

# Water from Rock Outcrops

A handbook for engineers and technicians on  
site investigations, designs, construction and maintenance  
of  
rock catchment tanks and dams



A rock catchment tank at Lakipia built by ASALCON Contractors in 1998.



An earth dam built at a rock outcrop at Mutha in Kitui by ALDEV in 1958.



A masonry dam, Kaseva Rock Catchment Dam, built by ALDEV at Mutomo in Kitui in 1956. The two persons walking on the crest give an idea of the dimensions of the dam.

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# 1 INTRODUCTION

## 1.1 How can rocks supply water?

It sounds contradicting that water can be obtained from rocks, but many people living in arid and semi-arid (ASAL) regions of the world, such as Gibraltar and Kitui in Kenya, are getting their domestic water from rocks. Kitui District has an impressive concentration of more than 400 rock catchment tanks and dams.

The technique applied for utilizing rocks for water supply is called *rainwater harvesting* and the structures built for harvesting rainwater from rocks are called *rock catchments*.

The design of rock catchments is simple:

Rainwater running off a rock surface (catchment) is gravitated to a reservoir by long lines of garlands made of rocks mortared onto the rock surface.



Garlands gravitating run-off rainwater to the reservoir of a rock catchment dam.

A water reservoir must always be situated at a lower level than its catchment area in order to facilitate run-off water to be gravitated to the water reservoir.

The reservoir of a rock catchment can either be *rock catchment tank* situated near a rock,



as this tank at Kibwezi,

or a *rock catchment dam* built of rubble-stone masonry onto a rock,



as this dam at Mutomo,

or an *earth dam* built of soil where rain water runs off a nearby rock as this earth dam at Mutomo.



## 1.2 The capacity of rocks to supply water

The capacity of rocks to supply water is significant, because a rock surface of 1 hectare (10,000 square metres = 2.47 acres) can provide 1,000 cubic metres (1 million litres) from every 100 millimetre of rain (Gould and Nissen-Petersen, 1999).

For example: If an ASAL area has two annual rainy seasons and each season has a rainfall of 300 mm, then 1 acre (4,049 square metres) of rock surface can produce:  
 $300 \text{ mm rain} \times 2 \text{ seasons} \times 4,049 \text{ sq.m.} = 2,429,400$  (2.4 million) litres of run-off water annually.

If a family uses 100 litres of water per day for its household, then the rock in the example can provide water for 66 households throughout a year, because  $2,429,400 \text{ litres} / 364 \text{ days} / 100 \text{ litres} = 66.7$  families.

However, some water will be lost as evaporation. For a roofed rock catchment the loss is about 10%, while it may be up to 50% for an open water reservoir on a windy and sunny rock. In the above example, an evaporation loss of 10 % reduces the supply capacity to about 59 households and to about 33 households for an open reservoir.



An open rock catchment at Voi.

## 1.3 Benefits of rock catchments

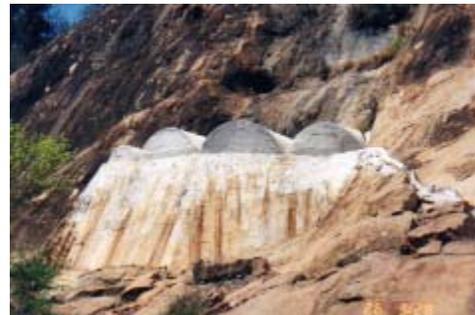
Rock catchments are the most economical and reliable water source in ASAL and desert regions with saline groundwater, low rainfalls, no rivers and large rock outcrops, because small rain showers falling on large rocks can provide huge volumes of run-off water.

Usually rock catchments are built and used by self-help communities. It is a labour-intensive work to construct rock catchments sufficient large to supply water for many households throughout dry seasons.

Most rock catchments have been constructed during droughts when the demand for water is highest and work in the fields at its lowest, which is the best combination for communal labour-intensive activities. Food-for-Work programmes are also very suitable for construction of rock catchments.

Maintenance of rock catchments consists only of cleaning the catchment and its reservoir before rainy seasons and to replace watertaps. Some rock catchments in Kitui are 50 years old and still supplying water without maintenance or any recurrent costs.

A roofed rock catchment at Kibwezi



## 1.4 Disadvantages of rock catchments

The quality of water might be low if a catchment and reservoir are not cleaned before rainy seasons, although the Sun's UV rays will sterilize most contaminants

Mosquitoes breed in open reservoirs and spread malaria. This problem can be overcome by raising *Tilapia Nilotica* fish in the dam reservoirs, because these fish feed on mosquito larvae.

Tanks and dams without roofs have high evaporation losses. Two solutions have been implemented successfully to compensate for the evaporation losses:

- a) The size of water reservoirs have been enlarged to accommodate about twice as much water as required.
- b) The reservoir of a rock catchment dam was roofed with ferro-cement as shown on the photo below.



A rock catchment dam being roofed.

Although both solutions doubles the construction cost, the roofing solution is preferable because it is more hygienic than open reservoirs.

## 1.5 History of rock catchments

The first time we hear of rocks yielding is when Moses provided water for 40,000 people daily from the Horeb Rock in the Sinai Desert (Exodus 17.6).

More recently, but still a few hundred years back, caravan travellers passing through the semi-deserts of the hinterland of eastern Africa survived on rainwater trapped in natural depressions



in rocks. Such water reservoirs are called *rock pools*.

A man standing in a rock pool at Taveta.

One of the rock pools near Mutomo in Kitui is called *Yamotomo*, which is said to mean *an easy place to kill elephants*. The reason being, that when a thirsty elephant had climbed into the deep rock pool and filled its stomach with water, it became so heavy that it was difficult for it to climb out of the rock pool. Hence it was fairly easy to kill elephants in the Yamotomo Rock Pool.

A third example of water from rocks, is the Gibraltar Rock neighbouring the south of Spain, where 6 hectares (15 acres) of rock and 14 hectares of corrugated iron sheets are providing 10% of the peninsula's water

requirements since 1869 (Gonzalez, 1972 and Doody, 1980).

In the 1950's, some 40 rock catchment dams were designed and built in Kitui by the District Agricultural Officer (DAO), Mr Classen, for a development project called African Land Development Board (ALDEV). All these rock catchment dams are still supplying water despite lack of maintenance.

In the 1970's, the Kitui County Council and a few NGO's built some rock catchment dams of different designs and quality in Kitui. Most of them were repaired by Danida's and MoA's *Mutomo Soil & Water Conservation* in the 1980's.

Also during the decade of 1980's, the Diocese of Kitui and Danida constructed several hundreds new rock catchment dams. The communities delivered free labour and local materials in return for ownership of the rock catchments. The Diocese used a step design, while Danida used 9 different designs.



The Kitui Diocese's step design for a rock catchment dam.



A single arch rock catchment dam.



A complicated slanting multi-arch rock catchment dam at Mutomo.

The communities preferred the ALDEV design because of its simplicity that made it easy for the communities to construct rock catchment dams themselves without external assistance.



The ALDEV design for a rock catchment dam.

A girl drawing water directly from the reservoir of a rock catchment dam.

## 1.6 Lessons learned

### Positive observations

The rural communities in Kitui and Mwingi prefer rock catchments more than any other type of water supply, except roof catchments, because rock catchments have the advantages of:

- 1) Even small rain showers falling on rock catchments produce large volume of run-off water that can easily be drawn from their reservoirs.
- 2) Maintenance is simple and cheap; the catchment area and reservoir should be swept and water taps replaced before rainy seasons.
- 3) Rock catchment dams do not occupy Farmland but only rocks that are nobody's property. However, for construction of earth dams near rocks, the ownership must be settled before any activities take place.
- 4) People have been used to draw water from rock catchments since the first structures were built in the middle of the 1950s.



### Negative observations

- 1) The evaporation losses are so high in open dam reservoirs that in extreme cases half of the water may be lost to evaporation. Reservoirs can be roofed to reduce evaporation but it requires good design and workmanship.
- 2) Water quality may be below WHO standards, but that is acceptable by the communities concerned. The sun's ultra-violet rays on exposed water sterilize water to an unknown standard.
- 3) Mosquitoes breed in the water of open dam reservoirs, thereby spreading malaria. This can be prevented by one of three methods;
  - a) Roof open dam reservoirs.
  - b) Raise *Tilapia Nilotica* fish in the water reservoirs.
  - c) Pour a few litres of clean oil onto the surface of a water reservoir.
- 7) Tanks and masonry dams provide domestic water, but are not capable of supplying water for livestock or irrigation due to their high demands.
- 8) Water for livestock and irrigation can be provided from earth dams situated at the foot or near rocks. Clean water for domestic use can be drawn

from earth dams by means of a hand-dug well sunk in a seepage area downstream of dam walls.

## 2 COMMUNITY PARTICIPATION

### 2.1 Social and cultural considerations

Experience has shown that where only a narrow technical focus is adopted, many projects have failed. The reasons for the failures are varied; sometimes the high cost of the systems prevents continued implementation and replication once donor funds for the pilot project have dried up. At other times, communal systems fail because responsibility for the management, maintenance and repair of the system has not been clearly defined.

A key factor in project success is community involvement at every stage from inception to long-term maintenance and operation. Involvement in planning and construction phases will not only help to build skills and a sense of self-reliance within communities, but also prepare the community better for any future maintenance and repair work.

For a rock catchment system to succeed, it must address a real felt need within a community and be socially acceptable. The administrative and leadership capacity within a community is also important factors influencing the prospects for communal water projects.

In Kenya, the tradition of *Harambee* (to pull together) on communal self-help projects has greatly assisted many villages with the affordable implementation of rock catchment dams.

In the semi-arid Machakos and Kitui in Kenya, the *Wakamba* communities have organized themselves into self-help groups, called *Mwethya*, many decades ago. They know that by working together they can cope with the harsh climatic conditions. This self-help spirit, combined with lack of fresh groundwater, has been the main drive in the construction of the hundreds of rock catchments built in that region for the last 50 years.

Since boreholes not situated next to riverbeds provide saline water, people prefer drinking rainwater from rocks and roofs because it is cleaner than water from hand-dug wells, ponds and earth dams.

Promotion of rock catchments in regions where these structures are unknown should include a study tour for their leaders to go to Kitui or Mwingi to see for themselves the benefits of rock catchments.



A community building their rock catchment dam at Wote in 1996.

## 2.2 Health issues

Although *Water is Life*, contaminated water may cause illness - and perhaps death. Rural people in arid and semi-arid regions often says *water is water* meaning that all water, whether clean or contaminated, is drinkable.

As a matter of fact, people used to drink contaminated water rarely get sick from it. The reason seems to be that the constant exposure to germs and bacteria has made the people immune.

Understandable, people having insufficient water supply consider quantity more important than quality. Women and girls often often have to fetch water on their backs many kilometers from home – and often that water is contaminated by people and animals sharing the same water in an unlined waterhole or an earth dam.

Although water in rock catchments without roofs is being sterilized partly by the Sun's ultra-violet rays, the water quality can be improved by carrying out the following maintenance procedures:

- a) The surface of the rock catchment should be swept before rainy seasons.
- b) Silt traps should be emptied after inflow of run-off water.
- c) Water reservoirs should be emptied and cleaned before rainy seasons.
- d) People should not enter water reservoirs for drawing water but take it from tap stands.

- e) Baboons, which loves rock outcrops, must be kept out of catchments and reservoirs.
- f) Mosquito breeding can be eliminated by raising *Tilapia Nilotica* fish in the reservoirs.

A new and proven method of sterilizing drinking water, called SODIS (Solar DISinfection), has been developed recently with the arrival of drinking water in transparent plastic bottles.

The SODIS method consists of filling empty transparent bottles with unclean water and exposing it to sunshine for at least 5 hours. The Sun's ultra-violet rays kill off all germs and bacteria within that period.

This method is cheaper and more environment-friendly than using firewood or charcoal to boil water for drinking.



Water can be sterilized in a transparent plastic bottle by the Sun's UV rays.

Should water contain dust or dirt particles, these can be made to settle by applying a few drops of seed oil from a *Moringa oleifera* tree, also called the Horseradish Tree or the Drumstick Tree that grows well in dryland.

## 2.3 Cost benefits

The cost benefits of rural water supplies comprise three components, namely:

- a) The construction cost of the water project.
- b) The annual cost (recurrent) of maintenance and repair of the water project.
- c) Compare the construction and recurrent costs of rock catchments with conventional methods of obtaining water such as boreholes, large earth dams or water sold by vendors.

The economic viability of rock catchments depends on the cost of conventional water sources. The local inhabitants can usually evaluate whether a rock catchment is the best option than for them

### Comparison of cost of 3 types of rock catchments

Earth dams are the cheapest type to construct using manual labour or animal draught.



The disadvantages of earth dams are loss of water by seepage and evaporation, and much maintenance due to:

- a) Spillways get eroded by overflowing surplus water.

- b) Dam walls get damaged by grazing livestock.
- c) Dam reservoirs get silted up if the silt traps are not cleaned.

**Rubble-stone masonry dams** that gain free storage capacity from natural rock pools or gorges are cheap to construct and maintain.



These dams have no seepage losses but half of the volume of water might evaporate. Evaporation can be prevented by roofing the reservoirs, as seen below, but that doubles the construction cost.



**Water tanks** are the most expensive type of rock catchments to construct but since they have no seepage loss or evaporation loss their disadvantage is limited storage capacity of water.

## 2.4 Environmental feasibility and impact

### Feasibility

The environmental feasibility depends on two items;

- a) **Availability of rock outcrops**, such as whalebacks, inselbergs, pediments, koppies, grund-level rocks and underground rocks
- b) **Rainfall**, even low and erratic showers can supply large volume of water provided the rock area is sufficient large to compensate for the low rainfall.

Remember; 1 acre of rock surface can produce 2.4 million liters of water on 600 mm of rainfall.



A man fetching water on a bicycle.



A woman coming home with water.

### Impact

No negative environmental impact is known for rock catchments.

A positive impact is that rock catchments harvest rainwater that otherwise would create soil erosion and flooding problems for people living adjacent to the rocks.

