"Harvesting Rainwater in Semi-arid Africa" consists of 6 Manuals:

Manual No. 1. Water Tanks with Guttering and Hand-pump.

Manual No. 2. Small Earth Dam built by Animal Traction.

Manual No. 3. Rock Catchment Dam with self-closing Watertap.

Manual No. 4. Shallow Wells with Bucketlift.

Manual No. 5. Sub-surface and Sand-storage Dams.

Manual No. 6. Spring Protections.

Each Manual deals with siting criteria, standard designs and bills of quantities in a simple text and drawings.

The Manuals are based on practical experience gained by building some 700 water structures for rainwater harvesting in semi-arid Kenya over the last 14 years.

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Erik Nissen-Petersen and Michael Lee

SURVEYORS AND CONTRACTORS MANUAL
ON
SUB-SURFACE AND SAND-STORAGE DAMS

C O N T E N T S **PAGE**

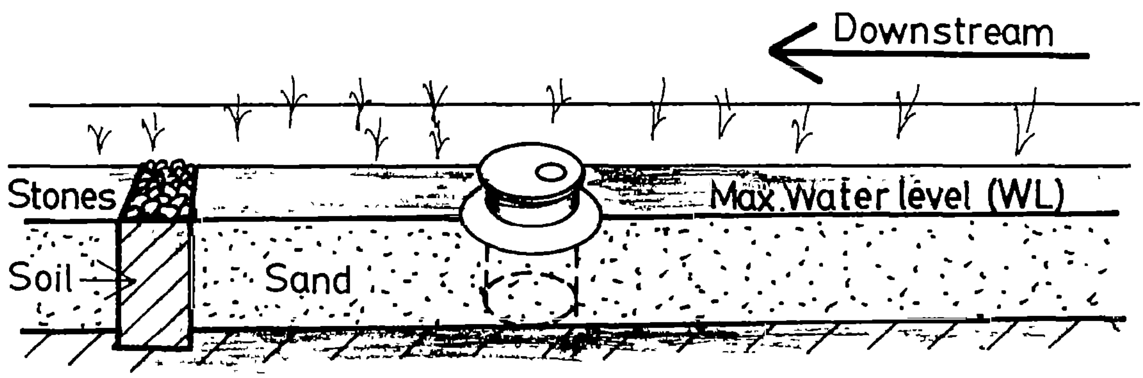
SURVEYORS MANUAL FOR SUB-SURFACE DAM

1. Introduction

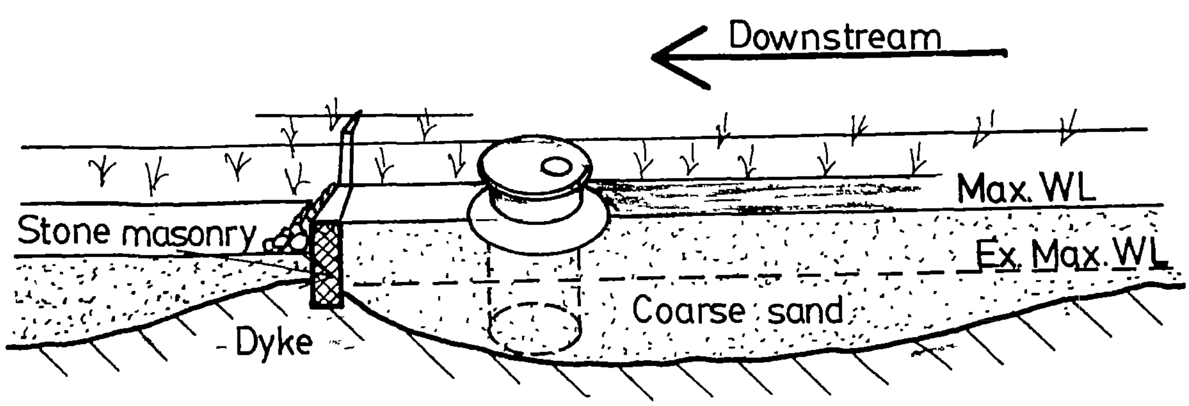
Sub-surface dams are seepage prevention structures which are built across sand-river beds to improve the productivity of shallow wells. Subsurface dams should only be built if a shallow well situated upstream has shown to produce water for nearly all months of the year.

There are three types of sub-surface dams designed to prevent seepage.

a) The clay-plug dam is a trench excavated down to an impermeable clay or rock layer below the river bed and filled with compacted clay soil to produce a relatively impermeable barrier. It is cheap to build and best for deep river beds and those with clay rather than rock below the sand in the riverbed.



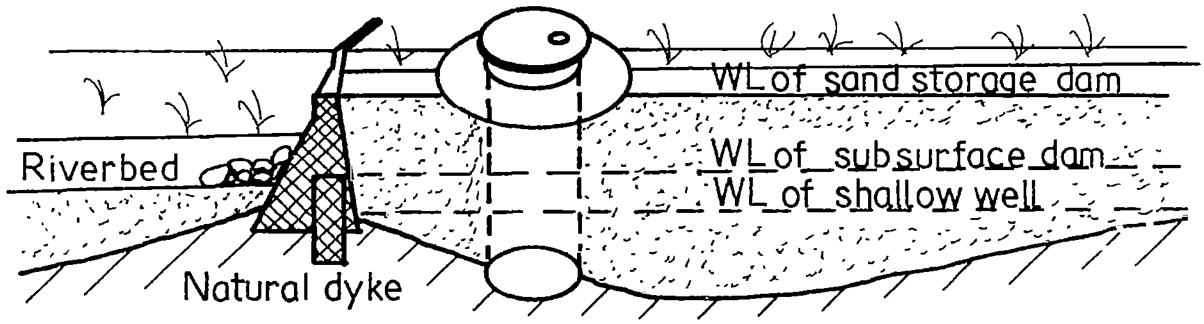
b) The masonry sub-surface dam is also a filled trench excavated into the bed, but a stone and mortar wall is built across the width of the river. This is more expensive and is best for those sites where a solid rock layer comes within 2 to 4 metres of the surface.



c) The sand-storage dam is a dam built where a rock outcrop is exposed or where the riverfloor below the sand consists of impermeable murram or clay.

The dam is built into a water-tight sub-surface reservoir. The wall is raised above the level of the riverbed in 50 cm increments until a final height of up to 5 metres is reached.

This builds up the riverbed with coarse sand which can hold up to 30% of water within the sand itself. This is important for extending the water-bearing period of a shallow well past the time it normally dries up. Masonry sub-surface dams can be converted into sand-dams whilst clay pug dams cannot.



2. Sub-Surface Dam of Clay-plug

To increase water seeping through the sand into a shallow well sited in the bed, a seepage prevention structure can be built at a suitable place downstream. The objective is to place an impermeable barrier across the river bed from the surface down to the point where another impermeable barrier is reached below. This lower barrier can either be unweathered bedrock, preferably where it is brought up towards the surface to form a natural dyke across the channel, or soil with low permeability such as a layer of clay.

With a clay-plug dam, the cross-channel barrier is made by digging a trench and filling it full of compact, fine-grained soils of the clay-rich types. Because water moves much more slowly through clay soils than it does through sandy soils the clay plug acts just like a dam.

3. Site Selection

The best site for this sub-surface dam is where the impermeable bed of clay soil is rising up towards the surface of the river bed. Not only does this reduce the size of the plug dam needed to prevent seepage, it also means that upstream there will be a depression under the river bed where more water will be stored.

The dam should be downstream of the well. If the channel narrows downstream of the well then the sub-surface dam should be built across this narrow section, again because it means a smaller dam can be built. A shallow well or an unlined dug pit with water for many months in a riverbed can indicate good sites for a sub-surface dam. Vegetation can also be a good indicator of key sites.

Depending on the depth of the shallow well, the sub-surface dam should be built relatively near to the well so that when recharge from upstream ceases, the water stored in the soil behind the dam can almost all be used. If the dam is too far downstream, the base of the dam will be below the bottom of the well. Thus some of the water stored behind the dam in the sandy soil will be below the reach of the well.

To find the best site for the dam, probes should be made with an auger or iron rod downstream from the well along the centre of the river bed every 5 or 10 metres. The depth to the bedrock or to a layer of clay-rich soil below the sandy bed should be noted. The dam should be built where this depth is the shallowest within the given distances.

To determine whether the soil is clay a simple hand-rolling and squeezing method can be used. When you rub clay soils between your fingers they feel smooth and sticky with only a few large or rough grains. If they are squeezed when they are dry they are very solid and form hard lumps. The lumps will not break apart easily. If they are squeezed when they are wet they can be formed into a long thin ribbon if they are then rolled between the palms of the hand. If they are dropped into a glass jar full of water and shaken they form a cloud that takes a long time to settle.

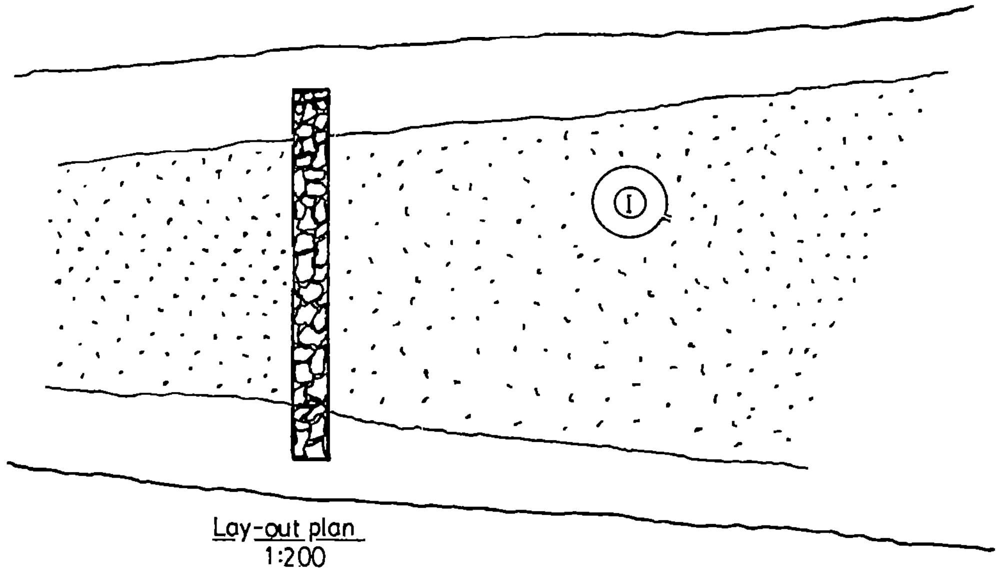
Vegetation Indicating a Sub-Surface Reservoir

Botanical Name.	Kikamba Name.	Depth to water level.
Cyperus rotundus	Kiindiu (Grass)	4 to 7 metres.
Arundinaria alpina	Nyaangi (Grass)	4 " 7 "
Vangueria roundata	Kikomoa (Tree)	5 " 8 "
Delonix eleta	Mwangi (Tree)	5 " 10 "
Grewia spp	Itiliku (Tree)	7 " 10 "
Maruhamia platycalyx	Muu (Tree)	8 " 15 "
Maruhamia hildebrandtii	Myuu (Tree)	8 " 15 "
Borassus aethiopium	Kyatha (Palm)	10 " 15 "
Hyphaene coriacea	Mlala (Palm)	10 " 15 "
Ficus walkenfieldii	Mombu (Fig Tree)	10 " 15 "
Ficus capensis	Mukuyu (Fig Tree)	15 " 20 "
Ficus natalensis	Muumo (Fig Tree)	10 " 15 "
Kigelia africana	Mautini (Tree)	15 " 20 "
Piptadenia hildebrandtii	Mukami (Tree)	15 " 20 "
Acacia seyal	Munina (Tree)	15 " 20 "

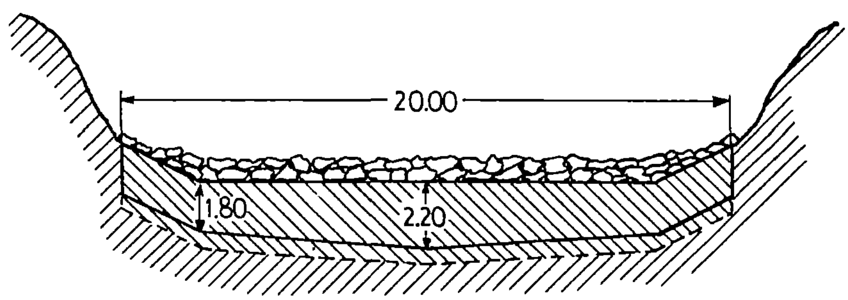
Clay-plug dams are very cheap because all the materials are freely available and only labour is required. They must be protected on the surface and compacted as firmly as possible as the trench is filled.

