Report A1 –Current Technology for Storing Domestic Rainwater (Part 1)

The work in this report forms the basis for the current DTU roofwater harvesting Web Site. The site can be found at:

http://www.eng.warwick.ac.uk/DTU/rainwaterharvesting/index.html

The work in this document is on-going and will be added to as the programme progresses. The aim is to collect examples of DRWH practice from around the world and to provide a useful resource for practitioners of DRWH. Many of the graphics shown in the Web Site are not shown in this document due to electronic storage requirement limitations. The report is in two parts so that the document remains manageable. This is Part 1.

Contents of report (Part 1)

Current Technology for Storing Domestic Rainwater

1. An Introduction to Domestic Roofwater Harvesting

A sufficient, clean drinking water supply is essential to life. Millions of people throughout the world still do not have access to this basic necessity. After decades of work by governments and organisations to bring potable water to the poorer people of the world, the situation is still dire. The reasons are many and varied. The poor of the world cannot afford the capital intensive and technically complex traditional water supply systems which are widely promoted by governments and agencies throughout the world.

Roof-water or rainwater harvesting (RWH) is an option which has been adopted in many areas of the world where conventional water supply systems have failed to meet the needs of the people. It is a technique which has been used since antiquity. Examples of RWH systems can be found in all the great civilisations throughout history. The technology can be as simple or as complex as required. In many African countries this is often as simple as placing a small container under the eaves of the roof to collect falling water during a storm. One 20 litre container of clean water captured from the roof can save a walk of many kilometres, in some cases, to the nearest clean water source. In the industrialised countries of the world, sophisticated RWH systems have been developed with the aim of reducing water bills or to meet the needs of remote communities or individual households in arid regions. Traditionally, in Uganda rainwater is also collected from trees, using banana leaves or stems as temporary gutters; up to 200 litres may be collected from a large tree in a single storm. Many individuals and groups have taken the initiative and developed a wide variety of different RWH systems throughout the world.

It is worth bearing in mind, however, that Domestic Rainwater Harvesting (DRWH) is not the definitive answer to household water problems. There is a complex set of inter-related circumstances which have to be considered when choosing the appropriate water source. Cost, climate, technology, hydrology, social and political elements all play a role in the eventual choice of water supply scheme which is adopted for a given situation. RWH is only one possible choice, but one which is often overlooked by planners, engineers and builders. The reason that RWH is rarely considered is often due to lack of information – both technical and otherwise. In many areas where RWH has been introduced as part of a wider drinking water supply programme, it was at first unpopular, simply because little was known about the technology by the eneficiaries. In most of these cases the technology has quickly gained popularity as the user realises the benefits of a clean, reliable water source at the home. In many cases RWH has been introduced as part of an integrated water supply system, where the town supply is unreliable or where local water sources dry up for a part of the year, but is also often used as the sole water source for a community or household. It is a technology which is flexible and adaptable to a very wide variety of conditions, being used in the richest and the poorest societies on our planet, and in the wettest and the driest regions of the world.

The aim of this web site is to enable readers to view a wide variety of these systems, with the aim of providing interested parties with a selection of possible technical solutions to their water problems. We try to provide guidelines for the sizing of RWH systems, a brief overview of the components of a RWHS, a critique for examining the systems with a mind to their possible application, and look at the cost of the system (or at least the material requirements). We also look at ways in which water quality can be improved and maintained before, during and after storage.

2. Styles of Roofwater Harvesting

User regimes

Rainwater harvesting is used in many different ways. In some parts of the world it is used merely to capture enough water during a storm to save a trip or two to the main water source. In this case only small storage capacity is required, maybe just a few small pots to store enough water for a day or half a day. At the other end of the spectrum we see, in arid areas of the world, systems which have sufficient collection surface area and storage capacity to provide enough water to meet the full needs of the user. Between these two extremes exists a wide variety of different user patterns or regimes. There are many variables that determine these patterns of usage for RWH. Some of these are listed below:

- Rainfall quantity (mm/year) – the total amount of water available to the consumer is a product of the total available rainfall and the collection surface area. There is usually a loss coefficient included to allow for evaporation and other losses. Mean annual rainfall data will tell us how much rain falls in an average year.
- Rainfall pattern - climatic conditions vary widely throughout the world. The type of rainfall pattern, as well as the total rainfall, which prevails will often determine the feasibility of a RWHS. A climate where rain falls regularly throughout the year will mean that the storage requirement is low and hence the system cost will be correspondingly low and vice versa. More detailed rainfall data is required to ascertain the rainfall pattern. The more detailed the data available, the more accurately the system parameters can be defined.
- Collection surface area (m2) - this, where rooftop catchment systems are used, is restricted by the size of the roof of the dwelling. Sometimes other surfaces are used to supplement the rooftop catchment area.
- Storage capacity (m3) - the storage tank is usually the most expensive component of the RWHS and so a careful analysis of storage requirement against cost has to be carried out.
- Daily consumption rate (litres/capita /day or lpcd) - this varies enormously – from 10 – 15 lpcd a day in some parts of Africa to several hundred lpcd in some industrialised countries. This will have obvious impacts on system specification.
- Number of users - again this will greatly influence the requirements.
- Cost – a major factor in any scheme.
- Alternative water sources – where alternative water sources are available, this can make a significant difference to the usage pattern. If there is a groundwater source within walking distance of the dwelling (say within a kilometre or so), then a RWHS that can provide a reliable supply of water at the homestead for the majority of the year, will have a significant impact to lifestyle of the user. Agreed, the user will still have to cart water for the remainder of the year, but for the months when water is available at the dwelling there is a great saving in time and energy. Another possible scenario is where rainwater is stored and used only for drinking and cooking, the higher quality water demands, and a poorer quality water source, which may be near the dwelling, is used for other activities.
- Water management strategy – whatever the conditions, a careful water management strategy is always a prudent measure. In situations where there is a strong reliance on stored rainwater, there is a need to control or manage the amount of water being used so that it does not dry up before expected.

Ideally, we would like to be able to classify the various common user regimes that are adopted. This can help us to develop a nomenclature for dealing with the systems we will look at later. We can simply classify most systems by the amount of ‘water security’ or ‘reliability’ afforded by the system. There are four types of user regimes listed below:

Occasional (or opportunist) - water is collected occasionally with a small storage capacity, which allows the user to store enough water for a maximum of, say, one or two days. During the wet season this means that the user will benefit considerably from having such a system and most, if not all, of the user needs will be met during this time. After a day or two of dry weather the user will have to return to using an alternative water source. This type of system is ideally suited to a climate where there is a uniform, or bimodal, rainfall pattern with very few dry days during the year and where an alternative water sources is close at hand.

Intermittent – this type of pattern is one where the requirements of the user are met for a part of the year. A typical scenario is where there is a single long rainy season and, during this time, most or all of the user needs are met. During the dry season an alternative water source has to be used or, as we see in the Sri Lankan case, water is carted/ bowsered in from a nearby river and stored in the RWH tank. Usually, a small or medium size storage vessel is required to bridge the days when there is no rain.

Partial – this type of pattern provides for partial coverage of the water requirements of the user, during the whole of the year. An example of this type of system would be where a family gather rainwater to meet only the high-quality needs, such as drinking or cooking, while other needs, such as bathing and clothes washing, are met by a water source with a lower quality. This could be achieved either in an area with a uniform rainfall pattern and with a small to medium storage capacity or in an area with a single (or two short) wet season(s) and a larger storage capacity to cover the needs during the dry season.

Full – with this type of system the total water demand of the user is met for the whole of the year by rainwater only. This is sometimes the only option available in areas where other sources are unavailable. Sufficient a/ rainfall, b/ collection area, c/ storage capacity is required to meet the needs of the user and a careful feasibility study must be carried out before hand to ensure that conditions are suitable. In areas where there is a bimodal rainfall pattern (i.e. two rainy seasons) this type of system is far more attractive, as the tank will be recharged during both wet seasons. Where there is a single (unimodal) wet season the storage capacity will normally be very large – and therefore expensive. A strict water management strategy is required when such a system is used to ensure that the water is used carefully and will last until the following wet season.

3. Components of a DRWH system

Introduction

Technically, DRWH systems vary in complexity. Some of the traditional Sri Lankan systems are no more that a pot situated under a piece of cloth or plastic sheet tied at its corners to four poles. The cloth captures the water and diverts it through a hole in its centre into the pot. On the other hand, some sophisticated systems used in the industrialised nations, incorporate clever computer management systems, submersible pumps, and links into the grey water and mains domestic plumbing systems.

Somewhere between these two extremes we find the typical DRWH system that is used in a typical developing country scenario. Such a system will usually comprise a collection surface, a roof, a storage tank, and guttering to transport the water from the roof to the storage tank. Other peripheral equipment is sometimes incorporated: first flush systems to divert the dirty water which contains roof debris after prolonged dry periods; filtration equipment and settling chambers to remove debris and contaminants before water enters the storage tank or cistern.

In this section we will look at the various components commonly found in typical DRWH systems. In the Case Studies section we will look at actual systems. In the Case Studies section, where possible, we have tried to look at full systems, showing how the various components interact. In some cases, however, we have been able to show only certain components of the system – usually the tank or cistern as this is the most costly and critical component of the DRWH system, and the area that has attracts most design attention.

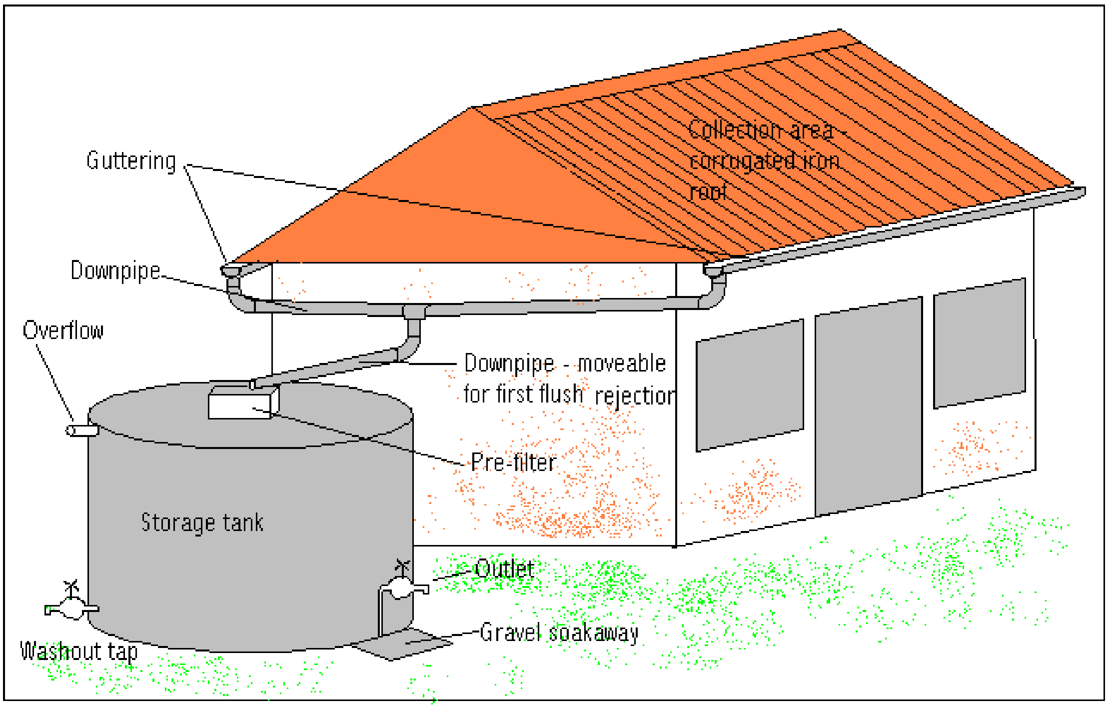


Figure 1 – Typical domestic roofwater harvesting system – showing the main components of the system

Storage tanks and cisterns

The water storage tank usually represents the biggest capital investment element of a DRWH system. It therefore usually requires the most careful design – to provide optimal storage capacity while keeping the cost as low as possible. The catchment area is usually the existing rooftop, and guttering can often be obtained relatively cheaply, or can be manufactured locally.

There are an almost unlimited number of options for storing water. Common vessels used for very small-scale water storage in developing countries include such examples as plastic bowls and buckets, jerrycans, clay or ceramic jars, cement jars, old oil drums, empty food containers, etc.

For storing larger quantities of water the system will usually require a tank or a cistern. For the purpose of this document we will classify the tank as an above-ground storage vessel and the cistern as a below-ground or under-ground storage vessel. These can vary in size from a cubic metre or so (1000 litres) up to hundreds of cubic metres for large projects, but typically up to a maximum of 20 or 30 cubic metres for a domestic system. There is a mind-boggling range of options open to the prospective rainwater harvester, with a wide variety of shapes, materials, sizes and prices on offer. The choice will depend on a number of technical and economic considerations. Some of these are listed below:

- Space availability
- Options available locally
- Local traditions for water storage
- Cost – of purchasing new tank
- Cost – of materials and labour for construction
- Materials and skills available locally
- Ground conditions
- Style of RWH (see link to this section)

One of the main choices will be whether to use a tank or a cistern. Both tanks and cisterns have their advantages and disadvantages. Table 1 summarises the pros and cons of each.

	Tank (above ground)	Cistern (below ground)

Pros	Above ground structure allows for easy inspection for cracks or leakage Many existing designs to choose from Can be easily purchased ‘off-the-shelf’ in most market centres Can be manufactured from a wide variety of materials Easy to construct for traditional materials Water extraction can be by gravity in many cases Can be raised above ground level to increase water pressure	generally cheaper more difficult to empty by leaving tap on require little or no space above ground unobtrusive surrounding ground gives support allowing lower wall thickness.
Cons	Require space Generally more expensive More easily damaged Prone to attack from weather Failure can be dangerous	water extraction is more problematic – often requiring a pump leaks or failures are more difficult to detect contamination of the tank from groundwater is more common tree roots can damage the structure there is danger to children and small animals if tank cover is left off flotation of the cistern may occur if groundwater level is high and cistern is empty heavy vehicles driving over a cistern can cause damage

Table 1. Pros and Cons of Tanks and Cisterns

Much work has been carried out on the development of the ideal tank for DRWH. The Case Studies section of this Web Site show a wide variety of tanks that have been built in many countries throughout the world.

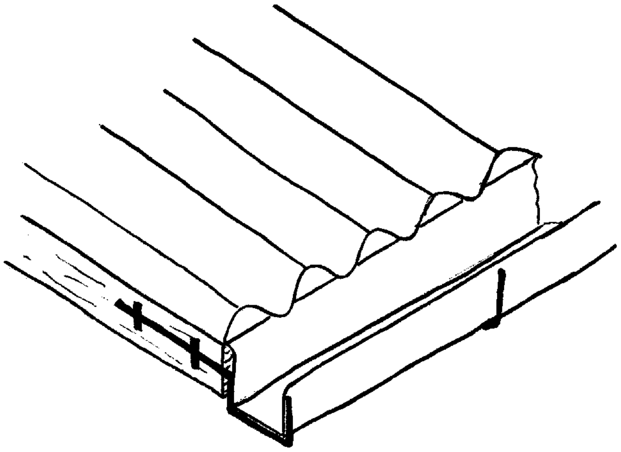
Collection surfaces

For domestic rainwater harvesting the most common surface for collection of water is the roof of the dwelling. Many other surfaces can and are used: courtyards, threshing areas, paved walking areas, plastic sheeting, trees, etc. Most dwellings, however, have a roof. The style, construction and material of the roof affect its suitability as a collection surface for water. Typical materials for roofing include corrugated iron sheet, asbestos sheet; tiles (a wide variety is found), slate, and thatch (from a variety of organic materials).