## 2.5 Gender issues

Until recently, one of women's many responsibilities was to fetch water, often far from their homes. This gender issue is now slowly changing. In places where bicycles are affordable, it is often the men who fetch water by carrying 2 or 3 jerry-cans of water on their bicycles.

If a husband is working far away from the homestead, the wife can usually ride the bicycle for fetching water.

It can sometimes be difficult to improve or construct a water project but by following the line of command in the administrative establishment, most obstacles can be overcome. Usually communities have already organised themselves into either:

- a) **Women groups** consisting of women only. These groups are usually well organized, reliable and always interested in water projects that can shorten the distance for fetching water.
- b) **Self-help groups** consist of both men and women. The majority of committee members are usually men, while women being a minority.

Since fetching water is the responsibility of women, they should be represented equally with men in committees.

## 2.6 Administrative guidelines

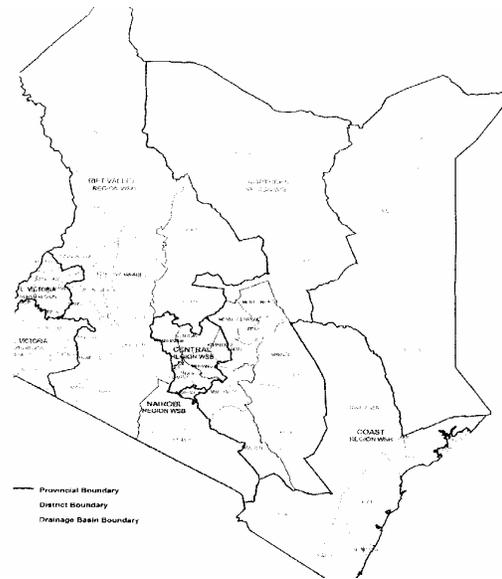
A self-help group, or a women group, is managed by a committee that has been elected by a group of people who have common interest in, for example; the construction of a rock catchment.

### A committee consists of:

- a) A Chairperson, who is usually an elderly and articulate person.
- b) A Treasurer, who is a person trusted in money matters and in keeping records.
- c) A Secretary, who can speak, read and write English.
- d) Deputies for each of the three persons mentioned above.
- e) A committee might have a Patron, who can be a respected politician or a well-to-do businessman capable of assisting the group with approvals or finances.
- f) The Assistant Chief of the area is also a member of self-help- and women groups.
- g) Preferably, half of the committee members should be women.

For a group to obtain an official status, it must be registered with the relevant department under a ministry dealing with community development.

Nowadays in Kenya, proposals for renovation and construction of water projects are presented to one of the 7 Water Services Boards (WSBs) covering the parts of the country shown below.



### WSB addresses are:

Athi WSB, Box 45283, 00100 Nairobi  
Tana WSB, Box 1343, Nyeri  
Coast WSB, Box 90417, Mombasa  
L. Victoria South, Box 3325, Kisumu  
L. Victoria North, Box 673, Kakamega  
Rift Valley WSB, Box 220, Nakuru  
Northern WSB, Box 495, Garissa



A self-help group stands where the wall for their rock catchment dam will be constructed.

## 2.7 Writing a proposal for a rock catchment project

When a community has decided they need a rock catchment dam or tank, the following guidelines can assist them to write a proposal for a rock catchment project that can be presented to their WSB.

First state the name, postal address and physical location of the proposed project. Add some committee members' telephone numbers.

Then state the number of people who will benefit from the project and the size of the area in which they live. Explain where they are fetching water at present and the benefits they will gain from the proposed project.

Thereafter describe the water project in words and with a design sketch and a bill of quantity (BQ) that shows the required materials and labour.

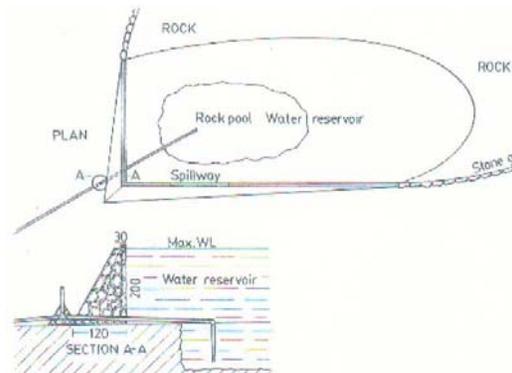
Then estimate the cost of materials and labour and present it as a budget divided into two sections:

- a) The cost of items to be purchased, such as technical assistance, tools, training, materials, transport, etc.
- b) The value of providing local labour and local materials that will be provided free of charge by the community. This value should amount to about 15% of the total cost of training and construction.

Thereafter explain how the community will manage the funds for the training and construction works as well as for future maintenance of the project.

Should it be too difficult for a committee to write an acceptable proposal, the WSB might recommend somebody who can write the proposal for a fee to be paid by the community.

When the project proposal been discussed and approved by the community members, the final proposal is presented to the Water Service Board covering that area.



A design sketch of a rock catchment dam.

After some time when the project proposal has, hopefully, being approved and financed by WSB, the detailed survey, design and construction work can be implemented by a consultant or contractor approved by the WSB.

In the unlikely event of WSB turning down the proposal, then the committee has to solicit funds from elsewhere.

If a donor agency cannot be found to sponsor the implementation, then the required funding has to be raised locally. This may not be an easy task, but some suggestions are mentioned on the next page.

## 2.8

### Methods of raising funds locally

Some time ago, the method of raising funds was to contact a donor and request them to finance a proposal. Nowadays, most donors give their money to WSBs. If therefore a proposal has not been granted by the WSB, the community must finance their project themselves.

In order to minimise the construction cost, a community can select one of the 3 low-cost types of water projects listed below. Each one of them require only a few bags of cement but much unskilled labour that can be supplied free of charge by a community itself.

- a) A rock catchment dam made by removing the vegetation and soil covering a rock pool. If required, the pool can be enlarged with a low wall built of rubble-stone masonry.
- b) A subsurface dam built of soil with a hand-dug well in a dry riverbed.
- c) A small earth dam (pond) built of soil and equipped with a hand-dug well.

These 3 types of water projects can be constructed in stages depending on the availability of cash and labour. The best season for construction work is after harvest when crops can be sold for cash and people are not busy in their fields. Another incentive is that the demand for water is at it highest during dry seasons.

The techniques for locating suitable sites, sketching designs, estimating costs and learning construction procedures can be found in this series of handbooks.

Although these 3 types of water projects are cheap to construct, cash is not easily found in the country side. People keep their capital in livestock and land holdings because the interest gained from bank accounts is too small compared with the value of offspring of livestock.

Nevertheless, rural people can still donate some cash from selling livestock or farm produce when they consider the matter sufficient urgent.

The usual methods of fund raising are:

- 1) Cash raised at *Harambee* meetings for e.g. students going for further studies, construction of churches and schools or payment of someone's hospital bill or funeral.
- 2) Monthly fees from members of a self-help group.
- 3) Merry-go-around payments.
- 4) Income from a self-help group's activities, such as making burnt bricks, sand, stones and ballast, rearing goats and chicken, selling tree seedlings, weaving baskets and ropes, selling water from rock catchments, etc.
- 5) Fines paid by members for being absent or late or failing to carry out tasks given by a self-help committee.

### 3 ROCKS SUITABLE FOR ROCK CATCHMENTS

#### 3.1 Suitable types of rocks

Most ASAL and desert regions have suitable rocks for rock catchments. Some rock surfaces are exposed while others are invisible due to being covered by soil and vegetation.

Long narrow rocks of granite raising from flat land are called *whalebacks*



as this whaleback situated in Tzavo.

*Inselbergs* are large dome-shaped rocks protruding from flat land

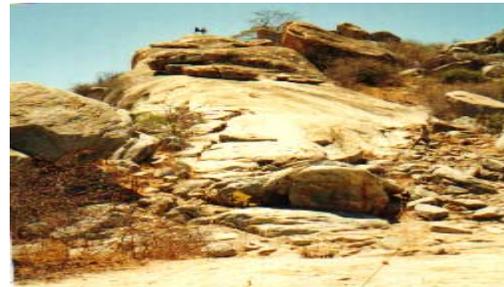


as this inselberg at Voi.

Hills with exposed rock surfaces at the highest end are called *pediments*



as this pediment at Sagalla.



Rocks protruding from the ground are called *kopjes* as this at Dodoma.



*Ground-level rocks* are, naturally, situated just above ground level such as this ground-level rock at Taveta.

*Underground rocks* can usually be identified by the stunted growth of vegetation in the soil covering a rock



such as this underground rock where some of its soil cover being removed at Wote.

### 3.2 How were rocks created?

Geology is the technical word for the subject dealing with rocks.

Some 500 million years ago, Africa collided with another continent. The slow collision heated up and faulted the granite bedrock deep underground whereby it was raised up to form mountains and rock outcrops.

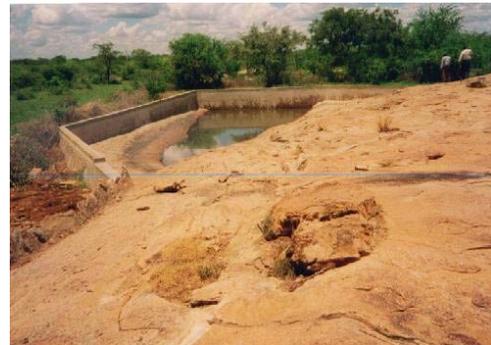
Granite constitutes the central core of many great mountain ranges and granite is the typical bedrock of the continents, often overlaying Basalt rock.

Rocks made of granite are viable for rock catchments. Granite can be recognized by its coarse-grained texture with colours of either reddish, white, light grey and speckled with hornblende or black mica.

Softer parts of granite rocks that are exposed to the Sun, rains and varying temperatures disintegrate and decompose by a process called *weathering*. Over the millennium, weathering may create depressions in granite rocks, called **rock pools**, where rainwater can accumulate. Rock pools can be used as water reservoirs when soil and vegetation is cleared out.



A rock pool partly filled with soil at Voi. Whenever possible, rock catchment dams should be built around the lower side of rock pools to gain free storage



volume for the water reservoir.

A three-winged wall has been built around a rock pool at Mutomo.

The surface of granite rocks are also weathering thereby make the granite rock surface scale off in loose and thin



stone slabs as seen below.

Such slabs can be used for building the outer sides of dam walls without using



formwork of timber as seen below.

### 3.3 Components of rock catchments

When looking for suitable sites for rock catchments, keep in mind that rock catchments consist of four components:

1) *A catchment area* of clean rock surface from where rainwater can run off without obstruction. Rocks can be cleaned by removing soil, vegetation, stones and loose parts from the surface.

Large fissures can be sealed with cement mortar or concrete. Smaller cracks can be sealed with Bitumen.



An uncleaned rock catchment at Sagalla.

2) *Garlands of gutters* divert rainwater run-off from a catchment to a water reservoir. Gutters can also be used to increase the catchment area of rocks..

Aqueducts can deliver water from gutters to water tanks and run-off water from adjacent rock surfaces to the main catchment area.



A garland of gutter at Kasigau.



An aqueduct gravitating run-off water from a rock to a tank at Kibwezi.

3) *A water reservoir* that can be a water tank, a rock catchment dam, as seen below, or an earth dam.



4) *Extraction of water* from rock



catchment dams consists of gravitating water via a pipe to a tap stand at the foot of the rock.

A tap stand with a self-closing watertap made locally in Mutomo.

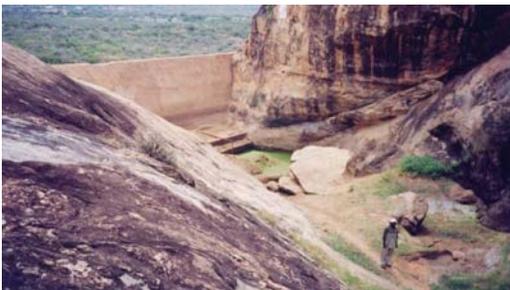
### 3.4 Where to find suitable sites for rock catchments

For a layman, it may be difficult to imagine how the shapes of a rock can be utilised for harvesting and storing rainwater because most rocks are covered with vegetation making it difficult to see the potential places for catchments and reservoirs.

Each of the three types of rock catchments has its specific site criteria that are explained in the following chapters:



Chapter 6 deals with water tanks.



Chapter 7 describes masonry dams,



Chapter 8 deals with earth dams at rocks

Generally, all three types of rock catchments can be constructed at almost any type of rock outcrops provided they can produce the required volume of rainwater run-off.

However, as explained in Chapter 7, masonry dams are more site-specific than tanks and earth dams because:

Gorges between two rocks can be closed with a straight dam wall.

Rock pools and rock shelves, the latter being nearly flat areas on rock outcrops, can be surrounded with two-winged or three-winged dam walls.

Despite being site-specific, masonry dams have the following advantages over water tanks and earth dams:

- They can be constructed in stages according to the availability of funds and community labour.
- They have no problems of erosion.
- Maintenance consists only of sweeping the catchment area before rains and occasional replacement of watertaps.
- They have no ownership dispute.
- They do not occupy farm-or grazing land.

## **4 Relation between catchment areas and reservoirs**

It is important that the catchment area of a rock and the seasonal rainfall of that region can fill its water reservoir. While the catchment area can be known by following the advice in the next chapter, the rainfall in arid and semi-arid regions may vary from 100 mm to 1,000 mm in a season, although its seasonal average is quoted as, say 300 mm.

The consequences are that if a catchment is too small and the rainfall is average, then its reservoir will not be filled up with water. On the other hand, if a catchment is too large and the rainfall is average, then most of the run-off water will be wasted by spilling over the water reservoir.

It is therefore a balancing act to determine the correct size of a catchment area due to the unpredictable rainfall. Experience has shown that most communities prefer their rock catchment to spill-over with water when the rainfall is average rainfall and above, instead their reservoir not filling up with water when the rainfall is below average and when water is in short supply everywhere.

Three factors can be used to estimate the volume of run-off water from a rock catchment:

- 1) Seasonal rainfall.
- 2) Evaporation loss from rains falling on rock surfaces.
- 3) Size and slope of a catchment area.

### **4.1 Seasonal rainfall**

Where the average rainfall of a season is known it is wise to use only half of that figure. For example, divide a seasonal rainfall of 300 mm with 2 = 150 mm and use that figure for calculation the volume of rainwater run-off.

