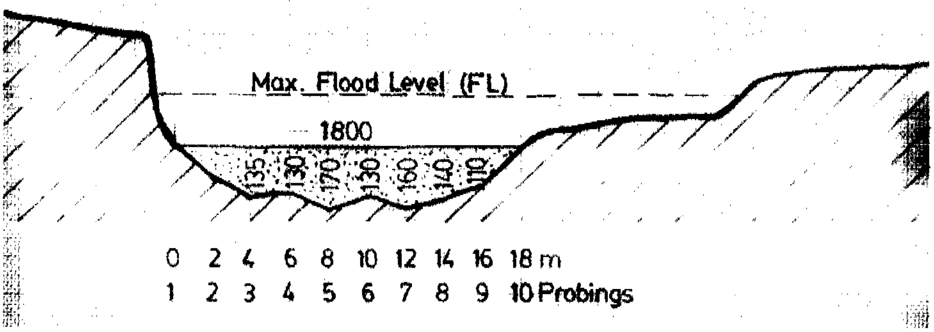


Probing profile of No. 14 in Mwiwe riverbed where the sand is deepest and therefore the most suitable place for the intake.

2.5.2 The most suitable site for the dam wall of Mwiwe Sand Dam

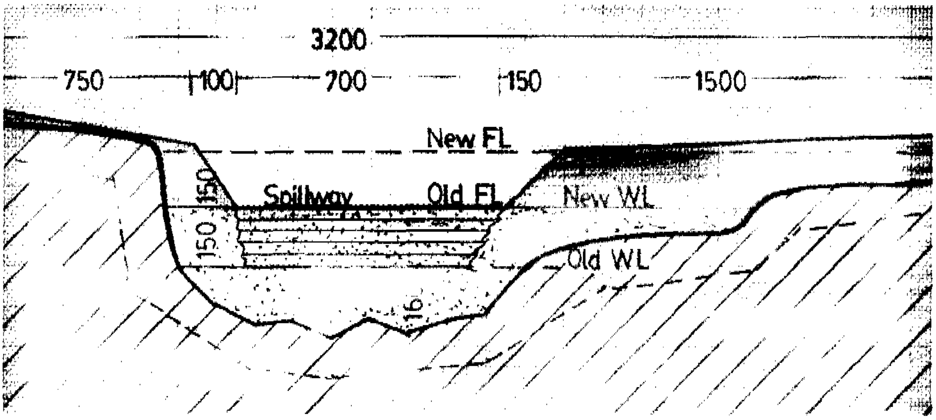
The longitudinal profile and several cross probings showed that the underground dyke at point No. 18 was the most suitable for the Mwiwe Sand Dam as shown below.

Probing No.	Distance between probings m	Depth of sand m	Type of sand	Type of floor under the sand
0	2	0.85	Coarse sand	Clay
1	2	1.35	Coarse sand	Clay
2	2	1.30	Coarse sand	Clay
3	2	1.70	Coarse sand	Clay
4	2	1.30	Coarse sand	Clay
5	2	1.60	Coarse sand	Clay
6	2	1.40	Coarse sand	Clay
7	2	1.10	Coarse sand	Clay
7.5	0.5	0.40	Coarse sand	Clay



LEFT BANK RIGHT BANK

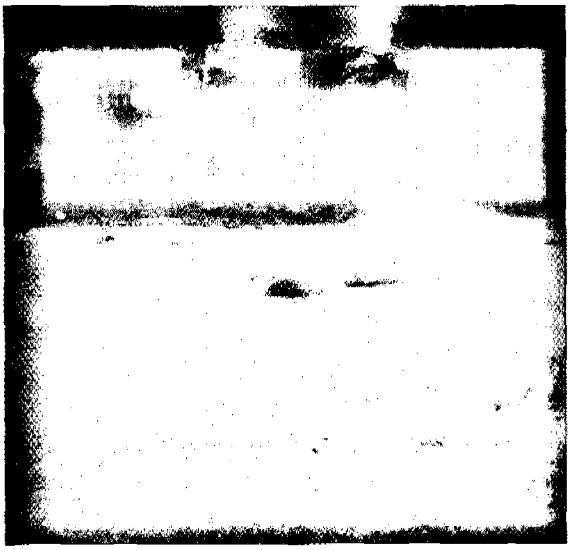
This cross profile shows the measurements of the most suitable underground dyke at No. 18 for Mwiwe Sand Dam. The design below was based on this profile.



Design of Mwiwe Sand Dam that was based on No. 18 cross profile

2.6 Trial pits

Trials pits were excavated down to the floor under the sand every 3 metres to confirm the correctness of the probing.



Underground dykes can sometimes be located by vegetation growing in soil situated just below the sand surface.

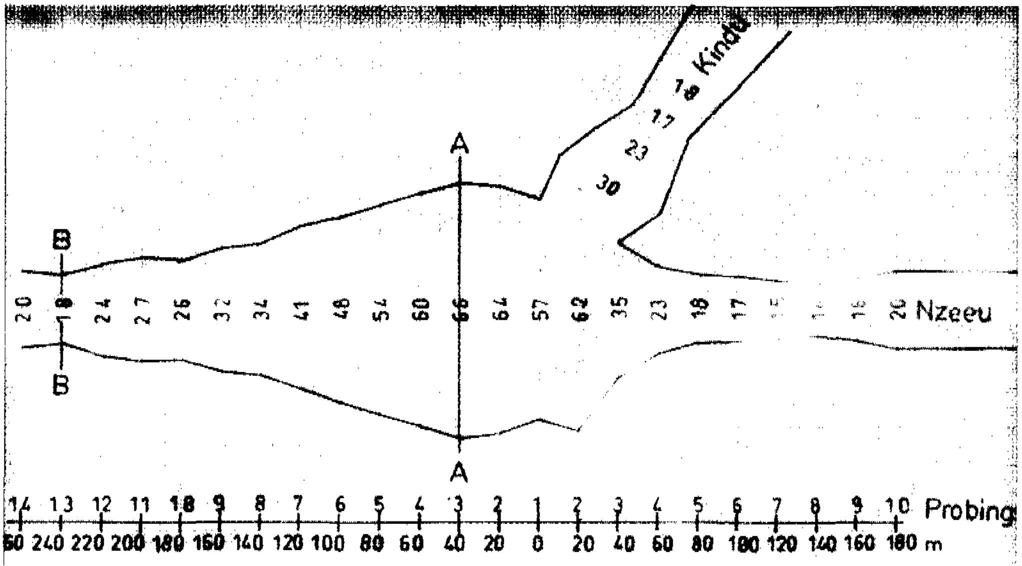
The surveyors prepared a ***Survey Report*** with all details and data compiled of Mwiwe riverbed. The report was handed over to a design engineer for his considerations which are presented in the next chapter.

Thereafter the surveyors surveyed a much larger riverbed, Nzeeu, for 25,000 people in Kisasi Water Project. The survey data is presented on the next pages.

On the left, a local expert is using a pendulum to find water under the ground.

On the right, a soda bottle is used for grading a sand sample

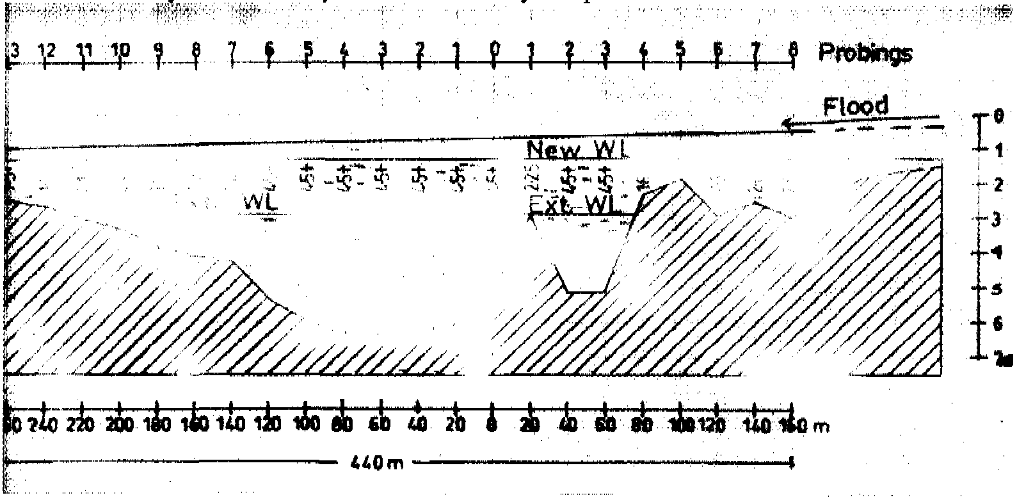
2.7 Plan and profiles of Nzeeu riverbed



DOWNSTREAM UPSTREAM

Plan of Nzeeu riverbed

The surveyors started probing from the junction of Nzeeu and Kindu riverbed at point 0. Thereafter they returned to point 0 and surveyed upstream as shown on these sketches.



RIGHT BANK LEFT BANK

Longitudinal profile of the probing in Nzeeu riverbed.

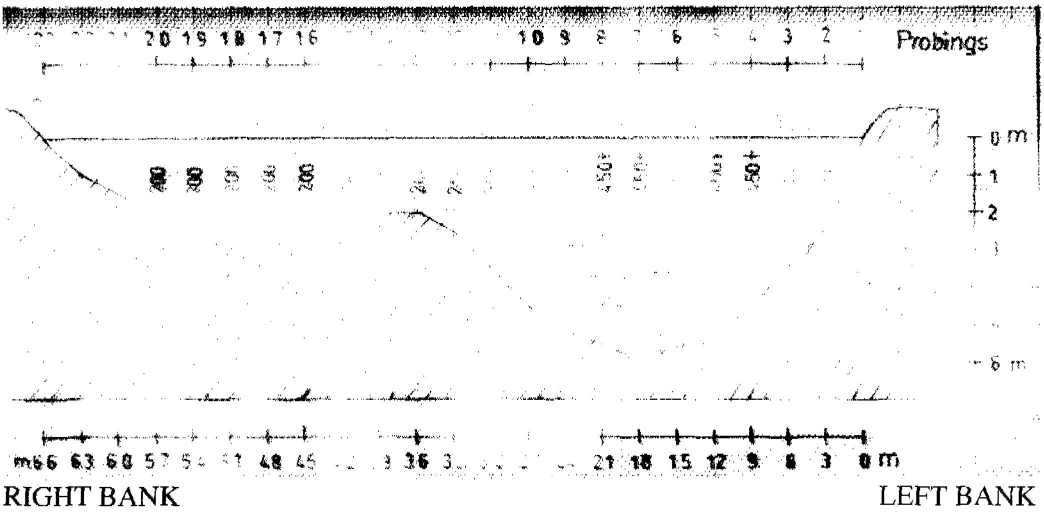
The plan and profile show a large underground water reservoir at No. 3 and an underground dyke with a narrow point at probing point No. 13 which is a perfect foundation for either a subsurface dam or a sand dam.

2.7.1 The most suitable site for the Nzeeu extraction point

A cross profile of Nzeeu riverbed at probing point No. 3 on the longitudinal profile confirms the large underground water reservoir from which water will be extracted.

Probing data across the deepest point at No. 3 of Nzeeu riverbed

Probing No.	Distance between probings m	Depth of sand m	Type of sand	Type of floor under the sand
1	0	0	Fine sand	Clay
2	3	2.50	Medum sand	Clay
3	3	3.50	Coarse sand	Not reached
4	3	4.50+	Coarse sand	Not reached
5	3	4.50+	Coarse sand	Not reached
6	3	4.50+	Coarse sand	Not reached
7	3	4.50+	Coarse sand	Not reached
8	3	4.50+	Coarse sand	Not reached
9	3	4.50+	Coarse sand	Not reached
10	3	4.50+	Coarse sand	Not reached
11	3	3.50	Coarse sand	Not reached
12	3	2.50	Coarse sand	Clay
13	8	2.00	Coarse sand	Clay
14	8	2.00	Coarse sand	Clay
15	8	2.00	Coarse sand	Clay



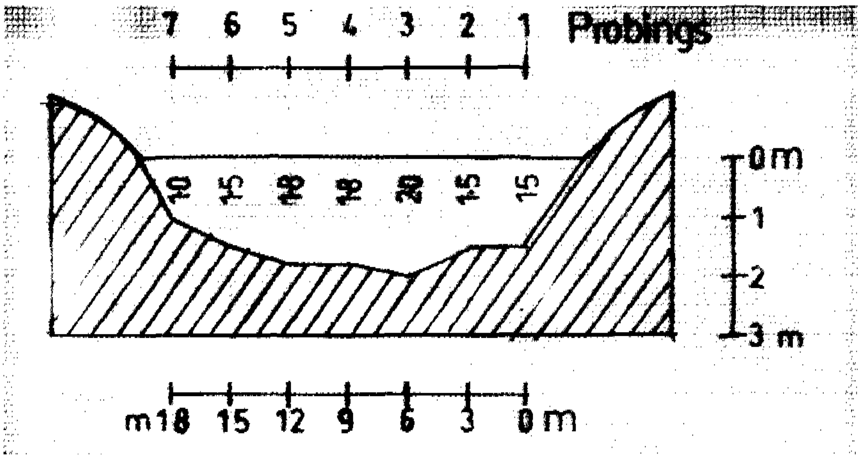
Cross profile of Nzeeu riverbed at point No. 3 (A-A) which will be the extraction point.

2.7.2 The most suitable site for the dam wall of Nzeeu Subsurface Dam

A cross profile of the underground dyke and narrow riverbed at point 13 confirms the location of the most shallow place for either a subsurface dam, a weir or a sand dam.