They are the best type of sub-surface dam to build if the depths to the impermeable layer are large and/or the impermeable material is clay soil. Building a masonry dam at such a location would be expensive and only slightly more effective.

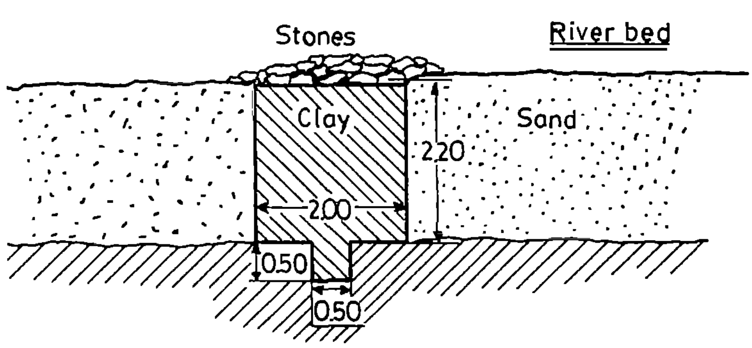
4. Standard Design



Lay-out plan
1:200



Longitudinal section
1:125



Cross section
1:50

5. Costing

To calculate the volume of the trench a few simple measurements should be taken. Because the width is a constant 2 metres, it is simply a case of measuring the dam length and knowing the average depth. By measuring the depth from the river bed at a number of places along its length, the average can be calculated.

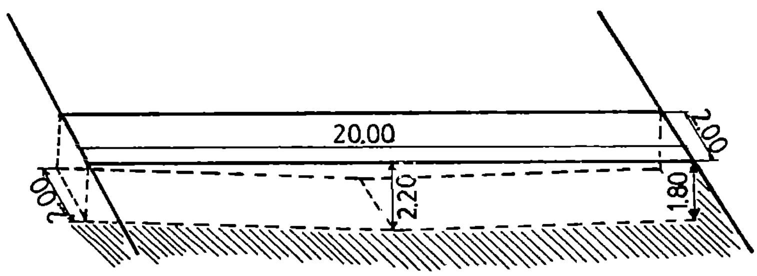
The following calculations are all based on

(a) A set of formulas, and

(b) Examples of a structure shown by drawing seen below.

<u>Example</u>: length x width 2.00 m x average depth = volume (cu.m)

<u>Example</u>: length 20.00 m x width 2.00 m x average depth $\frac{2.20 + 18.0}{2}$ = 80 cu.m



Labour Requirements

One self-help labourer should be able to transport by cart, fill and compact 1 cubic metre of trench per 4 days.

Thus to budget labour needs this is simply:

Formula: Volume 1 cu. m. x 4 days = number of unskilled days.

Example: Volume 80 cu. m. x 4 days = 320 unskilled days.

One contractor is required to supervise the trench digging, to make the calculations, and supervise the filling.

Since a contractor can supervise 15 labourers at a time, the number of skilled days are

Formula: $\dfrac{\text{Number of unskilled days}}{\text{15 labourers}}$ = number of skilled days for contractor.

Example: $\dfrac{\text{320 unskilled days}}{\text{15 labourers}}$ = 22 skilled days.

Costing.

Skilled labour; 1 contractor for 22 days	x Shs	=	Shs	
Value of self-help work; 320 unskilled days	x Shs	=	Shs	
	Total cost of clay-plug dam		Shs	

6. Quality Control and Maintenance

It is very important that all the sandy material is removed from the trench across the whole width of the river bed and right down and preferably into the impermeable layer. If a sand-filled layer is left, water will leak through this like a cracked calabash filled with water.

If the clay material is not compacted then the water moving through the bed can wash out some of the clay particles and gradually reduce the impermeable character of the clay plug. if the plug is not protected by a surface apron of large stones then the turbulent flowing river could rapidly wash-out parts of the trench.

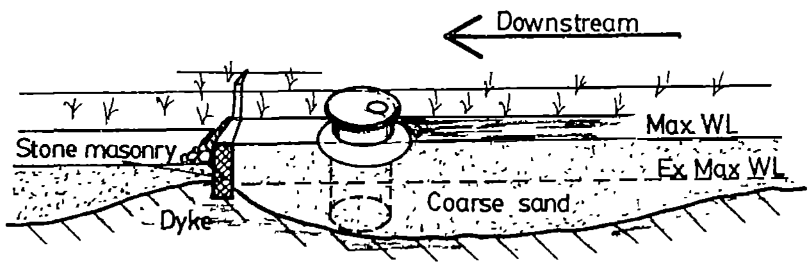
If built properly, the clay plug will act as an almost complete brake on the movement of water past this point in the river bed making conditions much more favourable upstream for the shallow well. After each large flood however, members of the self-help group should check the dam site to see if the banks have started to erode. Any erosion should be stopped by filling up with large rocks too heavy for the smaller flows to move.

7. Sub-Surface Dam of Stone Masonry

The objective of the sub-surface masonry dam is to place an impermeable barrier across the river bed from the surface down to the point where a solid and impermeable ground is reached.

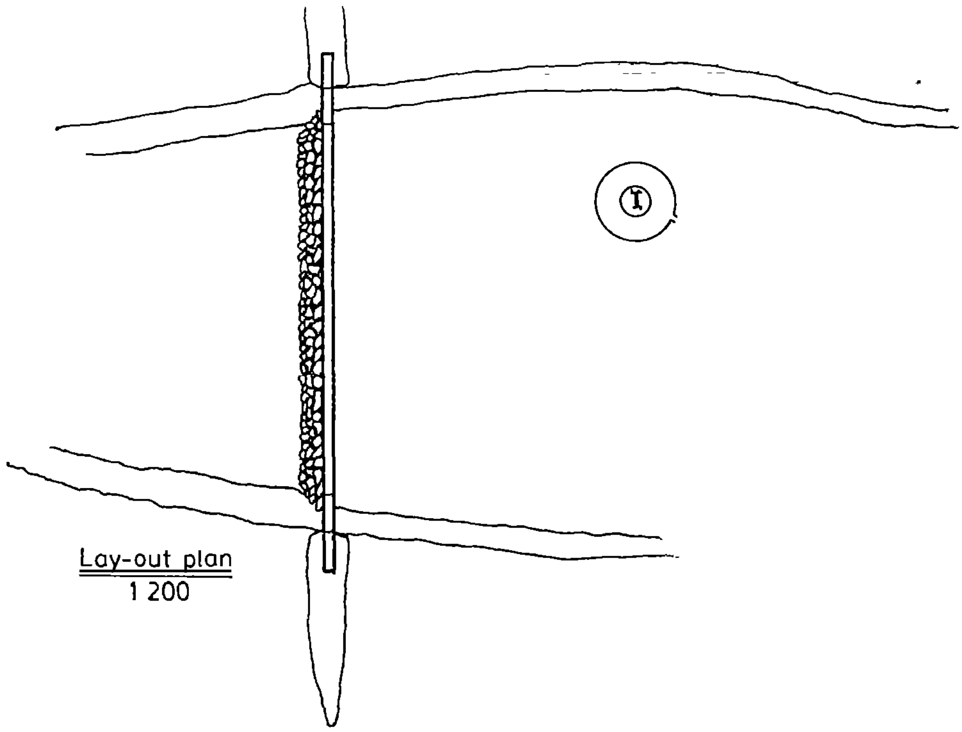
The sub-surface masonry dam is made by a digging a trench across the bed and into the banks, and then filling the trench with stones and mortar to form a masonry wall anchored to the impermeable ground below.

A sub-surface masonry dam is more expensive that a clay-plug dam because of the cost of cement. Its advantages are that it is stronger and more permanent and completely impermeable. It can be raised above the bed of the river to form a sand-storage dam which catches sand and increases the physical size of the reservoir as well as its water content.

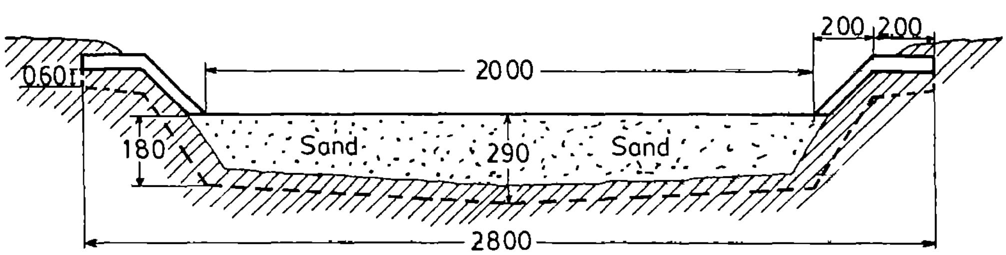


5 Subsurface dam of stone masonry

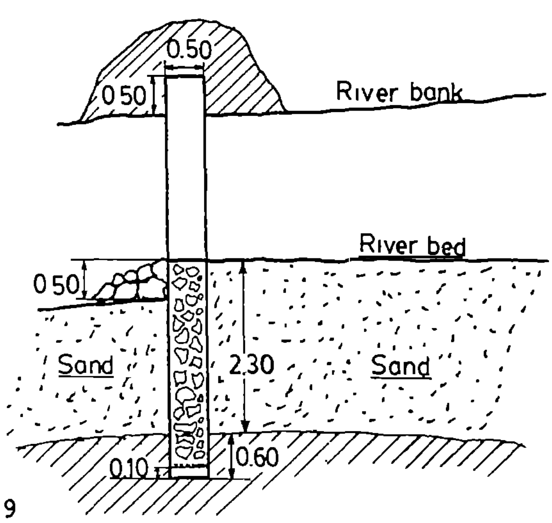
8. Standard Design



Lay-out plan
1 200



Longitudinal section
1 125



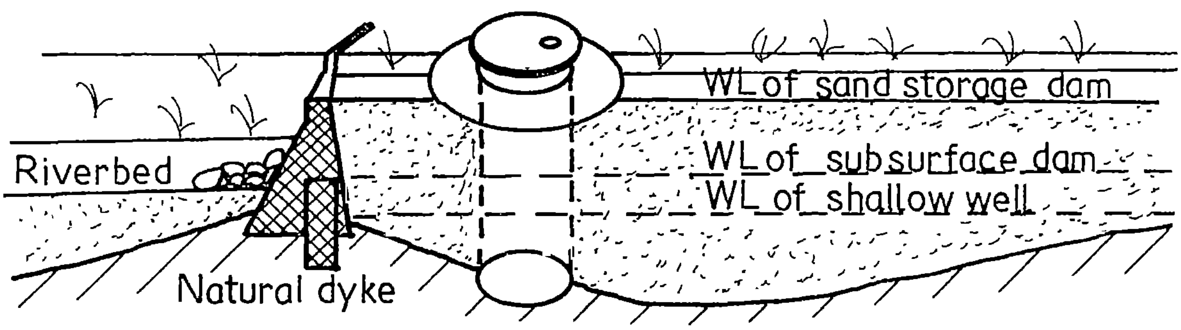
Cross section
1 50

9. Site Selection

Masonry sub-surface dams should be built downstream of shallow wells that keep water for several months into the dry season but dry up before the next rainy season starts. The best site is where an underground dyke rises up towards the river bed surface in the form of a rock or clay dyke. Not only does this reduce the amount of masonry required to prevent seepage, it also means that upstream there will be a depression under the riverbed where water will be trapped. If the riverbed narrows downstream of the well, then then masonry sub-surface dam should be built across this narrower section, again to reduce the amount of masonry required.

Depending on the depth of the shallow well, the sub-surface dam should be built relatively close to the well so that when recharge from upstream ceases, the water stored in the soil behind the dam can almost all be used.

Masonry sub-surface dams are permanent and can be raised to form a sand-dam at a later date.



10. Materials, labour and transport requirements.

The requirements of materials, labour and transport are calculated as follows:

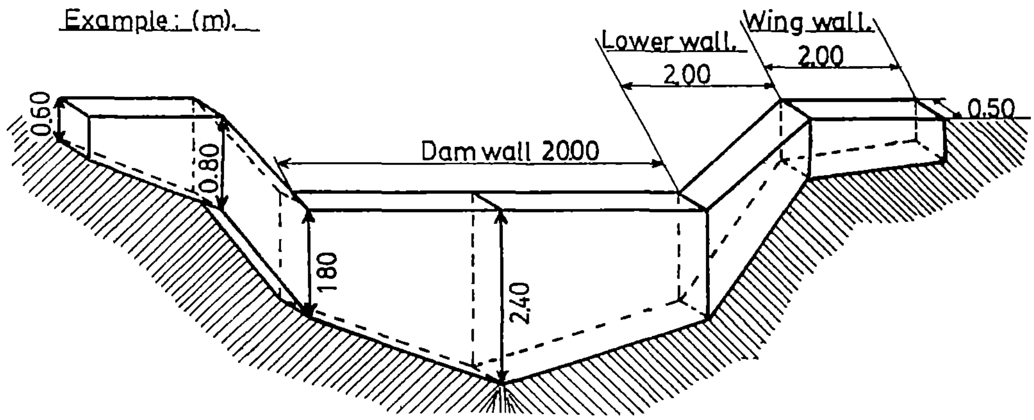
a. Volume of Structure.