### **4.2 Evaporation loss from rains falling on rock surfaces**

Almost all rainwater runs off rocks because they have a hard surface which water cannot infiltrate. However, some 15% of the rainwater might evaporate when it falls on rocks heated by the Sun during daytime. Since most rains fall at night or early mornings in the tropics, it can be assumed that the nightly evaporation loss is about 5 %. The evaporation loss might therefore be about 10% on average.

### **4.3 Size and slope of catchment areas**

A simple method to measure a catchment area is to use the known practice of one acre of land is a square measuring 70 steps on all four sides. When each step has length of 1 yard, equal to 3 feet or 91.5 cm, then  $91.5 \text{ cm} \times 70 \text{ steps} = 64,05 \text{ m} \times 64,05 \text{ m} = 4,102$  square meters which is close to the 4,047 square metres being the correct area of 1 acre.

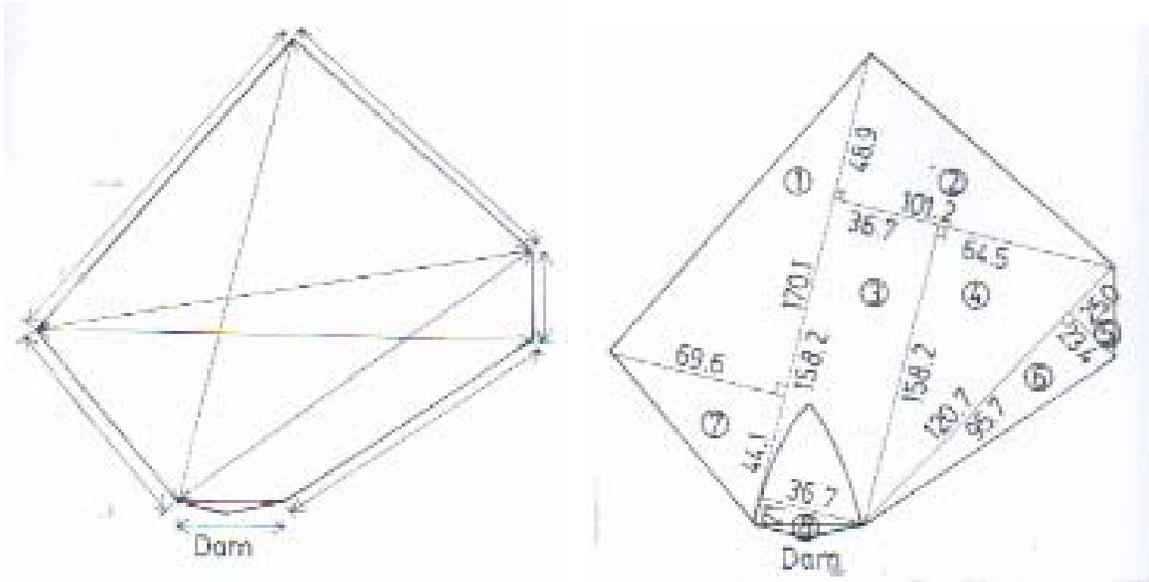
When the area of a catchment is known in square meters, then multiply with 4,047 to convert the area from acres to square meters.

A more accurate method consists of measuring the boundaries of a catchment area and the distances in between the boundaries using a long tape-measure and millimetre paper to draw a sketch as shown below to the left.

The catchment area is then divided into triangles and rectangles with corners of 90 degrees. The area can then be calculated using the formula of:

The area of a triangle = length x height / 2

The area of a rectangle = length x height



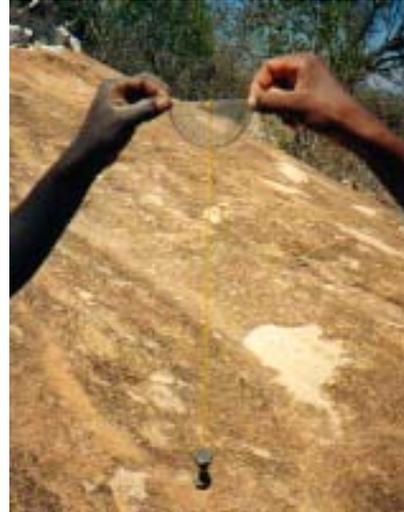
The catchment area in this example can now be calculated as:

- 1)  $170.1 \times 69.6 / 2 = 5,919.5$
- 2)  $101.2 \times 48.9 / 2 = 2,474.3$
- 3)  $158.2 \times 36.7 = 5,805.9$
- 4)  $158.2 \times 64.5 / 2 = 5,102.0$
- 5)  $25.0 \times 23.4 / 2 = 292.5$
- 6)  $95.7 \times 23.4 / 2 = 1,119.7$
- 7)  $69.6 \times 44.1 / 2 = 1,534.7$
- 8)  $36.7 \times 7.1 / 2 = 130.3$

Total catchment area 22,378.9 sq.m. say 22,380 square meters

Since the volume of rainfall falling on a sloping surface is less per square meter than on a horizontal surface, the following percentage of square meters has to be deducted from a sloping catchment area.

90 degrees gradient minus	100 %
80 degrees gradient minus	86 %
70 degrees gradient minus	68 %
60 degrees gradient minus	47 %
50 degrees gradient minus	38 %
40 degrees gradient minus	23 %
30 degrees gradient minus	13 %
20 degrees gradient minus	5 %
10 degrees gradient minus	2 %



A protractor for measuring slopes

The gradient of a sloping rock catchment can be found using a transparent protractor with a bolt or small stone tied to the centre of it with a string.

When the string is aligned with the 90 degree mark at the bottom of the protractor, the gradient of the rock can be seen by looking at the rock through the scale on the transparent protractor.

#### 4.4 Example of run-off water from a catchment of rock:

- 1) An average seasonal rainfall is quoted as 300 mm.  
As explained earlier, divide the figure by 2 = 150 mm.
- 2) The catchment area is 22,379 sq.m. and has a gradient of 40 degrees.  
According to the sketch above; a 40% sloping catchment receives 23 % less rainfall than a horizontal catchment.

The horizontal catchment area is therefore:

$$\frac{22,379 \text{ sq.m.} \times 23}{100} = 5,147.17 \text{ horizontal sq.m.}$$

- 3) The evaporation loss is 10 %.

Therefore the volume of run-off in this example will be:

$$150 \text{ mm rain} \times 5,147.17 \text{ horiz.sq.m.} - 10 \% \text{ loss} = \frac{694,868 \text{ litres}}{1,000} = 694,9 \text{ cu.m. water.}$$

As a rule of thumb, the storage volume of a reservoir for, say, 695 cu.m. of water can be reduced with 20% due evaporation and consumption of water from the reservoir during the rainy season.

Therefore, if the total seasonal run-off is 695 cu.m., then the reservoir should have a storage volume of:  $\frac{695 \text{ cu.m.} \times 20}{100} = 126 \text{ cu.m.}$  which is deducted from 695 cu.m. to get

the correct answer that the reservoir should have a storage volume of 569 cu.m.

## 4.5 Tools and equipment for survey and design

The type of tools and equipment required for carrying out surveys of rock catchments depends on the surveyor's level of sophistication. Since this handbook advocates low-cost and do-it-yourself techniques, the tools and equipment listed below will be sufficient for the task.

Item	Specification	Quantity	Approx. US\$
Note book	Any	1 nos.	1
Ball pens	3 colours	3 nos.	2
Tape measure	30 metres long	1 nos.	8
Protractor	Transparent with string and nut	1 unit	2
Spirit level	About 120 cm long	1 nos.	3
Timber with 2 legs	100 cm long + legs	1 nos.	1
Mason hammer	Any	2 nos.	3
Transparent hosepipe	1 metre of 12 mm to 18 mm diameter	1 length	1
Transparent hosepipe	30 metres or more	1 length	10
Builders' line	50 metres	1 length	2
Calculator	Any	1 nos.	5
Graph paper A3	Millimetres	1 pad	4
Drawing board	Size A3	1 unit	70
Drawing equipment	Secondary schools	1 set	10
White oil paint	1 litre	1 tin	8
Water	Drinking	5 litres	6
<b>Approx. Total</b>			<b>136</b>

## 5 How to estimate the volume of dam reservoirs

When a design and its construction cost have been made for a rock catchment dam or an earth dam, the volume of its water reservoir should be known so that it can be estimated whether it is economically viable to construct the dam.

Water reservoirs for rock catchments and earth dams can have many shapes. It is therefore a little complicated to estimate the volume of such water reservoirs. However, the following guidelines describe two methods on how to estimate the volume of dam reservoirs.

### **5.1 The simplest method**

The volume of dam reservoirs can roughly be estimated using a simple formula:

Volume = width of reservoir x depth of reservoir x length of reservoir / 6

For example: The maximum width (w) of the reservoir is 20 meters. The deepest part of the reservoir (d) is 4 metres and the length of the reservoir (l), also called the throw-back, is 60 metres.

Therefore: (w) 20 m x (d) 4 m x (l) 60 m / 6 = 800 cubic metres

### **5.2 A more precise but complicated method**

The volume of a water reservoir can be estimated more precisely by dividing it into horizontal layers spaced 100 cm apart. The upper and lower area of each layer is measured and its area calculated in square meters. When the two areas are added together and divided by 2, it gives the volume in cubic meters of the section between these two layers. When the volume of all the sections in the dam reservoir are added together, the total volume of the water reservoir is known.

Practically, this method can be applied by marking the maximum water level onto the sides of the rock, or an earth dam, using either a long transparent hosepipe filled with water as seen on the photo below or -

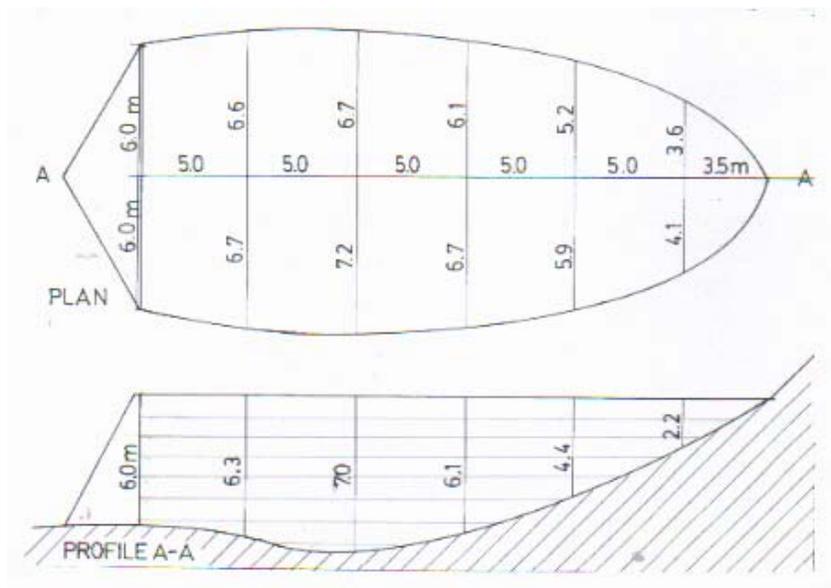




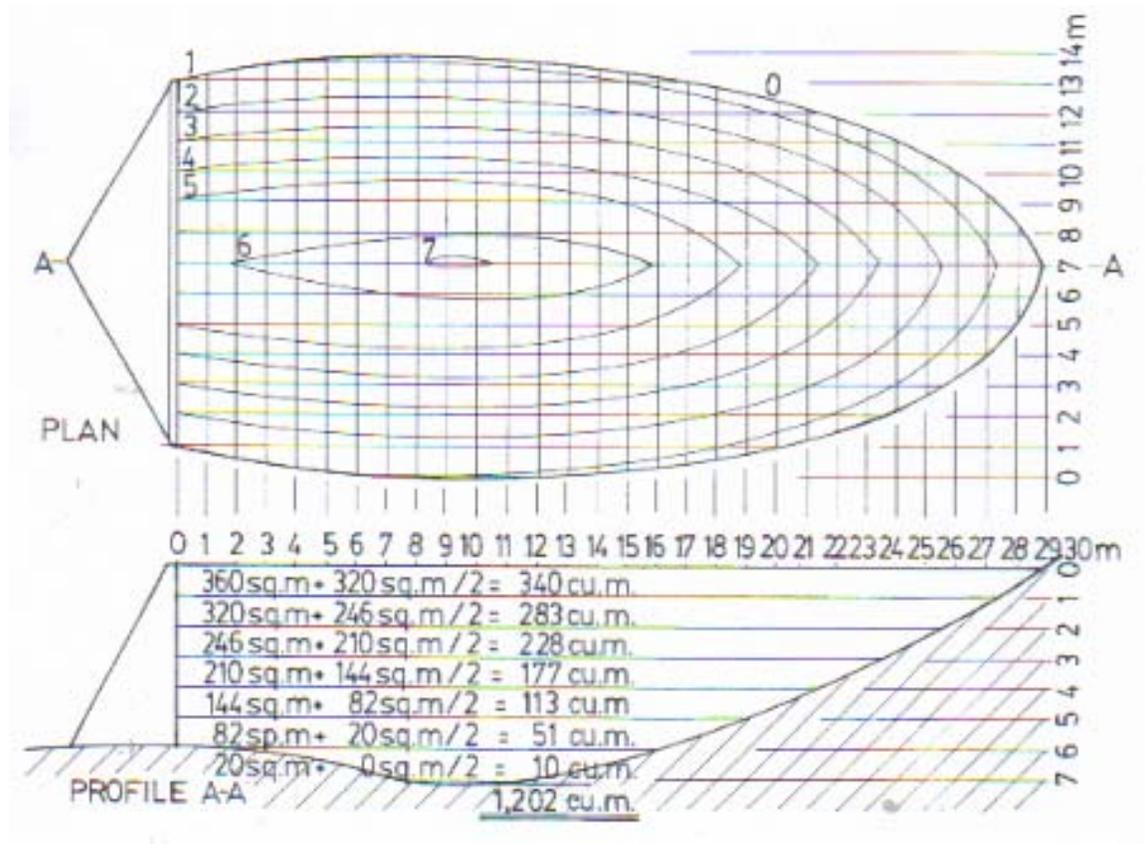
- or use a short length of a transparent hosepipe bent into a circle and filled halfway with water as shown above. The two water-levels in the transparent plastic pipes give two exact horizontal levels that can be used for sighting and marking the horizontal level of a water reservoir filled to its maximum with water.