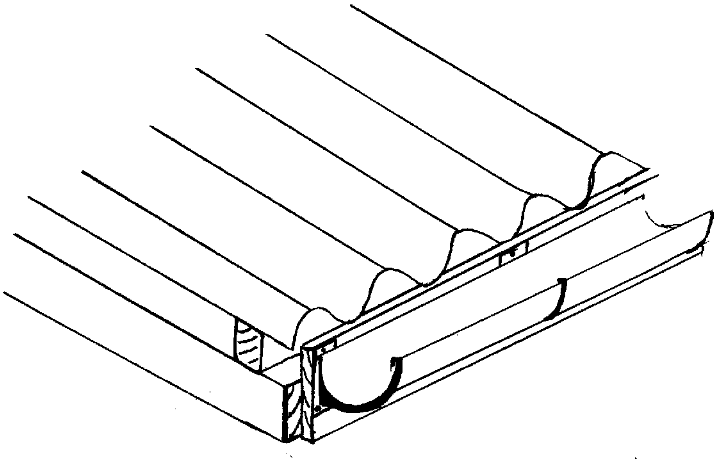
Guttering

Guttering is used to transport rainwater from the roof to the storage vessel. Guttering comes in a wide variety of shapes and forms, ranging from the factory made PVC type to home made guttering using bamboo or folded metal sheet. Guttering is usually fixed to the building just below the roof and catches the water as it falls from the roof. For a detailed analysis of the performance of various types of guttering see the DTU working paper titled ‘Guttering Design for Rainwater Harvesting – with special reference to conditions in Uganda’.

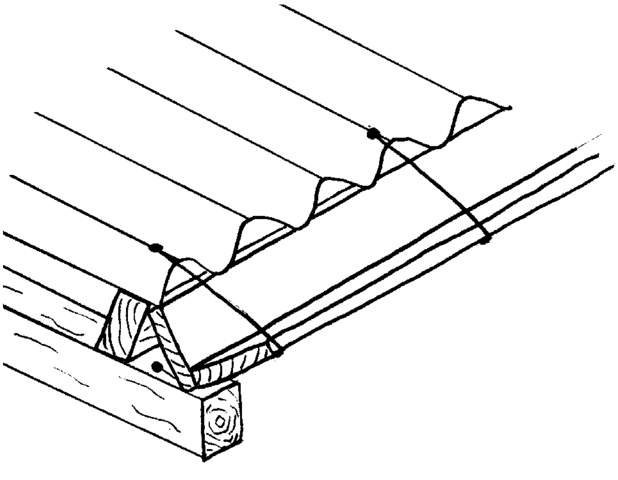
Below are shown some of the common types of guttering and fixings.



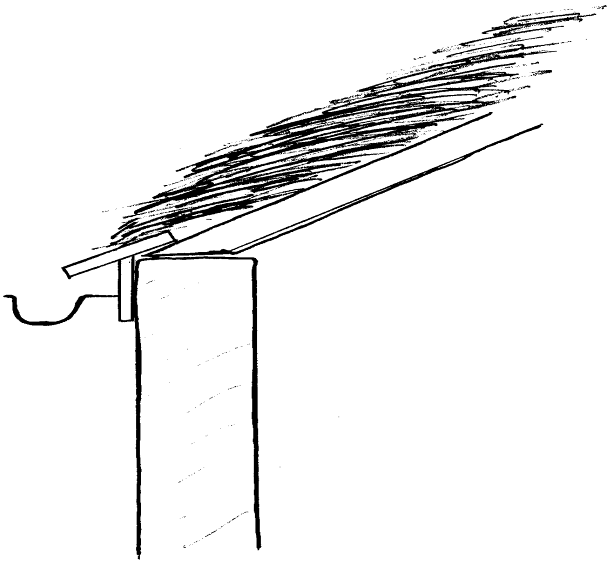
2a - rectangular section guttering fixed to rafter



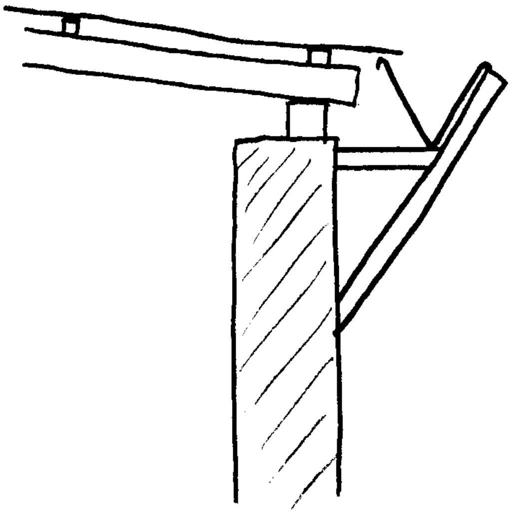
2b - semi circular trough gutter fixed to facia board



2c - timber V-shaped trough fixed with wire to rafter



2d - one configuration for guttering with thatch roof



2e - V-shaped gutter with wall mount

Figure 2 – a variety of guttering types showing possible fixings

Manufacturing low-cost gutters. Factory made gutters are usually expensive and beyond the reach of the poor of developing countries. They are seldom used for very low-cost systems. The alternative is usually to manufacture gutters from materials that can be found cheaply in the locality. There are a number of techniques that have been developed to help meet this demand; one such technique is described below.

V- shaped gutters from galvanised steel sheet can be simply made by cutting and folding flat galvanised steel sheet. Such sheet is readily available in most market centres and can be worked with tools that are commonly found in a modestly equipped workshop. One simple technique is to clamp the cut sheet between two lengths of straight timber and then to fold the sheet along the edge of the wood. A strengthening edge can be made be folding the sheet through 90o and then completing the edge
with a hammer on a hard flat surface. The better the grade of steel sheet that is used, the more durable and hard-wearing the product. Fitting a downpipe to V-shaped guttering can be problematic and the V-shaped guttering will often be continued to the tank rather than changing to the customary circular pipe section downpipe. Methods for fixing gutters are shown in figure 4.

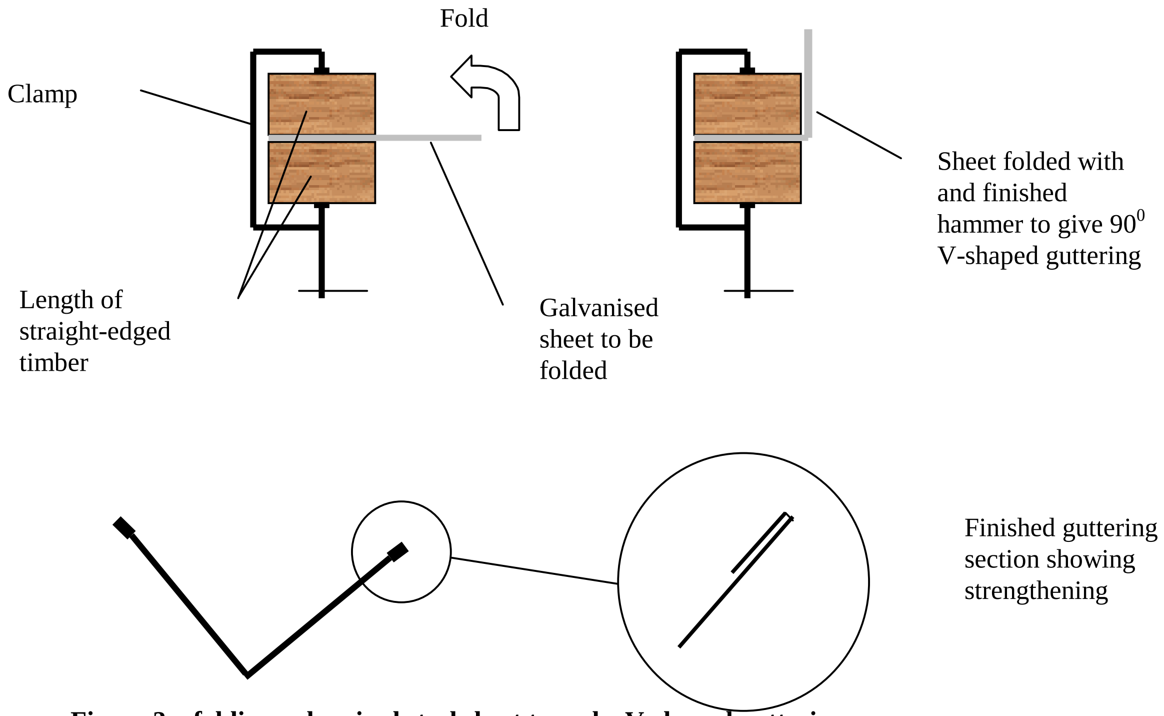


Figure 3 – folding galvanised steel sheet to make V-shaped guttering

Rectangular section gutters can be made in a similar way. It is somewhat easier to fit downpipes to rectangular section guttering.

First flush systems

Variations in Rainwater Quality from Roof Catchment

The quality of rainwater from a tile and a galvanised-iron type roof catchment were analysed over a period of 5 months. Examination of staggered 1 litre samples collected during a rainfall event showed that the concentrations of various pollutants were high in the first litre but decreased in subsequent samples with few exceptions. Faecal coliform and total coliform counts ranged from 8-13 (tile roof) and 4-8 (iron roof) to 41-75 (tile roof) and 25-63 (iron roof) colonies per 100 ml, respectively. However, no faecal coliforms were detected in the fourth and fifth litre samples from both roofs. The pH of rainwater collected from the open was acidic but increased slightly after falling on the roofs. The average zinc concentrations in the run-off from the galvanised-iron roof was about 5-fold higher compared to the tile roof, indicating leaching action but was well below the WHO limits for drinking water quality. Lead concentrations remained consistently high in all samples collected and exceeded the WHO guidelines by a factor of 3.5. For the roof area studied, a ' foul flush ' volume of 5l. would be the minimum to safeguard against microbiological contamination but the high metals content in the water indicate the need for some form of treatment. Rainfall intensity and the number of dry days preceding a rainfall event significantly affect the quality of run-off water from the catchment systems.

Source: Yaziz, M.I. Gunting, H. Sapari, N.,Ghazali, A.W.
Pertanian Malaysia Univ. Serdang, Dept. of Environmental Sciences.
Citation: Water Research WATRAG Vol. 23, No. 6, p 761-765, June 1989. 1 fig, 5 tab, 3 ref.

Debris, dirt and dust will collect on the roof of a building or other collection area. When the first rains arrive, this unwanted matter will be washed into the tank. This will cause contamination of the water and the quality will be reduced. Many RWH systems therefore incorporate a system for diverting this ‘first flush’ water so that it doesn’t enter the tank.

There are a number of simple systems which are commonly used and also a number other, slightly more complex, arrangements. The simpler ideas are based on a simple manually operated arrangement whereby the inlet pipe is moved away from the tank inlet and then replaced again once the initial first flush has been diverted.

This method has obvious drawbacks in that there has to be a person present who will remember to move the pipe. Slightly more sophisticated methods include arrangements such as those shown in Figure 4 below, where the stopper in the inlet chamber can be removed to allow the first flush to be diverted.

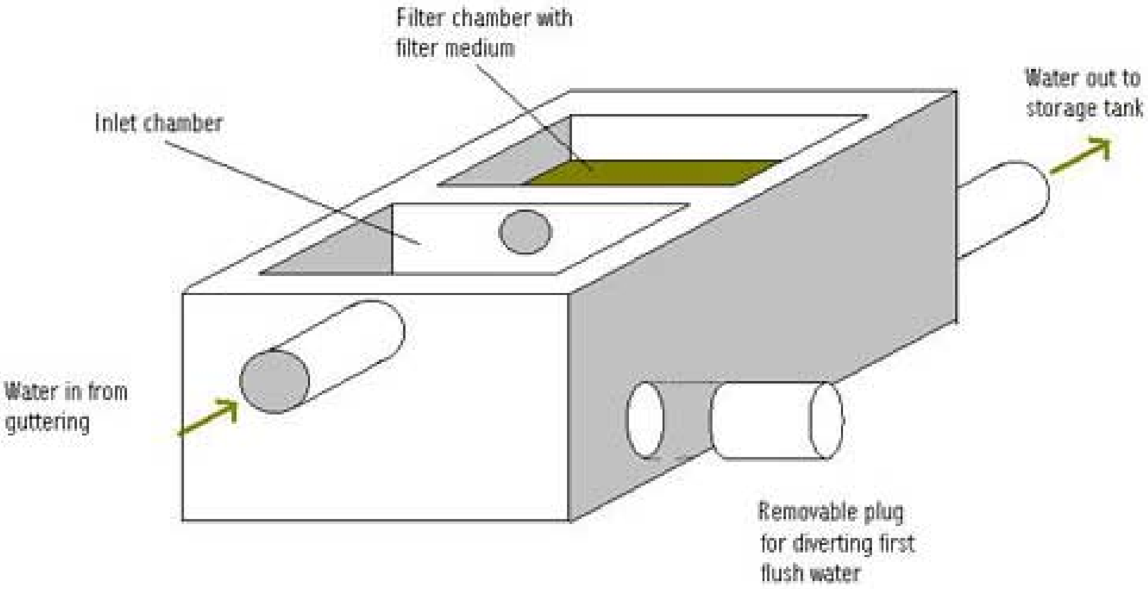


Figure 4 – First flush device using removable stopper in bottom of inlet chamber (above) and using diversion pipe (below)

Other systems use tipping gutters to achieve the same purpose. The most common system (as shown in Figure 5 below) uses a bucket which accepts the first flush and the weight of this water off-balances a tipping gutter which then diverts the water back into the tank. The bucket then empties slowly through a small-bore pipe and automatically resets. The process will repeat itself from time to time if the rain continues to fall, which can be a problem where water is really at a premium. In this case a tap can be fitted to the bucket and will be operated manually. The quantity of water that is flushed is dependent on the force required to lift the guttering. This can be adjusted to suit the needs of the user.