First calculate the total volume of the structure to be build by finding the volumes of the various parts of the structure and thereafter adding it all together. The result will be the total volume measured in cubic metres (cu.m.).

The top of the wall is marked out by the builders lines tied between a pair of wooden stakes. By measuring the height from the line between the stakes at each location down to the bottom of the trench, the depth can be known.

The heights from the tops of the stakes can be measured using a plumb-line and type-measure.

The volume of each section can be assumed to be the width of the wall (50 cm) multiplied by the average depth and the length.



Formula for calculating volume of stone masonry for dam wall

Wing Walls.

Formula: length x width 0.5 m x average depth x 2 walls = volume (cu.m.)
Example: length 2.00 x width 0.50 x average depth $\frac{0.60 + 0.80}{2}$ x 2 walls = 1.4 cu.m.

Lower Walls.

Formula: length x width 0.50 m x average depth x 2 walls = volume (cu.m.)
Example: length 2.00 x width 0.50 x average depth $\frac{0.80 + 1.80}{2}$ x 2 walls = 2.6 cu.m.

Dam wall.

Formula: length x width 0.50 m x average depth = volume (cu.m.)
Example: length 20.00 x width 0.50 x average depth $\frac{2.40 + 1.80}{2}$ = 21.0 cu.m

Total Volume 25.0 cu.m

Formula for calculating volume of 2 cm. plaster 1:3 with nil

Formula: Multiply the area to be plastered with 0.02 m
Example: Horizontal area 28.00 x 0.50 x 0.02 m = 0.28 cu.m.
Vertical areas 20.00 x 1.80 x 0.02 x 2 side = 1.44 cu.m
Total volume 1.72 cu.m. plaster

b. **Type and weight of materials.**

When the total volume of the structure has been found, the type and weight of the various components of that volume can be estimated by using the following formula:

Weight per 1 cubic metre (cu.m.) material.	Converted measurements.
Water 1 cu.m. weighs 1000 kg = 1.00 tonne	1 tonne = approx. 5 drums of water.
Cement 1 cu.m. weighs 1350 kg = 1.35 tonne	1 tonne = 20 bags of cement.
Sand 1 cu.m. weighs 1600 kg = 1.60 tonne	1 tonne = approx. 8 wheelbarrows of sand.
Stones 1 cu.m. weighs 2200 kg = 2.20 tonne	1 tonne = approx. 8 wheelbarrows of stones.

1 cu.m. Stone-masonry weighs 2900 kg = 2.9 tonne and consists of:

stone	75% 1700 kg = 1.7	tonne	= 14 wheelbarrow of stones
mortar 1:4 25%:			
cement	200 kg = 0.2	tonne	= 4 bags of cement
sand	800 kg = 0.8	tonne	= 7 wheelbarrows of sand
water	200 kg = 0.2	tonne	= 1 drum of water

1 cu.m. Mortar, 1:3 with nil weighs 2400 kg = 2.4 tonne and consists of :

cement	500 kg = 0.5	tonne = 10 bags of cement
sand	1600 kg = 1.6	tonne = 13 wheelbarrows of sand
water	300 kg = 0.3	tonne = 2 drums of water

Example:

For walls: Multiply volume with requirements for 1 cu.m. of stone masonry.

Volume of wall x 1 cu.m. requirements = tonnes = converted measurements.

25.0 cu.m. x cement 0.2 tonne = 5.0 tonnes x 20 = 100 bags of cement
25.0 cu.m. x stones 1.7 tonne = 42.5 tonnes x 8 = 340 wheelbarrows of stone
25.0 cu.m. x sand 0.4 tonne = 10.0 tonnes x 8 = 80 wheelbarrows of sand
25.0 cu.m. x water 0.2 tonne = 5.0 tonnes x 5 = 25 drums of water

For plastering: Multiply volume with requirements for 1 cu.m. mortar 1:3 with nil.

Volume of plaster x 1 cu.m. requirements = tonnes = converted measurements

1.8 cu.m. x cement 0.5 tonnes = 0.9 tonnes x 20 = 18 bags of cement
1.8 cu.m. x sand 1.6 tonnes = 2.9 tonnes x 8 = 24 wheelbarrows of sand
1.8 cu.m. x water 0.3 tonnes = 0.6 tonnes x 5 = 3 drums of water

Total Requirements of Materials.

Cement 5.9 tonnes = 118 bags of cement
Sand 45.4 tonnes = 363 wheelbarrows of sand
Stones 41.3 tonnes = 303 wheelbarrows of stones
water 5.6 tonnes = 28 drums of water

Enter these requirements on the bills of quantities

Labour requirements.

On experience it is known that one skilled artisan with the help of 15 self-help labourers can prepare the site, carry material, mix mortar and build 0.8 cubic metre of stone masonry per day. The estimate for labour requirements is therefore as follows:

Formula for wall: $\dfrac{\text{Volume cu.m.}}{\text{0.8 cu.m. per day}}$ = skilled days required. Unskilled days x 15

Example: $\dfrac{\cancel{\text{Volume 25.0}}}{\text{0.8 cu.m. per day}}$ = 32 days of skilled labour. Unskilled days 480

Enter the requirements on the Bills of Quantities

Transport requirements of material

Transport of materials is divided into two categories:

a. Transport of local materials, such as sand, stones and water, will be transported to the site by the self-help groups using oxen-donkey-and hand carts given to them by the project. The number of loads to be transported and the distances involved depends on local conditions and cannot be estimated here.

b. Transport of purchased materials, e.g. cement, reinforcement wire and templates is estimated according to tonnage, distance and cost per km.

Formula: Tonnes x return distance (km) x Shs. per km.

Example: (a) 60 tonnes of local materials by carts.

(b) 4 tonnes x return distance 86 km x Shs. 6/50 per km = Shs. 2,236/00

Enter the requirements on the bills of quantities

11. Bills of Quantities and Costing.

Two bills of quantities are needed, because about half the items will be delivered by the donor/ministry and the other half will be delivered free of charge by the community concerned. Since the community is supposed to contribute about half the cost of the project, a value of their input has to be calculated.

Example.

Bills of Quantities for items to be delivered by the donor/ministry

Skilled labour: 1 contractor for 32 days	x Shs	= Shs ....
Cement 5.9 tonnes = 118 bags	x Shs	= Shs ....
Polythene sheeting for curing: 20 metres	x Shs	= Shs ....
Transport of contractor and materials 8 tonnes x .... km	x Shs	= Shs ....
	Total cost	= Shs ......

Bill of Quantity for items to be delivered free of charge by the self-help group

Unskilled labour: 480 labour days	x Shs	= Shs ....
Sand: 45.4 tonnes (= 363 wheelbarrows)	x Shs	= Shs ....
Tones: 41.3 tonnes (= 303 wheelbarrows)	x Shs	= Shs ....
Water: 5.6 tonnes (= 28 drums)	x Shs	= Shs ....
Transport: 93 tonnes (= 186 cart loads)	x Shs	= Shs ....
	Total value of self-help	Shs ....

Grand total cost and value of project Shs ....

12. Quality Control and Maintenance

If the instructions given are not followed closely then the masonry sub-surface dam may not prove water-tight. The most important points are as follows:

a. If the foundations are not prepared properly, then the dam will leak and the reservoir will rapidly empty. The rock surface in the river floor must be cleared, washed and chiseled and a good base of cement applied. If this is not carried out, the water contained in the sand behind the dam will rapidly leak out underneath the dam.

b. The packing of mortar and ballast within the dam should be tight with stones and mortar pushed in hard and the stones wetted beforehand. A piece of wood should be used to poke the mortar in between the stones to fill all the airholes. If this is not done effectively, the dam could leak.

c. A spill-over apron can be made by placing large stones against the downstream side of the dam and wing walls to protect the walls from erosion and undermining by the flood wave that flows over the crest of the dam. The wing walls can be extended with embankments of soil and planted with grasses to avoid flood water passing around the ends of the masonry sub-surface dam and creating a new river bed in extreme circumstances. This however is very unlikely if the dam is built on a relatively straight section of channel.

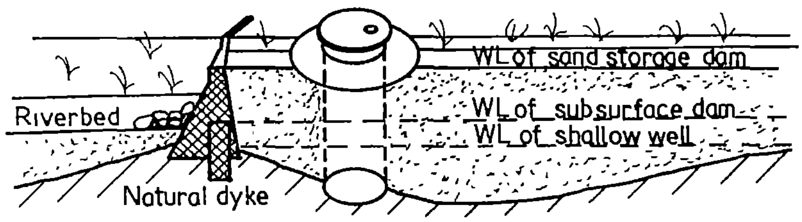
SURVEYORS MANUAL ON SAND-STORAGE DAM

C O N T E N T S

1. Introduction

To prevent water seeping through a river bed and draining the available moisture from around and upstream of a shallow lined well sited in a riverbed, a seepage prevention structure can be built at a suitable place downstream. The objective is to place an impermeable barrier across the river bed from the surface down to the point where a solid bedrock is reached.

A sand-storage dam should be built in stages of 50 cm high sections in order to trap a deposit of coarse sand from floods passing through the river. If a dam wall of a sand-storage dam is not build in such stages, it will trap silt and fine sand which cannot store water in between the grains of the sand. Coarse sand can store up to 30% of water, while fine sand can store only about 10%, and silt can store no water at all. It is therefore most important that a sand-storage dam is build in small stages of height.



Water from a sand-storage dam should be drawn in two ways:

a. From a draw-off pipe situated in the bottom section of the dam wall and leading water by gravity through a pipe to cattle troughs some 100 metres downstream of the dam wall.

b. From a shallow well sunk into the deepest part of the sand/water reservoir for domestic uses. Do not let livestock drink from the well, because they will pollute the reservoir.

2. Site Selection

The river in which the sand dam is built must be a relatively wide one in which large volumes of sand are known to be moved along the bed during floods. This can be seen by looking for shifting banks of sand that change position after the flood, or by shallow unlined wells that frequently fill with sand.

The best locations will be rivers leaving a rocky landscape and where the bed is quite steep. Here the flow will be fast and sand is likely to be carried from the bare rocks of the catchment. A good supply of sand will be more guaranteed at these sites.

In some cases, sub-surface masonry dams can be extended into sand-storage dams. Whichever, of most importance is that the bottom below is water-tight. If there is a rock dyke but a shallow well built upstream runs dry quickly, it may mean there is a seepage zone somewhere in the rock below and a sand-dam will be useless at this site. Only if the lined or unlined well keeps water for at least a few months of the dry season should a sand-dam be considered.

A sand-dam built below the well will raise the level of the bed in some cases by as much as 5 metres. This results in the well head being buried. You will need to remove the well cover and build up the level of the well after every one or two metre raise, depending on the position of the well.

Always remember that a sand-storage dam should only be build where a shallow well has proved that water can be stored in the riverbed for at least 6 months of the year.

Also remember that a sub-surface dam of stone masonry might improve the yield of water from a well just as good as a sand-storage dam, but for a fraction of labour and costs.

Determining the height of a dam wall.

The height of a dam wall has to be determined in such a way that even the biggest flood can pass over the dam wall without overflowing and eroding the banks of the riverbed.

In order to design the height following measurements must be taken on site:

Example (measured from the downstream side of the dam.)

1. The depths in three places from the sand level to the impermeable floor under the sand: (Probing with an iron rod and digging will produce these measurements).

   Example: Left side 0.5 m. Middle 0.5 m. Right side 0.5 m.