With the maximum water level marked for every 5 meters, or so, onto the sides of a water reservoir, the following measurements can be taken. Knots are made for every 5.0 meters on a long nylon string. The string is then inserted in the hook of a 30 meter long tape-measure and drawn tightly across the longest section of the dam reservoir at the height of the maximum water level.

The tape-measure hanging in the nylon string can now be used for taking vertical measurements from the string drawn at the maximum water-level to the bottom of the reservoir for every knot at 5 meters on the string. Similarly, the tape-measure is used for taking horizontal measurements from the nylon string to each side of the marked maximum water level of the water reservoir. The vertical and horizontal measurements can now be transferred to a millimetre graph paper in scale 1:100 as shown below.



By counting and adding together the numbers of full, half and quarter squares within the drawn lines, the surface area and volume for each of the 100 cm high sections and the total volume of the water reservoir can be found in cubic meters.



In this example, the total volume of the water reservoir was found to be 1,202 cu.m.

### 5.3 Tools and equipment for survey and design

The type of tools and equipment required for carrying out surveys of water reservoirs depends on the surveyor's level of sophistication. In this handbook for do-it-yourself the tools and equipment listed below will be sufficient for the task.

Item	Specification	Quantity	Approx. US\$
Note book	Any	1 nos.	1
Ball pens	3 colours	3 nos.	2
Tape measure	30 metres long	1 nos.	8
Transparent hosepipe	From ½" to 1"	50 meters	25
Builders' line	50 metres	1 length	2
Calculator	Any	1 nos.	5
Graph paper A3	Millimetres	1 pad	4
Drawing board	Size A3	1 unit	70
Drawing equipment	Secondary schools	1 set	10
Water	Drinking	5 litres	6
<b>Approx. Total</b>			<b>133</b>

## 6 Water tanks

### 6.1 Site criteria for rock catchment tanks

Water tanks can be constructed at almost any rock outcrop provided the tank can be placed on firm ground at a lower elevation than the catchment.

The rainfall and area of a catchment should be sufficient large to fill a tank from a rain shower of, say 20 mm. To fill a 50,000 litres (50 cu.m.) tank on 20 mm rain, the catchment must have an area of:

50,000 litres / 20 mm rain + 10 % evaporation loss = 2,750 sq.m.= about 2/3 of an acre.



A 50 cu.m. rock catchment tank at Kibwezi. A similar rock catchment tank at Lakipia

Water tanks that collect and store rainwater run-off from rocks are being used in many places because the technique is easy to understand and local builders usually know how to construct water tanks. However, the constraints with rock catchment tanks are:

- a) they can only storage a limited volume of water and therefore dry up in a few weeks, and
- b) they are expensive compared with masonry dams and earth dams.

It is an economical advantage to build water tanks with a height not exceeding 200 cm. If water tanks are built with a height of more than 200 cm they require more reinforcement than recommended in this handbook.

### 6.2 How to estimate the volume of a cylindrical tank

The volume of a cylindrical water tank is calculated using the formula of:

$$\text{Volume} = \text{radius} \times \text{radius} \times \frac{22}{7} \times \text{height} = r \times r \times \frac{22}{7} \times h = r^2 h$$

The volume of a 50,000 litres tank is therefore calculated as:

$$\text{Radius } 283 \text{ cm} \times \text{radius } 283 \text{ cm} \times \frac{22}{7} \times \text{height } 200 \text{ cm} = 50,342 \text{ litres (50.342 cu.m.).}$$

### 6.3 Design of a 50 cu.m. rock catchment tank

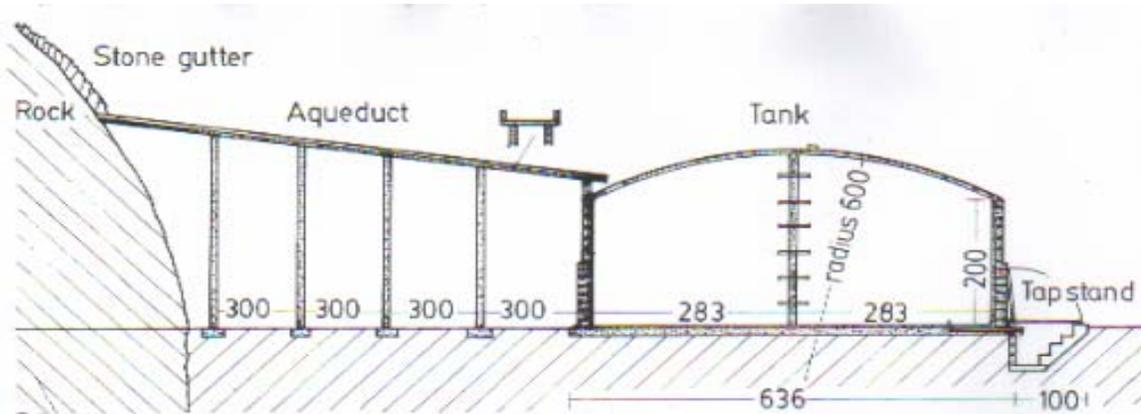


Fig. 6. Design of a cylindrical rock catchment tank with a storage volume of 50 cu.m..

### 6.4 Bill of quantity and cost of a water tank with dome & gutters

Item	Specification	Quantity	Total cost US\$
Materials	1 tank with dome	50 cu.m. storage	1,660
Materials	1 aqueduct	10 m. length	345
Materials	2 garlands of gutters	100 m. length	242
Tools	For tank & gutters	For 2 artisans	10
Form-work	For dome	US\$ 340 / 20 tanks	34
<b>Approx. Total</b>	<b>1 tank w. aqua.gut.</b>		<b>2,291</b>

Detailed costs of materials, tools and form-work are shown below.

Preferably, the communities should provide free of charge all locally-available materials, such as sand, crushed stones, rubble stones, water, store with store-keeper, skilled and unskilled labourers in return for the ownership of the rock catchment tank. Such a cost-sharing divides the cost as follows:

#### Cost-sharing of expenditure

Structure / Item	Value of community contribution US\$	External financial & technical assistance US\$	Total cost US\$
50 cu.m. water tank	805	855	1,660

10 m aqueduct	208	137	345
100 m gutters	178	64	242
Tools		10	10
Form-work		34	34
<b>Approx. Total</b>	<b>1,191</b>	<b>1,100</b>	<b>2,291</b>

### Bill of quantity and cost of materials for a 50 cu.m. water tank

Item	Specification	Quantity	Approx. US\$
Cement	50 kg bags	50 bags	400
Sand	Coarse river sand	15 tonnes	150
Water	200 litres oil-drum	25 oil-drums	75
Crushed stones	10 to 20 mm	6 tonnes	180
Rubble stones	10 to 15 cm	10 tonnes	10
Rubble stone blocks	40 x 19 x 14 cm	510 blocks	150
Weld-mesh	No.8, 2.4 m x 1.2 m	30 sheets	200
Barbed wire	Gauge 12.5	4 rolls @ 20 kg	100
Galvanised pipe	18 mm	3 metres	20
Round iron bars	12 mm	96 metres	50
PVC pipe	100 mm	3 metres	10
Skilled labour	Masons	2 masons x 15 days	180
Unskilled labour	Trainees	3 persons x 15 days	135
<b>Approx. Total</b>			<b>1,660</b>

### Bill of quantity and cost for 10 metres of aqueduct

Item	Specification	Quantity	Approx. US\$
Cement	50 kg bags	10 bags	80
Sand	Coarse river sand	10 tonnes	10
Water	200 litres oil-drum	5 oil-drums	15
Crushed stones	10 to 20 mm	5 tonnes	15
Rubble stone blocks	40 x 19 x 14 cm	160 blocks	48
Weld-mesh	2.4 m x 1.2 m	5 sheets	33
Skilled labour	Masons	2 x 6 working days	72
Unskilled labour	Trainees	4 x 6 working days	72
<b>Approx. Total</b>			<b>345</b>

### Bill of quantity and cost of 100 meters of stone gutters

Item	Specification	Quantity	Approx. US\$
Cement	50 kg bags	8 bags	64
Sand	Coarse river sand	6 tonnes	6
Water	200 litres oil-drum	4 oil-drums	12
Flat rubble stones	20 to 40 cm long	8 tonnes	8

Irregular stones	10 to 20 cm	8 tonnes	8
Water	200 litres oil-drums	8 oil-drums	24
Skilled labour	Mason	1 x 10 days	60
Unskilled labour	Trainees	2 x 10 days	60
<b>Approx. Total</b>			<b>242</b>

### **Tools for building a tank of blocks with a dome of ferro-cement**

<b>Item</b>	<b>Specification</b>	<b>Quantity</b>	<b>Approx. US\$</b>
Tape measure	3 m long	1	4
Mason hammers	Medium	2	6
Mason trowels	Medium	2	8
Square trowels	Steel	2	10
Mason chisels	Flat	2	6
Wooden floats	Medium	2	4
Straight edge	2 m long, 8 x 5 cm	1	2
Spirit level	120 cm long	1	6
Shovels	Medium	3	12
Pick-axe	Medium	1	6
Mould for blocks	40 x 19 x 14 cm	1	36
<b>Approx. Total</b>			<b>100</b>

Since the tools can be used for building at least 10 water tanks, the cost of tools for 1 tank is about US\$ 100 / 10 tanks = US\$ 10

### **Tools and materials for form-work for a dome of ferro-cement**

<b>Item</b>	<b>Specification</b>	<b>Quantity</b>	<b>Approx. US\$</b>
Carpenter saw	Medium	1	5
Carpenter hammer	Medium	1	3
Brace w. drill bits	9 mm drill bits	1	6
Old oil-drums	Made to flat sheets	30 sheets	160
Timber	275 x 20 x 2.5 cm	12 lengths	50
Timber	190 x 8 x 5 cm	12 lengths	40
Timber	180 x 8 x 5 cm	12 lengths	40
Bolts	8 mm, 15 cm long	12	4
Plastic basin	50 cm diameter	1	2
Skilled labour	Carpenter	5 days	30
<b>Approx. Total</b>			<b>340</b>

The form-work for the construction of a dome of ferro-cement can be reused for building about 10 domes, thereby reducing the cost for 1 tank to US\$ 340 / 10 tanks = US\$ 34

## 6.5 Construction of a water tank built of rubble stone blocks

Rubble stones found near the rock are compacted into concrete mixed of 1 part of cement to 4 parts of sand and 4 parts of ballast (crushed stones) in a mould.



The rubble stones save about 50% of the cost of cement, sand and ballast.

The circular foundation for the tank is excavated down to firm soil and levelled using a spirit level on a straight edge.

A 8 cm thick layer of concrete of mixture 1:4:4 is compacted onto the dry surface of the excavation. Weld-mesh is then cut, tied together and laid on the concrete.



The draw-off pipe is tied onto the weld-mesh with a wire and a 7 cm thick layer

of concrete 1:4:4 is compacted onto the weld-mesh and levelled with a rough surface.

After a couple of days, the rubble stone blocks are laid in a circle with equal spacing on the foundation using a radius wire attached to a pipe placed in the centre of foundation.



The blocks are mortared onto the foundation and to each course with mortar of a mixture of 1:4 without cutting any of the blocks.

When the tank has been built to its final height, barbed wire, gauge 12.5, is wrapped tightly around the wall in a spiral spaces 5 cm at the lower half of the tank and 10 cm at the upper half. The barbed wire is pulled tight using a carpenter's hammer while being nailed onto the wall of the tank.



The tank wall is then plastered on the outer side with mortar 1:3 and covered with Polythene sheets for curing. Thereafter the inner side and the floor are plaster with mortar and NIL (cement slurry) for water proofing.

The form-work for a dome is made of oil-drums that are cut open, flattened, cut into shape and laid upon a framework of timbers having the curve of a 6 m radius.



A centre pillar to support the form-work and dome is made of a vertical-standing PVC pipe filled with concrete. Short horizontal lengths of G.I. pipes are inserted in the PVC pipe before concreting it to function as a ladder.

The form-work is then covered with Polythene sheets or plastic sacks. Sheets of weld-mesh are cut and tied together on the form-work.



Mortar mixed of 1 part of cement with 3 parts of coarse sand is compacted onto the form-work in a 5 cm thick layer and smoothed to an even surface.

A circular plastic basin with a diameter of about 50 cm is used as mould for the man-hole.

The basin is placed on the form-work for the dome next to the pillar that will function as a ladder.

The basin is filled with concrete into



which a bend iron rod is inserted as a handle in the man-hole lid.

For curing the dome is covered with Polythene sheets or sacks covered with a layer of soil for 2 weeks.

Nobody should be allowed to walk or



stand on the dome while being cured.

An aqueduct for gravitating rainwater from the rock to the tank is constructed of a line of pillars, built of rubble stone blocks, that supports a concrete slab sloping towards the inlet of the tank.



## 6.6 Construction of stone gutters

Garlands of stone gutters built onto rock outcrops have two functions:

- a) they divert rainwater run-off from a rock catchment area to the water reservoirs of tanks and dams, and
- b) they increase catchment areas by winding their way around rocks. The lines of gutters can even extend to the opposite side of rocks.

Run-off water from adjacent rocks can also be gravitated to a water reservoir by aqueducts and garlands of gutters provided a sufficient gradient can be obtained.

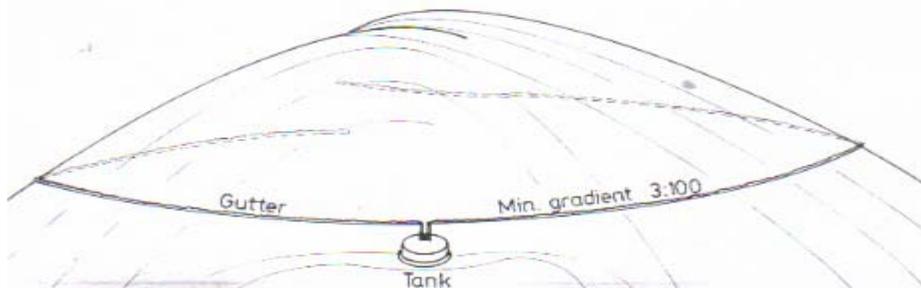


Fig. 7. Two garlands of gutters start from the aqueduct of a water tank or from the two ends of a masonry dam.