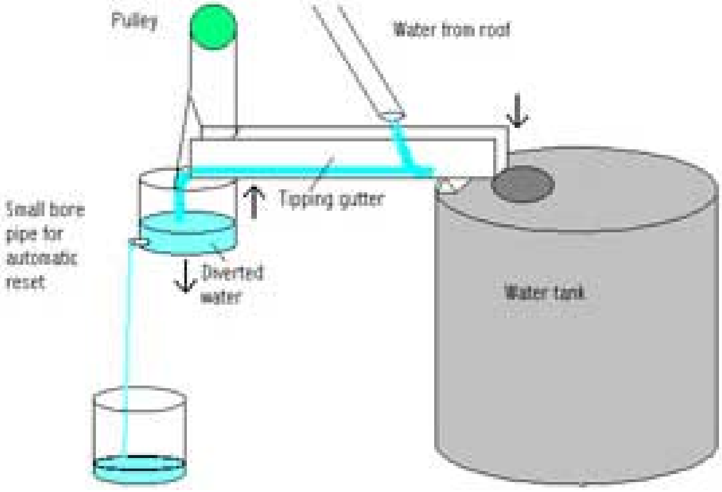


Figure 5 – the tipping gutter first flush system

Another system that is used relies on a floating ball that forms a seal once sufficient water has been diverted (see Figure 6 below). The seal is usually made as the balls rises into the apex of an inverted cone. The ball seals the top of the 'waste' water chamber and the diverted water is slowly released, as with the bucket system above, through a small bore pipe. Again the alternative is to use a tap. In some systems (notably one factory manufactured system from Australia) the top receiving chamber is designed such that a vortex is formed and any particles in the water are held in suspension in the vortex while only clean water passes into the storage tank. The 'waste' water can be used for irrigating garden plants or other suitable application. The debris has to be removed from the lower chamber occasionally.

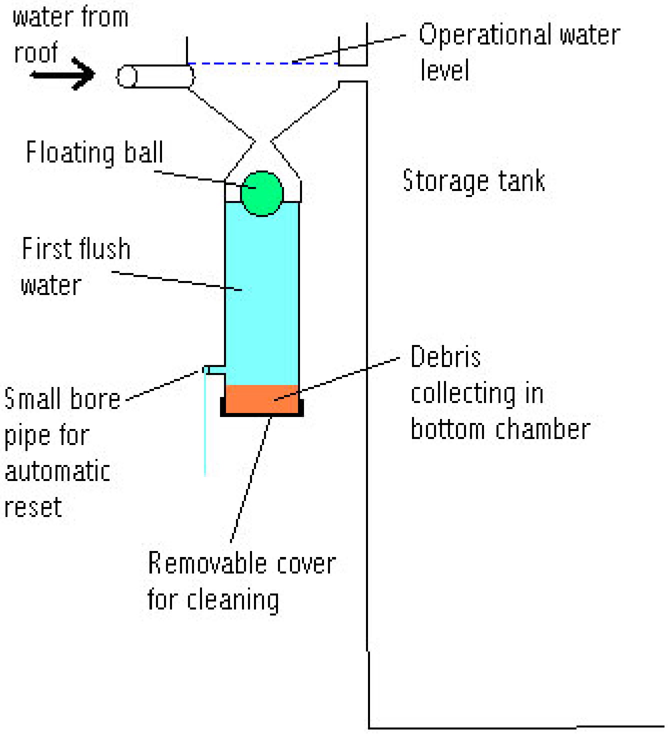


Figure 6 – the floating ball first flush system

Although the more sophisticated methods provide a much more elegant means of rejecting the first flush water, practitioners often recommend that very simple, easily maintained systems be used, as these are more likely to be repaired if failure occurs.

Filtration systems and settling tanks

Again, there are a wide variety of systems available for treating water before, during and after storage. The level of sophistication also varies, from extremely high-tech to very rudimentary. A German company, WISY, have developed an ingenious filter which fits into a vertical downpipe and acts as both filter and first-flush system. The filter cleverly takes in water through a very fine (0.17mm) mesh while allowing silt and debris to continue down the pipe. The efficiency of the filter is over 90%. This filter is commonly used in European systems.

The simple trash rack has been used in some systems but this type of filter has a number of problems attached: firstly it only removes large debris; and secondly the rack can become clogged easily and requires regular cleaning.

The sand-charcoal-stone filter is often used for filtering rainwater entering a tank. This type of filter is only suitable, however, where the inflow is slow, and will soon overflow if the inflow exceeds the rate at which the water can percolate through the sand.

Settling tanks and partitions can be used to remove silt and other suspended solids from the water. These are effective where used but add significant additional cost if elaborate techniques are used.

Post storage filtration include such systems as the upflow sand filter shown in Figure 7. Many other systems exist and can be found in the appropriate water literature.

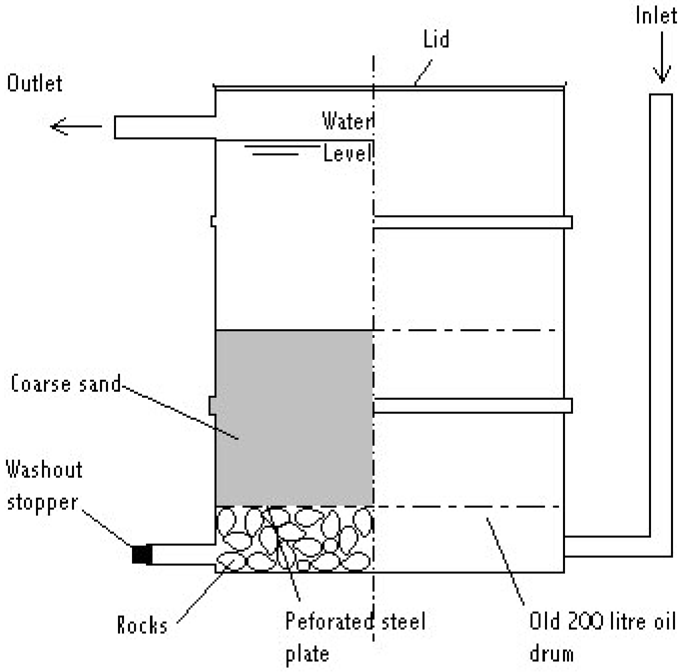
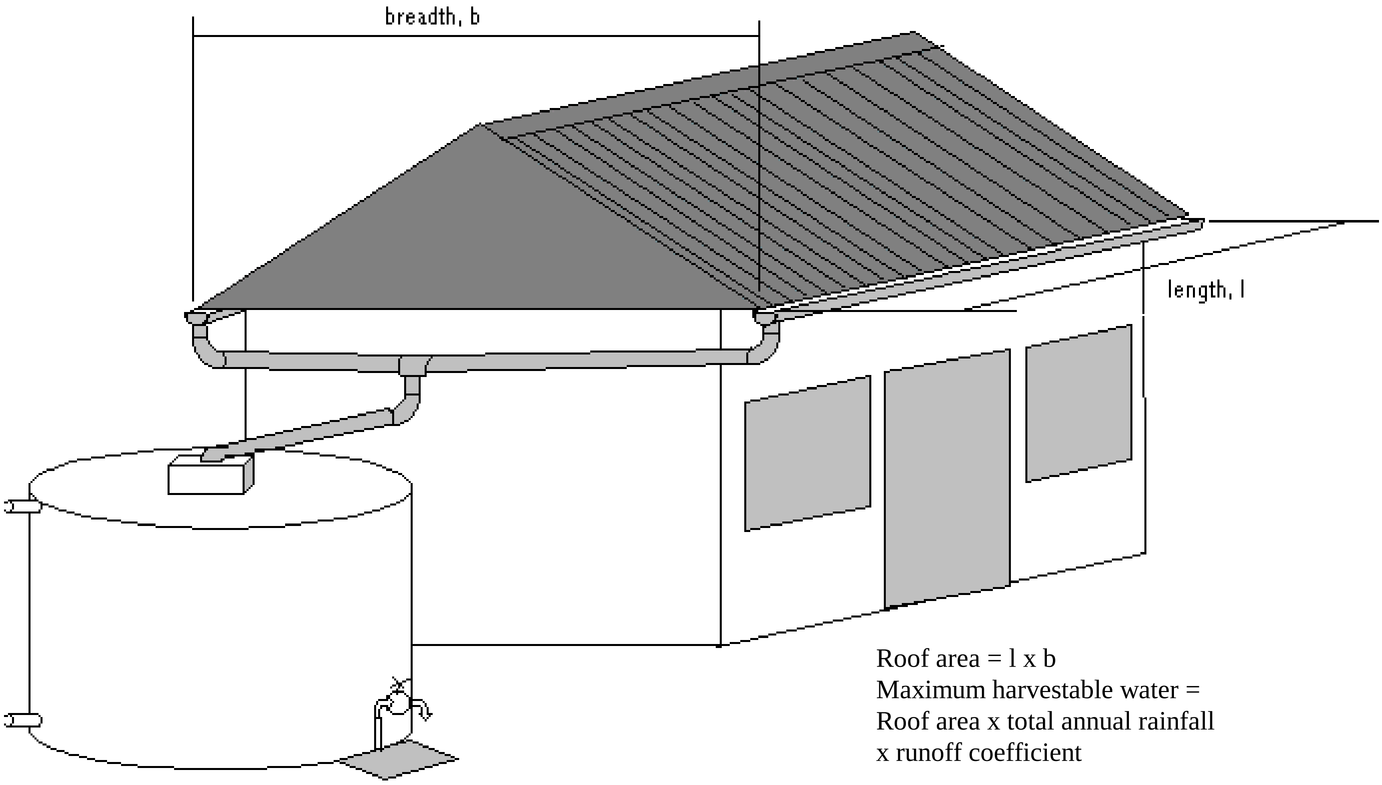


Figure 7 – Upflow sand filter for post treatment of stored water.

4. Sizing the DRWH system

Usually, the main calculation when designing a DRWH system will be to size the water tank correctly to give adequate storage capacity. The storage requirement will be determined by a number of interrelated factors. They include:

- local rainfall data and weather patterns
- roof (or other) collection area
- runoff coefficient (this varies between 0.5 and 0.9 depending on roof material and slope)
- user numbers and consumption rates



Roof area = l x b
Maximum harvestable water =
Roof area x total annual rainfall
x runoff coefficient

The style of rainwater harvesting (see Rainwater Harvesting Styles) will also play a part in determining the system components.

There are a number of different methods for sizing system components. These methods vary in complexity and sophistication. Some are readily carried out by relatively inexperienced first-time practitioners; others require computer software and trained engineers who understand how to use this software. The choice of method used to design system components will depend largely on the following factors:

- the size and sophistication of the system and its components
- the availability of the tools required for using a particular method (e.g. computers)
- the skill and education levels of the practitioner / designer

Below we will outline 3 different methods for sizing RWH system components.

Method 1 – demand side approach

A very simple method is to calculate the largest storage requirement based on the consumption rates and occupancy of the building.

As a simple example we can use the following typical data:

Consumption per capita per day, C – 20 litres
Number of people per household, n – 6
Longest average dry period – 25 days

Annual consumption = C x n x 365 = 43,800 litres

$$\text{Storage requirement, } T = \frac{43{,}800 \times 25}{365} = 3{,}000 \text{ litres}$$

This simple method assumes sufficient catchment area and rainfall and catchment area which is adequate, and is therefore only applicable in areas where this is the situation. It is a method for acquiring rough estimates of tank size.

Method 2 – supply side approach

In low rainfall areas or areas where the rainfall is of uneven distribution, more care has to be taken to size the storage properly. During some months of the year there may be an excess of water, while at other times there will be a deficit (see figure 1 below). If there is sufficient water throughout the year to meet the demand, then sufficient storage will be required to bridge the periods of scarcity. As storage is expensive, this should be done carefully to avoid unnecessary expense.

The example given here is a simple spreadsheet calculation for a site in North Western Tanzania. The rainfall statistics were gleaned from a nurse at the local hospital who had been keeping records for the previous 12 years. Average figures for the rainfall data were used to simplify the calculation, and no reliability calculation is done. This is a typical field approach to RWH storage sizing.

Example

Site: Medical dispensary, Ruganzu, Biharamulo District, Kagera, Tanzania (1997)
Demand:
Number of staff: 7
Staff consumption: 45 litres per day x 7 = 315 litres per day
Patients: 40
Patient consumption : 10 litres per day x 40 = 400 litres per day
Total demand: 715 litres per day or 260.97m^3 per month

Roof area: 190m^2
Runoff coefficient (for new corrugated GI roof): 0.9
Average annual rainfall: 1056mm per year
Annual available water (assuming all is collected) = 190 x 1.056 x 0.9 = 180.58m^3
Daily available water = 180.58 / 365 = 0.4947 m^3 / day or 494.7 litres per day or 150.48m^3 per month

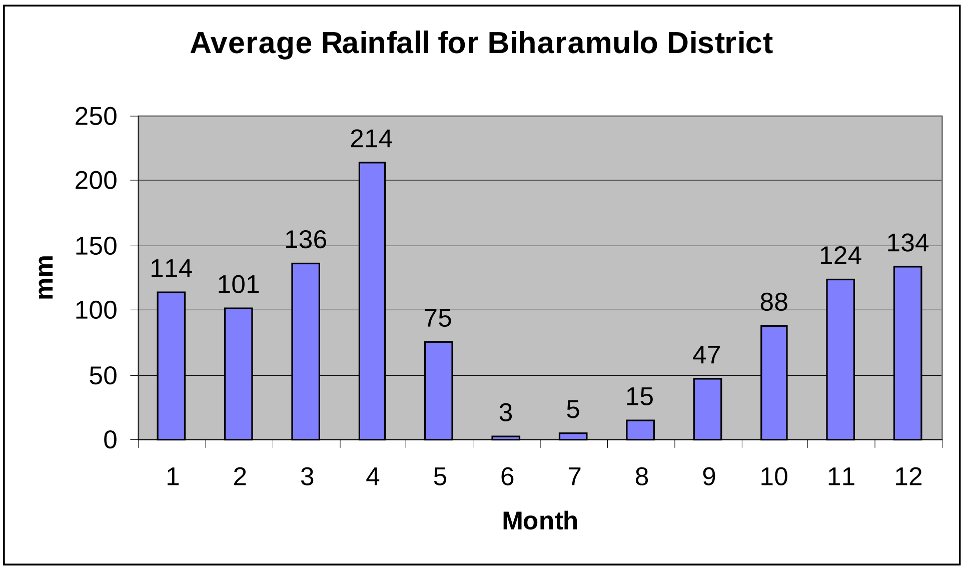


Figure 8 – average annual rainfall for the District of Biharamulo.

So, if we want to supply water all the year to meet the needs of the dispensary, the demand cannot exceed 494.7 litres per day. The expected demand cannot be met by the available harvested water. Careful water management will therefore be required.

Figure 9 below shows the comparison of water harvested and the amount that can be supplied to the dispensary using all the water which is harvested. It can be noted that there is a single rainy season. The first month that the rainfall on the roof meets the demand is October. If we therefore assume that the tank is empty at the end of September we can form a graph of cumulative harvested water and cumulative demand and from this we can calculate the maximum storage requirement for the dispensary.