2. The width between the banks at the level of the sand: Example: 10.00 m.

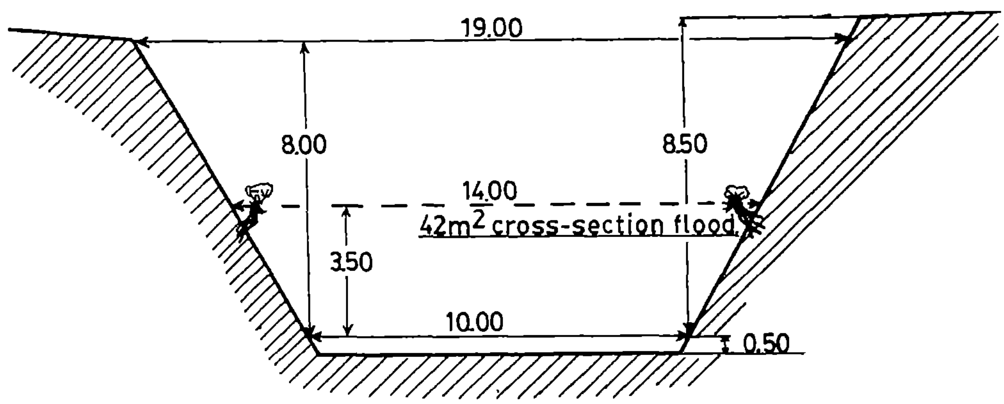
3. The width between the banks at the top of the banks: Example: 19.00 m.

4. The vertical heights from the sand level to the heights of the banks.

   (Use a tape measure attached to a string drawn across the riverbed).

   Example: Left side 8.00 m. Right side 8.50 m. measured from downstream.

5. The vertical height from the sand level to the highest visible mark of flooding e.g. straws hanging on branches or residents experience. Example: 3.50 m.



The size of the biggest flood can be estimated from the highest visible mark of flooding (see measurement 5) and the width of the riverbed as follows:

Formula: Height of flooding x average width of riverbed = size of flooding .... sq.m.

Example: Height 3.50 x average width $\frac{14.00 + 10.00}{2}$ = 42.00 sq.m. across-section of flood

Since the height of the dam must allow for this cross-section of flood to pass over the dam wall without overflowing the land next to the riverbanks, the cross-section over the dam wall must be bigger than the area below the crest (top) of the dam wall.

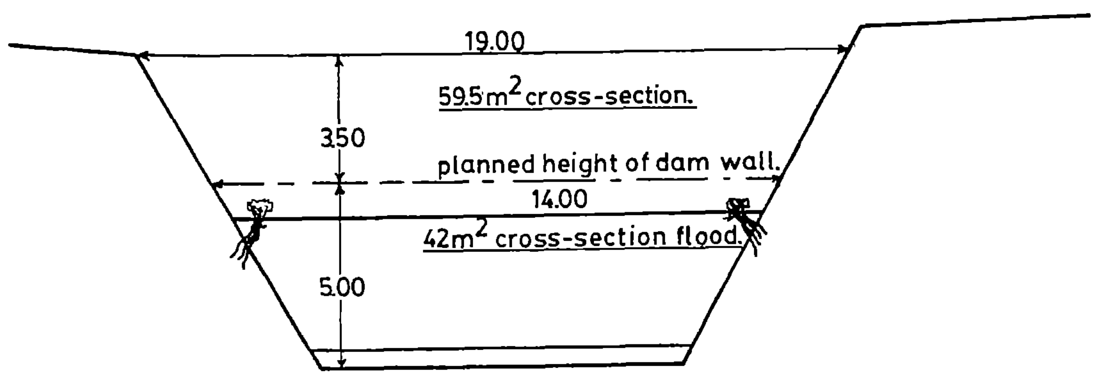
The easiest way of estimating this relationship between these two factors is to calculate some examples like this:

Example: If a dam wall is planned to be 5.00 m high from the watertight ground under the sand, then the area over the dam wall will be:

Depth of sand 0.50 + height of bank 8.00 - height of dam 5.00 = 3.5 m. height

Height for overflow 3.50 x average width $\frac{19.00 + 15.00}{2}$ = 59.5sq.m. cross-section

Since the cross-section of flood is 42.0 sq.m. and the space available for it to pass is 59.5 sq.m., the planned height of the dam wall, 5.00 m, is the maximum height the wall should be.



4. Estimating the volume of a subsurface reservoir.

Due to several unknown factors, such as volume and water-holding capacity, of an underground reservoir, it is only possible to estimate an approximately volume of a subsurface dam.

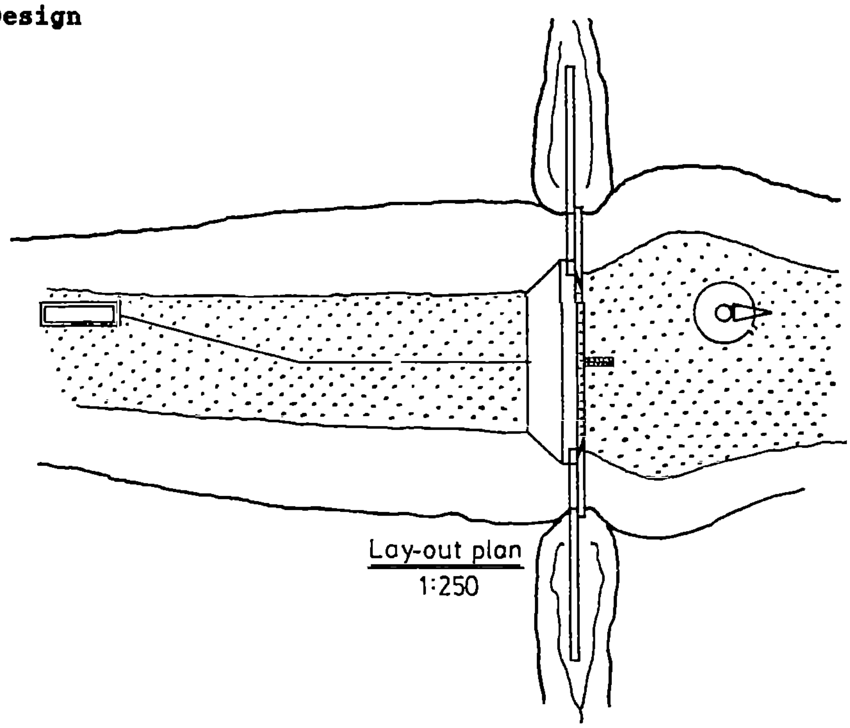
Formula for estimating the volume of a subsurface dam:

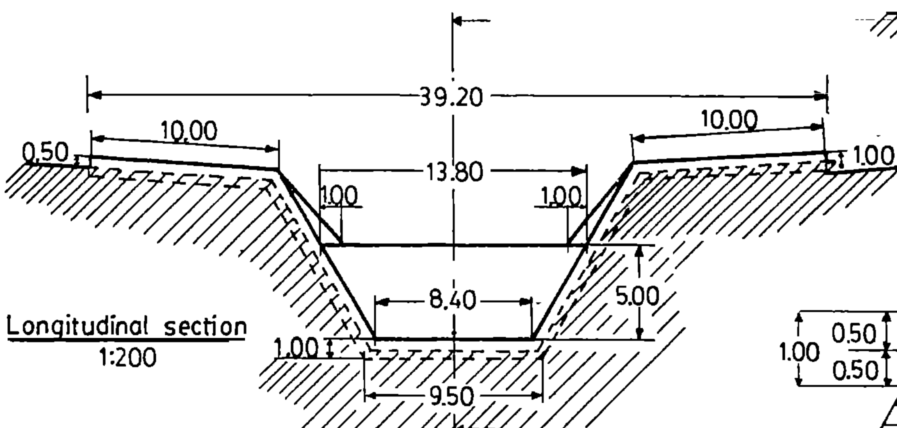
$$\frac{\text{Length of river holding water x width of riverbed at dam x depth of sand at dam}}{6}$$

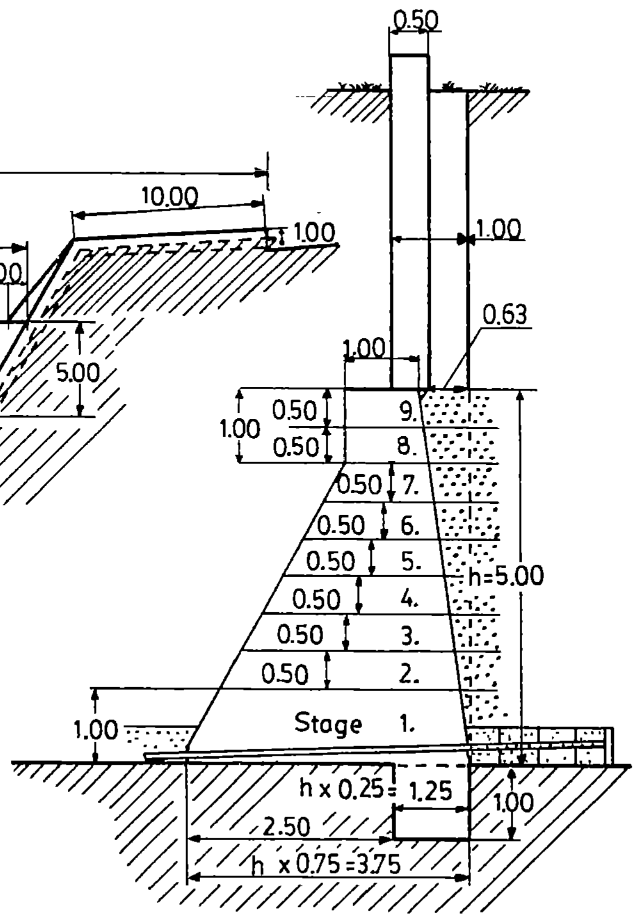
Example: $\frac{\text{Length of river 90.0 m x width of river 14.0 m x depth of sand 5.5 m =}}{6}$

1.155 cu.m water volume

5. Standard Design







6. Estimating the volume of the various stages.

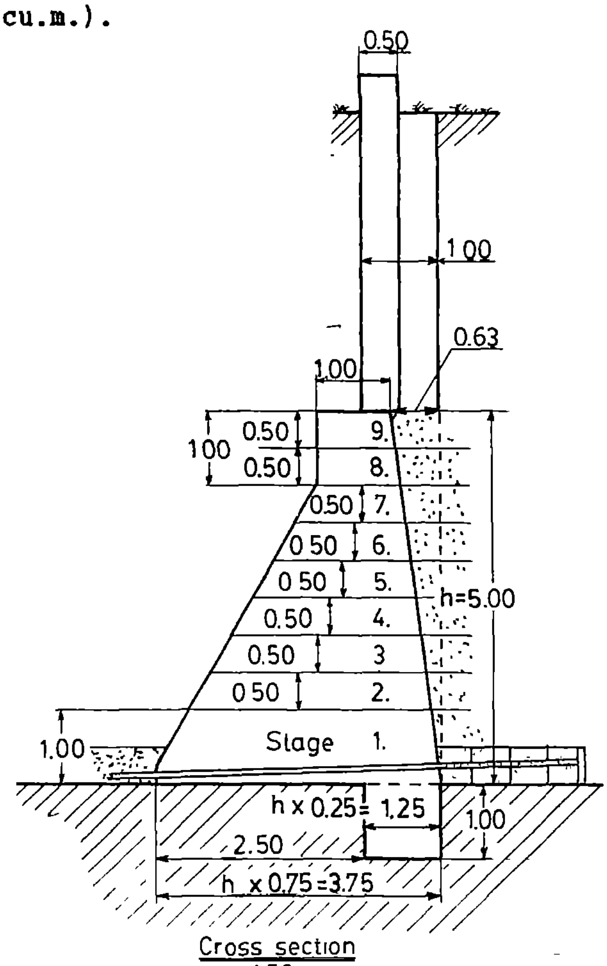
The following calculations are all based on:

a) a set of formulas, and

b) examples of a structure shown by the drawing seen below.

1. Volume of Structure.

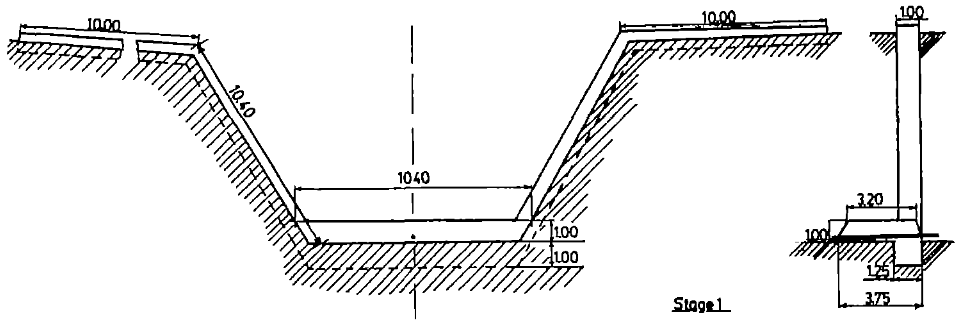
Calculate the total volume of the structure to be build by finding the volumes of the various parts of the structure and thereafter adding it all together. The result will be the total volume measured in cubic metres (cu.m.).