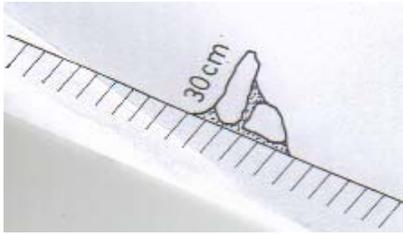


The gradient of 3:100 is marked onto a rock surface with a spirit level placed horizontally on a 100 cm length of timber that has two legs, one being 3 cm longer than the other.

Garlands of stone gutters start their upward gradient from the end of aqueducts, or the two ends of dam walls.



Fig. 8. Flat stones are supported by smaller stones that are mortared onto cleaned rock surfaces with a mixture of 1 part of cement to 3 parts of sand.



## 7 Masonry dams

### 7.1 The ALDEV (*African Land Development*) design

A series of rock catchment dams were constructed of the ALDEV design during the late 1950s in Kitui, the two most famous being *Ngomeni* built in 1955 near Kyuso and *Kaseva* built in 1956 near Mutomo in Kitui. Kaseva rock catchment had a storage volume of some 3,000 cubic metres that was enlarged to about 5,000 cubic metres by a Danida project *Mutomo Soil & Water Conservation* in 1989. The dam reservoir has only dried up 4 times during the last 47 years, namely during the long droughts of 1975, 1985, 1995 and 2002.

More than 100 rock catchment dams of the ALDEV design have been constructed in Kitui, Makeni, Taita-Taveta and Zambia without any failure by the author during the last 20 years. The success being due to the simplicity of the design that does not require any reinforcement provided the width of the foundation for a dam wall is equal to  $\frac{3}{5}$  of the height of the dam wall.

Rainwater falling on a rock is diverted to the dam reservoir by two garlands of gutters built of flat stones mortared onto the rock. The garlands are also used for enlarging the catchments so even a small rain shower can provide huge volume of run-off water.

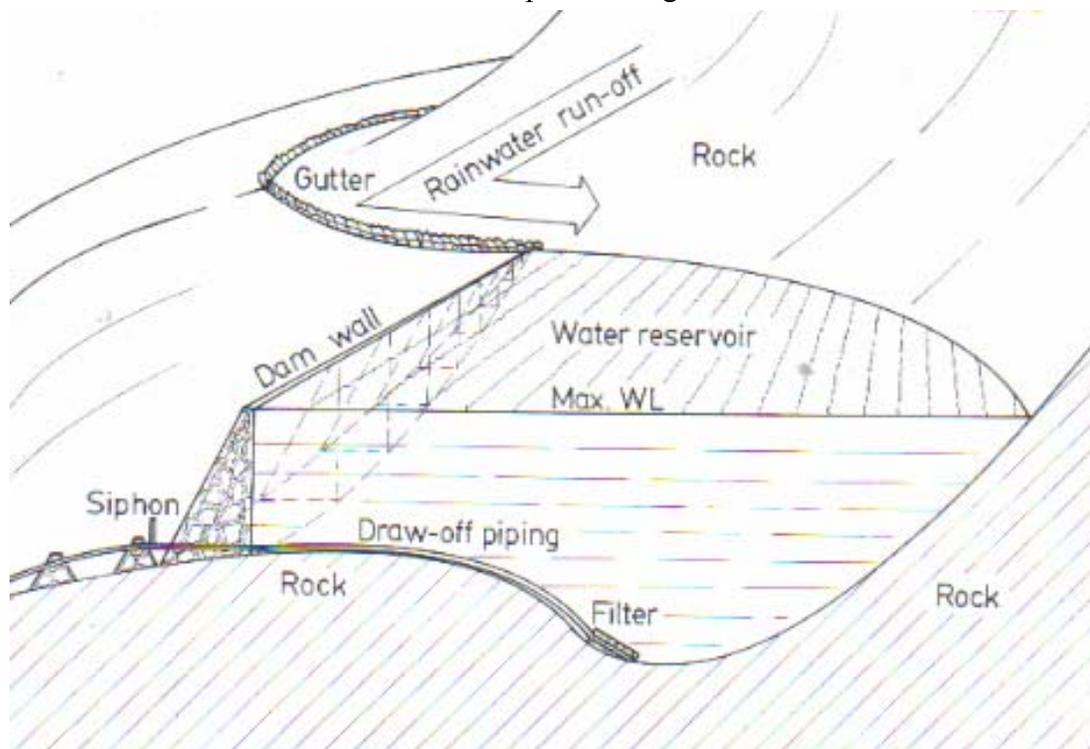


Fig. 9. A cut-through sketch of an ALDEV rock catchment dam with a garland of stone gutters. No reinforcement of the wall is required when the width of the base is  $\frac{3}{5}$  of the height of the wall because the factors of over-toppling and sliding are taken up by the weight of the dam wall. Water can be drawn by gravity through a galvanised pipe to a tap stand at the foot of the rock. A simple siphon device can lift water over a high point.

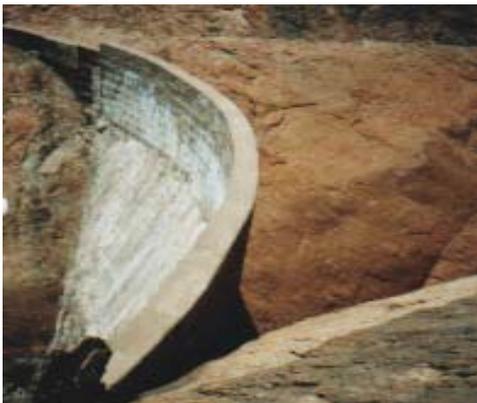
## 7.2 Other types of rock catchment dams



A dam wall filled with rubble stones packed in soil and covered with a coat of plaster was built at Kasiga in the 1950s. Twenty years later a large rock rolled down the catchment broke through the dam wall.



An underground rock was cleared of vegetation and soil in Mutomo. Deep rock pools were found where trees had grown. A low masonry wall was built along the lower side in 1985.



A single arch rock catchment dam built of concrete blocks in a gorge between two rocks in Mutomo in 1984.



A multi-arch rock catchment dam built of concrete blocks on a rock shelf in Mutomo in 1985.





A slanting multi-arch rock catchment dam built of concrete blocks at Mutomo 1986.

The less beautiful back side of the of the slanting dam wall.

### 7.3 Site criteria

Rock catchment dams should preferably be build on rocks that gives some free storage volume such as, gorges between two rocks, rock pools and rock shelves.

#### 7.3.1 Single-winged masonry dams in gorges



A dam wall built in a gorge at Kasigau.



Another dam wall in a gorge near Kasigau

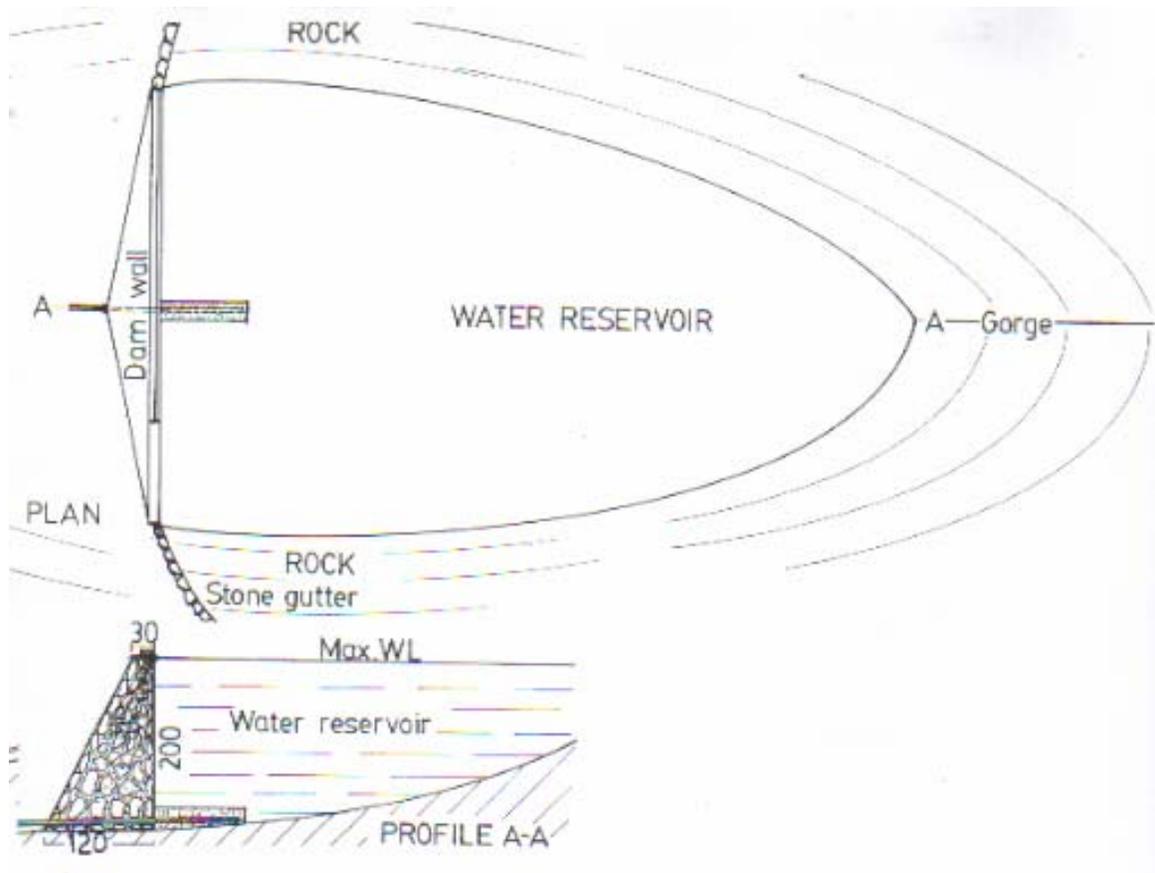


Fig. 10. Design of a rock catchment dam built as a straight masonry wall across gorges.

### 7.3.2 Two-winged masonry dams around rock pools, in gorges and on rock shelves



A rock pool near Taveta



A V-shaped dam wall with a siphon pipe built around a rock pool at Mutomo

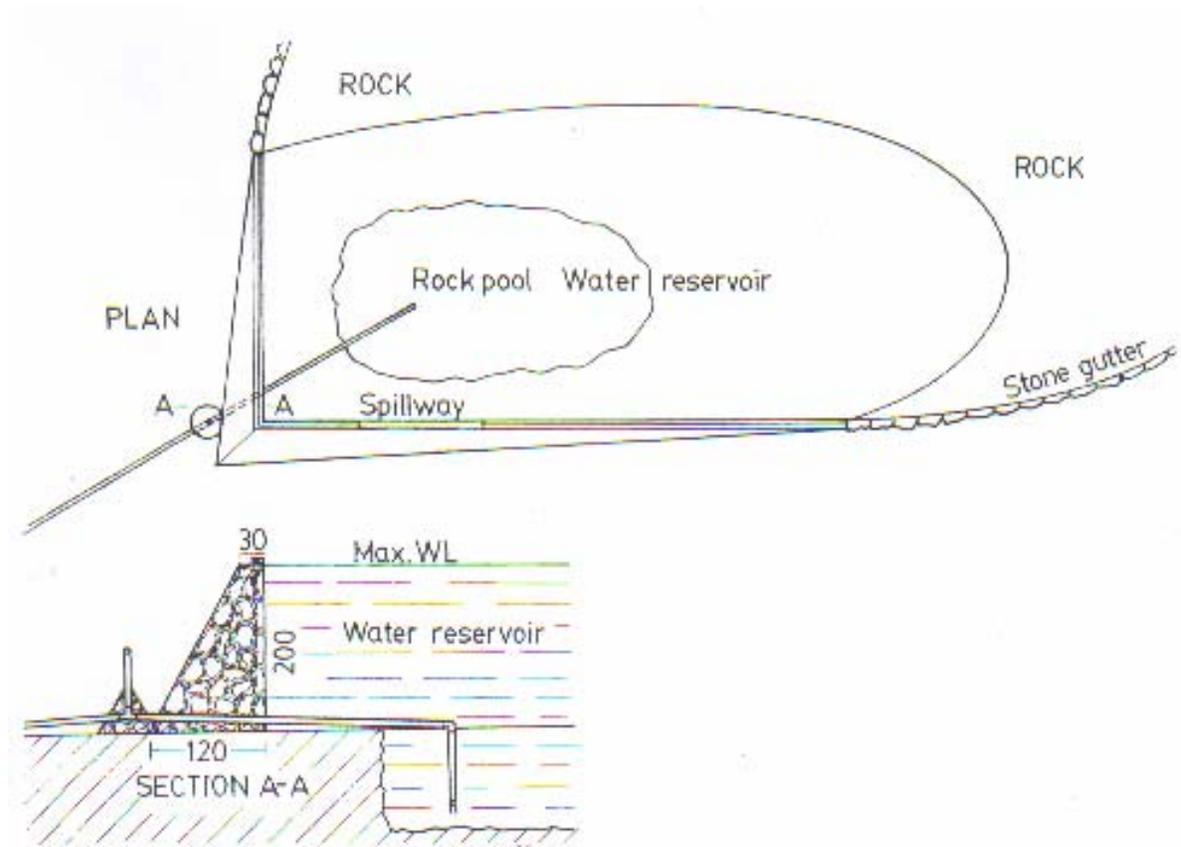


Fig. 11. Design of a rock catchment dam with two walls constructed in gorges, around the lower side of rock pools and on rock shelves.

### 7.3.3 Three-winged masonry dams around rock pools and on shelves



A rock shelf with trees and vegetation not yet scooped out at Sololo, Moyale.



A dam wall with three sides built on a rock shelf at Kisasai, Kitui.