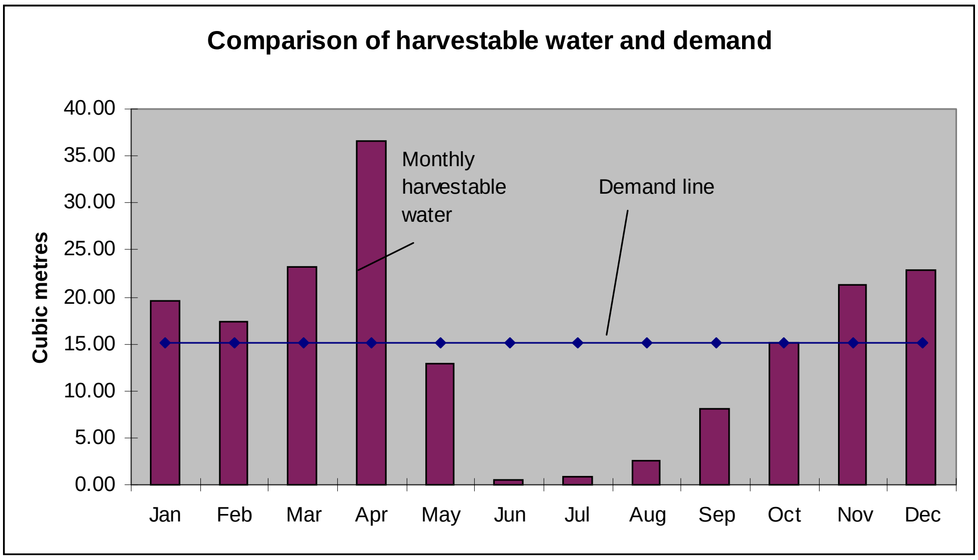


Figure 9 – comparison of the harvestable water and the demand for each month.

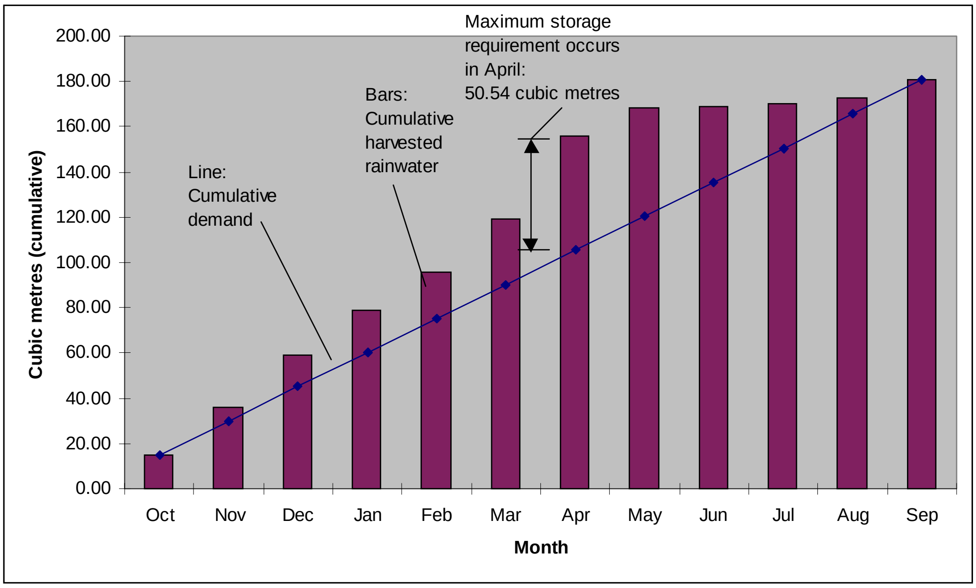


Figure 10 – showing the predicted cumulative inflow and outflow from the tank. The maximum storage requirement occurs in April.

Month	Rainfall (mm)	Rainfall harvested (cubic metres)	Cumulative rainfall harvested (cubic metres)	Demand (based on total utilisation)	Cumulative demand (cubic metres)	Difference between column 4 and 6
Oct	88	15.05	15.05	15.05	15.05	0.00
Nov	124	21.20	36.25	15.05	30.10	6.16
Dec	134	22.91	59.17	15.05	45.14	14.02

Jan	114	19.49	78.66	15.05	60.19	18.47
Feb	101	17.27	95.93	15.05	75.24	20.69
Mar	136	23.26	119.19	15.05	90.29	28.90
Apr	214	36.59	155.78	15.05	105.34	**50.45**
May	75	12.83	168.61	15.05	120.38	48.22
Jun	3	0.51	169.12	15.05	135.43	33.69
Jul	5	0.86	169.97	15.05	150.48	19.49
Aug	15	2.57	172.54	15.05	165.53	7.01
Sep	47	8.04	180.58	15.05	180.58	0.00
Totals		180.58		180.58		

Table 1 - shows the spreadsheet calculation for sizing the storage tank. It takes into consideration the accumulated inflow and outflow from the tank and the capacity of the tank is calculated as the greatest excess of water over and above consumption. This occurs in April with a storage requirement of 50.45 cubic metres. All this water will have to be stored to cover the shortfall during the dry period.

Method 3 – computer model

There are several computer-based programmes for calculating tank size quite accurately. One such programme, known as SimTanka, has been written by an Indian organisation and is available free of charge on the World Wide Web. The Ajit Foundation is a registered non-profit voluntary organisation with its main office in Jaipur, India and its community resource centre in Bikaner, India.

SimTanka is a software programme for simulating performance of rainwater harvesting systems with covered water storage tank. Such systems are called Tanka in western parts of the state of Rajasthan in India.

The idea of a computer simulation is to predict the performance of a rainwater harvesting system based on the mathematical model of the actual system. In particular SimTanka simulates the fluctuating rainfall on which the rainwater harvesting system is dependent.

Rainwater harvesting systems are often designed using some statistical indicator of the rainfall for a given place, like the average rainfall. When the rainfall is meagre and shows large fluctuations then a design based on any single statistical indicator can be misleading. SimTanka takes into account the fluctuations in the rainfall, giving each fluctuation its right importance for determining the size of the rainwater harvesting system. The result of the simulation allows you to design a rainwater harvesting system that will meet demands reliably, that is, it allows you to find the minimum catchment area and the smallest possible storage tank that will meet your demand with probability of up to 95% in spite of the fluctuations in the rainfall. Or you can use SimTanka to find out what fraction of your total demand can be met reliably.

SimTanka requires at least 15 years of monthly rainfall records for the place at which the rainwater harvesting system is located. If you do not have the rainfall record for the place then the rainfall record from the nearest place which has the same PATTERN of rainfall can be used.

The included utility, RainRecorder, is used for entering the rainfall data. Daily consumption per person is also entered and then the software will calculate optimum storage size or catchment size depending on the requirements of the user. SimTanka also calculates the reliability of the system based on the rainfall data of the previous 15 years.

SimTanka is free and is and was developed by the Ajit Foundation in the spirit that it might be useful for meeting the water needs of small communities in a sustainable and reliable manner. But no guaranties of any kind are implied.

For more information or to download the software see their website at http://www.geocities.com/Rainforest/Canopy/4805/

(Source: the information given here is taken from this website).

Further comments

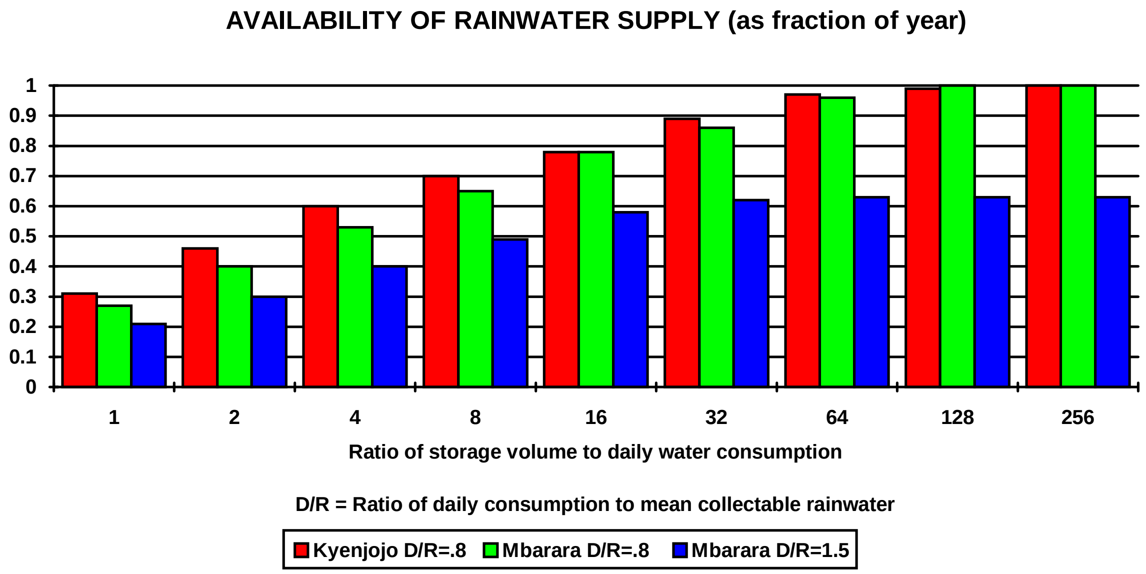
These methods outlined above can be further refined where necessary to use daily rainfall data. This is particularly important in areas where rainfall is more evenly distributed and more sensitive calculations are necessary.

Rainfall data can be obtained from a variety of sources. The first point of call should be the national meteorological organisation for the country in question. In some developing countries, however, statistics are limited due to lack of resources and other sources are often worth seeking. Local Water Departments or organisations, local hospitals or schools are all possible sources of information.

In reality the cost of the tank materials will often govern the choice of tank size. In other cases, such as large RWH programmes, standard sizes of tank are used regardless of consumption patterns, roof size or number of individual users.

Tank efficiency and the case for diminishing returns

On days when rainfall is heavy, the flow into a tank is higher than the outflow drawn by water users. A small tank will soon become full and then start to overflow. An *inefficient* system is one where, taken over say a year, that overflow constitutes a significant fraction of the water flowing into the tank. Insufficient storage volume is however not the only cause of inefficiency: poor guttering will fail to catch water during intense rain, leaking tanks will lose water, and an ‘oversize’ roof will intercept more rainfall than is needed.
Storage efficiency (%) =100 x (1 - *overflow / inflow*) provided that *inflow<demand*
System efficiency (%) = 100 x *water used / water falling on the roof*
In the dry season, a small tank may run dry, forcing users to seek water from alternative sources. *Unreliability* might be expressed as either the fraction of time (e.g. of days) when the tank is dry or the fraction of annual water use that has to be drawn from elsewhere. A RWH system may show unreliability not only because storage is small, but because the roof area is insufficient. The figure below shows how *reliability,* expressed as a fraction of year, varies with storage volume (expressed as a multiple of daily consumption) for two locations close to the Equator and therefore both with double rainy seasons.



From this graph one can see that increasing storage size, and therefore cost, gives diminishing returns. For example look at the left hand column of each triplet (Kyenjojo with roof sized such that average annual water demand is only 80% of average annual roof runoff). Assuming a say 100 litres per day demand, shows that increasing storage from 1 day (100 l) to 16 days (1600 l) raises the reliability from 31% to 78%, but storage has to be increased as high as 128 days (12,800 l) to achieve 99% reliability. Such high reliability is so expensive that it is an unrealistic design objective for a DRW system in a poor country. In any case, as we shall see below, users may change behaviour so as to reduce the effective unreliability of their systems.

System features (that affect tank sizing)

- An oversize roof slightly extent compensates for an undersize tank.
- If users are able and willing to adjust their consumption downwards during dry seasons, or when they find water levels in their tank lower than average, tanks can be sized smaller.
- ‘Partial’ RWH systems, either where it is accepted that RW will not meet needs throughout the year or where rainwater is only used to meet specific water needs like cooking/drinking, can be built with surprisingly small tanks.
- The reliability level appropriate to the design of a RWH system rises with the cost (in money, effort or even ill-health) of the alternative source that is used when the tank runs dry.

Rainfall data

Rainfall is very variable, especially where annual precipitation is less than 500mm. It also varies with location, so that data from a rain gauging station 20km away may be misleading when applied to the site of the RWH system. From the lowest to the highest quality of rainfall data we can think of at least 6 categories:

1. No numerical data available, but of course local people know quite well the seasonality of precipitation and which crops will grow (with what sort of water-stress failure rate).
2. There is no numerical data, but RWH has been practised for long enough locally for people to have a feel for what is an adequate tank size.
3. Only annual average rainfall is available, probably at a somewhat distant recording point, plus local knowledge of seasonality.
4. Monthly rainfall, averaged over at least 4 years, can be obtained.
5. Actual monthly rainfall records for at least 4 years, and preferably 7 years, are available for the site or for a location sufficiently nearby to give confidence or allow some systematic correction to be applied.
6. Daily rainfall data for a relevant location and lasting at least 4 years is available.

Daily data is adequate for all design methods except perhaps the optimisation of gutters for which *rainfall intensity* data is useful (e.g. the fraction of annual precipitation falling at a rate faster than say 1mm per minute). Rainfall data can be expensive to purchase and is often hard to locate even where it exists. Obviously methods of sizing tanks that require as an input rainfall data of a sort that is not locally available should not be used.

Possible methods for estimating likely future RWH system performance with a tank of given size

1. Ask local people with existing RWH systems and a comparable roof size what tank size they used and what has been their experience with it.
2. Mean dry season duration x daily dry season consumption. This may define an ‘ideal’ below which the designer chooses the ‘biggest affordable’.
3. Model *reliability* or *efficiency* using mean monthly rainfall data. (One variant of this is to compare the cumulative supply and usage loci to determine the maximum deviation of the former below the latter)
4. Test different tank sizes against actual *monthly* rainfall data over several recent years (or for tanks equivalent to less than 2 months water demand actual *daily* data) and thereby deciding the best reliability v cost trade-off.

5. Reasons for the current interest in DRWH

In the last decade there has been a large increase in the amount of interest in, and application of, DRWH in both developed and developing countries. There are a number of reasons for this growth. In developing countries these include: disillusionment with traditional technologies, which have failed to meet the needs of the people; a growing number of problems with groundwater sources; a realisation that DRWH is a viable alternative which gives the user autonomy and independence. In the industrialised countries the motivation has been: to reduce water bills, which have grown in some countries at alarming rates; to meet the ever growing needs (particularly for non-potable water) of ever more demanding societies; to offset the huge demand on depleted or polluted groundwater resources.

The following is a small collection of articles, reports and comments which illustrate these issues:

Rainwater Cistern Systems as an Alternative Drinking Water Source in Regions of Inadequate or Unsuitable Groundwater

The Canadian Province of Nova Scotia includes a population of approximately 850,000 persons in an area of 52,840 sq km. Approximately 320,000 persons are served by private well supplies. The quality of groundwater in Nova Scotia is generally good. However, there are areas of the province in which adequate reliable supplies of groundwater of acceptable quality are not available to individual dwellings. In these situations rainwater cistern systems have been used or proposed for use. An estimated total of up to 500 dwellings in Nova Scotia are now served by rainwater cistern systems. The rainwater system consists of a roof , which serves as a collection surface, and gutters and down-spouts that are connected to a storage reservoir located in a basement or underground. Treatment devices for disinfection and/or filtration have been installed by some owners on the household side of the cistern. The largest single reason for use of these systems is their location in areas where groundwater is completely unacceptable for domestic purposes because of local gypsum deposits. Other reasons include unsatisfactory well water caused by salt water intrusion, iron and manganese, or inadequate groundwater yield. Studies have indicated that a rainwater cistern can provide a reliable and effective method for the supply of water to an individual dwelling, provided that the size of the roof surface is adequate to meet the long-term demands of the occupants, and that the owner is prepared: (1) to install a cistern of adequate size; to provide a method for disinfection; and, (2) deal with routine maintenance in the form of cleaning of gutters and the cistern interior.