Cross section
1:50

Since a sand-storage dam has to be build in sections of 0.50 m high above the level of coarse sand deposited by floods, calculations have to be made of each stage of extensions.

Stage 1.



Calculating volume of foundation, side walls and wing walls:

Formula: length x width x height = volume

Examples:

Foundation:	length	10.40 x width	1.25 x height	1.00		=	13.0 cu.m.
Side walls:	length	10.40 x width	1.00 x height	1.00 x 2	walls	=	20.8 cu.m.
Wing walls:	length	10.40 x width	0.50 x height	1.00 x 2	walls	=	10.0 cu.m.
						Total	43.8 cu.m.

Calculating volume of extending dam wall 0.50 m above sand level in riverbed:

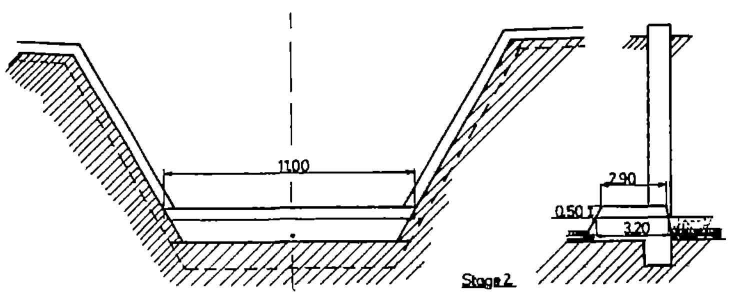
Formula: length x average width x height.

Example: for stage 1 which starts from 0.50 m below level of sand. The height is therefore 1.0 m.

$$\text{length } 10.40 \times \frac{(3.20 + 3.75)}{2} \times \text{height } 1.0 = 36.14 \text{ cu.m.}$$

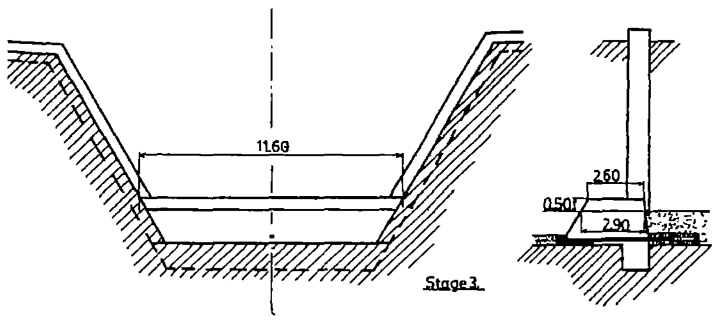
Total volume of stone masonry for stage 1 = 43.8 cu.m. + 36.14 cu.m. = 79.94 cu.m. volume

Stage 2



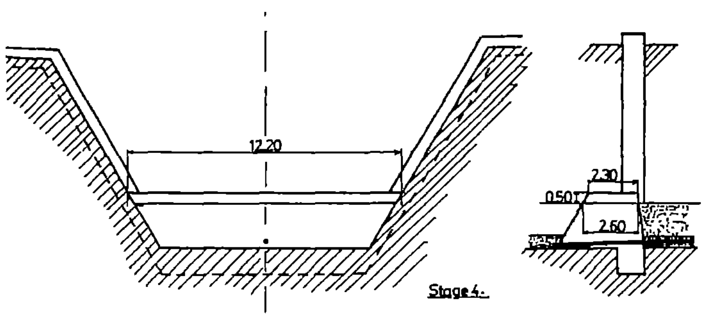
Example: $\text{length } 11.00 \times \frac{(2.90 + 3.20)}{2} \times 0.50$ = 16.78 cu.m. volume for stage 2

Stage 3.



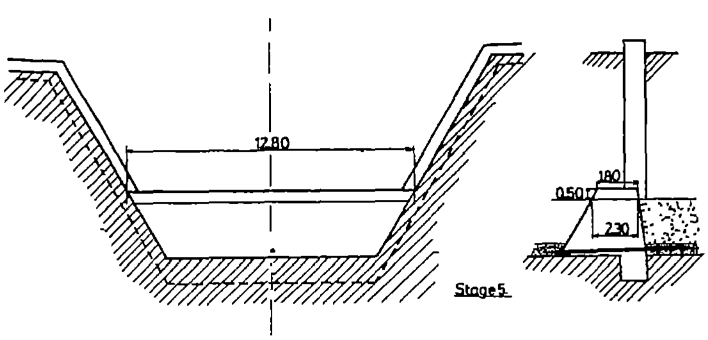
Example: length $11.60 \times \frac{(2.60 + 2.90)}{2} \times 0.50$ = 15.95 cu.m. volume for stage 3

Stage 4.



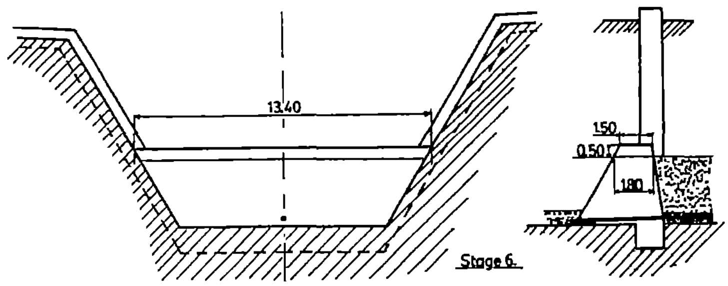
Example: length $12.20 \times \frac{(2.30 + 2.60)}{2} \times 0.50$ = 14.95 cu.m. volume for stage 4

Stage 5.



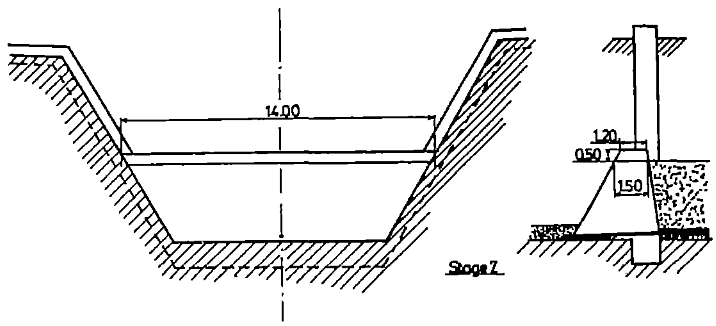
Example: length $12.80 \times \frac{(1.80 + 2.30)}{2} \times 0.50$ = 13.12 cu.m. volume for stage 5

Stage 6.



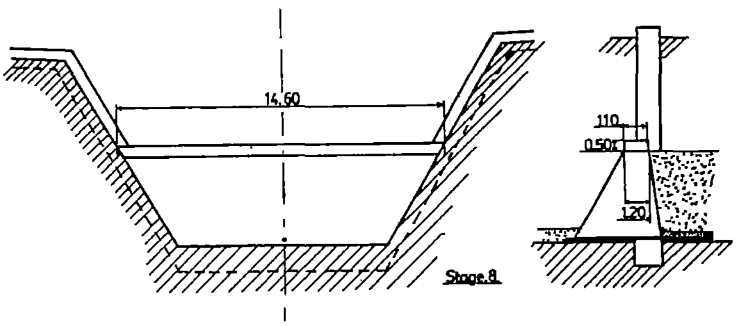
Example: length 13.40 x $\frac{(1.50 + 1.80)}{2}$ x 0.50 = **11.06 cu.m. volume for stage 6**

Stage 7.



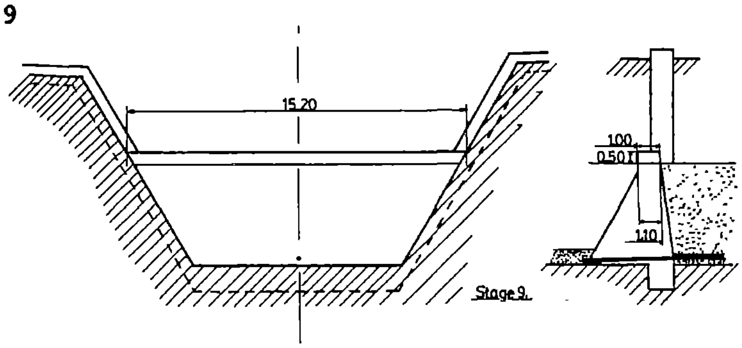
Example: length 14.00 x $\frac{(1.20 + 1.50)}{2}$ x 0.50 = **9.45 cu.m. volume for stage 7**

Stage 8.



Example: length 14.60 x $\frac{(1.10 + 1.20)}{2}$ x 0.50 = **8.40 cu.m. volume for stage 8**

Stage 9



Example: Length 15.20 x $\frac{(1.00 + 1.10)}{2}$ x 0.50 = 7.98 cu.m. for stage 9

The total volume of this example of sand-storage dam can be estimated by adding the various volumes of the stages:

Stage	1	requires	43.80	cu.m.	of	stone	masonry.
"	2	"	16.78	"	"	"	"
"	3	"	15.95	"	"	"	"
"	4	"	14.95	"	"	"	"
"	5	"	13.12	"	"	"	"
"	6	"	11.06	"	"	"	"
"	7	"	9.45	"	"	"	"
"	8	"	8.40	"	"	"	"
"	9	"	7.98	"	"	"	"
Total			141.49	cu.m. volume of stone masonry, say 142 cu.m.			

Plastering of the dam wall is estimated by multiplying the area to be plastered with the thickness 0.02 m of the plaster.

Example:

Dam wall: $\frac{11.80 + 9.50}{2}$ x 6.00 x 2 sides x 0.02 = 2.6 cu.m.

Wing walls: (1.00 + 0.50 + 0.50) x 10.00 x 2 walls x 0.02 = 0.8 cu.m.

Total volume of plaster 3.4 cu.m.

This figure of total volume is used for calculating the total cost and value of self-help.

However, since the dam has to be build in stages depending on the floodwaters ability to deposit coarse sand in the reservoir, the requirements of each stage has to be estimated on a bill of quantities for each stage, as well as a bill of quantities on the complete structure.

For reasons of simplifying this manual, only the bill of quantities for the complete structure is explained here.

7. Materials, labour and transport requirements

Type and weight of materials.

When the total volume of the structure has been found, the type and weight of the various components of that volume can be estimated by using the following formula:

Weight per 1 cubic metre (cu.m.) material.	Converted measurements.
Water 1 cu.m. weighs 1000 kg = 1.00 tonne	1 tonne = approx. 5 drums of water.
Cement 1 cu.m. weighs 1350 kg = 1.35 tonne	1 tonne = 20 bags of cement.
Sand 1 cu.m. weighs 1600 kg = 1.60 tonne	1 tonne = approx. 8 wheelbarrows of sand.
Stones 1 cu.m. weighs 2200 kg = 2.20 tonne	1 tonne = approx. 8 wheelbarrows of stones.

1 cu.m. Stone-masonry weighs 2900 kg = 2.9 tonne and consists of:

stones 75%	1700 kg = 1.7 tonne	= 14 wheelbarrow of stones
mortar 1:4 25%		
cement	200 kg = 0.2 tonne	= 4 bags of cement
sand	800 kg = 0.8 tonne	= 7 wheelbarrows of sand
water	200 kg = 0.2 tonne	= 1 drum of water

1 cu.m. Mortar, 1:3 with nil weighs 2400 kg = 2.4 tonne and consists of:

cement	500 kg = 0.5 tonne	= 10 bags of cement
sand	1600 kg = 1.6 tonne	= 13 wheelbarrows of sand
water	300 kg = 0.3 tonne	= 2 drums of water

1 cu.m. Mortar, 1:4 weighs 2200 kg = 2.2 tonne and consists of:

cement	400 kg = 0.4 tonne	= 8 bags of cement
sand	1600 kg = 1.6 tonne	= 13 wheelbarrows of sand
water	200 kg = 0.2 tonne	= 1 drum of water

Example:

For wall: Multiply with requirements for 1 cu.m. of stone masonry.

Volume of wall x 1 cu.m. requirements = tonnes = converted measurements.

142	cu.m. x cement	0.2	tonne =	28.4 tonnes x	20 =	568	bags of cement
142	cu.m. x stones	1.7	tonne =	241.4 tonnes x	8 =	1934	wheelbarrows of stone
142	cu.m. x sand	0.4	tonne =	56.8 tonnes x	8 =	455	wheelbarrows of sand
142	cu.m. x water	0.2	tonne =	28.3 tonnes x	5 =	142	drums of water

For plastering: Multiply volume with requirements for 1 cu.m. mortar 1:3 with nil.