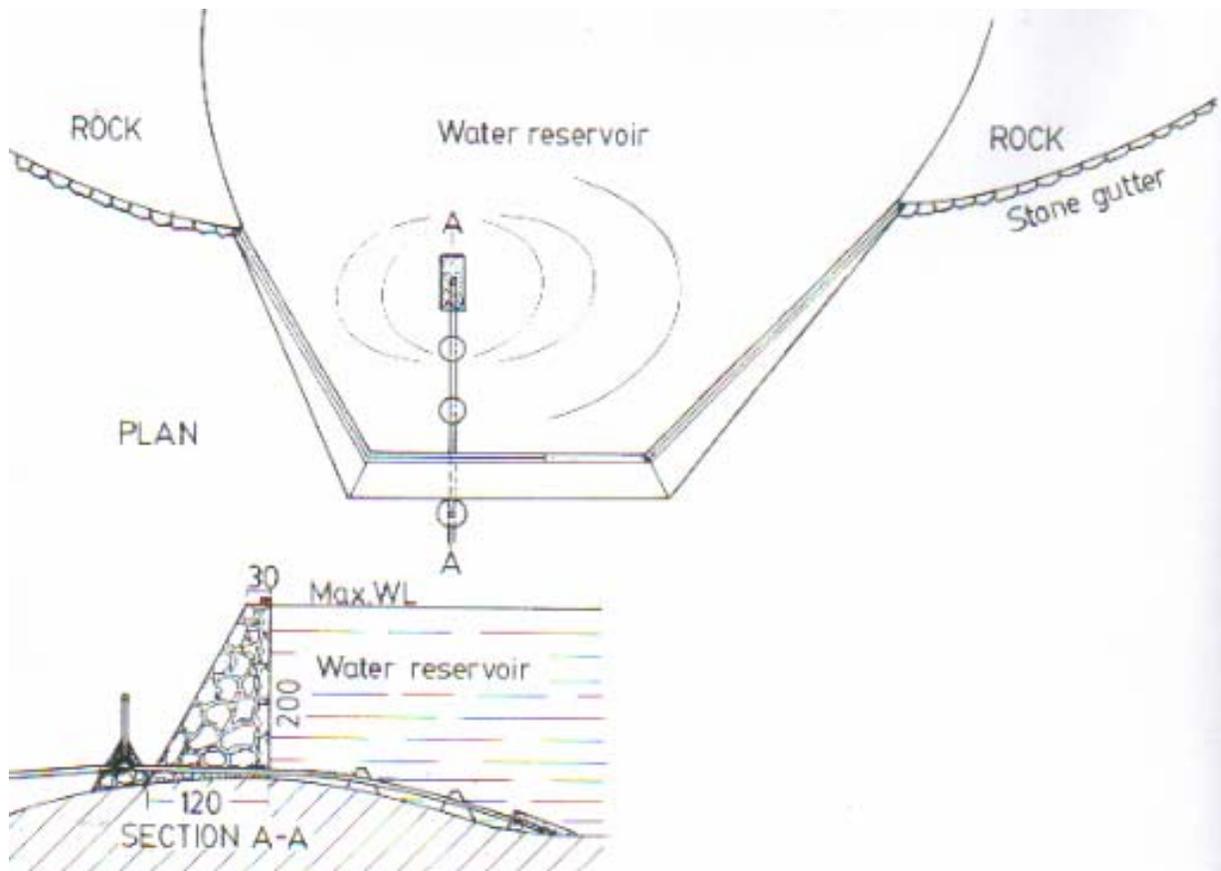


Fig. 12. Design of a rock catchment dam with three masonry walls built on the lower side of rock pools and on rock shelves.

#### 7.4 Roofs on rock catchment dams

Evaporation can consume up to half of the volume of water stored in open rock catchment dams without roofing. Roofs of galvanised iron sheets can be tied onto galvanised water pipes that are anchored onto pillars built of concrete blocks in the reservoir. The disadvantages are that: a) rodents can always find their way into a dam reservoir and drown there, b) water vapour corrodes the iron sheets and wires.

A more permanent option is to erect pillars of PVC pipes filled with concrete onto which beams of reinforced concrete carrying vaulted roof sections of ferro-cement is anchored.

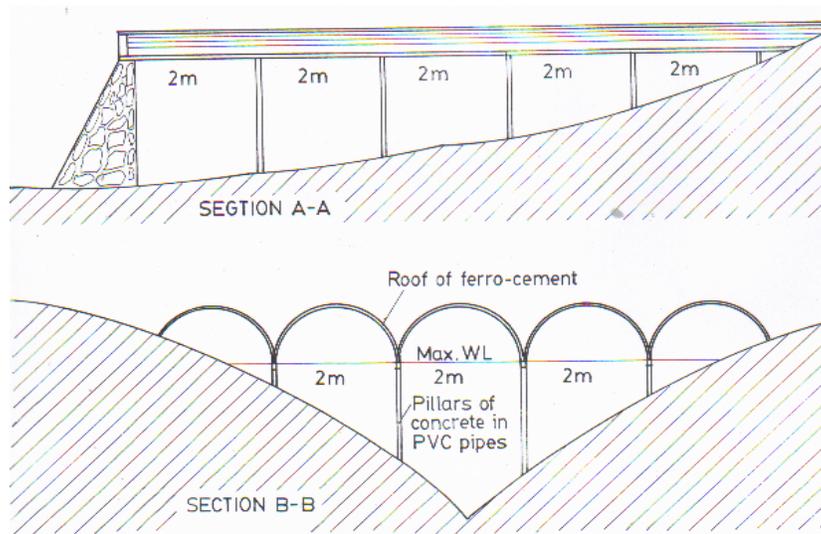


Fig. 13. A vaulted roof of ferro-cement covering the reservoir of a rock catchment dam.

### 7.5 Garlands of stone gutters

Rock catchments require garlands of stone gutters to:

- divert rainwater run-off from a catchment area to the water reservoirs of rock catchment tanks and dams, and
- increase catchment areas by winding their way around rocks, often to the opposite side.

Garlands of gutters must have an upward gradient (slope) of at least 3 cm for every 100 cm length to allow run-off water to flow towards the water reservoir by gravity.

If a dam wall is built in stages, the gutters should start at the points where the final height of the dam wall will reach.



Garlands of stone gutters start their upward gradient (slope) of at least 3 cm per 100 cm from the end of a dam wall.



The gradient of a 3 cm slope per 100 cm is found by holding a spirit level horizontal on a 100 cm length of timber that has a leg being 3 cm long.

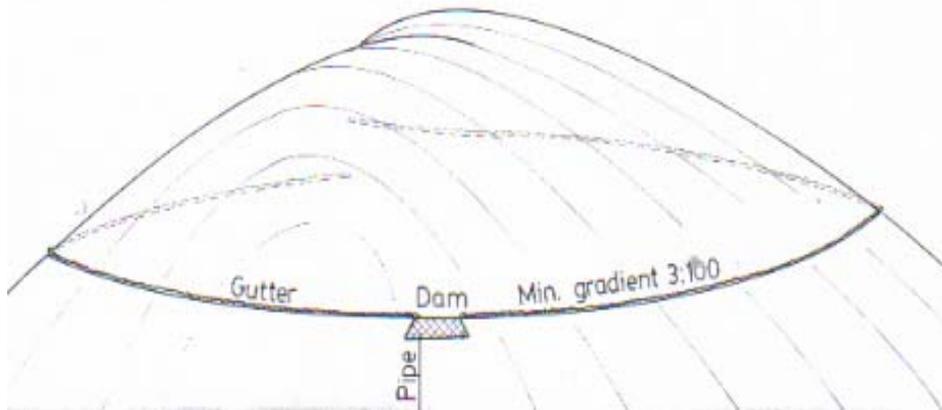


Fig. 14. Garlands of stone gutters for diverting run-off water to water reservoirs.

## 7.6 Masonry dams built in stages

It is advantageous to construct masonry dams in stages because:

- 1) A community can provide free labour to build one or two stages during a one dry season without the work being too tiresome for them.
- 2) When the first stage is completed, the dam can provide water from the first rain shower. This performance will encourage a community to build more stages.

- 3) Where funds are insufficient, people can sell some of the water from the first stages and use the money for buying cement for the next stages.
- 4) Any leakage in one stage will be closed by the following stages.



The first stage of a masonry wall being extended by a second stage.



Detail of the second stage being built onto the first stage.

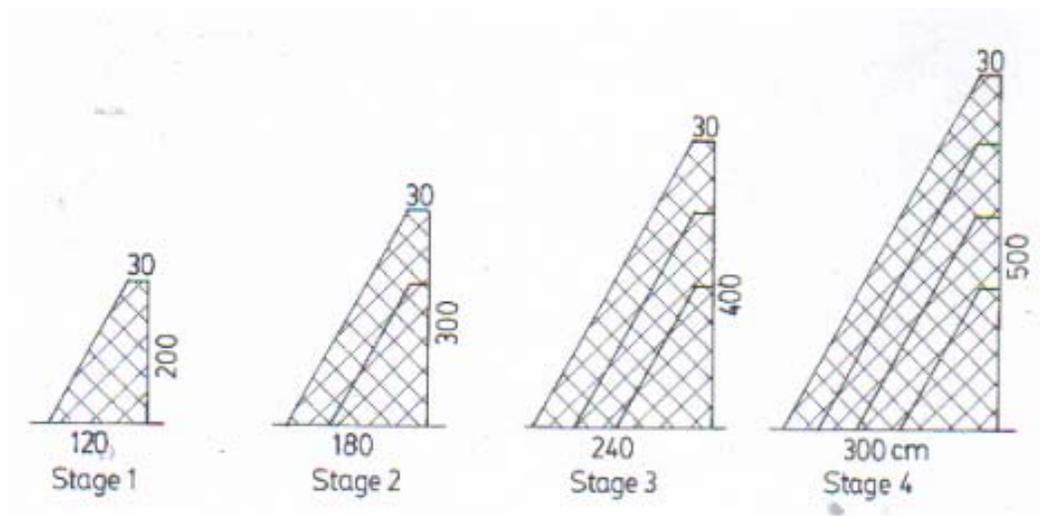


Fig. 16. Construction phases of a masonry dam wall built in four stages.

### 7.7 Setting out dams walls

Where a design and an estimate of the construction cost are required, the outline for the foundation of the dam wall must be marked on the rock. The site criteria are:

- 1) Dam walls may be built on rocks having a down- and outward slope less than 15 cm depth for every 100 cm .



The gradient of a rock is measured by holding a spirit-level horizontal on a 100 cm length of timber while measuring the distance to the rock. In this case, the gradient is more than 15 cm thereby proving that the gradient is too steep for the foundation for a dam wall.



2) Foundation for dam walls must consist of solid rock without loose parts. Loose sections of a rock surface are found by sounding the rock with a hammer. Loose parts of rocks are broken off with iron rods and hammers.

It is advisable to construct dam walls in stages with the first stage being 2 m high because: a) the dam is easy to build, b) water will be collected as soon as rains fall thereby encourage people to

build the following phases and c) any leakage will be sealed by the next stage.

The procedure for marking the foundation for a dam wall is as follows: Mark 2 meters height on a stick. Tie one end of a long transparent hosepipe onto the stick slightly above the 2 m mark. The stick is then hold vertically at the lowest part of the foundation while the other end of the pipe is laid on the rock towards the end of the dam wall. Water is poured into the pipe until the waterlevel has reached the 2 m mark on



the stick. The waterlevel in the other end of the pipe is now marked onto the rock. The other end of the wall is marked in the same way.

Then mark with white paint both ends of the dam wall and the place with the stick, which is the lowest point of the foundation.

Thereafter the width of the foundation can be marked onto the rock using two design criteria:

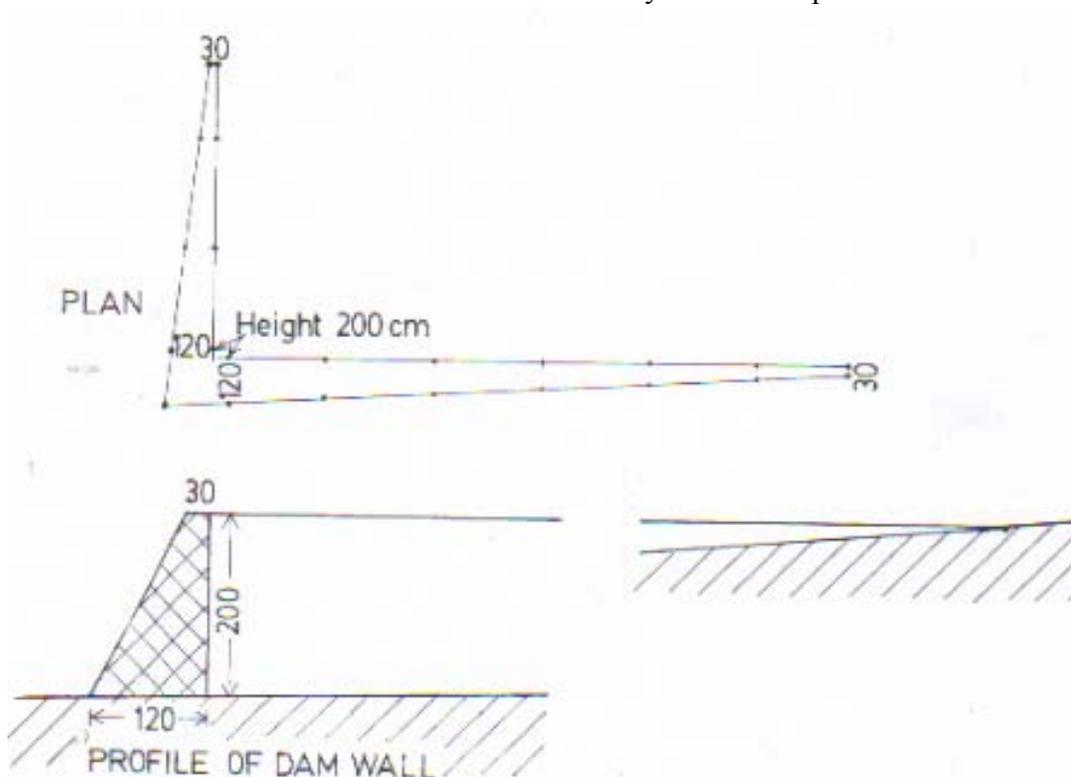
1) The width of a foundation must always be  $\frac{3}{5}$  of the height of the dam wall.