Author(s): D. H. Waller, R. S. Scott.
Citation: IN: International Groundwater
Symposium on Hydrogeology of Cold and Temperate Climates and Hydrogeology of Mineralized Zones. Proceedings of the Symposium held May 1-5, 1988, Halifax, Nova Scotia, Canada. (1989). pg 247-255, 1 fig, 7 tab, 14 ref.

The town of Avadi in Tamil Nadu, India, is using rainwater harvesting to augment its scarce groundwater resources. Not only were groundwater levels dropping but also groundwater quality has deteriorated, limiting water availability to only 4 litres per capita per day (lpcd). A consultant calculated that supply can be at least be doubled by channelling rainwater collected from roof tops and vacant areas around houses via percolation pits and a filter into household wells. Total costs for a system are INR 5,000 (US$ 118) of which INR 3,000 (US$ 71) for piping and the remainder is for sinking percolation pits. So far 10 houses have employed a rainwater harvesting system. The recharging method can be modified to tap water from storm-water drains, canals and boreholes.

Source: The Hindu, 21 September 1998

A survey of 3014 people across South Australia was undertaken to determine the sources of water for drinking and cooking. Overall, rainwater was found to be the main source of water for drinking – 42.2% of households used tank water for drinking, followed by mains supply at 40.3%. For cooking, mains supply was used by 64.3% of households, followed by 29.9% of households using rainwater from tanks. In the Metropolitan area, on average 25.6% of households used rainwater for drinking, whereas in rural areas, on average 81.5% of households use rainwater with use in some areas approaching 100%.

Source: Water – Journal of the Australian Water and Wastewater Association, January/ February 1998

The Tokyo Metropolitan Government is also promoting the use of RWH in the city, and have included for RWH in the Water Policy Guidelines. This is in response to an inability to meet urban demand because of inadequate sources of water.

In Germany there are increasing concerns about nitrates and pesticides in ground water. The concentrations of both of these is growing notably. Also an increased demand for drinking water (e.g. 1200% increase in consumption between 1975 and 1994 in the Oberfranken area of Northern Bavaria) is causing a major headache for water supply companies and the government.

Arsenic poisoning in Bangladesh and India

An estimated 18 million people in Bangladesh and West Bengal (India) are poisoning themselves by drinking arsenic-contaminated groundwater. Victims suffer a painful death, from one of several forms of cancer, with skin lesions on hands and feet as advanced signs of poisoning. The crisis is a result of extensive UNICEF and government-sponsored well drilling programs for over 25 years which successfully cut mortality rates attributed to diarrhoea but did not carry out water testing. Despite continued warnings by analytical chemist, Dr. Dipankar Chakraborty, as far back as 1988, government officials generally dismissed him as an alarmist. In late August 1998, the World Bank announced a US$ 32.4 million loan for the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP). The IRC International Water and Sanitation is helping prepare the operations steps and manuals for BAMWSP.
New York Times, 10 November 1998

An estimated 100 people in Bangladesh have died of arsenic-related diseases so far in 1998 and 1,000 have become ill. Most deaths are not known, however, because the problem was not officially recognised until 1993 [1]. In one of several articles on the arsenic crisis, journalist Sylvia Mortoza mentions that over 2,500 have died in Bangladesh over a few months [2]. Now major donor help is underway, nowhere near the 70 million people potentially at risk will fall ill. The issue has also raised awareness of arsenic poisoning in the US where environmentalists took the Environmental Protection Agency to court for dragging its feet on the adoption of the World Health Organization (WHO) arsenic guideline value of 10 ppb [3]. An overview of current arsenic research projects can be found at the West Bengal and Bangladesh Arsenic Crisis Information Centre site: http://bicn.com/acic/
http://www.wsscc.org/source/weekly/9839.html#arsenic_poisoning
[1] - Fox news, 16 November 1998, http://www.foxnews.com/js_index.sml?content=/news/wires2/1116/n_ap_1116_139.sml
[2] - http://bicn.com/acic/infobank/mortoza6.htm
[3] - Chemical & Engineering News, vol. 76, no. 46, November 16, 1998, http://pubs.acs.org/cgi-bin/bottomframe.cgi?7646inter
Source: SOURCE Weekly Bulletin No. 40, 23rd November 1998

Process and Progress
Where they have been installed, government tubewells and handpumps have been poorly maintained in rural areas and delays of several months before repairs are carried out are not uncommon. The urban context differs in that water infrastructure exists with both intermittent and unreliable supply.

Benefits from government sanitation programmes to rural communities in the project areas visited have been limited, and sanitation and drainage in the urban project area were inadequate before the project intervention.
Source: Water Aid Evaluation Report – South India 1995

Rainwater harvesting-Kibwezi project
This project includes the provision of guttering and the construction of rainwater storage tanks at 46 schools in the area. The purpose of the programme is to provide sufficient water throughout the year for the pupils, both for drinking and for cooking their midday meal. The work is carried out under KWAHO supervision with the assistance of parents who excavate the pit in which the ground tank is cast, and provide sand for its lining. At the time of evaluation, this installation had been completed in 27 schools, of which 10 incorporated ferro-cement tanks above ground with a capacity of 30 cubic metres and 17 are below ground with a capacity of 75 cubic metres. It is possible that low lift pumps installed in certain schools may not be suitable, in that they are mounted at about 45 degrees to the vertical.

Mfangano Island Project
Shallow wells constructed on Mfangano Island were intended to respond to endemic cholera, dysentery, diarrhoea and billharzia found in the Lake water from which inhabitants draw their supplies. To provide sources of safe water for inhabitants who tend to cluster around the lake shore, a trial programme for the construction of ten shallow wells has been carried out but with very limited success. In almost all cases, the water was saline and unacceptable to villagers.

Ngusuria Project
In Ngusuria, villagers have laid 12 km of 50 mm diameter GS pipe to supply three villages from a spring and impoundment high up on the side of the escarpment surrounding the area. Service mains, storage tanks and break pressure tanks have also been installed serving some 25 stand pipes and private connections. The discharge from the spring often reduces to zero at the end of the dry season. In this event, supplies are provided from a deep, copious borehole in which an electro-submersible pump has been installed. This was unserviceable at the time of the visit. Arrangements to lift the pump and motor for repairs were being made.

Source: Water Aid Evaluation report – Kenya 1991

6.Criteria for the analysis of DRWH systems

The possible applications of rainwater harvesting are endless. For each circumstance, be it an affluent South Australian urban dwelling or a poor African rural household, there will be a desirable solution. The requirements of each individual will be different. For some, space will be limited, while for others cost may be the over-riding factor. It is therefore impossible to suggest a suitable DRWH system without knowing the context for which it will be used. We can however carry out a broad analysis for the systems considered here.

To facilitate such an analysis to be carried out we have developed a set of criteria by which the DRWH systems can be assessed by the reader. The list is by no means exhaustive and in most cases is purely subjective. Where actual facts and figures are available, they are given in the Case Study and the reader can judge him/herself the suitability of the system in question. The table shown below is completed for each example and shown at the end of each Case Study.

A cost analysis of DRWH systems is somewhat meaningless when the value of world currencies varies so widely. We have therefore considered not only local costs (and converted this into US Dollars for easy reference, but also considered this cost as a percentage of the average monthly income for the region in question.

Material requirement and costs	
Labour costs	

Unit costs (i.e. cost per m^3)	
Unit cost as a percentage of average monthly income	
Skills required	
Equipment / tools required	
Space requirement	
Suitability for incremental adoption	
Reliability	
Durability	
Water quality, safety and health	
Impact on insect breeding	
Ease of operation	
Suitability	
Stage of maturity or experience	
Other	

(This work has yet to be done on our Web Site)

7.Health and DRWH

The literature on health aspects of RWH is surprisingly sporadic Gould & McPherson 1987, S Australia 1981, even in countries where RWH use is widespread and of long standing. We are interested in the mineral quality of roof run-off, in its bacteriological quality, in the connections between RWH and the breeding of disease vectors (especially mosquitoes), and in the risk of accidents such as children drowning. We would like to know not only how new systems might perform and do actually perform, but also whether that performance declines with the age of a RWH system. On the positive side, we should like to be able to quantify the undoubted health benefits of women spending less time collecting water - benefits such as fewer accidents to unattended infants, better nutrition, less female back injury and of course the hygiene benefits of greater water consumption which introducing RWH sometimes brings.

RWH may not be competing on a ‘level playing field’ when it comes to health criteria. Because there are few specific health standards defined for harvested run-off, there is the danger that inappropriate norms will be demanded of it. Competently harvested roofwater generally has negligible levels of pollution by minerals and low levels of bacterial pollution. In almost all developing country situations its quality is likely to be superior to that of such alternatives as discontinuously-pressured piped water, shallow well water and even deep well water. Conversely it may not achieve the bacteriological quality of treated water entering mains from a water works, or that of delivered water in rich countries. Roofwater that is incompetently collected or stored may indeed be turbid and a possible source of pathogens.

There have been concerns that rain may pick up unhealthy substances whilst falling through the atmosphere, whilst running down a roof or whilst resting in a store. The danger from the first of these, namely atmospheric pollution, seem slight. Measurements of precipitation even in industrialised areas Thomas & Greene 1993 indicate a fairly low take-up of heavy metals from the air and wholly tolerable levels of acidity; however no doubt it would be unwise to harvest rainwater immediately downwind of say a smelter. The probability of finding truly-airborne ingestible pathogenic viruses or bacteria seems low and of finding larger airborne pathogens negligible. Interest therefore focuses mainly upon contamination of roofs and the performance of water stores in reducing or increasing pathogens.

Roofs and gutters are made of a variety of materials. For most practical purposes we can exclude discussion of ‘organic’ roofs such as grass, reed and palm because they yield such dirty run-off that they are rarely used for RWH. The common materials of interest are ceramic, cementitious, rock and metallic (plastic roofs being neither cheap nor durable). Contamination of water might arise from the roofing material itself or from substances that have accumulated on a roof or in a gutter.

Metal roofs are normally of treated steel or less commonly of aluminium. Aluminium is very inert unless in contact with very acid water. However the effect on health of ingesting tiny amounts of aluminium are controversial; there has been some debate in Europe about a possible link between such ingestion (from the aluminium saucepans popular up to 1960) and the development of Alzheimer's Disease that causes premature senility. Corrugated steel roofing employs mild steel protected by hot-dip or electrolytic galvanising or by painting, since stainless steel is too expensive to use. Galvanising entails zinc compounds: fortunately zinc has a low toxicity, so that roof run-off water does not exceed WHO-permitted zinc levels. Roof paints including bitumen may entail some risk to health and/or may impart unpleasant taste to roofwater and should probably be avoided for RWH. More seriously although no one can now afford lead sheeting on roofs, localised lead 'flashing' is still used at joints. One study in Malaysia Yaziz 1989 reported lead levels of up to 3.5 times WHO limits in roof runoff but this is not a general finding and seems to have arisen from lead in dust deposition rather than the roofing material since it reduced rapidly with storm duration. Not surprisingly the safety of water harvested from 'asbestos' (= asbestos-reinforced cement mortar) roofs has been queried, but the consensus is that the danger of developing cancer from ingested asbestos is very slight Campbell 1993. The danger from inhaled asbestos dust is however sufficiently high that working with asbestos sheeting, for example sawing it, without special protection is now generally banned in industrial countries. The iron in a rusting roof will also enter the runoff, but in such small quantities that it does not prejudice either health or taste.

Metal roofs are comparatively smooth and are therefore less prone to contamination by dust, leaves, bird-droppings and other debris than rougher tile roofs. They may also get hot enough to sterilise themselves. However contamination may be substantial on all roof types and it has been common for many years to design 'first-flush diverters' into RWH systems. During a dry spell debris builds up on roofs, so that the initial run-off during the first following rainfall event can be full of sediment and highly turbid. Overhanging trees, especially coconut palms, make this sediment problem worse, as well as increasing the likelihood of bird and rodent droppings. A common strategy therefore is to divert to waste the first say 5 litres of runoff at the beginning of each rain event. This can be done automatically using proprietary devices, or where the seasons are well defined it can be done manually by temporarily displacing the pipe connecting gutter to storage tank. If this first flush is excluded, we have a water source with modest levels of turbidity and typically medium levels of bacterial contamination (e.g. <10 FC per 100ml). Modern 'no-maintenance' separators, or more traditional screens, cloth or sand filters will reduce turbidity and contamination further and any good tank design will reduce it further still.

Not all tanks are however designed, made and maintained well. One can commonly see tanks which offer access to insects, lizards and rodents and which permit enough light to enter that algae can grow. Such tanks take longer to lower the contamination level of the entering flow and may even permit new infection for example by pathogens carried on the feet of cockroaches. Water abstraction is occasionally by lowered bucket - with all the opportunities for contamination that offers - and not uncommonly by a tap set too low in the tank so that tank-bottom sediment may be drawn into the outflow. However tests in even poorly designed tanks commonly give levels of bacterial contamination (rarely over 5 FC per 100ml) that compare well with those in competing water sources in developing countries. The technique of filling a RWH tank then sealing it for a month or more produces excellent water quality. It seems it is possible even without such steps to meet the highest international standards for bacteria and dissolved substances with well-made RWH systems incorporating effective prefiltration and careful in-tank flow guidance. Cleaning tanks, say annually, should improve water quality, provided any remaining disturbed sediment is allowed to resettle for several days before the tank is used again. With the best pre-tank separators however, the rate of entry of organic material is so low that (provided no photo-synthesis occurs) such material can be entirely removed by aerobic bacterial action and no cleaning is required.

Water tanks are close to houses. Moreover they usually contain water during some or all of any dry season, a time when alternative breeding grounds for mosquitoes dry up. For both these reasons it is important that they do not act as significant breeding sites. The design of tanks and guttering to exclude insect breeding requires a mixture of common sense and professional engineering or entomological knowledge. It is common sense to so align gutters, and keep them clear of blockages, that they do not hold stagnant pools after rainfall finishes. It is engineering expertise or long experience that generates good designs for self-clearing gutters or filters. It perhaps requires entomological expertise to identify tank shapes that lower the chance of successful larval development. Mosquito eggs are sufficiently small that they could pass through most filters with entry water: such filters cannot be very fine if they are to be able to handle the sudden and large flows during intense tropical rainfall of up to 1 millimetre per minute. Mosquito control is therefore a matter of preventing the entry and exit of adult insects and interfering with larval growth. The former may be difficult to achieve if tank maintenance is poor or if users place greater importance on maximising tank inflow than on maintaining mosquito defences. It is therefore attractive to have the ‘defence-in-depth’ of larval control. This may take the form of active control with fish predators, surface oil films and suchlike but a more rewarding general policy is to starve larvae. Maintaining darkness in a tank prevents photo-synthesis and the growth of algae. Preventing the entry of suspended materials reduces the general nutrient levels supporting any biological chain. Research is underway into these factors and it seems likely that fairly straightforward measures can render a tank unsuitable for dry-season breeding of anopheles, aedes and culecine mosquitoes. Moreover, broadly speaking, if mosquitoes can be controlled it should be relatively easy to control larger disease vectors like cockroaches.