Volume of plaster x 1 cu.m. requirements = tonnes = converted measurements

3.4	cu.m. x cement	0.5	tonnes =	1.7 tonnes x	20 =	34	bags of cement
3.4	cu.m. x sand	1.6	tonnes =	5.5 tonnes x	8 =	44	wheelbarrows of sand
3.4	cu.m. x water	0.3	tonnes =	1.1 tonnes x	5 =	5	drums of water

Total requirements of materials

Cement	30.1 tonnes x	20 =	602	bags of cement
Sand	62.3 tonnes x	8 =	499	wheelbarrows of sand
Stones	233.5 tonnes x	8 =	1868	wheelbarrows of stones
Water	29.4 tonnes x	5 =	147	drums of water

Labour requirements.

On experience it is known that one skilled artisan with the help of 15 self-help labourers can prepare the site, carry material, mix mortar and build 0.8 cubic metre of stone masonry per day. The estimate for labour requirements is therefore as follows:

Formula for wall: $\frac{\text{Volume cu.m.}}{\text{0.8 cu.m. per day}}$ = skilled days required. Unskilled days = x 15

Example: $\frac{\text{Volume 141.5 cu.m.}}{\text{0.8 cu.m. per day}}$ = 177 days of skilled labour. Unskilled days 2655

Enter the requirements on the Bills of Quantities

9. Transport requirements of material

Transportation of materials is divided into two categories:

a. Transport of local materials, such as sand, stones and water, will be transported to the site by the self-help groups using oxen-donkey-and hand carts given to them by the project. The number of loads to be transported and the distances involved depends on local conditions and cannot be estimated here.

b. Transport of purchased materials, e.g. cement, reinforcement wire and templates is estimated according to tonnage, distance and cost per km.

Formula: Tonnes x return distance (km) x Shs. per km.

Example: (a) 35 tonnes x return distance 86 km x Shs. 6/50 per km = Shs. 19,565
(b) 325 tonnes of local materials by carts.

Enter the requirements on the bills of quantities

8. <u>Bills</u> of Quantities and Costing.

Two bills of quantities are needed, because about half the items will be delivered by the donor/ministry and the other half will be delivered free of charge by the community concerned. Since the community is supposed to contribute about half the cost of the project, a value of their input has to be calculated.

Example.

<u>Bills</u> of Quantities for items to be delivered by the donor/ministry.

Skilled labour: 1 contractor for 177 days	x Shs	Shs ....
Cement 30.1 tonnes = 602 bags	x Shs	Shs ....
G.I. piping, 1" : 90 metre/6 = 15 lengths	x Shs	Shs ....
Polythene sheeting for curing: 20 metres	x Shs	Shs ....
Transport of contractor and materials 35 tonnes x ...... km ...	x Shs	Shs ....
Cattle trough	x Shs	Shs ....
Tap Station	x Shs	Shs ....
	Total cost by Donor	Shs ....

Bill of for items to be delivered free of charge by the self-help group

Unskilled labour: 2,655	x Shs	Shs ....
Sand: 62.3 tonnes (= 499 wheelbarrows)	x Shs	Shs ....
Stones: 233.5 tonnes (= 1868 wheelbarrows)	x Shs	Shs ....
Water: 29.4 tonnes (= 147 drums)	x Shs	Shs ....
Transport: 325.0 tonnes (= 650 cart loads)	x Shs	Shs ....
	Total value of self-help	Shs ....

Grand total cost and value of project Shs ....

CONTRACTORS MANUAL ON SUB-SURFACE DAMS

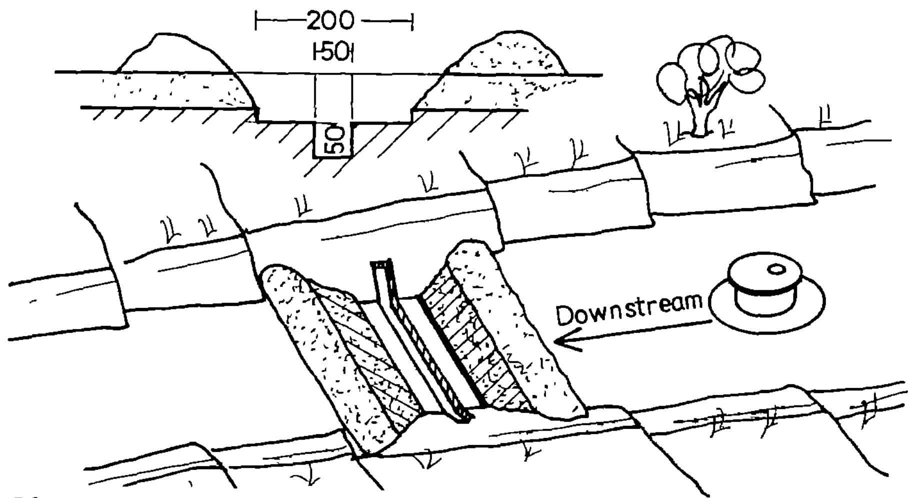
CONTRACTORS MANUAL FOR SUB-SURFACE DAMS

1. Clay-Plug Sub-Surface Dam

2. Foundation

a. Dig a trench 2 metre wide across the riverbed until the impermeable strata of clay soil is reached at both the bottom and the ends of the trench.

b. Dig a groove, 50 cm deep and 50 cm wide, along the length of the middle of the trench, in order to secure a watertight connection for the dam wall.



3. Dam wall

a. Fill the groove with soil, e.g. a dry mixture of red laterite and black cotton soil. Pour water onto the clayish soil and compact it well into the groove by ramming it with short sections of a tree trunk or by foot.

b. Fill up the trench with 25 cm thick layers of clayish soil, each layer compacted well together with water. Herds of livestock, driven through the trench make excellent compactors.

c. When the clay plug has almost reached the level of the top of the sand in the river bed, place large stones on top of it. These stones will protect the clay plug from eroding. The remaining unfilled sections of the trench into the banks can be filled with the excavated sand and have rocks piled on top of them against their sides.

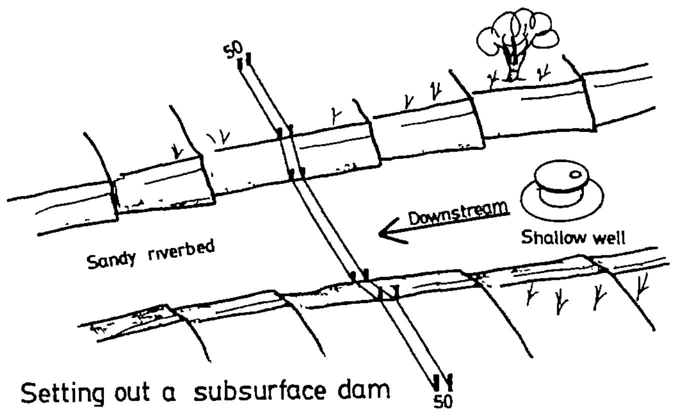
4. Stone-Masonry Sub-Surface Dam

5. Site Preparation for Construction

Foundation

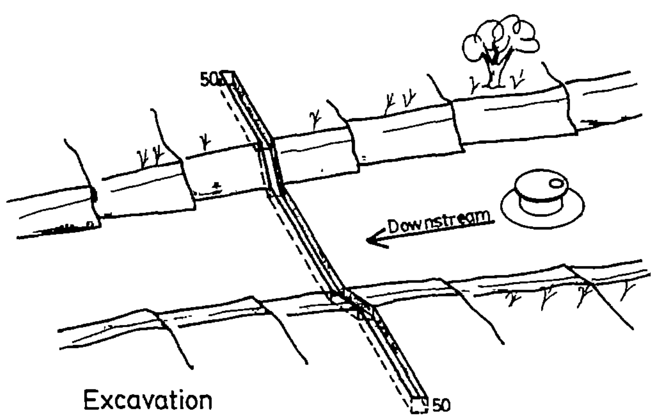
Preparing the site for construction of a masonry sub-surface dam involves digging a trench down to the underlying bedrock.

a. Set out two parallel builders lines, spaced 50 cm apart to mark the dam wall at the site. The two lines are first tied to wooden pegs across the river bed and then drawn to the top of both river banks to mark the wing walls. These lines should be straight extensions of the lines marking the dam wall in the bed.



Setting out a subsurface dam

b. Dig out a trench, 50 cm wide within the two sets of builders lines. Enough sand must be removed from the trench so that the banks do not collapse into it hindering the construction of the wall.



Excavation

c. To help calculate the volume of the dam and help build a level dam wall, wooden pegs should be knocked into the ground alongside the trench at the ends of the trench wing walls, at the bottom and the tops of the banks, and at the deepest point of the trench across the river bed.

d. The wooden stakes at the deepest point and at the bottoms of the banks should be knocked in until they are one metre above the bed and those at the ends of the trench and the tops of the banks until they are 0.5 metres above the ground. A level should be used to check the tops of all the pairs are horizontal, and builders lines should be tied to the tops and pulled tight marking each side of the dam crest above the bed.

6. Building Instructions

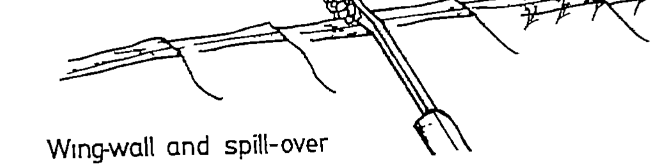
Filling the Trench with Stone Masonry

a. Mix mortar (1:4), and pour a layer of about 10 cm thickness into the whole length of the excavated trench. Place 10 lengths of barbed wire, gauge 12, on the wet mortar in the trench to reinforce the dam foundation.

b. Place as many clean stones as can fit into the wet mortar without the stones touching each other or the soil side of the excavation. This will be roughly 1 parts mortar to 4 parts stones.

c. Pour more mortar (1:4) over the stones set in the first layer and compact it well against the soil side and between the stones with a stick. Set another batch of cleaned stones into the mortar and continue like that until the whole trench is filled with compact stones and mortar.

d. Build a 50 cm wide wall of stone masonry onto the top of the filled trench. This wall is built by setting stones in mortar (1:4) along the inner lines of the two builders lines attached to the stakes. The flatter sides should face outwards. The space between these two lines of mortarted stones is filled out with mortar (1:4) and clean stones (1:4), just as with the trench.



Wing-wall and spill-over

e. The height of this stone masonry wall is 50 cm above ground level at the wings, and 50 cm above the bed in the sand river as marked by the heights of the stakes.

f. Cure the wall under polythene sheeting for two weeks keeping it moist.

Plastering the wall

a. Plaster the top of the dam and wing walls with mortar (1 cement: 3 sand). Thereafter, plaster the upstream side and ensure the plaster reaches down onto the impermeable floor of the river bed to obtain a water-tight bond. While this plaster is still wet, apply a waterproof coat of cement slurry (Nil) with a square steel trowel.

b. Pack clayish soil against the upstream side of the dam and wing walls. Make a spill-over the dam wall. This allows the water to pass without causing erosion.

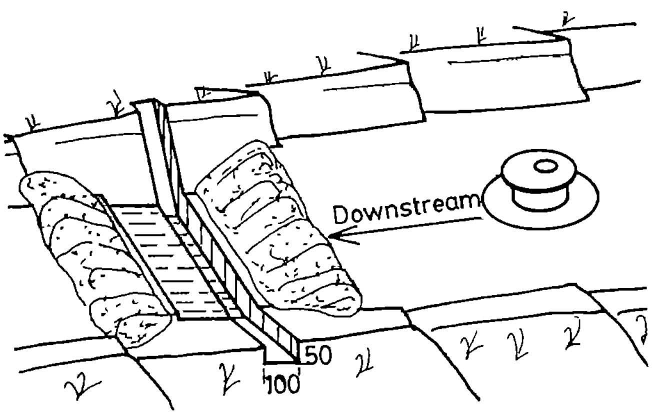
c. If necessary, extend the wing walls with low embankments of earth so that an extraordinary flood cannot erode the ends of the wing walls. Back-fill the sand in the river bed to the level it was before the construction took place.

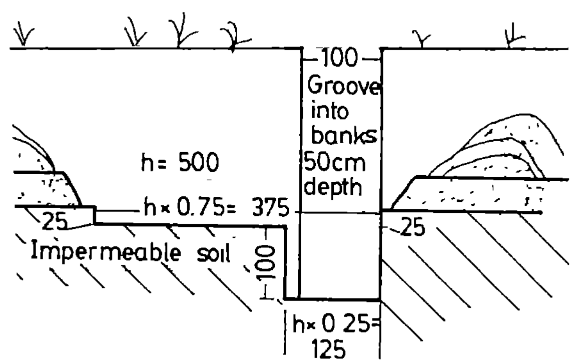
CONTRACTORS MANUAL ON SAND-STORAGE DAM

1. Foundation

a. If the sand-storage dam is to be built on a clay dyke, the foundation base must consist of impermeable soil with a groove dug or chiseled into the soil all the way across the river bed and into the riverbanks all the way from the bottom of the groove in the riverbed to the top of the banks.