Probing data across the shallow dyke at No. 13 (B-B) of Nzeeu riverbed

Probing No.	Distance between probings m	Depth of sand m	Type of sand	Type of floor under the sand
1	0	1.50	Coarse sand	Sandy clay
2	3	1.50	Coarse sand	Sand
3	3	2.00	Coarse sand	Sandy clay
4	3	1.75	Coarse sand	Sandy clay
5	3	1.75	Coarse sand	Sand
6	3	1.50	Coarse sand	Sand
7	3	1.00	Coarse sand	Sandy clay



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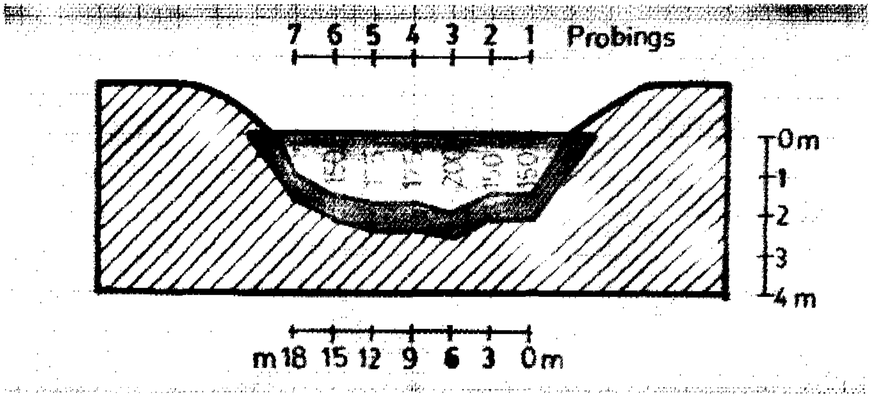
Cross profile of Nzeeu riverbed at probing point No. 13 (B-B). The profile was used for the design of the subsurface dam as shown below.



2.8 Volumes of sand and water in Mwiwe and Nzeeu riverbeds

The porosity and extractable percentage of water from the sand in Nzeeu riverbed was found to be 35% and 30% respectively.

The approx. volume of a dam reservoirs can be found by this rule of thumb:
Maximum depth x maximum width x maximum throw-back / 6 = Volume.
(A through-back is the horizontal length of water in a dam).

The volume of sand and water in the reservoirs of the two riverbeds were found to be:

	Max. depth m	Max. width m	Throw-back m	1/6	Sand Volume m^3	% Water extraction	Water volume m^3
Mwiwe	3.25	25.70	40.00	1/6	557	25	139
Nzeeu	5.00	66.00	380.00	1/6	20,900	30	6,270

An unknown volume of subsurface flow of water in the sand replenishes the two reservoirs which should be added to the volume of water shown above.

In order to increase the yield of water from Mwiwe riverbed it was decided to construct a a sand dam upon the dyke at No. 18, because that would increase the storage capacity from 139 m^3 to 2,997m^3 as shown under WL 4 in the table below.

Three options for increasing the volume of sand and water in Mwiwe riverbed

	Max. depth m	Max. width m	Throw-back m	1/6	Sand Volume m^3	% Water extraction	Water volume m^3
WL 1	3.25	25.70	40.00	1/6	557	25	139
WL 2	0.8 + 3.25	26.00	260.00	1/6	4,563	25	1,141
WL 3	1.4 + 3.25	28.00	300.00	1/6	6,510	27	1,758
WL 4	2.3 + 3.25	30.00	360.00	1/6	9,990	30	2,997

Three options for increasing the volume of sand and water in Nzeeu riverbed

	Max. depth m	Max. width m	Throw-back m	1/6	Sand Volume m^3	% Water extraction	Water volume m^3
WL 1	5.00	66.00	380.00	1/6	20,900	30	6,270
WL 2	0.8 + 5.00	68.00	420.00	1/6	27,608	30	8,282
WL 3	1.4 + 5.00	70.00	440.00	1/6	32,853	30	9,856
WL 4	2.3 + 5.00	72.00	480.00	1/6	42,048	30	12,614

Key:
WL 1 = Existing natural reservoir in the riverbeds
WL 2 = Increased volume by a subsurface dam wall built to 30 cm below sand level
WL 3 = Increased volume caused by a weir built to 30 cm above sand level
WL 4 = Increased volume caused by a sand dam wall built to 150 cm above sand level

A ***Survey Report*** was then given to the engineer to determine whether the dam should be a cheap subsurface dam or a low cost weir or the more expensive sand dam. The considerations for this assessment are described in the next chapter.

Chapter 3. Design considerations

3.1 Sustainability and affordability

Sustainability and affordability are two key words that should always be remembered when designing water projects.

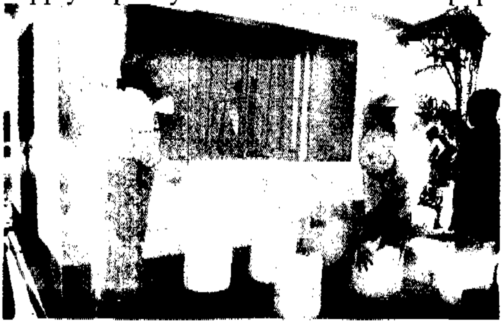
Sustainability of water projects can be achieved by designing tested and simple structures that the community can construct, operate, maintain and repair themselves.

For example, initially it was planned to drill two boreholes and equip them with submersible pumps at Mbitini and Kisasi water projects at a total cost of about Ksh 3 million. Instead, some local builders were contracted to sink two hand-dug wells with infiltration pipes at a total cost of Ksh 425,000, all inclusive. Not only was the construction cost reduced by Ksh 2.5 million but it was much easier and cheaper for the community to service the pumps in the hand-dug wells than it would have been in the boreholes.

Affordability is also achieved by designing tested and simple structures using a maximum of locally available skills and materials that the community can afford to procure, construct, operate, maintain and repair. The example described above with boreholes versus hand-dug wells describes exactly what affordability is all about.

The supply capacity of a water project should be able to satisfy a community s water demand for the next 20 years. If the supply capacity is less than the demand, people will complain that their water supply is insufficient and they have wasted their money and time. Where a water project is over-designed, the construction works and operation costs are higher than necessary and the extra cost has to be levied on the sale of water. The supply capacity and the water demand should therefore balance.

Another factor to consider is the population increase. When water is available, many people living outside the project area will be attracted to settle in the project area. The supply capacity must also include this population in addition to the normal increase.



Water is sold at kiosks from Ksh 2 to Ksh 4 per 20 litre jerrycan. The price of water depends on the cost of operation, maintenance and repairs.

A Kiosk Attendant s sales record is checked. The income from sale of water must be sufficient to pay for salaries, fuel, operation, maintenance and repairs.

3.2 Water demand

With reference to an appraisal report produced by Development Impact Consulting (DIC) in August 2004, the combined water demand for Mbitini is projected as shown in the table below.

Daily Water Demand for Mbitini. The water demand by Kisasi is similar to Mbitini.

Category	**m^3/day 2004**	**m^3/day 2005**	**m^3/day 2015**	**m^3/day 2025**
General population	169	172	210	256
Livestock units	20	20	23	26
Schools	11	11	14	17
Health and Adm. Centres	5	5	5	5
Shopping centres	12	14	18	21
Total daily water demand (m^3/day)	**217**	**222**	**270**	**325**
Total annual water demand (m^3/year)	**80,000**	**81.000**	**98,000**	**118,000**
Demand in 6 months without rains	**40,000**	**41,000**	**49,000**	**59,000**

3.3 Water yield in year 2004

Volume of sand and water in the underground reservoirs

	Max. depth m	Max. width m	Throw-back m	1/6	Sand volume m^3	% Water extraction	Water volume m^3
Mwiwe	3.25	25.70	40.00	1/6	557	25	139
Nzeuu	5.00	66.00	380.00	1/6	20,900	30	6,270

3.4 Three options for increasing the water yields

The three available options for increasing the water yields are to construct dam walls for either:

1) A subsurface dam built of soil to 30 cm below the surface of sand in a riverbed, or

2) a weir built of concrete or rubble stone masonry to 30 cm above the sand level, or

3) a sand dam built of concrete or rubble stone masonry to a maximum of 5 metres above the level of sand in a riverbed.

These dam walls should be constructed on the identified underground dykes situated downstream of existing underground water reservoirs.

In other riverbeds, the three types of riverbed dams should, preferably, be constructed on underground dykes. The dams can, however, also be built in riverbeds not having underground reservoirs or underground dykes.

3.5 Design decisions

The following decisions on the designs were taken on the basis of the evaluation report and the considerations described above as well as during several meetings with the Kisasi and Mbitini project committees:

3.5.1 Decision on extraction point in Mwiwe riverbed

As mentioned above, it was found more sustainable and affordable to lay infiltration pipes in the riverbed to drain water into a hand-dug well to be sunk in the riverbank, instead of drilling a borehole and equipping it with a submersible pump.

The extraction point will consist of 72 metres of infiltration pipes made of perforated 160 mm UPVC laid in crushed stones as deep in the riverbed as the water level would allow at point No. 14 in Mwiwe riverbed. The infiltration pipes will be laid with a gradient towards the riverbank to facilitate water flowing into a hand-dug well that will be sunk in the riverbed.

The hand-dug well will have a diameter of 3 metres and be sunk as deep as the water table will allow. The well will be built of curved concrete blocks reinforced together on a circular foundation/cutting ring of reinforced concrete.

Extraction of water from the well will consist of a surface pump powered by a diesel generator that will be installed in a pump house to be constructed.

The pump will deliver the water to a 100 m^3 head tank to be constructed of concrete blocks and situated 0.96 km from the pump at an elevation of 80 metres above the pump. From this head tank water will gravitate through 2 water tanks and 22.9 km of pipelines to 11 water kiosks.

3.5.2 Decision on a sand dam in Mwiwe riverbed

For Mwiwe riverbed it was decided to construct a sand dam of rubble stone masonry to a height of 1.5 metres above the existing sand surface at probing point No. 18. The sand dam will raise the water table from 1.7 metres below the sand level to 1.5 metres above, which is a total of 3.2 metres. This will increase the storage capacity from the existing 139 m^3 to 2,997 m^3 as shown under WL 4 (Water Level 4) in the former chapter.

After the infiltration pipes have been laid in the riverbed and the hand-dug well has been sunk as deep as possible, the water table in the riverbed will be raised by construction the sand dam in the required stages.

3.5.3 Decision on extraction point in Nzeeu riverbed

The extraction point in Nzeeu riverbed will be a replica of the extraction point in Mwiwe riverbed, except for the pump, which will deliver the water to a 50 m^3 elevated head tank to be constructed of steel plates. The tank will be situated 5.3 km from the pump at an elevation of 154 metres above the pump. From this head tank water will gravitate through 2 water tanks and 16 km of pipelines to 10 water kiosks.

3.5.4 Decision on a subsurface dam in Nzeeu riverbed

The selected option for Nzeeu was a subsurface dam whose wall will be built of soil to 30 cm below the existing sand surface, which will raise the water table 170 cm. This will increase the water storage capacity from the existing 6,270 m^3 to 8,282 $m^{3.}$

The subsurface dam will have two purposes, namely, a) to increasing the yield of water, and, b) to compare its construction cost and performance with the sand dam at Mwiwe.

Survey and design data are being compiled into a Survey Report by some participants of a training course dealing with water from dry riverbeds.

Chapter 4. Riverbed intakes

4.1 Suitable seasons for surveys and construction works

Surveys of riverbeds should always be carried out in the driest seasons when water levels are at their lowest. Information and mobilization of communities should also be implemented in the dry seasons when water supplies are scarce and people are concerned about their water supplies. Designs, bills of quantities, costs and work plans can be drawn up during rainy seasons.

Construction of water projects should always start with sinking of the wells and laying of the infiltration pipes and that should always take place during a dry season. By doing so, the minimum yield of water can be known and used for calculating the required capacity of the pump and generator, pipelines, water kiosks, etc.

The minimum yield is also used to determine whether the riverbed can supply sufficient water or whether a subsurface dam, weir or sand dam has to be built to increase the yield of water.
If so, the construction work of such structures should take place in the beginning of short dry season or in the middle of long dry season when there is no risk of an unexpected thunder shower that can flood the construction site.

Excavation of trenches for pipes and the laying of pipes should also take place in the dry seasons when the fields have been harvested to avoid spoiling crops in the field. Other activities that demand much manual labour should also be implemented when the farmers are less busy in the dry seasons.

Another big advantage of constructing water projects during dry seasons is that the provision of water is usually the biggest issue during those periods. It is therefore fairly easy to mobilize and organize people to carry out manual work.

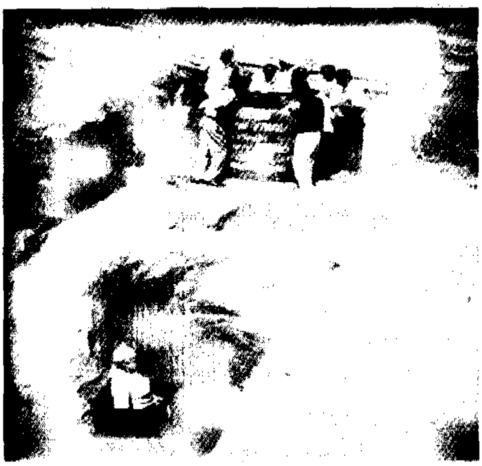
More detailed information on survey and design is given in another handbook of this series called ***Water Surveys and Designs.***

4.2 Intakes in riverbeds

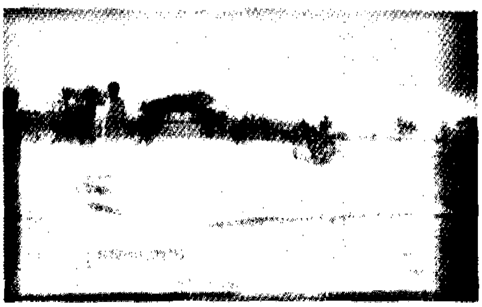
There are several technologies for lifting water from riverbeds that are affordable and sustainable for individuals and community water projects.