If a child falls into a tank, even if that child can swim, there is a real danger of drowning. Many existing tanks have no covers or easily displaced covers and stories of children deliberately bathing in free-standing RWH tanks are to be heard. Perhaps of most concern are underground tanks whose covers have been opened for inspection, maintenance or even for drawing water. It is not normal to fence underground tanks, to extend them above the ground high enough to deter access by crawling babies or to socially control children from playing on them. However fencing and/or partial raising could have advantages including reducing danger of contamination by surface water and lowering the chance of cover damage by vehicles as well as reducing the risk of children or night-moving adults falling in. Accidents like drowning are most likely where a new technology is being introduced and therefore should be the particular concern of technology-change agents.

Every technology has its obscure and rarely-met failure and danger modes. Clearly any aspect of RWH that involves human activity on high roofs, handling rusty metal or working ‘underground’ involves some risk of accident. A particular danger, known to have asphyxiated at least one builder recently, is the possibility of deoxygenation within a closed tank during the process of mortar setting and curing.

Finally, under health considerations, one might mention floods. If flood levels are higher than the entry point of RWH tank entrances, there is the real danger of serious contamination of the stored water. This danger may be avoided by suitable tank location or by the permanent presence of a say slow-sand entry filter.

Report A1 –Current Technology for Storing Domestic Rainwater (Part 2)

The work in this report forms the basis for the current DTU roofwater harvesting Web Site. The site can be found at:

http://www.eng.warwick.ac.uk/DTU/rainwaterharvesting/index.html

The work in this document is on-going and will be added to as the programme progresses. The aim is to collect examples of DRWH practice from around the world and to provide a useful resource for practitioners of DRWH. Many of the graphics shown in the Web Site are not shown in this document due to electronic storage requirement limitations. The report is in two parts so that the document remains manageable. This is Part 2.

Contents of report (Part 2)

Current Technology for Storing Domestic Rainwater (Part 2)

Case study 1 - The Sri Lankan Pumpkin Tank

Background Information

The Sri Lankan Pumpkin Tank, and the associated construction technique, was developed as part of a World Bank sponsored Water and Sanitation Programme which was implemented in the country between 1995 and 1998. The Community Water Supply and Sanitation Programme (CWSSP) covered 3 districts within the country – Badulla, Ratnapura and Matara Districts. Hundreds of these tanks were built in areas where conventional supply schemes, such as piped supplies or groundwater supplies, were difficult to provide. In some areas members of the target community were given the choice of a RWH system for individual households or a groundwater supply for a group of households. The choice varied. In all cases there was a choice of type of tank – either the Pumpkin tank or an underground tank which is described in Case Study 2. The choice was usually a function of ground conditions rather than personal preference. Both tanks have a capacity of approximately 5m^3.

The Abikon family of Demetaralhina in Badulla District chose a pumpkin tank. Their village is in a rural highlands area of the country and the ground conditions were not suitable for a groundwater supply or for digging a pit for a below ground tank. Average annual rainfall is 2250mm with a bimodal rainfall pattern and a dry period, usually between December and April. Their per capita consumption was well below the 20 litres per day that each family member now consumes. The water is used for drinking (but only after boiling), cooking, personal and clothes washing. Mr Abikon also uses the water from their tank to water their 4 cows. Only towards the end of the dry season does the tank sometimes dry and then the family has to walk to the spring, about ½ a mile from their home.

Technical details

Rainwater is collected from only 1 side of the pitched roof, a collection area of 32m^2. The roofing material is a mix of zinc and asbestos sheeting. The guttering is a PVC U-channel, factory manufactured, found commonly in the nearby town, fitted to a facia board with similarly manufactured brackets, spaced at 300mm centres. The downpipe is a standard 3” PVC pipe, although some of the neighbours use less costly downpipes made from string and plastic tubing. The cost of the guttering is approximatley SLR5,600, about Sterling £86.00.

This pumpkin tank was built 3 years ago and is in very good condition. The construction is of ferrocement. The construction detail is given later. The cost of the tank is approximately SLR5,000 or Sterling £77.00. The materials and specialist labour for the tank were provided by CWSSP and the guttering was purchased by the Abikon family.

Water extraction is through a tap piped to a point slightly away from the tank, where the ground falls away and allows a bucket to be placed easily under the tap. There is a first flush mechanism fitted in the form of a simple PVC elbow with a length of pipe which diverts the dirty first water away from the inlet chamber. The inlet chamber also acts as the prefilter chamber. The chamber is approximately 600mm cubed and contains subsequent layers of stone, charcoal and sand, through which rainwater passes.

Construction details:

The following construction details are given in the instructions which are handed out to masons during their training session:

Pumpkin (Wataka) Tank – Construction details

1. Prepare skeleton / framework legs (see Figure 1) as shown in the drawing. 10 no. required. Prepare the crown ring. This can be used again for many tanks.

(Figure 1 photo – one of the 10 framework legs used as the skeleton for the tank – shown in Web Page)

2. Lay the concrete base using two layers of chicken wire as reinforcing. Allow 300mm of chicken wire to protrude all around the edge of the base. This will be connected to the wall mesh later. Lay 10 anchor bolts for the legs in the base while casting (the diameter will depend on the diameter of the holes in the legs).
3. Leave the base for 7 days to cure, wetting each day.
4. Secure the 10 skeleton legs using the bolts and the crown ring.
5. Take 6mm steel rod and wrap it around the outside of the legs, starting at the bottom and working up at 10cm intervals.
6. Fix 2 layers of chicken wire over the outside of the skeleton. The filter tower can be added at this point if a filter is to be fitted.

(Figure 2 photo – a Pumpkin tank under construction – shown in Web Page)

7. Plaster the outside of the mesh. Leave for 1 day.
8. Go inside the tank and remove the skeleton.
9. Plaster inside the tank and cure for 7 days.

Water proofing can be added to the mortar. This can be a specialist additive or liquid dishwashing soap.

Cure the tank by wetting for 7 – 10 days. Fill the gradually starting on day 7, filling at a rate of approximately 300mm per day.

(Figure 3 photo – a finished Pumpkin tank)

Materials and labour breakdown

Material	Unit	Qty	Unit Cost	Total cost
Cement	Bag	8	265	2120

Sand	ft^3	55	3.5	192.5
Metal	ft^3	6	18	108
½” Chicken Mesh	ft^2	366	4	1464
Mould		1	325*	325
Transport				500
Skilled labour	hr	56	22	1232
Unskilled labour	hr	112	12.5	1400
				7341.5

*Assuming mould is used for 10 tanks
All costs given in Sri Lankan Rupees

65 SL Rupees = Sterling £1.00

Case study 2 – Underground brick dome tank, Sri Lanka

Background

This is another RWH system, as with the previous case study, which was developed by the CWSSP programme in Sri Lanka (see Case Study 1 for more detail). The tank, a 5m^3 underground brick built tank, is based loosely on the design of the Chinese below ground biogas tank. Indeed, the Sri Lankan engineer who designed the system had studied for some years in China. This is a good example of cross fertilisation of technologies across cultures, as well as the application of appropriate technology.

Again, this system was introduced due to the difficulties faced in bringing water to this community in a conventional manner. There was a lot of opposition to the RWH technology in the area at first, as it was a technology which was not widely known in the. Now, after 2 years using the rainwater falling on her roof, Mrs. Emsayakar, of Batalahena Village near the town Matara, sees things very differently.

The alternative offered by CWSSP was a handpump per 10 households. This still means walking to collect water. Mrs. Emsayakar joked that they can still use the handpump of their neighbours when they wish. She has not, however, had to do so yet as the harvested water meet all the needs of the family of 5, as long as they conserve water carefully. She also said, however, that she would prefer a piped / pumped supply which would mean that they could use as much water as they wish.

Technical detail

The tank

The tank is a 5m^3 below ground cylindrical brick construction based on the design of a Chinese biogas digester (see Figure 1 below). It has a diameter of 2.5m and a height of 1.3m to the base of the cover. The cover is a constructed using a clever brick dome design which can be left open to provide access. Water extraction is either by bucket, by handpump (more detail later) or by gravity through a pipe / tap arrangement where the topography and ground conditions are suitable. The cost of the tank is in the region of Rps.6,500 (UK£100). The construction details given to local masons are given below.

Figure 1 – detail drawing of the Sri Lankan brick dome tank (see Web Site)

The Chinese Brick Dome Tank – Construction details

1. Find suitable site
2. Dig pit 0.5m larger than the tank diameter
3. Plant an iron rod in the centre of the pit, making sure it is vertical.
4. Construct concrete base.
5. Start constructing walls using wire from iron rod to maintain the radius.
6. Once walls are complete backfill the gap between wall and pit with sand.
7. Make concrete ring beam to the shape shown. No reinforcing is required. Fit overflow pipe at this point if required.
8. Prepare two wooden sticks – one end an ‘L’ shape and the other a ‘V’ shape. The length of the stick is 2/3 that of the internal diameter of the tank.
9. Keeping the ‘L’ shaped end of the stick to top of the tank wall, place the ‘V’ end against the iron rod and wrap string or wire around the rod to support the stick.
10. Start to build the dome shaped roof of the tank with dry bricks.
11. To start, stick the first brick to the lintel with mortar and support it with the first stick.
12. For the second brick, stick this to the lintel and the first brick and support it with the second stick.
13. Push the third brick into place (with mortar) next to the second brick and move the second stick to hold the third brick.
14. Continue the process as with brick 3 until the first course is almost complete.
15. The final ‘key’ brick should be shaped to fit tightly allowing for the mortar.
16. Remove the sticks once the first course is complete.
17. Continue in this fashion for the subsequent courses.
18. The dome mouth is constructed in a similar way, but using the bricks length-ways.

19. Plaster the outside of the dome, then plaster the inside of the dome.
20. Plaster the inside of the tank.
21. Plaster the floor o the tank
22. Cure the tank by wetting for 7 – 10 days. Fill the gradually starting on day 7, filling at a rate of approximately 300mm per day.

Water proofing can be added to the mortar. This can be specialist additive or liquid dishwashing soap.

Water extraction is performed, at this sight, by two methods. A tap is fitted which allows water to flow by gravity from the tank, as shown if Figure 2. The second option is a simple handpump which has been developed, as part of the CWSSP programme, for use with below ground tanks. The pump is known as the Tamana pump, after the Pacific island on which it’s predecessor was originally observed.

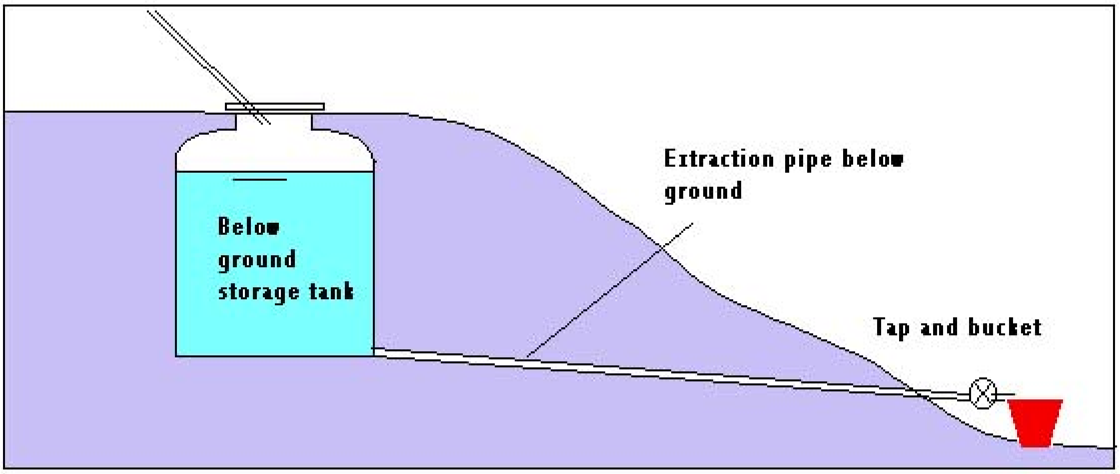


Figure 2 – Water is fed by gravity from the tank when the conditions are favourable

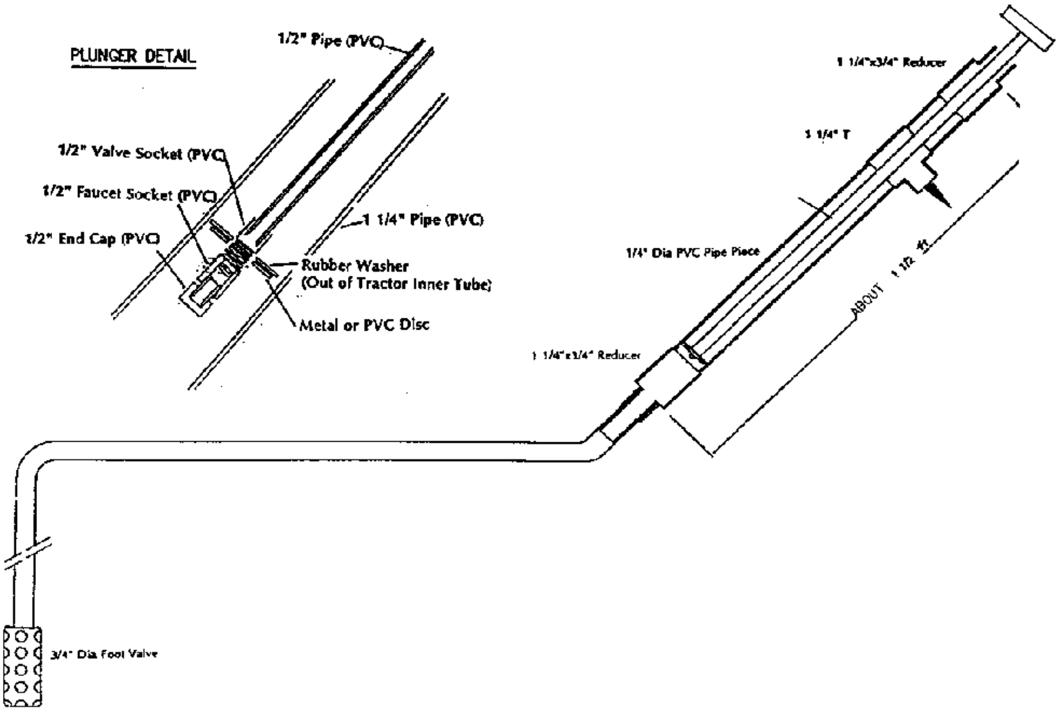


Figure 3 – The Tamana pump – design drawings

The Tamana pump is designed to be very low cost, approximately UK£5, using only locally available PVC fittings and rubber from a tractor inner tube. The location of the pump is shown in Figure 1 and technical details of the pump are shown in figure 3. This particular pump was fitted by the owners son, a mechanic, who has fitted many of these pumps for other community members. The pump has been brought via a ¾” PVC pipe to the kitchen of the house.