If the sand storage dam is to be built onto a sub-surface stone masonry dam, this dam will provide the impermeable base for the sand-dams foundations and the river bed.



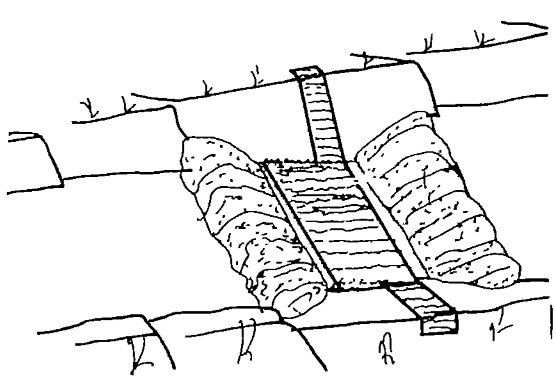


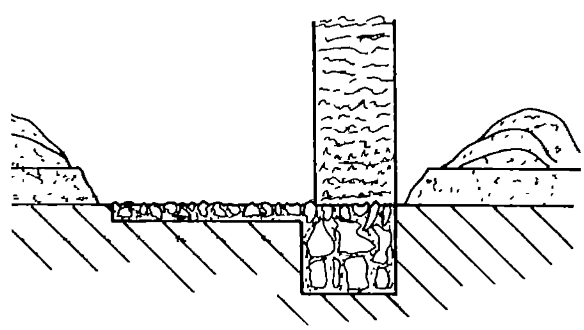
b. Fill the groove in the riverbed and the two grooves in the banks with clean boulders sat in mortar 1:4. Ensure that the spaces between the boulders and the sides in the excavation is filled out with mortar and compacted well with a short stick.

Also ensure that the spaces between the boulders themselves are filled with mortar and compacted well.

When the grooves are filled up completely, then fill the remaining part of the floor in the excavation with boulders and mortar 1:4 in the same way as described above.

Leave a rough surface of the floor for better bonding to the next section of wall to be build.

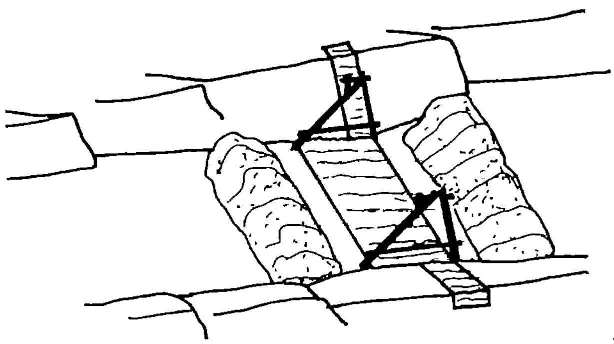


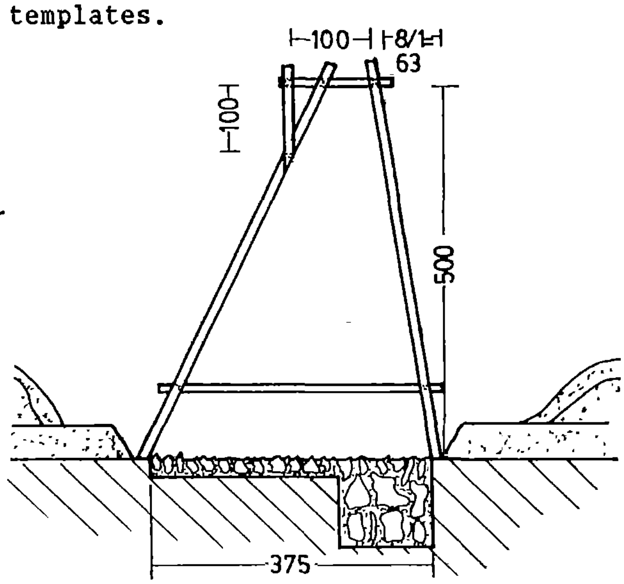


c. If the dam wall is to be build on a rock bar, then clean the rock surface carefully with water. While the rock surface is still wet, sprinkle a thin layer of dry cement onto the moist surface for proper bonding. Within the same hour, compact a 3 cm thick layer of mortar 1:3 onto the cement-sprinkled surface.

2. Templates and draw-off pipe

a. Together with the Building Inspector set up the two templates as near the banks as possible. Be sure the top level of the templates is exactly horizontal by using a hosepipe filled with water. Secure the templates in the position by mortaring some boulders around the legs of the templates.



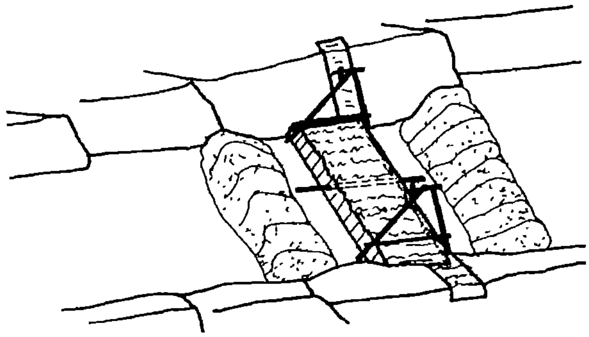


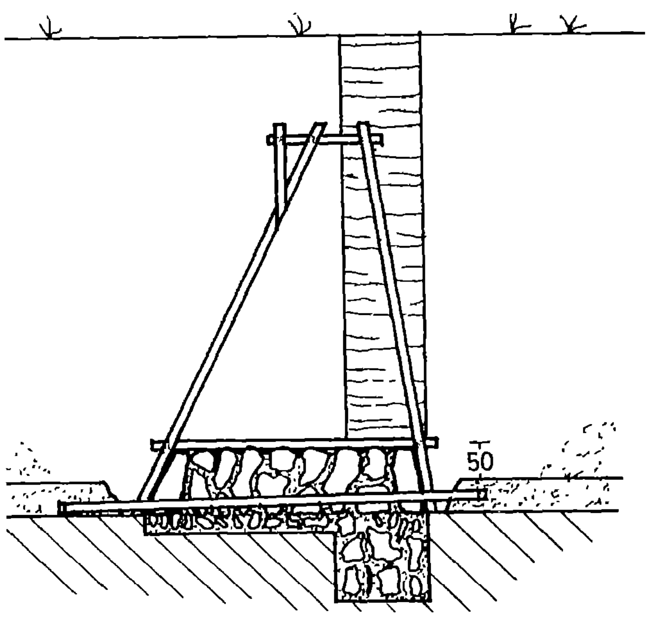
c. Place the draw-off pipe made of 6 metres of 3.8 cm (1.5") galvanized iron pipe (GI) at the lowest point of the rock dyke. Ensure that the downstream end of the pipe is lower than the upstream end and a good flow is produced by pouring a little water down it. Compact mortar (1:3) around the pipe to get a waterproof seal. Close the ends of the pipe.

3. First extension of wall

Draw a builders line alongside the bottom of the inner sides of the legs of the templates. Draw a second builders line along the same sides but 50 cm above the floor.

Build two walls of large flat stones set in mortar 1:4 along the inner sides of the builders lines. Since the downstream wall is sloping inwards the stones might have to be supported by small sticks until they are firmly held.





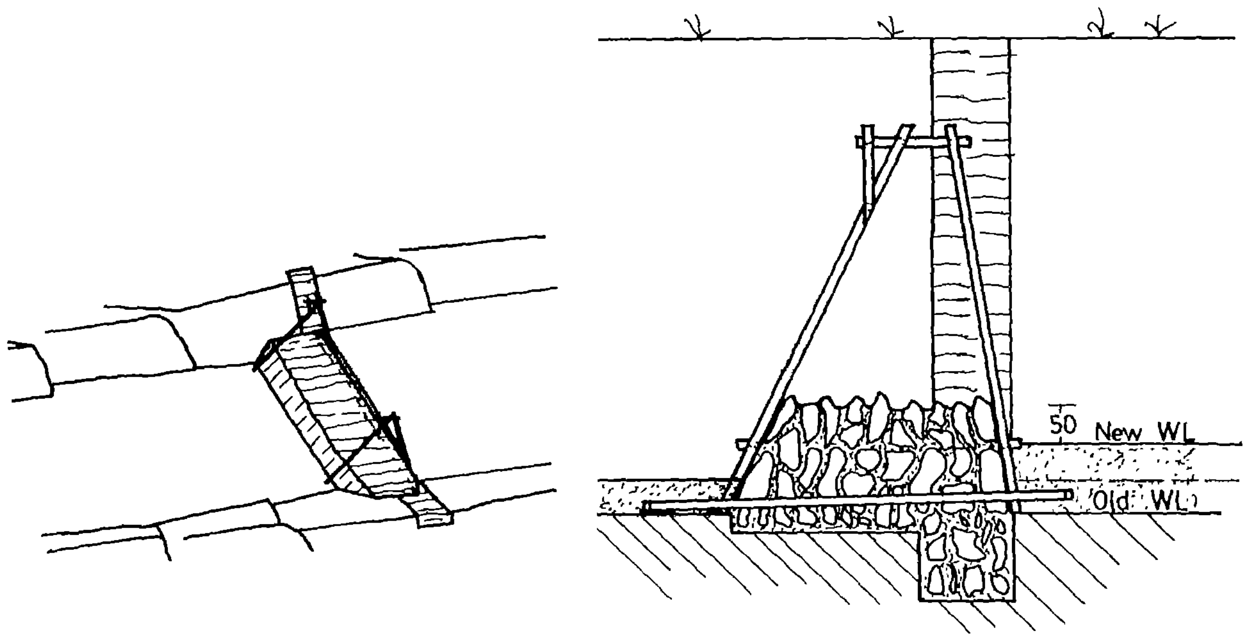
Fill the space between the two walls and the excavations in the banks with mortar (1 cement: 4 sand) and stones (1 mortar: 4 stones). Compact the stones well into the mortar. Leave a very rough surface with stones protruding out of the mortar to improve the bonding for future extensions.

Plaster the upstream and downstream sides of the dam with mortar (1 cement: 3 sand). Cure the structure with polythene sheeting and keep it moist for 2 to 3 weeks.

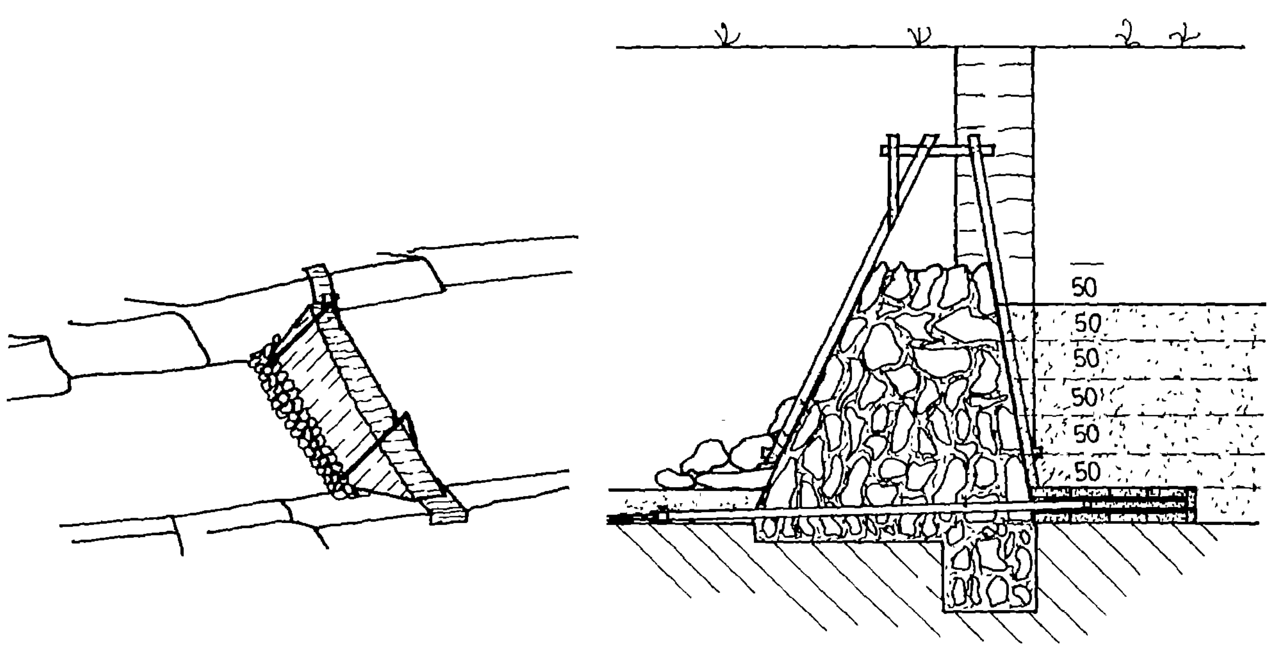
Do not extend the wall any further until floods will have deposited a bed of coarse sand up to the level of the present dam wall. If the wall is extended earlier than that, then fine sand will be deposited by floods, and fine sand cannot store as much water than coarse sand.