The oldest and simplest method is to dig a waterhole in a riverbed and use a calabash cut in half to scoop water into a calabash or a jerrycan.

A safer and cleaner option is to sink a hand-dug well next to the waterhole in a riverbed.

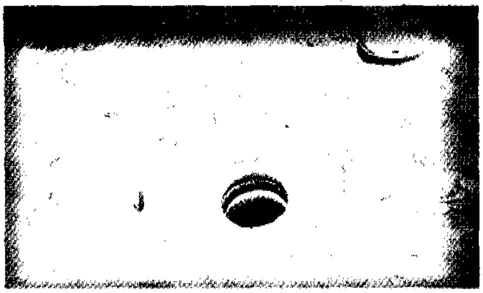


Hand-dug wells situated in riverbeds must be equipped with a well-head to prevent the well shaft being filled with sand during floods such as this hydro-dynamic well-head used in Sudan.



Another type of hydro-dynamic well-head shaped as a wedge to break the force of floods.

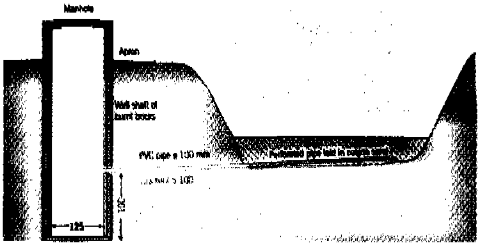
A well-shaft can also be lined with worn-out lorry tyres and closed by a lid made from the bottom of an oil-drum.



4.3 Intakes in riverbanks

Although sinking of wells directly into riverbeds is the cheapest way to extract water, the wells might be damaged by unusually large flash-floods. It is therefore safer to build hand-dug wells on the riverbanks and draw water from there provided the underground soil is sandy soil that allows water to seep into the hand-dug wells.

If underground water cannot seep into a hand-dug well, an infiltration pipe can be laid in a trench to drain water into the hand-dug well. The design can be made cheaper by filling the trench with stones covered with polythene sheeting instead of laying the infiltration pipe.

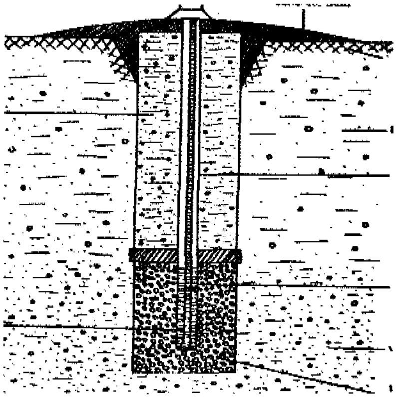


Well shafts can be lined with burnt bricks when built upwards from the bottom of hand-dug wells. However, this procedure is risky because collapsing soil can bury the builders alive.

A safer method is to build ***sinking wells*** whereby curved concrete blocks are reinforced together onto a foundation ring made of concrete. The foundation ring and infiltration course are built at ground level in a riverbed.

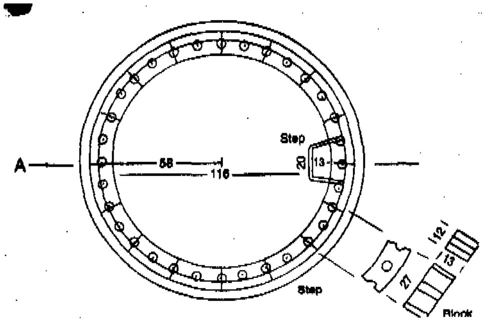
Then sand is removed from the inside of the shaft causing it to sink into the sand. When the shaft has sunk to ground level, more blocks are added onto the shaft. Sand is then removed and the shaft sinks. The procedure is repeated until the shaft has reached its final depth.

Concrete culverts can be sunk in a similar way but they are more difficult to handle.

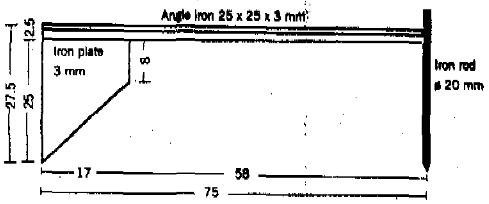


The cost of lining well shafts can be reduced by placing a large perforated PVC pipe in the centre of the excavation and filling stones and gravel all around it upto the ground level.

4.4 Design and cost of a sinking well

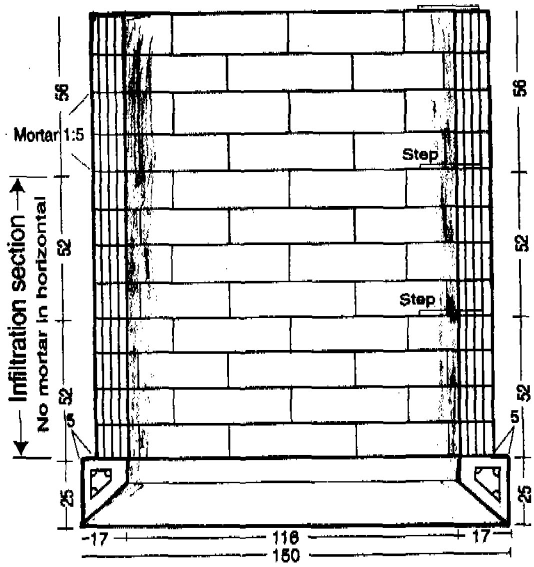


Plan of well-shaft and curved concrete block



A tool made of iron for cutting grooves

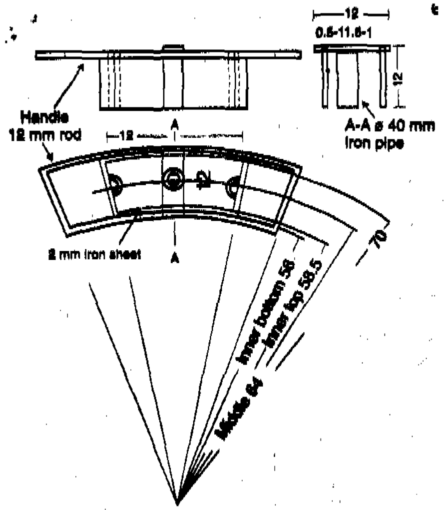
A groove being cut for a foundation ring with the tool seen above. The groove will be filled with reinforced concrete.

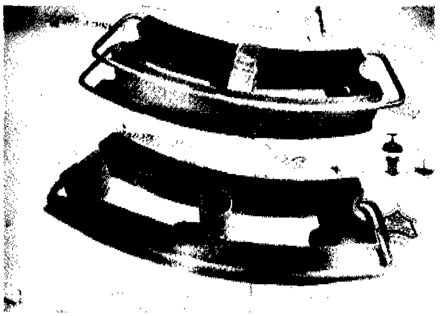


Section of well-shaft

Curved concrete blocks are made of mortar in the ratio 1:5 and compacted into a mould made of iron sheets.

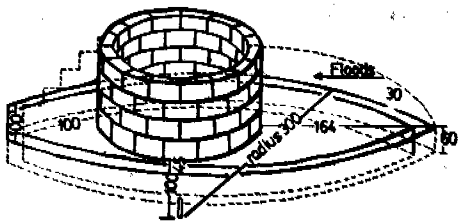
It takes 16 blocks to make a circular course with a diameter of 140 cm and 112 blocks to build 1 metre of shaft.





4.5 Design and cost of a hydro-dynamic well head

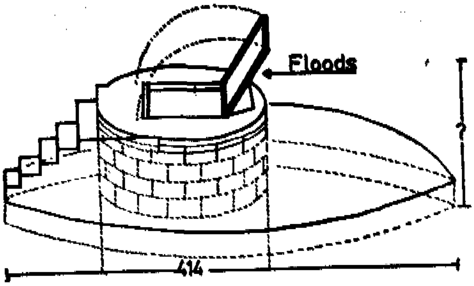
A hydro-dynamic well head can be built around a well shaft directly into riverbeds to prevent the well shaft being damaged or filled with sand from flash-floods.



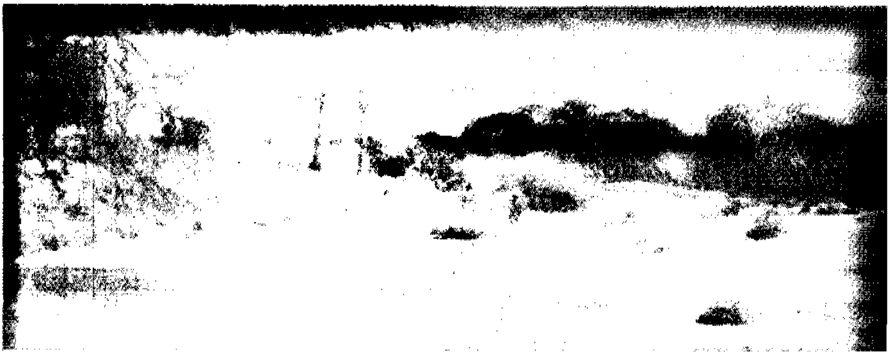
The lay-out of a hydro-dynamic well head in the middle of a riverbed.

Foundation being built of rubble stones reinforced with barbed wire.

A well head is constructed of rubble stones set in mortar, 1:4, and reinforced with barbed wire and chicken mesh.



An open steel cover the well shaft should be in the position shown to allow flash-floods to close the lid if people have forgotten to close it.



A hydro-dynamic well head in the middle of a riverbed.

Bill of quantity and cost of a well with hydro-dynamic well head, Ksh

Description 6 metre deep hand-dug well with a hydro-dynamic well head **Labour cost**	**Unit**	**Quantity**	**Unit cost**	**Total cost**	**Value of community contribution**
Supervisor	Supervisor	3 days	1,200/day	3,600	
Contractor	Contractor	6 days	800/day	4,800	
Artisan	1 mason	24 days	200/day	4,800	4,800
Trainees	2 trainees	24 days	100/day	4,800	4,800
Labourers	4 labourers	24 days	100/day		9,600
Cost and value of labour				**28,000**	**19,200**
Materials Cement	50 kg bags	26 bags	600	15,600	
Weldmesh	1.2 m. x 2.4 m	1 sheet	400	400	
G.I. wire	4 mm	20 kg	50	1,000	
Chicken mesh	0.9 m x 30 m	4 meters	100	400	
Barbed wire	Gauge 12.5	10 kg	80	800	
Windlass	Two handles	1 unit	3,000	3,000	
Iron bar	Y12 mm	1 length	500	500	
River sand	Tonnes	4 tonnes	200		
Crushed stones	2.5 mm	2 tonnes	600	1,200	1,200
Rubble stones	Tonnes	4 tonnes	200	600	600
Water	210 litre drums	10 drums	100		1,000
Cost and value of materials				**23,500**	**3,600**
Transport cost Trailer loads **Cost of transport**	3 tonnes	4 loads	900	**3,600**	**1,800**
Total cost and value				**45,100**	**24,600**
Total cost				**69,700**	

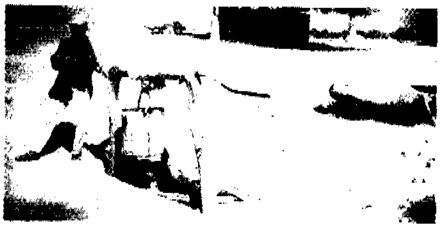
The first part of a well shaft has been built onto the foundation ring in an excavation dug as deep as safety allows in a riverbed.

Insulated electric wires bent as U s are inserted in the mortar between the blocks in the lowest part of the well shaft. When the sinking of the shaft has been completed, the wires are pulled out, thereby creating many small holes through which water can seep into the well shaft. Also, note the bent iron bars that are mortared into the shaft to function as a ladder.

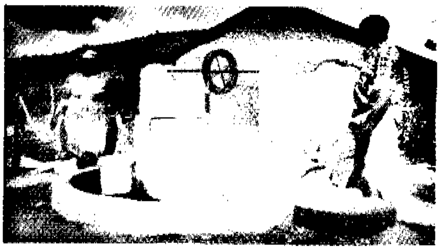
4.6 Water lifts and pumps

Water can be drawn by several types of lifts and pumps. The simplest and cheapest is a bucket tied to a rope.

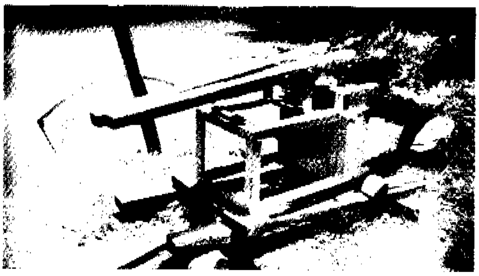
A windlass made of a few Sisal poles.



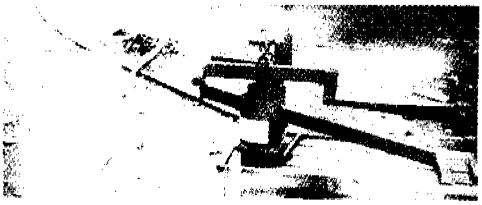
A windlass with an iron handle.



A rope and washer pump.



A hand-operated pump with a cylinder head made of concrete.