The first flush system is quite simple – the inlet chamber has a hole in its bottom, which is plugged with a bottle. When the bottle is removed water is allowed to flow away from the tank . The inlet chamber leads otherwise to a pre-filter chamber which contains layers of stone, charcoal and sand. The owner has experienced some problems with infestations of ants in this chamber. The inlet pipe to the tank has a protective mosquito mesh to stop mosquitoes entering and breeding in the tank.

Catchment area

The catchment area is the roof of the dwelling. This is a pitched roof of pan-tiles. Only one side of the roof is used. The other side is actually used to supply water for a neighbours tank which is situated at the other side of the house. The guttering is a factory manufactured U section type fitted to a facia board with specialist clips. The cost of the guttering is 1000 Rps. (UK£15.50). There is only about 8m of guttering for the 28m^2 of catchment surface.

User pattern

Average annual rainfall is 2600mm with a bimodal rainfall pattern and a dry season which lasts for 3 months. When properly managed the water collected can last throughout the dry period, with occasional trips to the nearby well for washing water. The average consumption rate for the whole family is about 75 litres per day but this is reduced during the dry season. The water is used for all domestic applications and there is no anxiety about the quality of the water, as is seen often where rainwater is used.

Item	Unit	Unit cost	Quantity	Cost (SL Rupees)
Cement	bag	310	8.5	2635
Sand	m^3	1700	0.4	680
¾ “ Metal bar	m^3	4000	0.1	400
Brick	Number	2.10	800	1680
Padlo cement	kg	100	0.5	50
Skilled labour	days	250	4	1000
Unskilled labour	days	150	12	1800
			Total	**8245**
The unskilled labour is often provided by the recipient hence reducing the cost of the tank.				

Case study 3

3.0m^3 brick built storage tank, Sri Lanka

Background

This case study is an example of local initiative in design and manufacture in DRWH. The tank in question was constructed in the village of Ahaspokuna, near Kandy, in the highlands area of Sri Lanka. The tank was built 10 years ago by a local mason for the Rajasomasari family and has since been copied so that there are now several of these tanks in the area. The setting is a high rainfall area (almost 3000mm annually) with a bimodal rainfall distribution. There is a dry season which lasts a maximum of 4 months. The Rajasomasari family fit the low to middle income range and their dwelling is a single storey bungalow with an electricity supply, latrine and shower room.

Technical detail

The tank

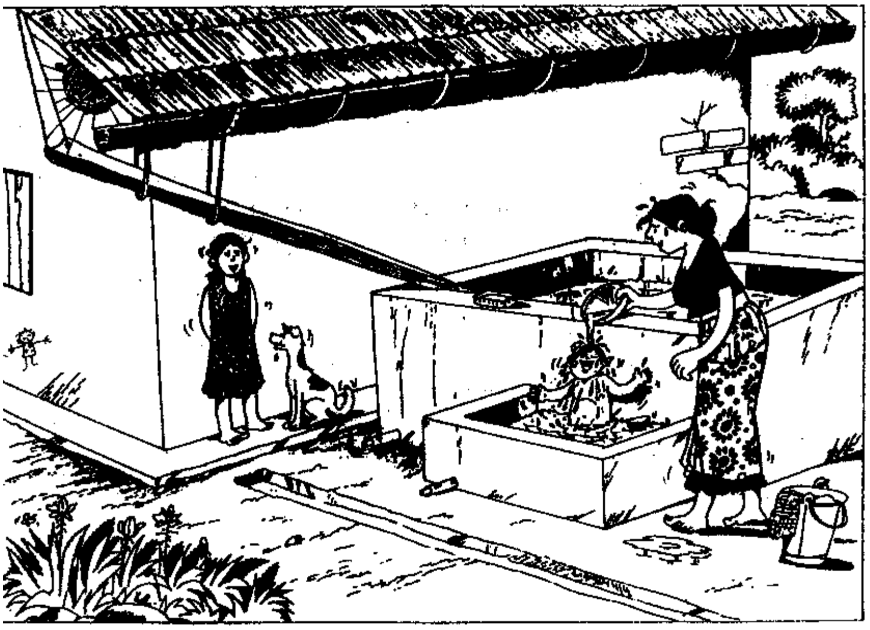
The tank is a simple brick built rectangular structure which has been cement rendered both inside and outside and sits at ground level. The tank has a concrete base. The cover is a removable wooden frame covered with a fine nylon mesh which filters out all larger debris such as leaves and twigs. The dimensions of the tank are 1.5 x 1.5 x 1.5m, giving a usable storage capacity of around 3m^3. The tank has an overflow and washout fitted. Small fish are kept in the tank, which helps to prevent algae growth and build up of organic materials. Water is extracted using a small bucket – there is a small removable section in the nylon mesh. The tank is usually cleaned when it is empty. The owner mentioned that the tank is very easy to clean because the top of the walls are only at chest height.

Catchment

The catchment area is the zinc sheet roofing of the house which totals about 90m^2. It is a pitched roof with a small gradient, say about 10^o. The guttering is, as is commonly found in Sri Lanka, S-Lon brand, U-channel, factory produced guttering as used for conventional rainwater protection /removal from houses. The cost of the guttering was approximately Rs. 5,000 (about £75.00). It is interesting to note that as much has been spent on the guttering as on the tank. Fittings for the guttering are also factory manufactured. The downpipe empties straight into the tank through the nylon mesh and can be diverted away from the tank as a first flush mechanism.

Water uses

The per capita consumption of water is in the region of 30 litres per day. They have a family of four people. The water is used for all domestic applications except drinking – water from the groundwater pump in the nearby valley is used for this purpose. The family is unsure of the cleanliness of the harvested water. The water in the tank lasts only about 15 days in the dry season, which is not very satisfactory in the eyes of the owner who would prefer a bigger tank.



Case study 4 – 10,000 litre partially below ground brick built tank, Sri Lanka

Background

This tank was built by Mr G. Victor A. Goonetilleke in the hill town of Kandy , Sri Lanka. Mr Goonetilleke decided to build his RWH tank after experiencing difficulty in sinking a well to sufficient depth to have a reliable perennial source of groundwater at the site of his newly built home. Drilling through the bedrock was too costly and there was no guarantee of securing a reliable supply. After 6 years of carrying water during the dry season Mr Goonetilleke started to research the idea of building a tank to store the rainwater that fell on his roof. There was very little encouragement from friends and neighbours who said that the water would provide an ideal site for mosquito breeding and algae growth. At the time there were no organisations to give advice on the benefits and drawbacks of roofwater harvesting. Three years after first contemplating the idea of a RWH tank, and after many helpful discussions with an Australian Radio Ham who convinced Mr Goonetilleke that RWH was a viable technolgy (and widely used in Australia), he decided to go ahead and build.

Technical details

The tank

Once the decision was made to build then certain design choices presented themselves. The determining factors for the tank capacity were:

sufficient capacity to store 100 litres of water for a period of 60 days
sufficient capacity to hold two bowser loads of water – during the dry season it is possible to purchase bowsers of water, but storage is required for this purpose. Each bowser contains 5,000 litres of water, but are not always available immediately upon request.

It was therefore decided to build a tank which would hold 10,000 litres. The next choice was what kind of tank to build. Mr. Goonetilleke had 3 obvious choices:

an underground tank - this type of tank needs excavation, care is needed to prevent roots penetrating the tank, contamination from ground can occur if not properly sealed, leaks are hard to detect and, finally, a strong cover is required to prevent children or animals from falling in. This type of tank does have the advantage, however, of being unobtrusive and benefitng from the support of the surrounding ground, making it cheaper to build.
a surface level tank – these require more space and can be ugly, but water is easier to extract under the influence of gravity and leakage is easier to detect. Covers need not be so sturdy, as little weight will be placed upon them.
an overhead tank – this type of tank is good in as much as little space is needed at ground level and the water is pressurised due to the ‘head’ of water. They are, however, expensive and it is difficult to transport water from the catchment system to the tank.

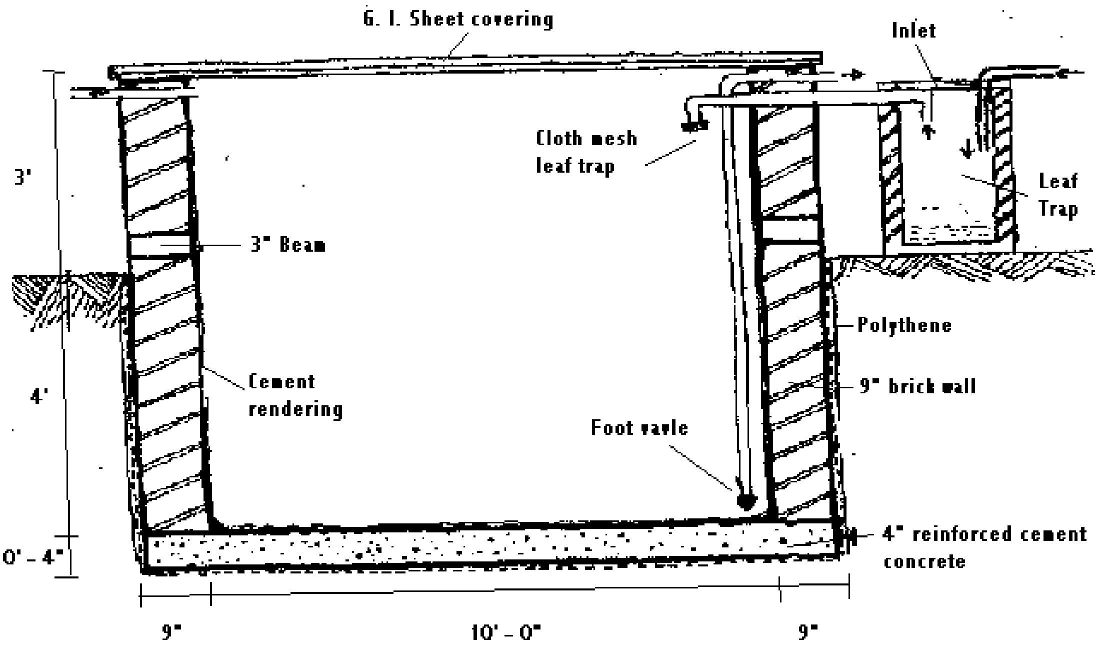


Figure 1 - sketch of 10m^3 brick-built tank.

The decision was made to build a tank which combined the advantages of the below ground and the surface tanks. Figure 1 shows a plan of the tank which was eventually built, partly below ground with 3 foot walls protruding from the surface of the ground. The next choice was what material to use for constructing the tank. Locally available plastic tanks were expensive and so Mr Goonitelleke decided to hire a mason to build a brick tank with a concrete base. Bricks are available locally.

The tank has a 4”, 10 foot square, concrete base which is reinforced with ribbed steel bar. Polythene was laid underneath the concrete and brought up to ground level. The walls of the tank are of 9” brickwork. A 4” concrete ringbeam was cast at ground level to give added strength. The gap between the walls and the excavated pit were lined with concrete to allay fears of root penetration. The wall was then continued to 3 foot above ground level. The inside of the tank and exposed external walls of the tank were rendered – no waterproofing additive was added. The tank was covered with some galvanised steel sheets. A pump was fitted to pump water to a header tank situated in a tower near the house (which also houses an old 200 litre oil drum which collects rainwater for irrigating the garden). The overflow from the main tank goes into a shallow ditch where there is a flourishing stand of bamboo.

The total cost of the system was around Rs. 25,000 (US$550), but Mr Goonetilleke says that minimum cost was not the primary objective.

The roof and guttering
The roofing material is asbestos sheeting with an area of about 2000 square feet being used for catchment which is half the total roof area. S-lon brand, PVC, U-channel guttering is used to catch the water and the downpipe leads to a 1” PVC pipe (not ideal but it was freely available at the time) which then transports the water to the tank. The first flush system is a simple connector which enables the pipe to be diverted to the garden pond. The filtration system is simply a piece of mesh and some discarded mosquito net, but the aim is to improve on this.

Maintenance
During the 4 years the tank has been in use there has been no need for any major repair. The tank is cleaned once or twice a year and the cover is swept of leaves and dust regularly. Internal inspection of the tank is easy because of the low walls.

Uses for the harvested water
The water is used for mainly for washing and bathing and is occasionally used for drinking, but is then boiled. During the dry season waste (grey) water is used for watering the plants. There is little need to be overly conservative with the water because it is possible to order a bowser when the water level gets low (4500 litres at a cost of approximately US$7.00), although so far this has not been necessary.

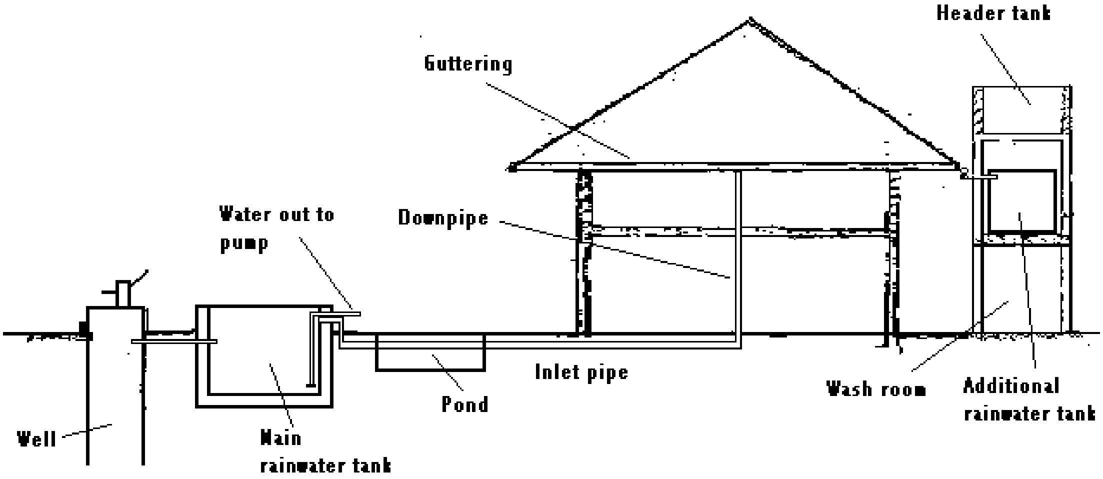


Figure 2 – Sketch showing the whole scheme including the water tower

Mr. Goonetilleke gives the following suggestions for improved awareness of RWH techniques:

- better information dissemination and educational awareness should be carried out at all levels.
- where possible, credit and technical advice should be made available in conjunction with other incentives.
- more concern should be given to the improper application of treated water – there is no need for water to be of exceptionally high standards if it to be used for clothes washing or bathing.
- architects should be aware of the principles of RWH and incorporate the technique in the house design where this is appropriate.
- care and attention are necessary (moreso than money), to maintain and improve the quality of harvested water.
- there are many myths associated with the concept of RHW which can be easily dispelled when the technology is put into practice.