4. Further extensions of wall

When the level of sand in the riverbed has reached the height of the dam wall, another 50 cm height can be added to the dam wall. Build that extension as described above under f.



As explained earlier on, the wall should only be raised in a 50 cm high stage when floods have raised the level of coarse sand to the level of the dam wall. However, since a good rainy season can facilitate several floods capable of depositing sufficient sand, a dam wall could be raised several stages each 50 cm during one rainy season, if the builders are prepared to do so.



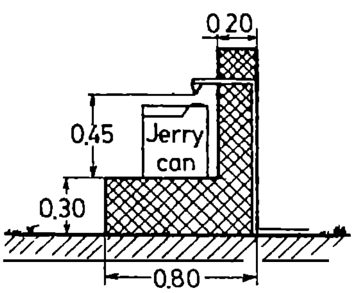
5. Filterbox and Tap Station

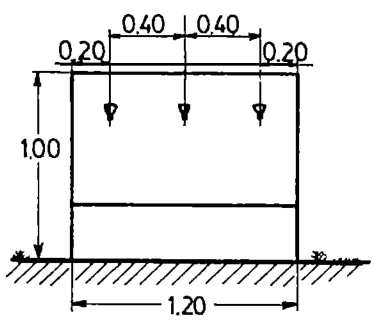
a. A filter box is built onto the end of the draw-off pipe that protrudes upstream of the dam wall. Extend the galvanized pipe with a perforated PVC pipe about 100 cm long. Build a box of filterblocks made of cement and small stones all around the PVC pipe with the end closed to prevent sand from entering the pipe. No valve is connected.

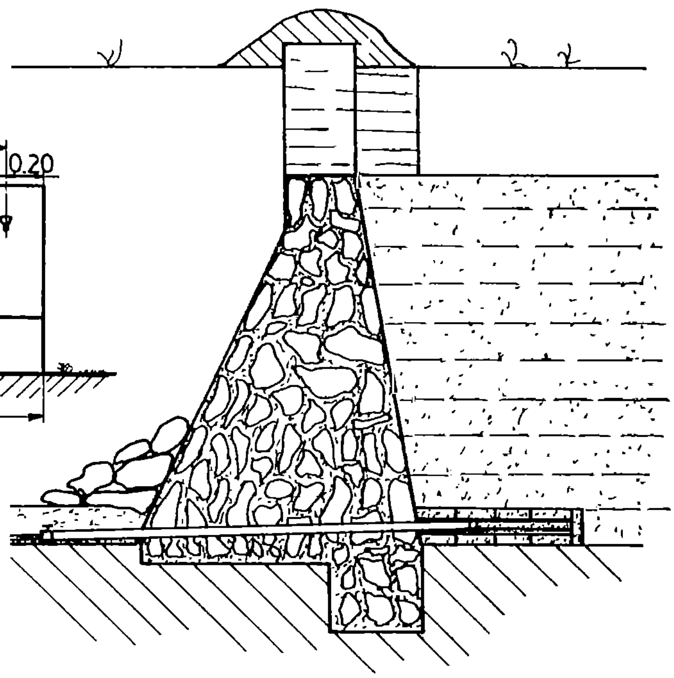
b. Build a tapping station downstream of the sand-dam. The height of the water tap must be lower than the bottom of the dam so that all the available water will flow out. The tapping station should be away from where it could be damaged by floods. Screw on a 3.75 cm (1.5") gate valve to the downstream end of the draw-off pipe. Thereafter, reduce the piping to 2 cm (3/4") down to the tapping station.

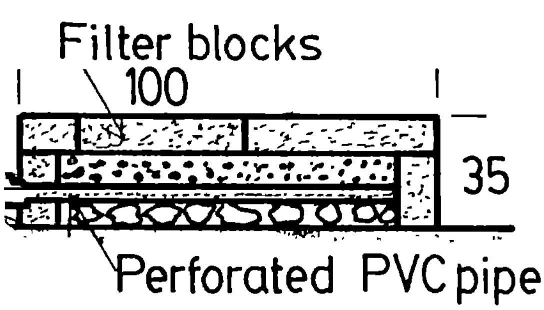
   The tapping station should be made of stones and mortar. Divide the cm GI Pipe with tees to feed two water taps. Build the tapping station so there is enough room to stand two jerrycans or gourds under the two taps at the same time. Build also a cattle trough, but situated downstream of the tap station, so that the animals do not pollute the tapping point for domestic use.

c. Place some big boulders against the downstream side of the dam wall and against the sides of the banks adjacent to the dam wall. these big boulders will prevent floods causing erosion, which could otherwise spoil the dam.





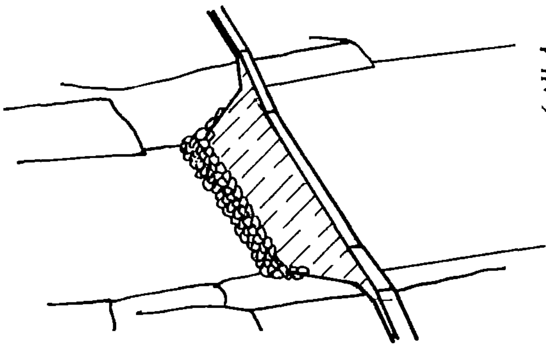


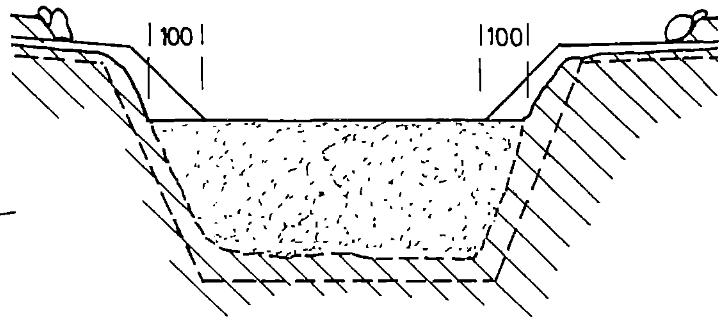


6. **Wing Walls**

When the dam wall has reached its final height the templates are removed.

a. Thereafter the two lower wing walls are build out from the grooves in the banks to a point at least 100 cm from the bank in order to protect the bank from erosion. Lack of wing walls will allow flood water to erode around the end of the dam wall which will result in collapse of the whole dam str'ictures.

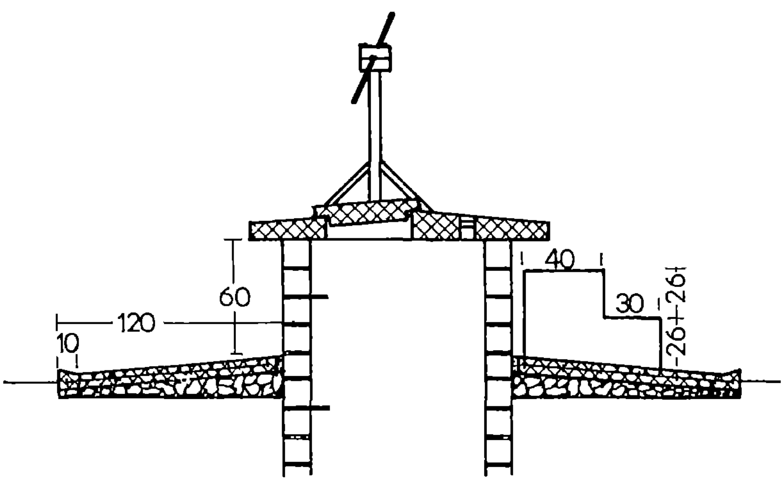


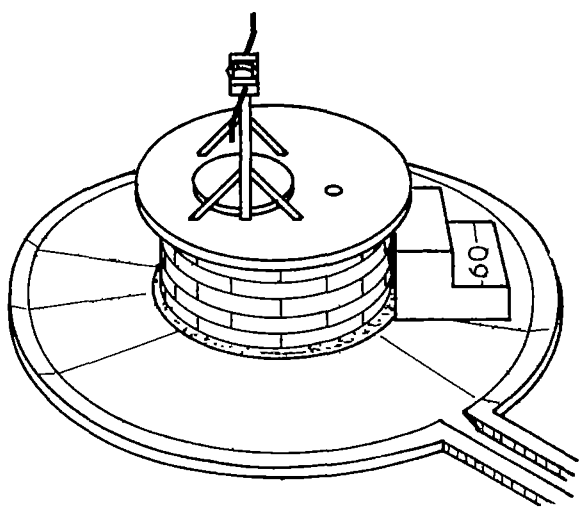


7. **Shallow well**

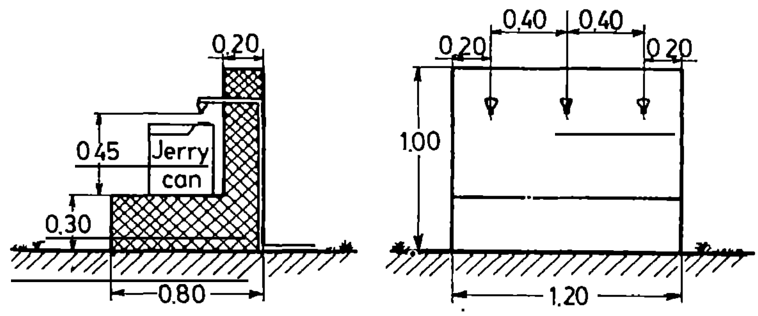
a. A shallow well might be sunk into the deepest point of the sand reservoir for the purpose of utilizing water stored at a lower level than the draw-off pipe.

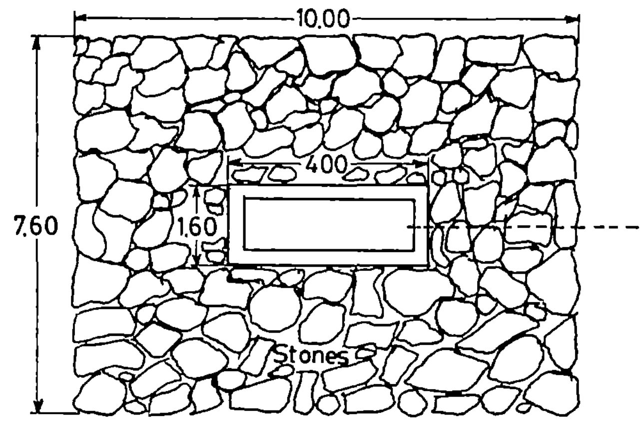
By having a shallow well in the reservoir for domestic water, and a cattle trough at the end of the draw-off pipe, a natural division between domestic and livestock water is ensured for the benefit of hygiene.

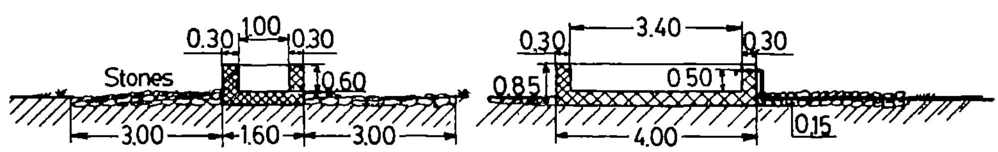


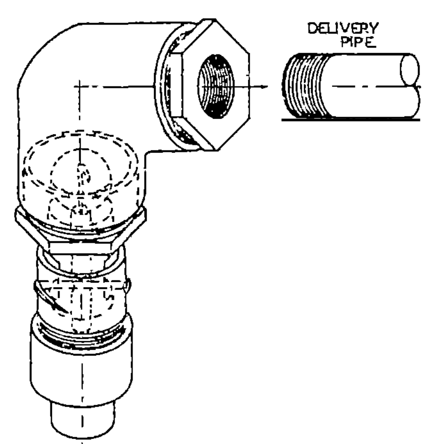


8. Tapping Station and Livestock Trough









Self-Closing Water Tap