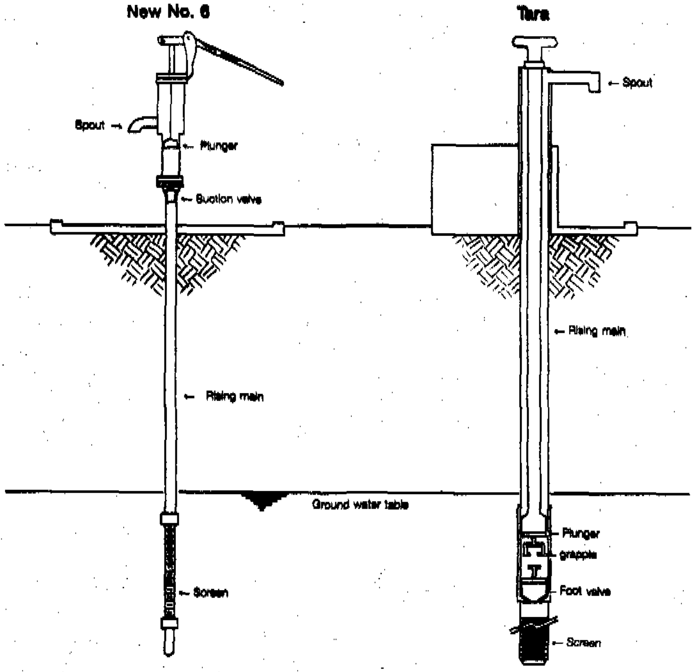


A foot-operated money-maker pump.

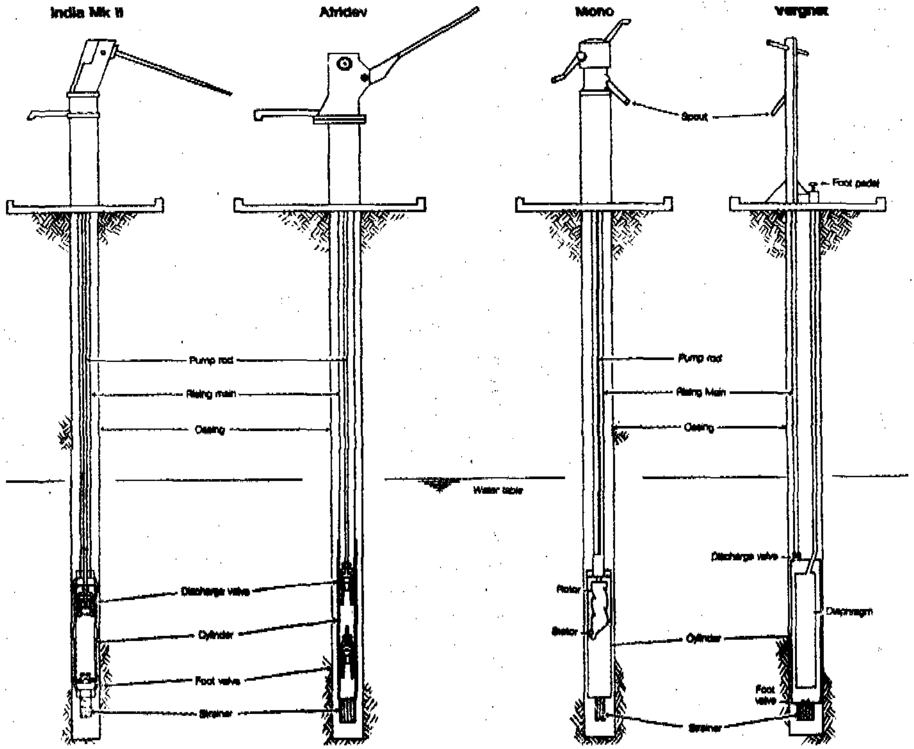
A direct action pump.

A broken down India Mark II hand pump replaced with a windlass made of Sisal.

Shallow water pumps (Reference Technical paper No. 13, ITDG).



Deep water pumps

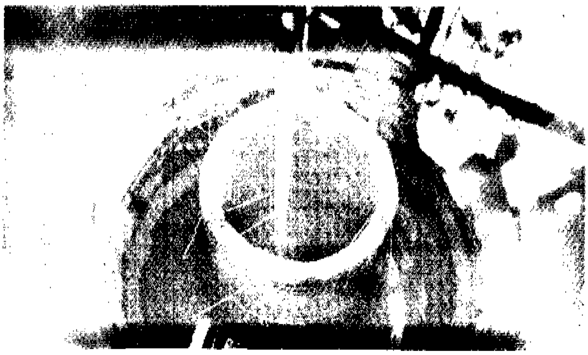


4.7 Design and cost of large river intakes

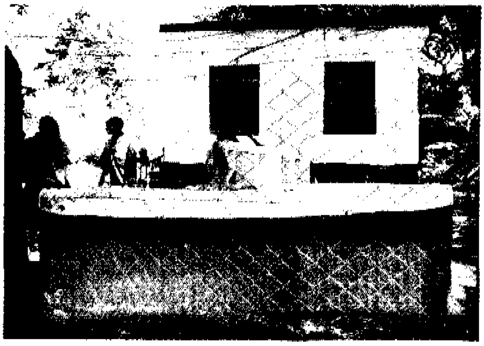
According to the evaluation report, each of the intakes at Mwiwe and Nzeuu riverbeds is required to supply 217,000 litres (217 m^3) of water daily, which amounts to 80,000 m^3 annually equal to 40,000 m^3 during a 6 month period without flooding of the riverbeds.

For each of the two intakes, this yield of water was obtained by sinking a well shaft made of curved concrete blocks on a foundation ring with an internal diameter of 300 cm. Short lengths of insulated electric wires were bent into a U*f* shape and inserted in each course of the concrete blocks for every 30 cm with the U facing inwards. The well shaft was sunk as deep as a petrol-powered suction pump could remove the inflowing water.

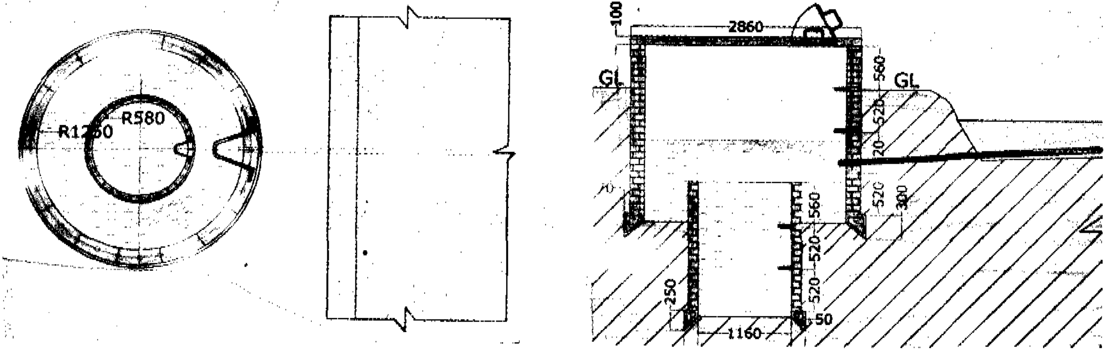
When the capacity of the pump was reached at about 4 metres depth, the internal diameter of the shaft was reduced to 110 cm in order to reduce the inflow of water. The well-diggers then sunk the well shaft to an additional 3 metres before the inflow of water became too much for the diggers and the pump. When the shaft has reached its final depth, the insulated bent wires were pulled out of the shaft, each wire leaving two small infiltration holes in the shafts for replenishing of the well.



A small well shaft being sunk inside a wide well shaft of a river intake.



The completed well head with the pipe from the well to the pump.



Plan and section of the intake wells at Mwiwe and Nzeeu (mm).

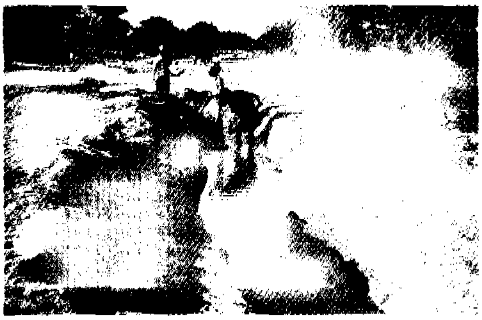
Bill of Quantity and cost of the Nzeeu intake well

Description 8 m deep intake well	**Unit**	**Quantity**	**Unit cost Ksh**	**Total cost Ksh**	**Value of community contribution**
Labour cost					
1 Surveyor	Surveyor	2 days	1,200/day	2,400	
1 Supervisor	Supervisor	10 days	1,200/day	12,000	
1 Contractor with	Contractor	1 x 20 days	800/day	16,000	
2 artisans and	Artisan	2 x 20 days	200/day	8,000	8,000
2 trainees	Trainees	2 x 20 days	100/day	4,000	4,000
10 labourers	Labourers	10 x 20 days	100/day		20,000
Cost of labour				**42,400**	**32,000**
Materials					
Cement	50 kg bags	10	600	6,000	
River sand	Tonnes	3	200		600
Crushed stones	Tonnes	3	600	1,800	1,800
Curved well blocks	Blocks	700	50	35,000	14,000
Galvanised wire, 4mm	Kg	50	150	7,500	
Iron bar, Y8	20 m length	10	500	5,000	
Dewatering pump	Days	10 days	800	8,000	
Cost of materials				**63,300**	**16,400**
Transport of materials					
Tractor trailer loads	3 tonnes	1 load	900	900	900
Cost of transport				**900**	**900**
Cost and value				**96,600**	**49,000**
Total cost				**145,900**	

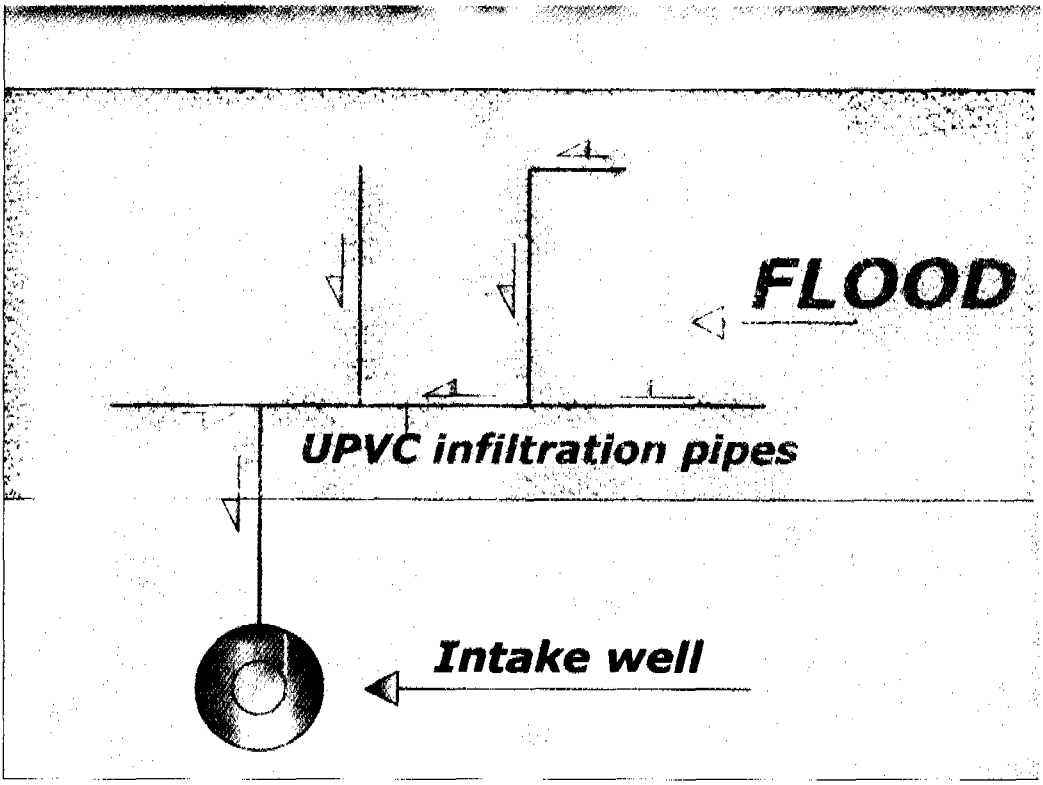
4.8 Design and cost of infiltration pipes

In order to increase the recharge even further, 72 metres of 160mm PVC pipes, into which thousands of small holes were burnt with red-hot nails, were connected to the intake. The infiltration pipes were laid in crushed stones as deep as possible and with a gradient towards the intake well to enable the water to drain from the sand into the intake.

Infiltration pipe connecting to the intake.



A flooded trench for infiltration pipes.



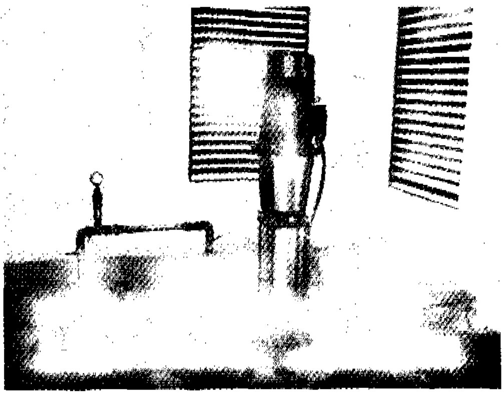
Plan of the infiltration pipes laid deep in the sand of the riverbed.