Since the first stage will be 200 cm high at the lowest point on the rock, the foundation will be 120 cm wide at that point because 200 cm divided by 3/5 is 120 cm.

- 2) The crest must be at least 30 cm wide.

and the width of the crest, 30 cm, has been marked at each end of the dam wall, strings are drawn between these points to show the outlines of the foundation.

The outlines are marked with dots of white paint so that the builders can identify the correct place without



When the width of the foundation, 120 cm, has been marked at the lowest point

problems.

Fig. 16. The outline of the foundation for a 200 cm high dam wall has been marked onto the rock with white paint.

### 7.8 Calculating the cost of constructing dam walls

The cost of constructing a rock catchment dam can be calculated when the volume of its dam wall is known because that determines requirements of materials and labour.

#### Volume of dam walls

The volume of dam walls can be calculated by drawing sketches with the length and height of the dam wall bearing in mind that the base of a dam wall must always be  $\frac{3}{5}$  of its height and that the crest should always be 30 cm wide.

The sketches are then divided into triangular (A) and rectangular (B) units whose volume can be calculated using the formula below. The volume of the units can then be added together to give the total volume of the dam wall.

Fig. 17. A cross section of a dam wall can be divided into a triangle (A) and a rectangle (B) as seen on the right.

The formula for calculating the area of a triangle is:  $\text{Area} = \text{base } (b) \times \text{height } (h)/2$

The formula for calculating the area of a rectangle is:  $\text{Area} = \text{base } (b) \times \text{height } (h)$

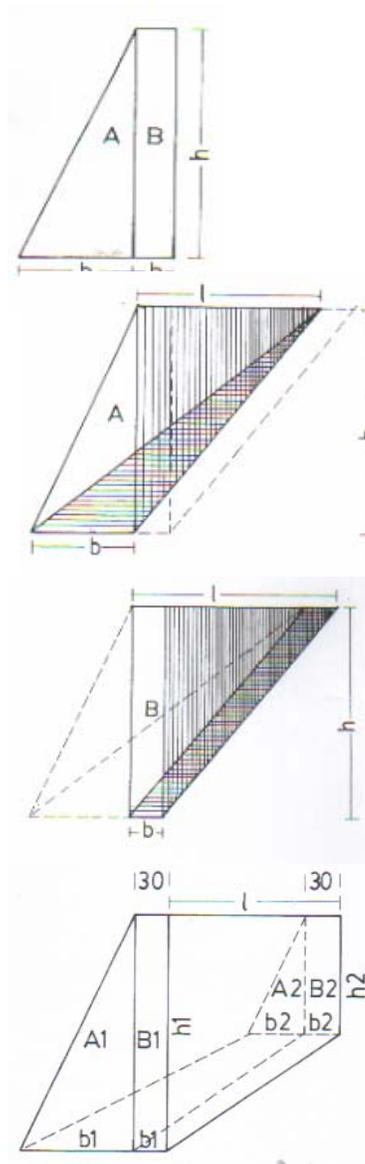
Fig. 18. The triangular section of a dam wall (A) can be calculated using the formula for a three-sided pyramid with a pointed end:

$\text{Volume} = \text{base area} \times \text{length } (l) / 3.$

Fig. 19. The rectangular part of a dam wall with a pointed end can be calculated using the formula of:

$\text{Volume} = \text{base} \times \text{height} \times \text{length}/2.$

Fig. 20. The middle part of a three-sided dam wall can be calculated by adding together the area of the two ends and divide the result with 2. That will give the average area of the cross section which is then multiplied with the length to get the total volume of the wall.



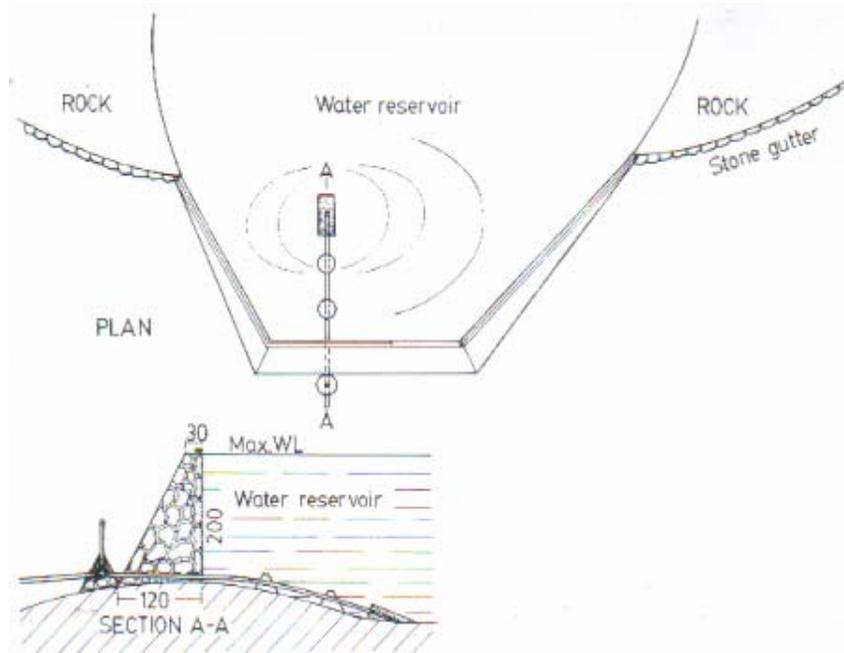


Fig. 21. An example of estimating the volume of a dam wall.

The measurements of the dam wall in the example are:

Height of middle wall	2.0 m
Base of middle wall $2.0 / 3/5 =$	1.2 m
Width of crest	0.3 m
Length of left wall	12.0 m
Length of middle wall	10.0 m
Length of right wall	14.0 m

**Volume of left wall**

Area base: Height 2.0 m x base  $2.0 / 3/5 +$  height 2.0 m x base 0.3 m = 3.0 sq.m.

Volume: Area base 3.0 sq.m. x length 12.0 m / 3 = 12.0 cu.m.

**Volume of middle wall**

Area base as left wall: 3.0 sq.m.

Volume: Area base 3.0 sq.m. x length 10.0 m = 30.0 cu.m.

**Volume of right wall**

Area base as left wall: 3.0 sq.m.

Volume: Area base 3.0 sq.m. x length 14.0 m / 3 = 14.0 cu.m.

**Total volume of the three walls**

Left wall 12.0 cu.m. + middle wall 30.0 cu.m. + right wall 14.0 cu.m. = 56 cu.m.

## 7.9 Bill of quantity and cost of dam walls

When the total volume of a dam wall has been found, the numbers of cubic meters is multiplied with the required materials and labour for 1 cubic meter of rubble stone masonry which is:

75% rubble stones + 25% mortar with a mixture of 1 part of cement to 4 parts of sand.

### Materials and labour for 1 cubic metre of rubble stone masonry

Item	Specification	Quantity	Approx. US\$
Cement	50 kg bags	4 bags	32
Sand	Coarse river sand	0.7 tonne	1
Water	200 litres oil-drum	1 oil-drum	3
Rubble stones	Any size up 60 cm	2.1 tonne	2
Skilled artisan	Mason	1 x 2 man/days	12
Unskilled labour	Trainees	2 x 2 man/days	12
<b>Approx. Total</b>			<b>62</b>

Preferably the communities should provide free locally available materials, skilled and unskilled labour as their contribution for their water project. In the above example, that amounts to US\$ 30 which is about 49% of the total construction cost.

### Bill of quantity and cost for the 56 cu.m. dam wall shown on the former page

Item	Specification	Quantity for 1 cu.m.	US\$ for 1 cu.m.	Quantity for 56 cu.m.	US\$ for 56 cu.m.
Cement	50 kg bags	4 bags	32	224 bags	1,792
Sand	River sand	0.7 tonne	1	39.2 tonne	56
Water	Oil-drums	1 oil-drum	3	56 oil-drums	168
Draw-off piping from dam reservoir	18 mm galvanised pipe with tap stand	100 m pipe, fittings and tap stand	(Average 500 for a dam reservoir)	(Average 500 for a dam reservoir)	500
Rubble stones	Any size up to 60 cm	2.1 tonne	2	117.2 tonnes	112
Skilled artisan	Mason	1 x 2 days	12	112 man /days	672
Unskilled labour	Trainees	2 x 2 days	12	224 man /days	672
<b>Approx. Total</b>			<b>62</b>		<b>3,972</b> <b>Say 4,000</b>

Preferably the communities should provide free locally available materials, skilled and unskilled labour as their contribution for their water project. In the above example, that would amount to US\$ 1,680 which is about 49% of the total construction cost.

## 7.10 Construction of dam walls built of rubble stone masonry

The maximum height and width of a dam wall to be constructed is drawn on the ground. Four pieces of 4" x 2" timbers are cut and nailed together over the drawn shape of the dam wall so that the inner lines of the timbers are even with the shape of the dam wall.

The width of the base for a wall must always be  $\frac{3}{5}$  of its height and the width of the crest must be 30 cm as follows:

Height of wall	Width of base	Width of crest
200 cm	120 cm	30 cm
300 cm	180 cm	30 cm
400 cm	240 cm	30 cm
500 cm	300 cm	30 cm

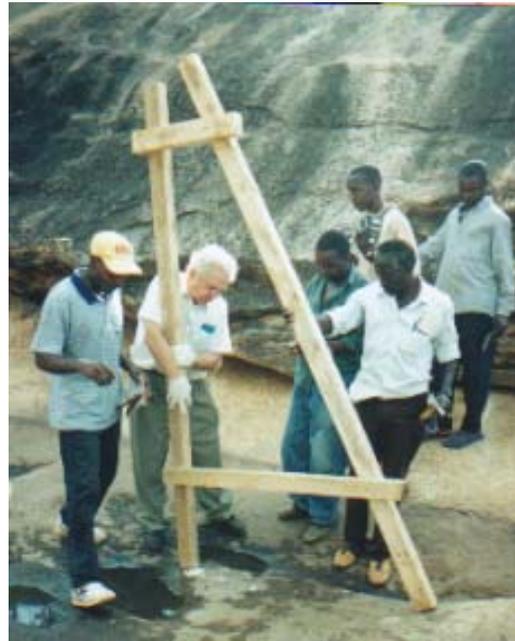
Templates are erected at the deepest point of a dam wall and at 90 degrees to the upstream side of the dam wall.

Remember that the foundation of walls cannot be built onto a rock surface sloping downwards more than 15 cm per 100 cm and that the rock must not have any loose parts.

Where a dam wall has a bend, two templates are erected, both being at 90 degrees to the upstream side of the wall.

Where more than one template is required, their crest must be at the same level.

Templates are mortared onto the rock surface with their upstream sides being vertical.



When the template, or templates, are mortared into their vertical position the level of the crest is transferred from the template(s) onto the two places on the rock where the two ends of the dam wall will be mortared onto. The two places should be protruding parts of the rock that can provide good support for the dam wall.

The crest level of the dam wall can be transferred onto the rock using a transparent hose-pipe. One end of the pipe is tied to the upper part of the template while the other end of the pipe is laid on the rock where the dam wall will end.



Water is filled into the pipe until the water-level reaches the height on the crest on the template. The water-level in the other end of the pipe laying on the rock is now horizontal with the crest and is marked onto the rock. Both ends of the dam wall are marked on the rock using the two water-levels in the pipe.

Strings are now drawn along the inner sides of the templates to the two places on the rock where the 30 cm wide crest has been marked. All loose sections on the rock are removed and the rock surface is roughen with hammers within the strings.



Rubble stones, which have been brought to the construction site, are cleaned for all dirt and soil in a wheelbarrow with water.

The largest and flattest of the stones are laid out along the marked outline of the dam wall where they will be used for building the outer sides of the wall.

Smaller and rounder stones are also cleaned. They will be used for filling in the wall.



The rock surface between the strings is swept and cleaned with water thoroughly. If any dirt or loose part are left it might create leakage under the dam wall.

Dry cement is then dusted onto the moist rock surface within the strings until all parts have been covered in a thin layer of moist cement.

Simultaneously, mortar has been mixed of 1 part of cement to 3 parts of coarse and clean sand, called 1:3.

The mortar is laid onto the cement-dusted rock surface in a layer being about 3 cm thick (about 1 inch).



Within the same hour, mortar of mixture 1 cement to 4 sand (1:4) is made and used for mortaring the flatter stones onto the foundation along the strings. Short sticks are used to support the stones.



A draw-off pipe is made from a length of 1 1/2" (38 mm) galvanized iron pipe being 3 meters long with thread at one end.

The surface of the pipe is roughened by a hammer to ensure a good bond with the stone masonry that will not create leakage.

The draw-off pipe is concreted into in the lowest part of the dam wall in an exact horizontal position to facilitate extracting water from the dam reservoir by gravity.



After about 12 hours the mortar in two lines of stones lining the sides of the dam wall have hardened so much that the construction of the wall can continue.

The space between the two lines of flat stones can now be filled with smaller and rounder stones compacted into mortar of mixture 1:4.

Ensure that no stone is touching another stone without mortar because that may cause leakage.

The surface of the filled-in stones and mortar is left with a rough surface to ensure a water-tight bond with the next course of stones as seen below.



The next lines of flat stones can now be mortared onto the wall in mortar 1:4.

The following day, the space between the two lines of flat stones is filled with smaller and rounder stones in mortar 1:4 and so on until the whole wall has been built up to the crest.



The upstream side of the wall and the crest are then plastered with mortar 1:3 and coated with cement slurry (NIL) for water-proofing. The downstream side do not need plastering.

## 7.11 Construction of draw-off piping

Water can be drawn manually from the water reservoirs of rock catchment dams it is a tiresome and dangerous to climb up to a dam situated high above the ground and climb down again with 20 kg of water in a jerry-can on the back.

Since it is fairly easy and cheap to gravitate water from rock catchment dams to tap stands at the ground level, a draw-off pipe should always be installed. Besides reducing labour and danger on drawing water, contamination of the water is also reduced because people do not enter the water reservoir.