Bill of Quantity and cost of 72 metres of infiltration pipe

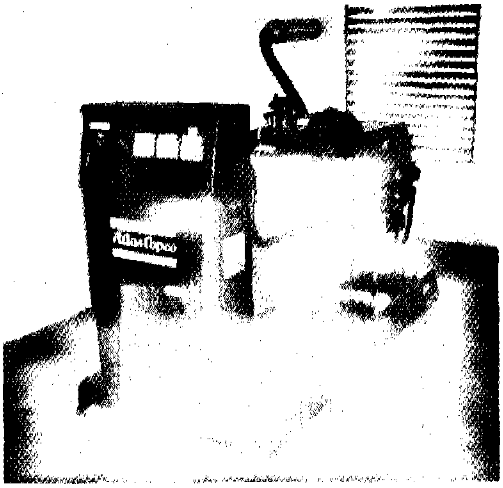
Description Perforating and laying 72 meters of 160 mm PVC pipe deep in a riverbed and sloping towards a well in the riverbank	**Unit**	**Quantity**	**Unit cost** **Ksh**	**Total cost** **Ksh**	**Value of community contribution** **Ksh**
Labour cost					
1 Surveyor	Surveyor	4 days	1,200/day	4,800	
1 Supervisor	Supervisor	6 days	1,200/day	7,200	
1 Contractor with	Contractor	1 x 15 days	800/day	12,000	
2 artisans and	Artisans	2 x 15 days	200/day	6,000	6,000
4 trainees	Trainees	4 x 15 days	100/day	6,000	6,000
10 labourers	Labourers	10 x 15 days	100/day		15,000
Total cost of labour				**38,000**	**27,000**
Materials					
Dewatering suction pump	8 days		800	6,400	
Perforated PVC pipes,160 mm	6 m length	14 pipes	3,048	42,672	
Cost of materials				**49,072**	
Transport of materials					
Tractor trailer loads	3 tonnes	1 load	900	900	450
Cost of transport				**900**	**450**
Cost and value				**85,972**	**27,450**
Total cost and value				**109,422**	

4.9 Cost and capacity of pumps, generators and pump houses

The pump in Nzeeu pump house is a Grundfoss CR15-17, 15.0 KW, 3 Phase booster pump with a capacity of $19m^3$/hr at 154 m head. Together with control panel and 60A isolator, float switch, chlorine doser and installation the unit cost Ksh 560,305 in December 2004.

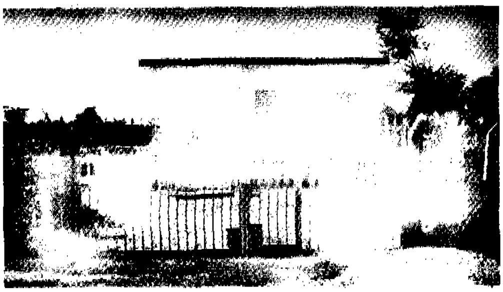


The pump seen in the photo is the pump in Mwiwe and is a Grundfoss CR32-6, 11.0 KW, 3 Phases electric booster pump with a capacity of $32m^3$m/hr at 71 m head. Together with accessories and installation the cost was Ksh 558,200 in December 2004.



The diesel generator seen in the photo is an Atlas Copco 41, KVA, QUB41 that powers the Mwiwe pump. The cost was Ksh 876,550 in December 2004.

The Nzeeu pump is also powered by an Atlas Copco diesel generator with a bigger capacity of 41 KVA, QUB41. The cost was Ksh 876,550 in December. 2004.



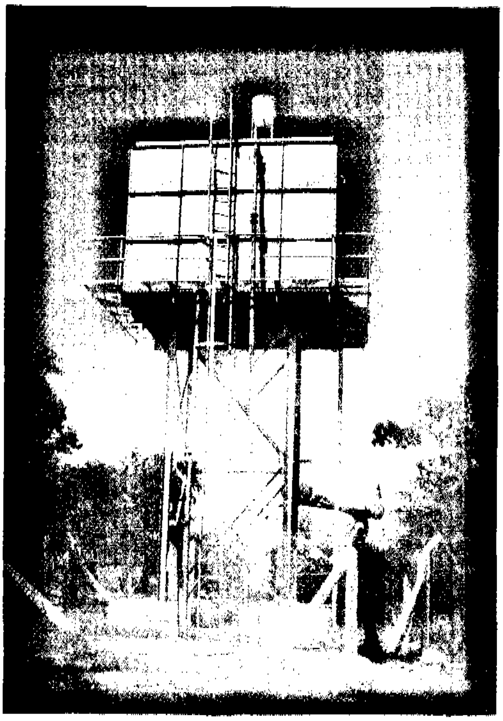
The Nzeeu pump house seen in the photo is similar to the Mwiwe pump house. Both houses have a private room for the Pump Operator.

The cost of the pump house with fence was Ksh 793,866 including value of local labour and materials.

4.10 Calculations and cost of rising mains and head tanks

The head tank for the Mbitini Water Project is a 100 m^3 tank built of concrete blocks for a cost of Ksh 797,590. The tank is situated at a distance of 0.916 km from the Mwiwe intake and at an altitude of 35.1 m above the intake. The pumping head with 100 mm G.I pipe delivering 30 m^3/hr is:

Delivery head	= 35.1 m
Frictional losses	= 25.7 m
Tank height	= 3.0 m
10% residual (extra) head	= 6.4 m
Total pumping head	**70.2 m**
Pumping head of the pump	**71.0 m**



The head tank for the Kisasi Water Project is a 50 m^3 elevated tank made of steel plates costing Ksh 1,277,621. The tank is situated at a distance of 5.3 km away form the Nzeeu intake and at an altitude of 74.2 m above the intake. The pumping head with a 100 mm and 80 mm G.I. pipe delivering 19 m^3/hr is the following:

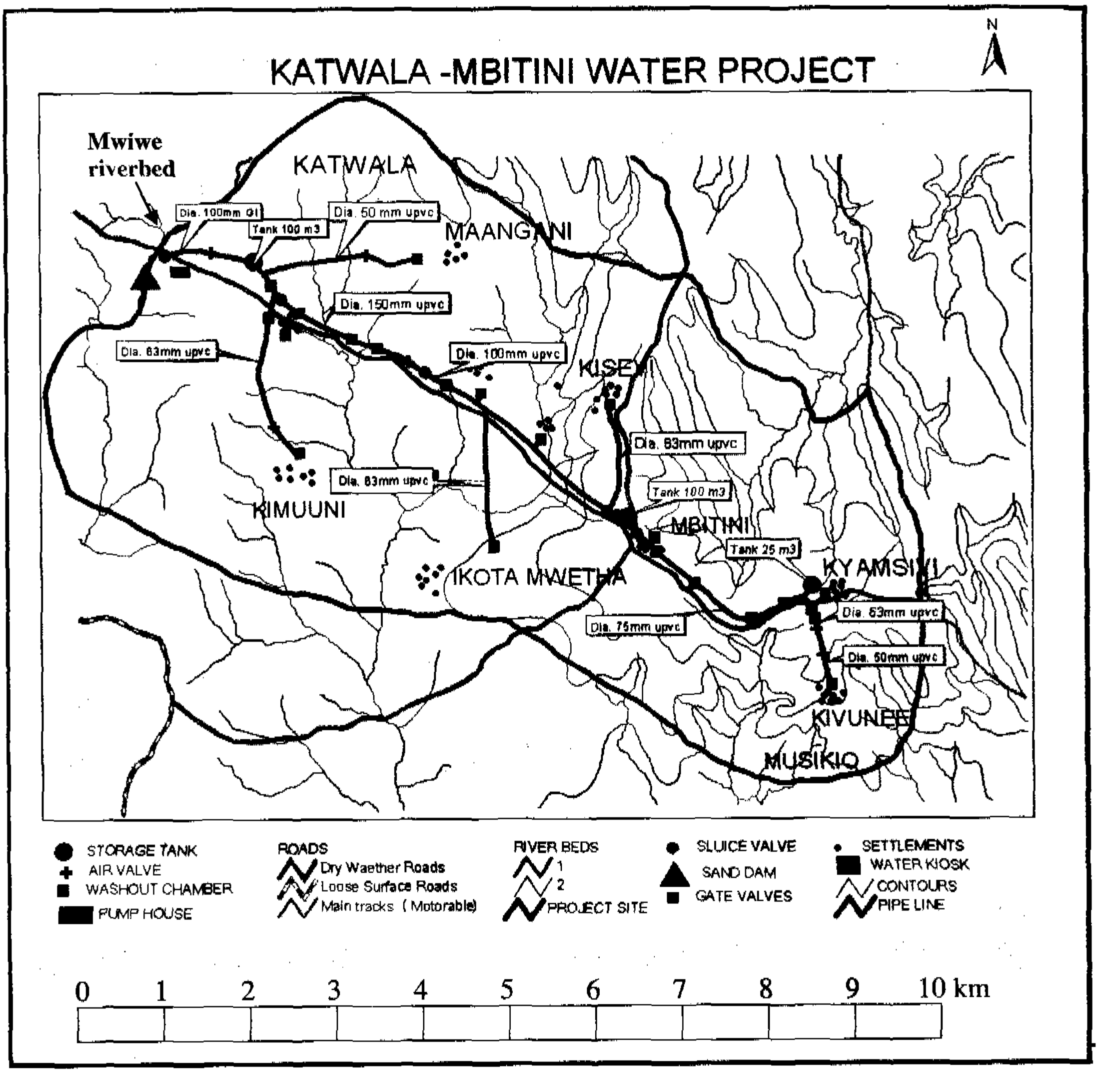
Delivery head	= 74.200 m
Frictional losses	= 57.023 m
Tank height	= 8.000 m
10% residual (extra) head	= 13.922 m
Total pumping head	**153.922 m**
Pumping head of the pump	**154.000 m**

The cost of the rising main pipes were:

Intake to head tank	**Km**	**Ksh**
Nzeuu to steel tank	5.310	7,461,435
Mwiwe to block tank	0.916	1,878,867

Water is delivered from the head tanks through ***Distribution pipelines*** to the water kiosk by means of gravity as shown on a map of the Mbitini project area on the next page.

4.11 Map showing pipes, tanks, kiosks and valve chambers of Mbitini Water Project.



More technical details and costs on the Mbitini Water Project are given in another handbook o f this series: ***Water Surveys & Designs.***

Chapter 5. Subsurface dams built of soil

5.1 History of subsurface dams

The oldest subsurface dams known were constructed in the almost waterless area around Dodoma, in then Tanganyika and now Tanzania, when the railway was built around 1905. The purpose of the subsurface dams was to provide water for the steam locomotives which they successfully did so for many decades.

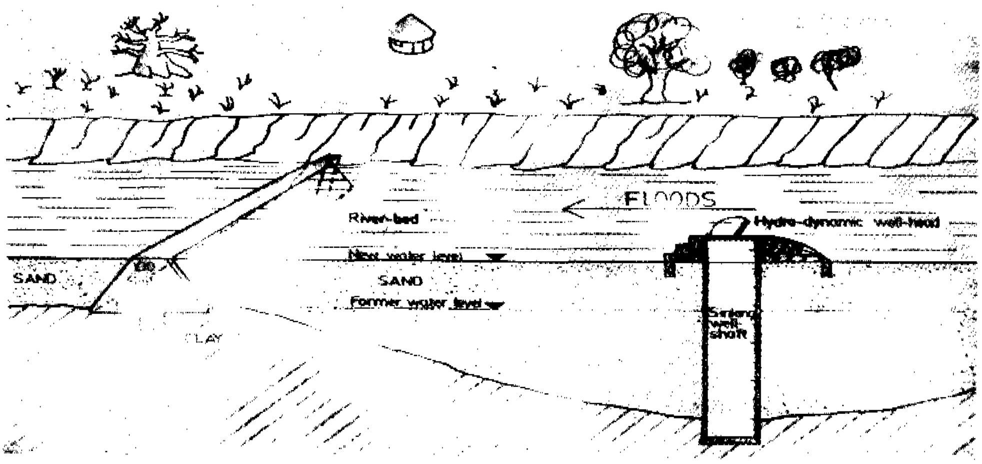
A subsurface dam was built of soil and documented by Bihawana Mission near Dodoma in the early 1950s and is still functioning well. A similarly successful subsurface dam was built in the same area in the 1920s. Several subsurface dams were built of various materials, such as soil, burnt bricks, concrete blocks and reinforced concrete during a training course for ILO in the Dodoma region in 1991. Many more subsurface dams could probably be located in many other places, but if so, they would be invisible below the sand surface of riverbeds.

5.2 Function of subsurface dams

Should the water yield from a river intake be insufficient for the demand, then a subsurface dam can be constructed cheaply of soil. The function of subsurface dams is to:

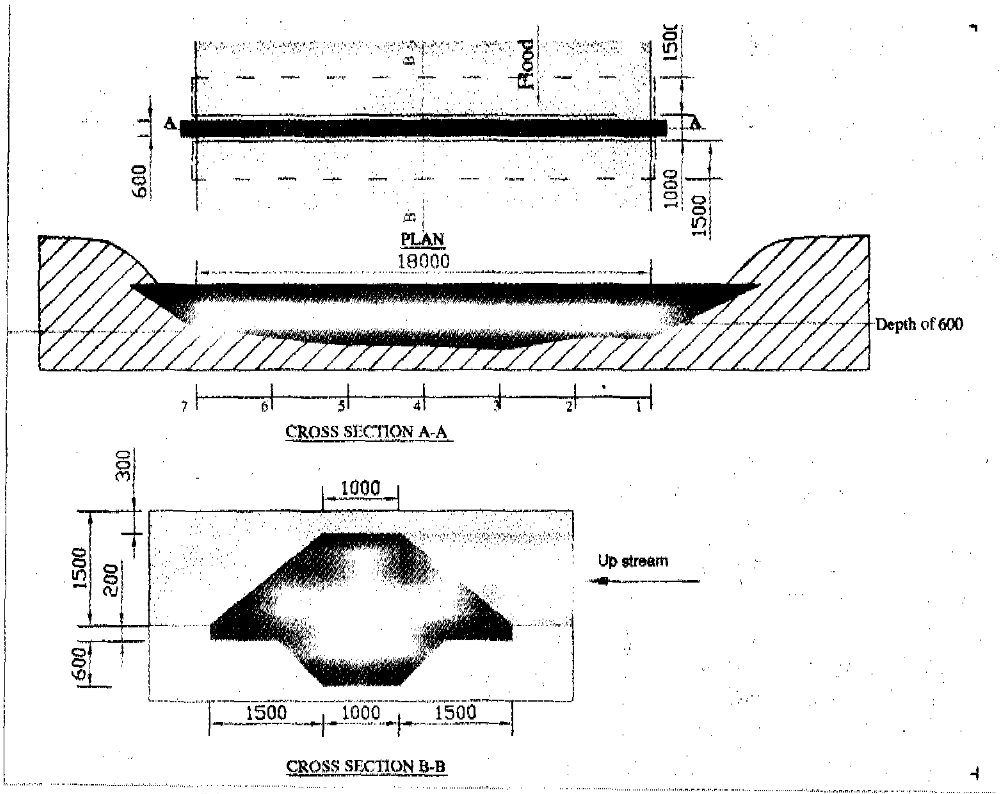
a) Block the underground flow of water between the voids in the sand, and
b) to raise the water level in the sand to about 30 cm below the surface of riverbeds.

With regard to Nzeeu riverbed, it was decided to construct a subsurface dam of soil that would increase the yield from the existing 6,270 m^3 of water to 8,282 m^3 which, together with the substantial underground replenishment would be sufficient to meet 6 months demand of 40,000 m^3.



Longitudinal profile combined with a three dimensional view of a subsurface dam built of soil.

5.3 Design and cost of Nzeeu Subsurface Dam



Plan and section of Nzeeu subsurface dam

Bill of Quantity and cost of Nzeuu Subsurface Dam

Description	Unit	Quantity	Unit cost Ksh	Total cost Ksh	Value of community contribution
Labour cost					
Surveyor/designer	Surveyor	1 x 2 days	1,200/day	2,400	
Supervisor	Supervisor	1 x 6 days	1,200/day	7,200	
Contractor	Contractor	1 x 22 days	800/day	17,600	
Artisans	Artisans	2 x 20 days	200/day	8,000	8,000
Trainees	Trainees	4 x 20 days	100/day	8,000	8,000
Labourers	Labourers	10 x 20 days	100/day		8,000
Cost of labour				**43,200**	**24,000**
Materials					
Clayey soil	Tonnes	69	100	6,900	6,900
Cost of materials				**6,900**	**6,900**
Transport of materials					
Hiring suction pump					
Tractor trailer loads	3 tonnes Days	23 loads	900	20,700	10,350
Hiring dewatering pump		4 days	800	3,200	
Cost of trans. and pump				**23,900**	**10,350**
Cost and value				**74,000**	**41,250**
Cost of subsurface dam				**115,250**	

The sand in a riverbed has been removed and the 60 cm deep key has been excavated in the floor.

The excavation is being filled with compacted moist clayey soil by a community in Myanmar (Burma)

Subsurface dams being constructed by a self-help community in Makueni.

5,3 Guidelines on construction

In order to get a maximum volume of water for a minimum of work and investment, subsurface dams, weirs and sand dams should, whenever possible, always be constructed on underground dykes that are situated downstream of underground water reservoirs, such as waterholes and water-indicating vegetation.

When a suitable site has been identified in a riverbed, the most clayey soil for construction of the dam wall has to be found. This is done by collecting some soil samples from nearby riverbanks and fields. The equipment for analyzing the soil samples consistsof some plastic bottles of equal size of which the caps have been removed and the bottoms cut off.

The bottles are placed upside down in the sand, or sloping against a wall, and filled halfway with soil samples. Water is poured on top of the soil samples several times. After some minutes it can be observed which soil sample has the slowest infiltration rate due to having the highest clay content. This soil is the most suitable for building the dam wall.

Soil samples being tested for their clay content by pouring water onto the soil samples. The sample having the slowest infiltration rate is the most suitable for dam walls. When a suitable site has been identified, all the sand in the riverbed is removed in a 3 metre wide stretch between the two riverbanks so that the floor under the sand is fully exposed.

Thereafter a 100 cm wide trench, called a key, is excavated into the floor right across the riverbed and into the two riverbanks. The depth of the key must be at least 60 cm into solid soil to prevent seepage under the dam wall.

The clayey soil identified by the testing mentioned above, can now be transported to the dam site by means of sacks, donkeys, ox-carts, wheelbarrows or a tractor with a trailer.

First the whole length of the key is filled with a 20 cm thick layer of soil that is moisten with water and compacted using either short lengths of tree trunks or cows or a tractor driven back and forth until all air is forced out of the soil. Thereafter other 20 cm thick layers of soil are laid out along the whole length of the key and dam wall, moistened and compacted until the height of the dam wall has reached to 30 cm below the surface of the sand in the riverbed.

The upstream and downstream sides of the dam wall, having a slope of about 45 degrees, are then smoothened using shovels and wooden floats. Especially, the upstream side of the dam wall should be plastered with clay or cow dung to prevent water from seeping through the dam wall.

Finally, the excavated sand is back-filled against both sides and the top of the dam wall.

It is wise to hammer two short iron bars into the riverbanks at each end of the dam wall because the dam will be invisible after the first flooding.

Chapter 6. Weirs

6.1 Various types of weirs

Weirs are water-tight structures built across flowing water streams, dry sandy riverbeds and gullies. Only weirs built across dry sandy riverbeds and gullies are described here.

Although such underground water reservoirs might only be recharged with floodwater a few times annually, they may be perennial water sources provided the storage capacity is sufficient large and without underground leakages. Weirs can be constructed of various designs and materials, such as;

A wall of soil supported on both sides with plastic sacks filled with soil and a spillway at one end of the dam wall.

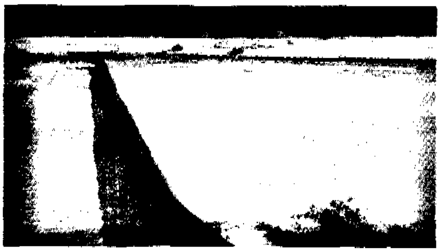
Rubble stones mortared together with a spillway at the middle of the dam wall.

A similar but more sophisticated weir.

The above weirs were built across gullies to provide for sand harvesting.

This long weir was built of rubble stone masonry across a sandy riverbed. It supplies water throughout the year.

Once or twice a year, the underground water reservoir is replenished by floods.



A hand-dug well is sunk upstream of this weir for extraction of water

The above weirs were built across riverbeds to supply domestic water.

This simple and low-cost weir was constructed across a small stream by a farmer himself in Central Kitui. He uses the water for bucket irrigation of vegetables for sale.

Many similar weirs have been built by farmers themselves. Some of the farmers use small petrol-powered pumps for irrigation of vegetables and fruit trees.

This is a weir constructed across a small stream on the Sagalla Hill at Voi long time ago.

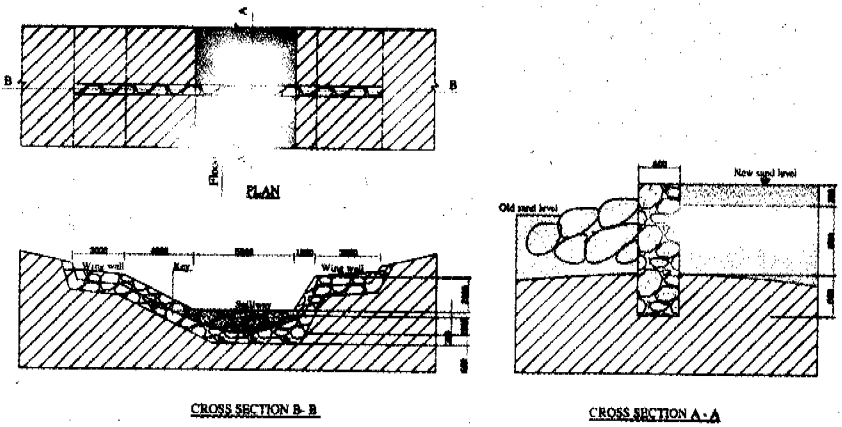
The water is gravitated down to a piped water scheme in the lowland near the foot of Sagalla Hill.

This weir was built across Voi riverbed by Mau Mau prisoners in the 1950s.

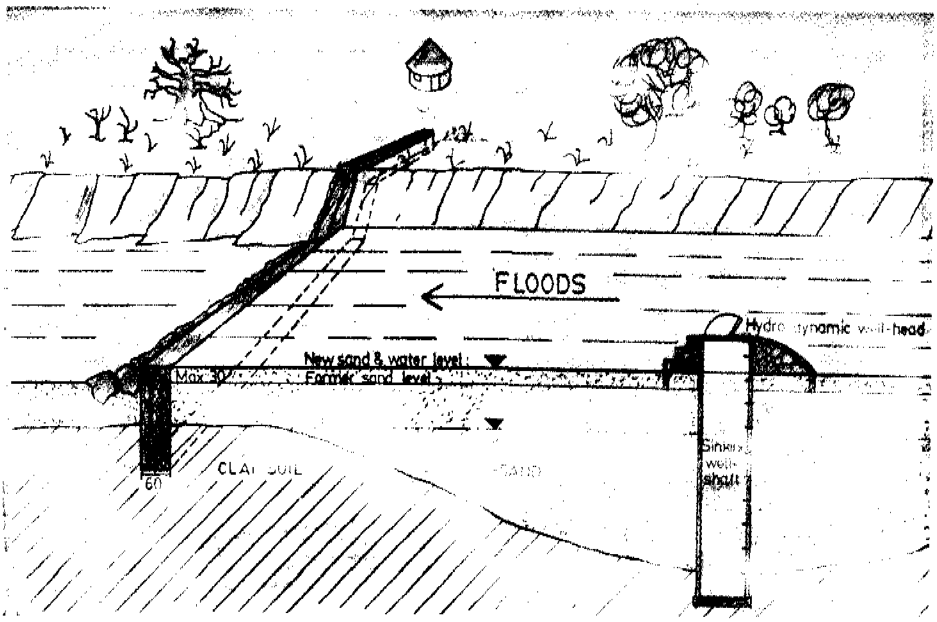
The purpose was to divert flood water for large scale seasonal irrigation of farmland situated at a lower elevation.

The required volumes of water were regulated by opening the gate covering the hole seen in the wing wall. Released water would pass from the hole through a canal to the field.

6.2 Design and cost of weir



Plan and profiles of Talek weir.



longitudinal profile combined with a three-dimensional view of a weir built on an underground dyke and stretching across a riverbed.

A hand-dug well equipped with a hydro-dynamic well head is sunk at the deepest point of the underground water reservoir.

The Talek weir under construction. Some PVC pipes were inserted in the dam wall to discharge the water accumulating upstream. After completion of the wall , the pipes were removed and the holes in the dam wall were sealed.

Bill of Quantity and cost of Talek weir built of rubble stone masonry. Ksh.

Description A weir with wing walls having a total length of 18 metres	**Unit**	**Quantity**	**Unit cost**	**Total cost**	**Value of community contribution**
Labour cost					
A surveyor/designer	1 Surveyor	6 days	1,200/day	7,200	
A supervisor	1 Supervisor	12 days	1,200/day	14,400	
A contractor with	1 Contractor	26 days	800/day	20,800	
his/her team of	3 Artisans	24 days	200/day	14,400	14,400
builders and	4 Trainees	24 days	100/day	9,600	9,600
community workers	10 Labourers	24 days	100/day		24,000
Cost of labour				**80,800**	**48,000**
Materials					
Cement	50 kg bags	105 bags	600	63,000	
Barbed wire, g 12.5	25 kg rolls	2 rolls	2,500	5,000	
River sand	Tonnes	15 tonnes	200		3,000
Crushed stones	Tonnes	15 tonnes	600		9,000
Hardcore	Tonnes	40 tonnes	200		8,000
Water	Oil-drums	50 drums	100		5,000
Cost of materials				**68,000**	**25,000**
Material transport					
Tractor trailer loads	3 tonne loads	17 loads	900	15,300	
Cost of transport				**15,300**	**7,650**
Cost and value				**134,800**	**50,700**
Total cost of weir				**185,500**	

6.3 Construction procedures

A 60 cm wide trench was dug across the riverbed and into the banks of Talek riverbed bordering the Maasai Mara.

A small stream of water in the riverbed was diverted over the trench in some PVC pipes. A petrol pump sucked water out of trench while it was being excavated to its final depth of 60 cm into solid and impermeable soil.

Thereafter the trench was filled with concrete packed with rubble stones and reinforced with double lines of barbed wire, g.12.5.

When the trench had been filled with concrete, rubble stones and barbed wire for every 30 cm height, large flat stones were mortared onto the concrete to form the outside shuttering of the dam wall.

Concrete, rubble stones and lines of barbed wire were filled in between the flat stones. The PVC pipes were removed and the dam wall plastered.

6.4 Maintenance

Flood water passing over spillways always try to remove the sand from the downstream side of weirs. It is therefore always important to place as large boulders as possible against the downstream side of weirs. It might be necessary to use reinforced concrete to bond the boulders together and place them properly in the event of violent flooding.

The photo below shows a weir that was built 20 years ago in the dry area of Mutha. The weir supplies water all year round for the hand-dug well into the riverbank as seen on the front cover of this handbook.