There are two types of draw-off piping, namely

- 1) **Direct gravity flow** from water reservoirs whose floors are at a horizontal or higher level than the dam wall as shown below.

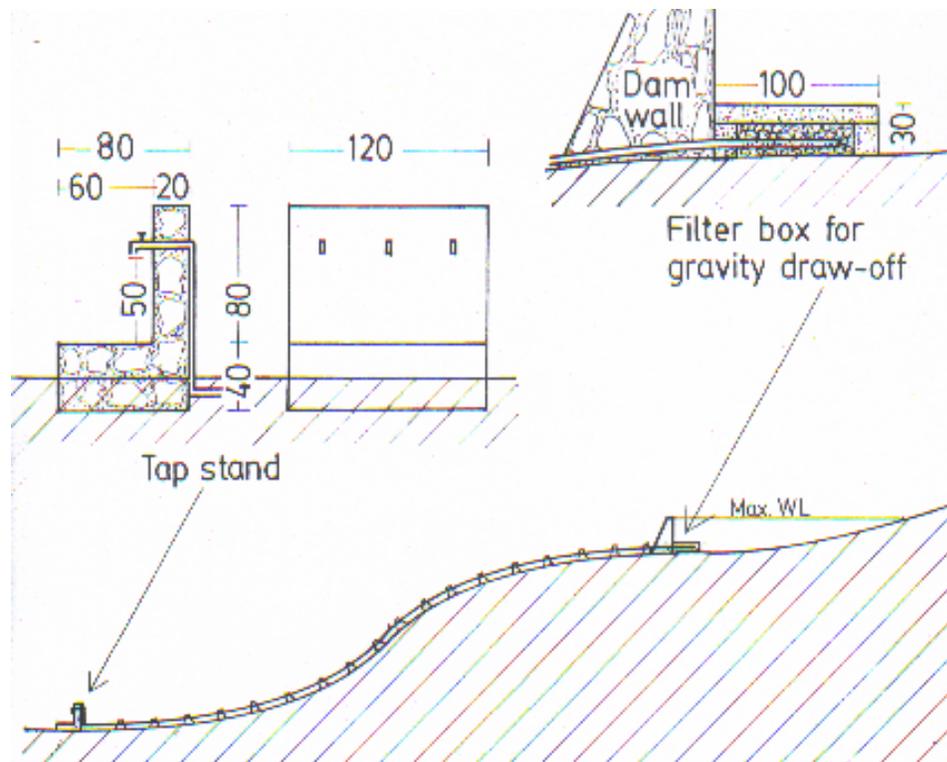


Fig. 22. Water is gravitated directly from a water reservoir situated on a rock shelf or in a gorge between two rocks by means of 18 mm galvanized piping. A perforated PVC pipe is pressed onto the upper end of the pipe that is placed in a filter box made of porous concrete blocks.

The lower end of the pipe is connected to a tap stand with watertaps. The whole length of piping between the intake and tap stand is mortared onto the rock with large stones for every 5 meters or so. Although this anchoring of the pipe prevents baboons from breaking the pipe, it cannot keep elephants from pulling the pipe apart when they are thirsty and cannot enter the water reservoir.

- 2) **Gravity flow over a siphon** is applied when the floor of a water reservoir is situated at a lower elevation than the dam wall as shown below.

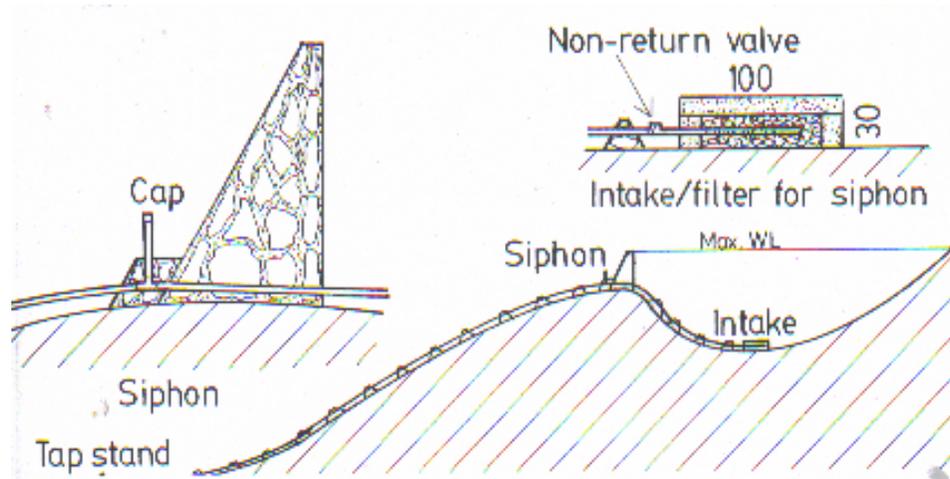


Fig. 23. As with direct gravity flow, the intake/filter box is situated at the lowest point in the water reservoir. However, for a siphon flow a non-return valve must be installed in the pipe just outside of the filter box. The valve is mounted at that it allows water to flow out of the box and prevents water from flow into the box.

The second feature for a siphon system is that a vertical pipe with a removable G.I. cap is connected to the highest point of the draw-off pipe, which should, preferably, be next to the downstream side of the dam wall.

The draw-off pipe for a siphon system should therefore slope towards the reservoir, while the draw-off pipe for direct gravity flow should slope away from the reservoir.

The flow of water is started by closing the watertaps at the tap stand and unscrewing the cap on the vertical pipe. Water is then poured into the vertical pipe slowly until all air bubbles have left the pipe. The cap is thereafter screwed airtight onto the pipe. Water will now flow to the watertaps when they are opened.



A filter/intake box with a non-return valve is placed in the deepest part of a rock pool in a rock catchment dam in Mutomo, Kitui.



The pipe from the filter/intake box is mortared onto the rock until it reaches the tap stand.

## 7.12 Ferro-cement roofs over dam reservoirs

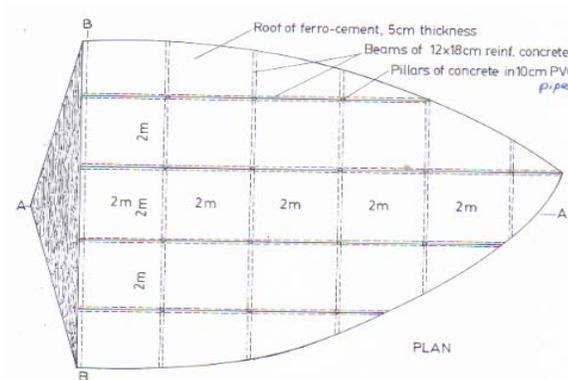


Fig. 23. Plan of a vaulted ferro-cement roof anchored onto beams of reinforced concrete that are supported by pillars made PVC pipes filled with concrete.

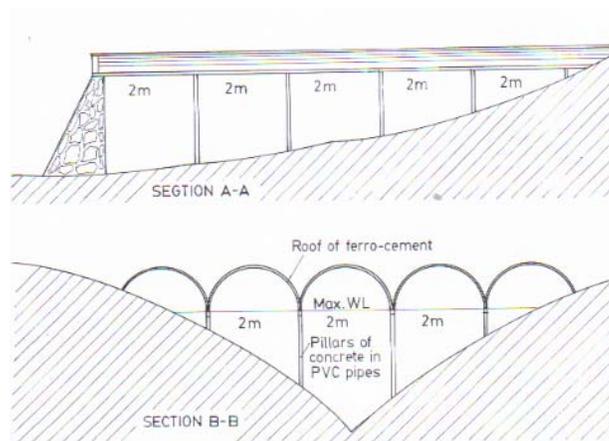


Fig. 24. Sections of a ferro-cement roof on the reservoir of a rock catchment dam.

## 7.13 Bill of quantity and cost of roofs

The above roof has a horizontal area of about  $10 \text{ m} \times 6 \text{ m} = 60 \text{ sq.m.}$  but due to the curved vaults the actual roof surface is larger, because the 2 m wide vaults have a surface of:  $D \ 2.0 \text{ m} \times 22/7/2 = 3.14 \text{ m}$  surface instead of 2 m. The actual width of the roof area is therefore:  $6 \text{ m} \times 3.14 \text{ m} / 2 \text{ m} = 9.4 \text{ m}$  = Actual roof area of :  $9.4 \text{ m} \times 10 \text{ m} = 94 \text{ sq.m.}$

### Materials and labour for 1 sq. m. of ferro-cement roof with beams and pillars

Item	Specification	Quantity	Approx. US\$
Cement	50 kg bags	0.3 bag	2.7
Sand	Coarse river sand	1.0 tonne	0.3
Water	200 litres oil-drum	0.2 oil-drum	0.2
Twisted iron rod	12 mm	5 metres	2.2
PVC pipe	100 mm diameter	2 metres	3.1
Weld-mesh	2.4 m x 1.2 m	0.5 sheet	3.3
Skilled artisan	Mason	0.5 man/days	3.0
Unskilled labour	Trainees	1.0 man/days	3.0
<b>Approx. Total</b>			<b>17.80</b>

## 7.14 Manual on construction of a ferro-cement roof

Small depressions in the rock surface of a dam reservoir are chiseled out with a horizontal spacing of 2 metres x 2 metres.

PVC pipes with a diameter of 10 cm are placed vertically in the chiseled out depressions and their height cut to the level of the crest of the dam wall. The PVC pipes are supported in their vertical position by a scaffold made of poles and timbers.



Timbers are laid upon the top of the PVC pipes to make the form-work for the concrete beams.

A twisted iron rod is placed in each PVC pipe and tied to 4 iron rods tied together in the form-work for the beams.



Concrete of mixture 1:2:3 is poured into the PVC pipes while vibrating the pipes by slapping them gently with a length of timber. Thereafter concrete is compacted into the form-work for the concrete beams.

After the pillars and beams have been kept moist under cover of polythene sheets for at least a week, the form-work for the roof, made of curved corrugated iron sheets or old oil-drums, can be placed on the concrete beams.

It is important to construct the roof in lines of vaults spanning against the rock so that the pressure of the line of vaults is taken up evenly across the roof.



The form-work is then covered with sheets of weld-mesh that is tied together with binding wire.

Mortar made of 1 part of cement to 3 parts of clean and coarse river sand is then compacted onto the form-work in a 5 cm thick layer with the weld-mesh placed in the middle.



The mortared roof is covered with polythene sheets that are covered with a layer of soil for two weeks during which nobody should be allowed to walk or stand on the roof.

The polythene sheets covered with soil will retain the moisture evaporating from the mortar as droplets that drips back onto the mortar in a self-curing process.



The openings between the roof and the crest of the dam wall are closed with concrete blocks and plastered.

After three weeks of curing, the surface of the roof should be coated with a mixture of 1 part of cement to 10 parts of lime and water to give the roof a white paint that will cool and weather-proof the roof over the water-reservoir.

Thereafter the form-work can be removed and the water reservoir cleaned before rain will fill it up.



## 8 Ponds and earth dams

Ponds and earth dams can be built on land where rainwater runs off a rock outcrop. However, due to the often enormous volume of run-off from thunder showers, such earth dams must have very wide spillways at both ends of the dam wall. For this reason, the design of curved hillside ponds is the most suitable for rock catchments.



A curved hillside dam full of water from Lukenya Rock near Nairobi.



A self-help group desilting their curved hillside dam at a rock near Voi.

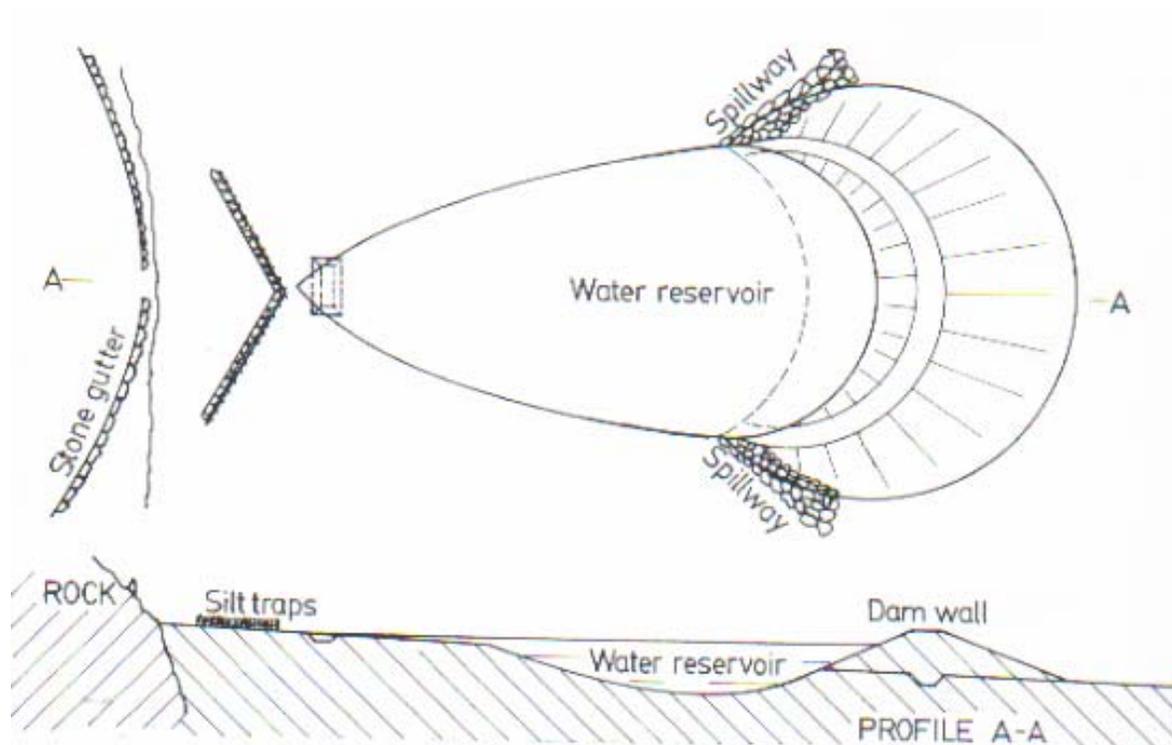


Fig. 22. Design of a curved hillside pond/dam for a rock catchment.