The boulders that were concreted to the downside of the weir were washed away a long time ago. The weir and riverbed are now exposed to erosion that may cause the weir to be undermined by flood water. That in turn will result in the weir being washed away, thereby leaving the hand-dug well dry until a new weir can be built.

Chapter 7. Sand dams

7.1 History of sand dams

Sand dams have been constructed and used in India for centuries. The first sand dams known in Kenya were built by the District Agricultural Officer, Eng. Classen, as part of a development project named *African Land Development Board* (ALDEV). That project constructed many earth dams, rock catchment dams, sand dams, boreholes and rangeland schemes in Ukambani from 1954 to independence in 1964.

Some of the sand dams built 50 years ago are still functioning despite lack of maintenance. An example of the successful sand dams built in the 1950 s is Manzui at Kyuso.

Some 200 sand dams have been constructed in Machakos, Makueni, Kitui, Mwingi, Embu and Meru by various agencies and ministries since the early 1970s. An evaluation showed that only about 5% of the dams built during the last 40 years were functioning. This high failure rate is not surprising upon learning that the engineers of today had not learnt about subsurface dams, weirs and sand dams during their studies.

This handbook is based on the techniques used for survey, design and construction of sand dams built according to the ALDEV design in Tanzania, Burma, Somalia, Eritrea and Kenya since 1978.

Should a reader find that he or she still needs more information on the survey, design, construction, etc. before starting on construction of sand dams, please turn to the References on the last page.

Hopefully, this will assist relevant agencies and ministries to realise the big potential for turning some of thousands of dry riverbeds in the arid and semi-desert regions of Kenya into perennial water sources for people, livestock and irrigation.

7.2 Functions of sand dams

Water supply

The main function of sand dams is to increase the volume of sand and water in riverbeds.

The Mwiwe sand dam increased the volume of extractable water from139 m^3 to 2,997 m^3. Despite the fact that the reservoir has only been recharged once by a small rain shower during the last 18 months, 75 m^3 of fresh water is extracted daily from the riverbed.

Sand harvesting and rehabilitation of gullies

Sand dams can also be built in gullies to supply both sand and water, while healing the gullies. 10 sand dams built in gullies harvest sand instead of the sand silting up Lake Victoria. The construction cost of the sand dams was recovered in less than 18 months through the sale of sand.

If the purpose of building sand dams is to harvest sand and rehabilitate gullies, then weirs built of plastic bags filled with soil are more profitable.

Riverbed crossings

Rural roads often cross riverbeds. In remote areas, people simply drive across such riverbeds. Passable crossings can be made by concreting a curved and reinforced concrete slab over the riverbed called ? Irish Bridges? by humorous Englishmen.

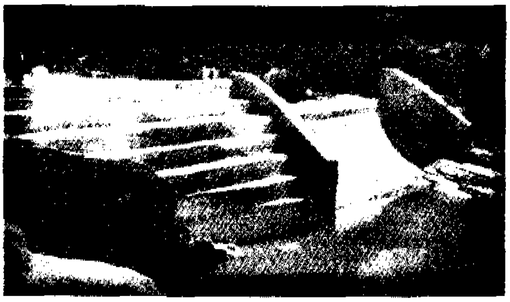
Riverbed crossings can be made into sand dams capable of holding water upstream of the crossing as seen in this photo from Mulango at Kitui where SASOL has constructed about 480 weirs.

7.3 Five types of sand dams

This photo is of a sand dam built according to the ALDEV design which has functioned for 50 years without failure. 35% of water can be extracted from its sand reservoir if the spillway is raised in stages of 30 cm height above the level of sand deposited by floods. The design criteria and construction procedure are explained on the following pages.

The spillway of this sand dam in Tharaka, Meru, was not built in stages. Therefore its reservoir contains fine-textured sand and silt from which no water can be extracted.

The sand reservoir of this sand dam in Taveta was also silted up with silt and fine-textured sand due to not building the spillway in stages. No water can be extracted from this dam.



USAID built this interesting sand dam in Kitui in the 1980s. The dam reservoir contains coarse sand from which people draw water.

Although the dam has two spillways; one made of steps and being higher than the other without steps, the left side of the spillway is heavily eroded by floods.

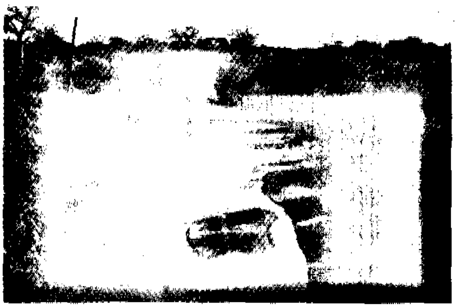
7.4 Criteria for construction of successful sand dams

The major reasons for many failed sand dams are due to insufficient knowledge of:
a) Identifying suitable sites for dam walls and dam reservoirs.
b) Design criteria and flood dynamics.
c) Construction procedures.
d) Maintenance requirements.

Should a specific site not meet all the criteria shown on the following pages it is not advisable to construct a sand dam.

7.4.1 Site criteria

1) Suitable riverbeds must have two high riverbanks to enable the wing walls to keep over-flowing flood water within the spillway and not flowing over the riverbanks.



If flood water is allowed to flow over the wing walls and riverbanks, it will erode the riverbanks and cause the river to change its course, thereby leaving the sand dam as a ruin, as seen on one of the riverbanks here.

2) Dam walls should never be built on fractured rocks or large boulders because such walls cannot be made water-tight. Water will always seep out between the boulders as seen in this photo.

3) Dam walls should therefore always be built either on a solid bedrock base or keyed 1 metre into solid and impermeable soil.

If dam walls are keyed less than 1 metre into solid and impermeable soil, water will find its way out under the dam wall and cause the wall to hang in its wing walls over the riverbed.

4) Suitable sites for dam reservoirs should be without boulders and fractured rocks because they will drain water from the reservoir into the ground below.

While such seepage is unwanted for sand dams it can be beneficial for recharge of ground water and nearby boreholes.

5) Riverbeds with fine-textured sand originating from flat land are also unsuitable for sand dams, because less than 5% of the water stored in the voids between the sand particles can be extracted.

6) Wide riverbeds, say of more than 25 metres width, are also unsuitable for sand dams because they become too expensive due to the reinforcement required for the long dam walls.

Riverbeds exceeding 25 metres in width are suitable for subsurface dams built of soil because that material is plastic and do not crack like concrete.

7) The whitish stones seen on the right side of the photo are called *calcrete*. Calcrete is licked by livestock and wild animals because it contains salt and other minerals needed by them.

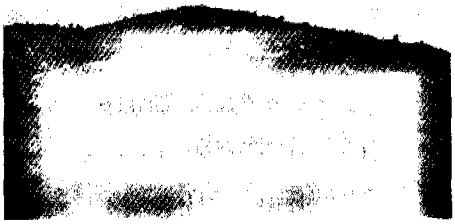
If calcrete is situated upstream on the riverbanks where the dam will be located then the water will be saline and therefore only useful for livestock.

8) Water-indicating vegetation, that requires water all year round, should be growing on the banks where the reservoir will be located as proof of the riverbed capacity to store water.

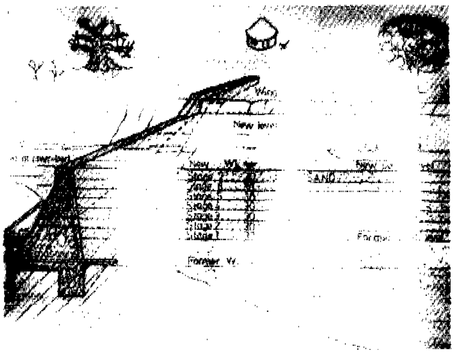
A list of water-indicating vegetation, such as the Mukuyu (wild fig) seen next to a hand-dug well in a dry riverbed in the photo.

9) Waterholes, even temporary ones, should preferably also be located where dam reservoirs will be located to prove that the riverbed has no leakages draining water into the ground below.

10) Catchment areas should contain stones or stony hills, from where rainwater and floods can transport eroded stone particles, which coarse sand is made of, to the riverbeds and deposit them into the dam reservoirs.



11) As mentioned earlier, sand dams, weirs and subsurface dams should always be constructed on natural underground dykes to gain free storage of water while also reducing construction costs.

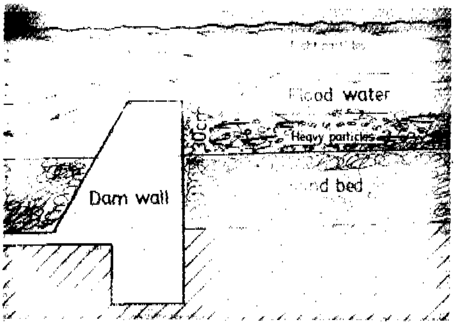


7.4.2 Design criteria

1) The most important design criteria is to ensure that flood water will deposit coarse sand into the dam reservoir from where up to 35% of water can be extracted. Most reservoirs contain silt and fine textured sand from where little or no water can be extracted as seen in the photo.

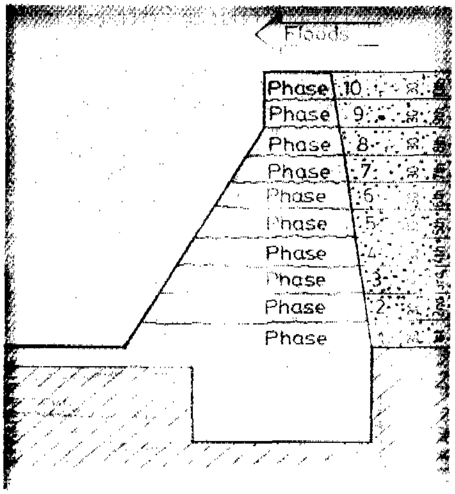
Flood water contains all sizes of silt and sand particles. Since sand is heavier than silt, sand will always be transported in the lowest part of the current of the flood water, while silt being lighter will float in the upper part of the flood water.

Therefore, if flood water is made to pass over a barrier being about 30 cm high, the barrier will trap the heavy coarse sand while the lighter silt will pass over the barrier on its way downstream to the riverbed.



Practically, this method of harvesting coarse sand is obtained by raising the spillway of sand dams in stages of 30 cm height over the sand level in riverbeds.

When flood water has deposited coarse sand to the first stage of 30 cm height, the spillway is again raised by another phase of 30 cm. When the sand from next flood has reached the height of the second stage, the spillway is again raised by yet another stage of 30 cm and so on until the final height of the spillway is reached as seen in the sketch.



The photo shows the spillway of a sand dam at Makueni that has reached the second stage of raising the spillway in stages of 30 cm above the sand level.

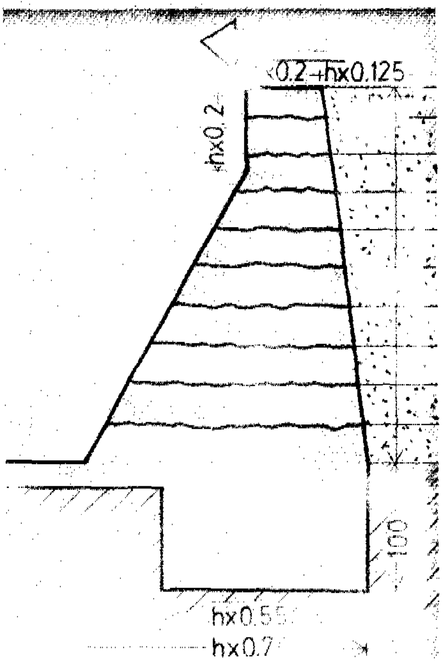
Judging from the height of the person standing on the spillway, another 6 stages, each of 30 cm, are to be raised when the next 6 floodings have deposited their coarse sand.

2) The force of water and sand in dam reservoirs against the wall of sand dams is counter balanced by making the width of the base for dam walls 0.75 (3/4) of the height of its dam wall.

3) As mentioned earlier, dam walls must be keyed at least 1 meter into solid and impermeable soil. The thickness of the key should be 0.55 (1/22) of the height of its dam wall.

4) The width of the crest and its height on the downstream side should be 0.2 (1/5) of the height of its dam wall.

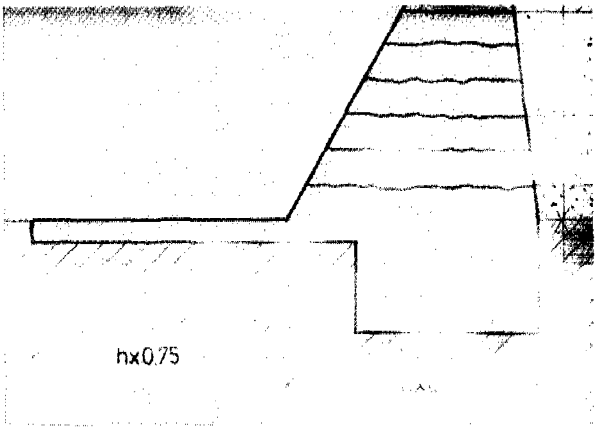
5) In the ALDEV design shown here the front of the dam wall is leaning downstream with a gradient of 0.125 (1/8) of the height of its dam wall.



6) The spill-over apron onto which the over-flowing water will fall with force, must be reinforced onto the dam wall.

The apron should be of the same width as the dam wall and extend up along the wing walls.

Large stones should be set into the concrete to break the force of water.



7) The key under the dam wall must extend all the way up to the end of the wing walls, otherwise water might seep underneath them, thereby eroding the riverbanks.

8) Water can be extracted from sand dams by one of the types of river intakes mentioned earlier or gravitated through a galvanised pipe inserted into the dam wall to a tapping point somewhere downstream. Note the stage of closing the spillway.

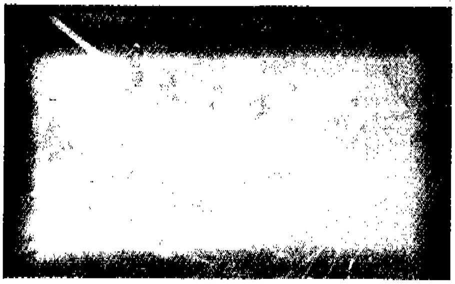
7.4.3 Maintenance criteria

Sand dams require careful maintenance and immediate repair during flooding where hundreds of tonnes of water fall over the spillway and onto the spill-over apron. Flood water may also spill over and erode the wing walls and, perhaps, even over the riverbanks during heavy rains.

Owners of private sand dams can usually mobilize repair works quickly and keep their sand dams functioning well for many years. Maintenance and repair of community-owned sand dams take much longer time because the committees have to meet and decide what to do and how to pay for it.

This sand dam was surveyed, designed and constructed successfully according to all criteria during a training course at Wote in Makueni in 1996.

During a study tour to the sand dam a couple of years later, the community was advised to repair the eroded apron at the wing wall. It didn t. The dam wall was washed away during the next flood.



The lower part of the spill-over apron was washed away by heavy floods due to insufficient reinforcement.

If the repair had not been carried out promptly, water would have seeped under the dam wall and destroyed it.

Note the sand harvesting activity and the phases of the closed spillway.

This sand dam at Kibwezi has a number of problems due to having been built on large boulders and complete lack of maintenance since it was built by MoA in 1978.

Despite all the criteria listed above, sand dams have a great potential for supplying water from small riverbeds in the semi-arid, arid and semi-desert zones of Africa, provided the criteria are adhered to.

Chapter 8. Mwiwe Sand Dam

8.1 Yield of water from Mwiwe Sand Dam

As mentioned earlier, Mwiwe sand dam was constructed to increase the volume of the water reservoir from 139 m^3 to 2,997 m^3 from a small riverbed, Mwiwe, in Kitui.

Although the spillway was closed only to the second stage, which is 60 cm above the original sand level, 75 m^3 of fresh water was pumped from the reservoir every day for 18 months amounting to a total 40,500 m^3. Part of the recharge came from a small flooding and a small continuous underground flow of seepage from some weirs situated a few kilometres upstream in the riverbed.

When more floods have deposited sand in the reservoir the spillway will be raised in stages, each of 30 cm height.

8.2 Design calculations for Mwiwe Sand Dam

The Mwiwe Sand Dam was designed according to the specifications of ALDEV (African Land Development Board) design that has proven to be successful since the mid 1950s. The main specifications of this particular design are:

The height of the spillway is determined by the maximum height of floodwater that can safely spill over the spillway without eroding the upper ends of the wing walls and the riverbanks. The maximum height of floodwater can usually be known by interviewing elderly residents who can point out how high the water level had reached during the highest flooding in their time.

In Mwiwe riverbed the highest flood level was found to be 100 cm above the sand level. Since the two riverbanks were 250 cm above the same sand level the maximum height of the spillway was found be:

Height of riverbanks:	250 cm
Highest flood level:	100 cm
Maximum height of spillway:	**150 cm**

The Mwiwe dam wall has the required criteria of:

a) A base that is 0.75 (3/4) of the height of the spillway equal to:
height 150 cm x 0.75 = 112.5 = **113 cm.**
The key under the dam wall has a depth and width of:
100 cm into solid and impermeable soil and have a width of:
height of dam wall x 0.55 equal to 150 cm x 0.55 = 82.5 cm = **83 cm**

b) The upstream side of the dam wall has a gradient of:
height x 0.125 equal to:150 cm x 0.125 = 18.75 cm = **19 cm.**

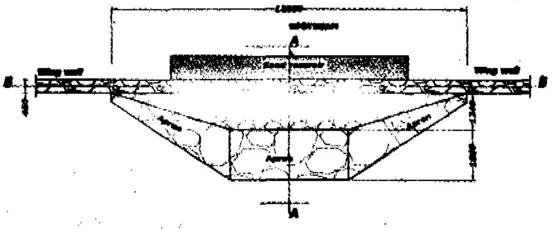
c) The crest has a width of: height x 0.20 equal to 150 cm x 0.20 = **30 cm**
and is vertical on the downstream side for a similar distance of **30 cm.**

d) The spillway was only raised in stages 30 cm above the level of sand in the reservoir.

The keys under the two wing walls have:
A width of **45 cm** and a depth of **60 cm into solid and impermeable soil**

The spill-over apron is:
Reinforced together with the base of the dam wall.
Has a width being equal to the base = **113 cm.**
Stretch all along the downstream side of the dam wall and wing walls with large rubble stones set in the concrete.

8.3 Design of Mwiwe Sand Dam



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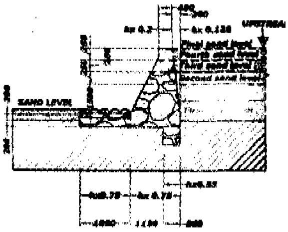
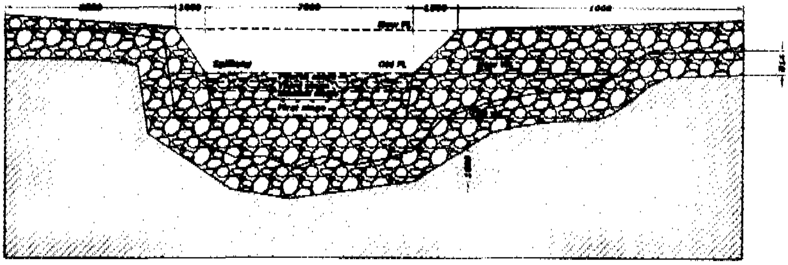


SECTION A - A



SECTION B-B

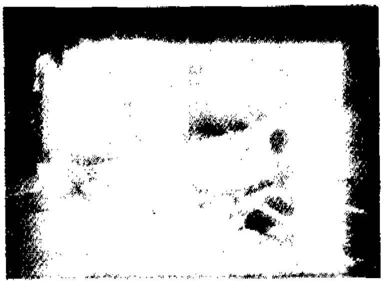
8.4 Construction procedures for Mwiwe Sand Dam

1) The outline of the wing walls, dam wall and spill-over apron was marked with wooden pegs and nylon strings according to the measurements given on the design criteria.

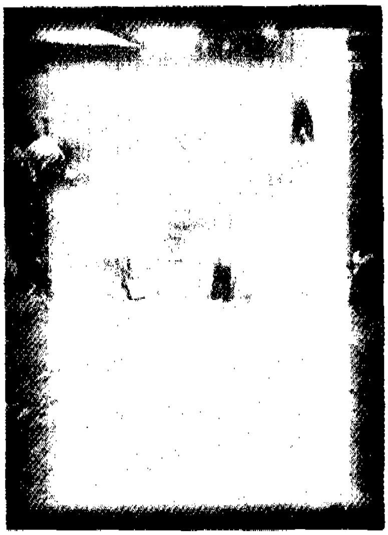
2) All top soil, sandy soil and roots within the marked areas were removed until solid and impermeable soil was reached.

3) The key and base were excavated into solid and impermeable soil below any layer of sand and sandy soil encountered as follows:

Structure of sand dam	Depth	Width
Base of dam wall	30 cm	113 cm
Base of spill-over apron	30 cm	113 cm
Key under dam wall	100 cm	83 cm
Key under wing walls	60 cm	45 cm



4) Two templates were made of timber. The inner sides of the templates gave the outline of the spillway and dam wall given under the design criteria. The height of the wall was 150 cm. The upstream wall had a gradient of 19 cm to the vertical. The crest was 30 cm wide. The downstream wall had a vertical drop of 30 cm from where it sloped towards the base that was 113 cm.



5) The completed excavation was then filled with 30 cm high layers of cement mortar of mixture 1:4 into which many boulders were compacted without touching each other.

6) The rubble stone masonry was reinforced with Y8 twisted iron bars laid in the concrete for every 30 cm height.

7) After the excavation was filled with rubble stone masonry, the two templates were erected at the ends of the spillway for the purpose of giving the outline of the dam wall, spillway and wing wall.

8) Nylon strings were drawn tightly from the inner corners of the templates to pegs hammered into the soil next to the upper end of the wing walls.

9) Flat stones were then set in cement mortar 1:4 along the inner lines of the strings to make the outer sides of the wing walls.

10) Next day the space between the flat stones was filled with mortar 1:4 into which round rubble stones were compacted. Thereafter flat stones were mortared onto the wing walls so that they could be filled with mortar and stones next day.

11) The base of the dam wall, the spill-over apron and the spillway, the latter being situated between the two templates, were only raised to 30 cm above the original sand level in the riverbed.

12) Luckily, a small flooding deposited a 30 cm thick layer of coarse sand that reached the first stage of the spillway. The spillway was therefore raised another 30 cm above the sand level for the next stage of the spillway.

13) Large boulders were concreted into the spill-over apron to reduce the velocity of surplus water falling over the spillway and wing walls.

14) The wing walls were thereafter plastered while the spillway was left open until the next flooding

15) The next flooding deposited coarse sand to the level of the spillway. The spillway was raised another 30 cm above the new sand level.

16) The process of rising a spillway in stages of 30 cm height may be completed in one rainy season provided the required number of flooding occur and builders are ready for their work without delay.

8.5 Bill of quantity and cost of Mwiwe Sand Dam

Description A sand dam being 2 m high and 12 m long	**Unit**	**Quantity for Mwiwe sand dam**	**Unit cost Ksh**	**Total cost Ksh**	**Value of community contribution**
Labour cost					
A surveyor/designer	1 Surveyor	10 days	1,200/day	12,000	
A supervisor	1 Supervisor	18 days	1,200/day	21,600	
A contractor, inclusive his/her	1 Contractor	1 x 42 days	800/day	33,600	
team of builders and community	3 Artisans	3 x 40 days	200/day	24,000	24,000
workers	4 Trainees	4 x 40 days	100/day	12,000	12,000
	10 Labourers	10 x 40 days	100/day		40,000
Cost of labour				**103,200**	**76,000**
Materials					
Bags of cement	50 kg bags	245	600	147,000	
River sand	Tonnes	150	200		30,000
Hardcore 2" to 6"	Tonnes	120	200		24,000
Water	Oil-drum	30	100		3,000
Barbed wire, g 12.5	25 kg rolls	4	3,000	12,000	1,500
Y 8 twisted iron bars	Length	30	350	10,500	
Cost of materials				**169,500**	**58,500**
Transport of materials					
Hardware lorries	7 tonne	2 loads	5,000	10,000	
Tractor trailer loads	3 tonnes	44 loads	900	39,600	19,800
Cost of transport				**49,600**	**19,800**
Cost and value				**322,300**	**154,300**
Total cost of Sand Dam				**476,600**	

Bill of Quantity and cost of closing spillway

Description Closing last 3 stages of 30 cm height of spillway	**Unit**	**Quantity for closing spillway**	**Unit cost Ksh**	**Total cost Ksh**	**Value of community contribution**
Labour cost					
Supervisor	1 Supervisor	2 days	1,200/day	2,400	
Contractor, inclusive his/her	1 Contractor	1 x 3 days	800/day	2,400	
team of builders and community	1 Artisan	1 x 6 days	200/day	1,200	1,200
workers	2 Trainees	2 x 6 days	100/day	1,200	1,200
	10 Labourers	10 x 6 days	100/day		6,000
Cost of labour				**7,200**	**8,400**
Materials					
Bags of cement	50 kg bags	20	600	12,000	
River sand	Tonnes	4	200		800
Hardcore 2" to 6"	Tonnes	10	200		2,000
Water	Oil-drum	15	100		1,500
Cost of materials				**12,000**	**4,300**
Transport of materials					
Hardware lorries	3 tonne	1 load	3,000	3,000	
Tractor trailer loads	3 tonnes	3 loads	900	2,700	1,350
Cost of transport				**5,700**	**1,350**
Cost and value				**24,900**	**14,050**
Total cost of spillway				**38,950**	

Total cost of Mwiwe Sand Dam

Sand dam with open spillway	322,300	154,300
Completing spillway in 3 stages	24,900	14,050
Cost and value of sand dam with spillway	**347,200**	**168,350**
Grand total of sand dam with completed spillway	**515,550**	

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Training, implementation and documentation of rainwater harvesting in ASAL regions

Introduction

ASAL Consultants Ltd. promotes affordable water in dryland using locally available skills and materials to construct affordable and sustainable water projects together with communities in ASAL (Arid and Semi-arid Land).

Rock catchment tank and dams.

An earth dam built manually.

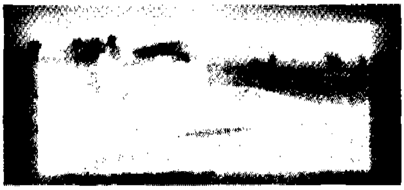
We are specialised in implementing a combination of practical and theoretical training courses for engineers, technicians and artisans.

The participants learn hands-on how to survey, design and construct water projects in co-operation with self-help groups.

Services offered

ASAL Consultants Ltd. offer technical services on:

* Ponds and earth dams.
* Subsurface and sand dams.
* Hand-dug wells, river intakes.
* Roof, rock, road and ground catchment systems.



A hydro-dynamic well-head on a deep hand-dug well in a lugga.

A subsurface dam being constructed of rubble stone masonry.

ASAL Consultants Ltd. was registered in Kenya in April 1990 as a consulting firm.

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