Source: Mr. G. Victor A. Goonetilleke, Rainwater Harvesting, a case from Pilyandala, Proceedings of the Symposium on Rainwater Harvesting for Water Security, February 1998, Lanka Rainwater Harvesting Forum and the Open University of Sri Lanka.

Case study 5 – 10m^3 ferrocement tank, Nagercoil, India

Introduction and background

This RWH system is an example of a suburban solution to inadequate water supply from the municipal authorities. Although the family have a piped supply connected to the main town supply, the reliability of this supply is very poor – the piped supply provides water only every 8 to 10 days and the quality of the water is questionable. The family also has a groundwater supply but this, too, is unreliable. Their solution was to construct a RWH tank and harvest water from their roof. The traditional Nalluketta building style of this area, as shown in Figure 1, lends itself well to RWH. The central rooftop courtyard above a single storey dwelling makes an ideal collection area.

The system was installed as part of a programme run by the Centre for Appropriate Technology, an n.g.o. based in the town of Nagercoil. They have installed more that 100 such systems in the area.

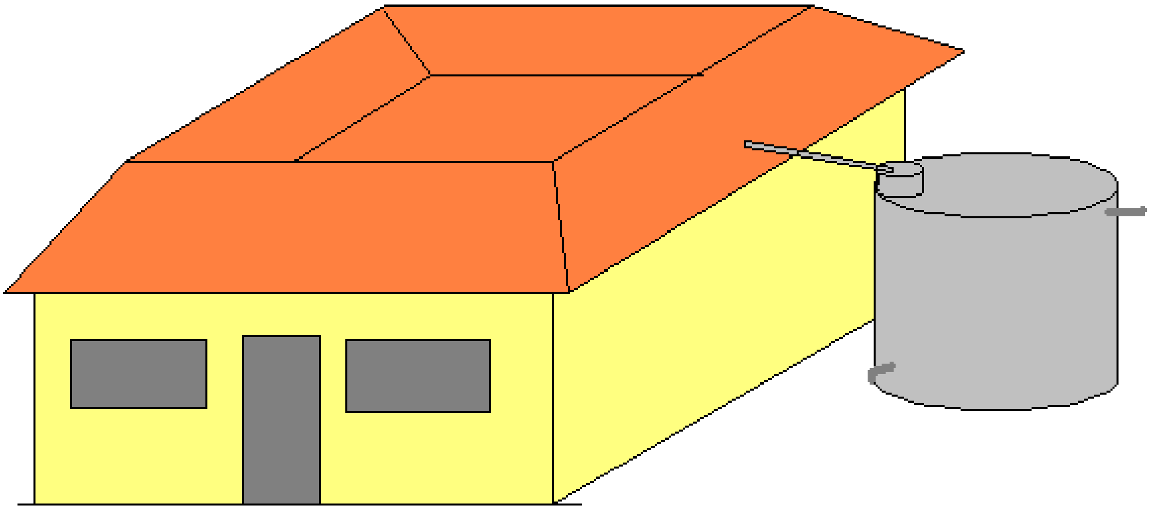


Figure 1. Traditional Nalluketta building style

Technical detail

Tank details

The tank is a cylindrical ferrocement structure, with a diameter of 2.5m and a height of 2m. There was little detail available regarding construction details but it appears from the corrugations on the exterior that a zinc sheet mould had been used to cast the tank. The tank is set on an 18” concrete plinth which means that a bucket can be placed comfortably under the extraction tap while still keeping the extraction pipe near the bottom of the storage area, therefore not wasting any storage capacity. The tank cover is formed using corrugated asbestos sheets. The tank is fitted with an overflow pipe near cover level.

First flush is achieved by simply moving the down pipe away from the inlet basin. There is a pre-filter basin which sits on top of the cover. It contains a plastic bowl which has been punctured repeatedly to allow water to pass through, as with a sieve. The bowl is filled with small stones and sand which acts as a filter. The bowl and basin have been cemented in place to prevent water entering the tank through the joints. A water level ‘sight tube’ has been fitted but is too discoloured by sun and silt to be of any use.

Catchment area

The catchment area, as mentioned earlier, is the rooftop of the house. Because the rooftop is rather unusual in design (see Figure 1) and the collection area is the internal rooftop courtyard, it is required that the downpipe pass through the roof structure (see Figure 3). This can present problems if sealing is not effectual. The catchment could take place on the outer faces of the pitched roof but this would entail fitting guttering and facia board, all extra expense. The catchment area is approximately 100m^2.

The pitched section of the roof slopes at approximately 35° and is of pantiles. The central rooftop courtyard area is mostly flat with a a vriety of tiled and cement rendered surface. There are many trees overhanging the roof and it quickly becomes covered in leaves which could block the downpipe.

(Figure 2 photo – catchment area)

Annual rainfall in the region is about 1200mm. Normally there is a single wet season with a dry season which lasts about 4 months.

User pattern
The catchment is about twice the size required to fill the tank, so the tank can be filled early in the rainy season. The families procedure during the rains is:
to sweep the roof clean and divert the first rain runoff
to fill the tank early in the wet season
to then seal the tank (e.g. tape up the entry against mosquito entry)and divert flow away from it
to use the water for premium quality purposes only during the following dry season: the stored water usually lasts until the next rains

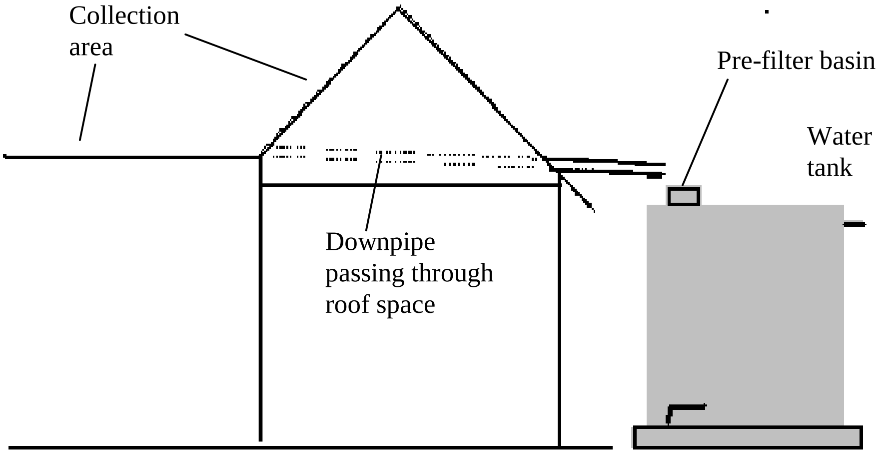


Figure 3. Cross section of the building showing the downpipe passing through the roof structure

Case study 6 – Below ground low-cost water storage cistern – 4 to 10 m^3 – Uganda

Introduction

This tank (or cistern) was developed in Uganda by members of the Development Technology Unit, Warwick University and members of the Uganda Rural Development and Training Programme (URDT), between 1995 and 1997. Work is still continuing on the refinement of the tank. URDT is a service NGO located at Kagadi in Mid-Western Uganda. Several of these cisterns were built and tested with the aim of developing a low-cost (under US$150), all-year, domestic, water storage technology for the surrounding region. The information for this Case Study is taken from a document titled 'Underground storage of rainwater for domestic use' by T. H. Thomas and B. McGeever, which is available as a working paper from the Development Technology Unit (see the list of partners on our home page).

Uganda is well suited to RWH practice for several reasons:
rainwater harvesting is a technology which is traditional to Uganda, albeit on a very ad hoc, very low-tech basis, e.g. buckets under the eaves to catch water during storms, or old 200 litre oild drums used for short term storage.
it has a bimodal rainfall pattern with very short dry seasons which are rarely completely dry.
annual rainfall in many parts of the country is in excess of 1200mm, which means that even the smallest house would have sufficient roof collection area to provide sufficient rainwater to meet demand (based on 15litres per capita per day).
corrugated iron roofs are becoming common, even in rural areas .
the lateritic soils in the area make well sinking a difficult task (yet provide ideal ground conditions for below ground tank construction).
there are many hilly areas where water (for irrigation and domestic use) has to be carried uphill from the valleys.
gravity-fed piped water is rare outside the main towns both because it is technically difficult (absence of strong high level springs, lack of mains electricity) and because the organisation to install and operate gravity water supplies is lacking in rural areas.

Ntale[1996] carried out a study of costs of existing water storage technologies based on a tank capacity of 8000litres. The results are shown below.
$340 in total for unreinforced mortar jars (at least 4 jars),
$390 for a brickwork tank, 50% more if reinforcing is deemed necessary,
$450 for a galvanised iron tank,
$1432 for a PVC tank,
$480 to $880 (various sources for E Africa) for a ferrocement tank,
$182 (quoted from Brazil) for a plastered tank of stabilised rammed earth, a material currently hardly known in Uganda..
These sums seem generally beyond the purchasing capacity of Ugandan rural households where even finding $200 for an iron roof is often not possible, although the last technique has promise.

Technical detail

Materials, tools and skills

The paper describes how to make a 6,000 to 10,000 litre underground cistern, suitable for construction where the soil is firm and hard but not rocky. *Variant A* has a 20 mm thick cement-mortar dome (mix = 1:3), a 25 mm cement mortar lining to its Chamber, and employs a little chicken mesh reinforcing. *Variant B* has a 20 mm cement/lime-plastered Chamber. Both variants have similar shapes and construction procedures. The materials necessary for the tank's construction meet the test of ready availability even in African small towns. They are, for an 8,000 litre cistern:

Material	Quantities	
	Variant A	Variant B
bags (ea. 50 kg) cement	5$^1/_2$	3$^1/_2$
bags (ea. 25 kg) lime	0	3
wheelbarrows of sand	15	15
lengths (ea. 12m) of 6mm reinforcing bar	1	1

chicken mesh (1.8m width)	1.5m	0
plastic bucket, say 10 litre	1	1

(also wood to make the template mentioned under *Step 1* below - 130 cm x 100 cm thin ply or 3m x 300 mm x 20 mm plank - and a large plastic washing bowl)

The tools needed for tank production are:

- digging and plastering tools
- a large plastic basin (say 45 cm diameter)
- a bucket on a rope for lifting out soil
- a spirit level
- a template for the dome (see *Step 1*)

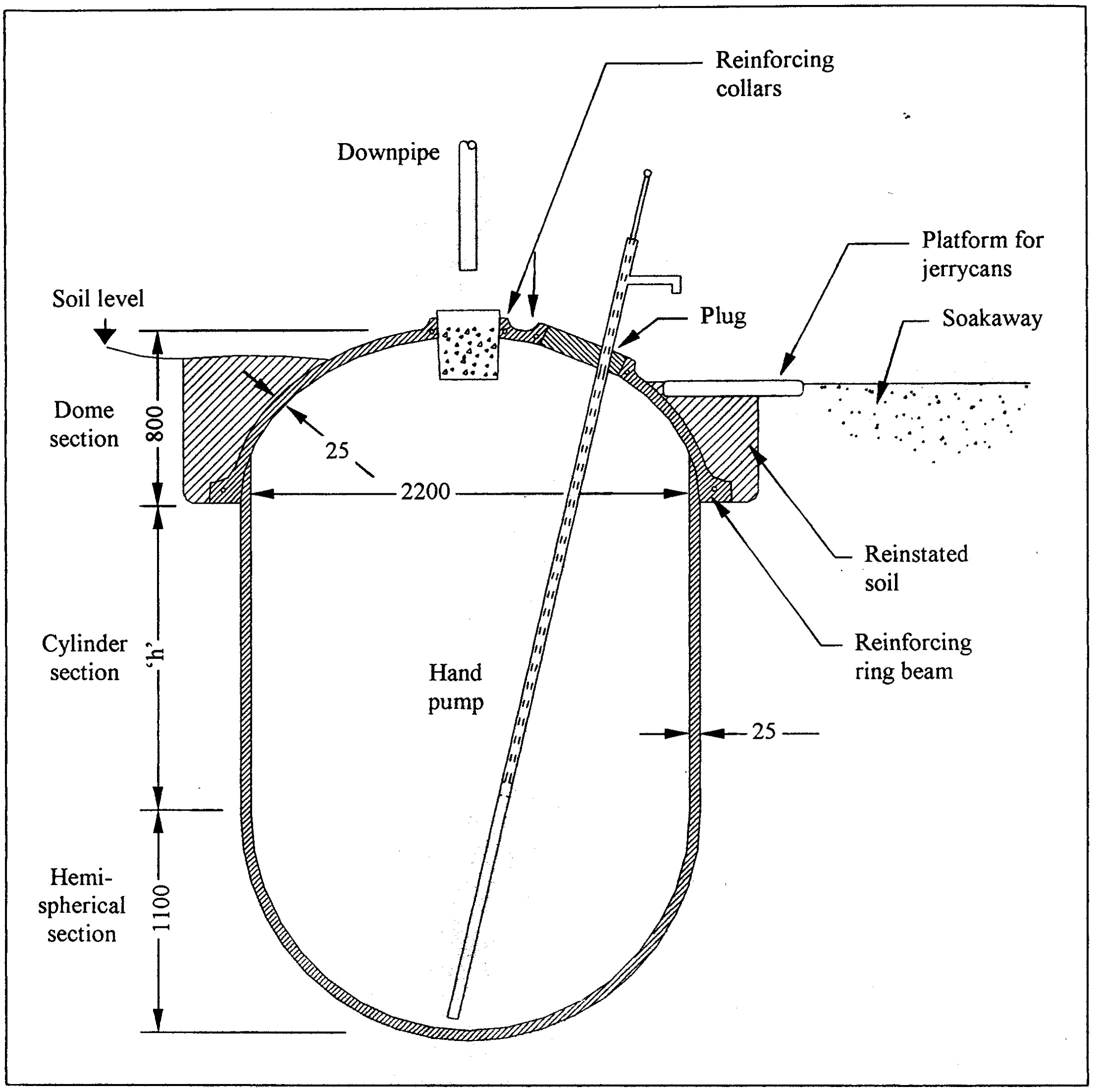


Figure 1 - General side view of cistern with pump

Parts of the DTU/URDT rainwater storage cistern and steps in its construction

The cistern is divided into four parts, namely the Chamber, the Cover, the Pump and Extras. Figure 1 shows a sectioned-elevation view of the tank and pump (what you would see if you could dig it out and cut it in half from top to bottom).

The Chamber has to have adequate volume and be waterproof. Because the overall cost of a cistern is dominated by the cost of the walls and cover, these should be as small as possible. For a given cistern volume, their total area is a minimum, for either a rectangular or cylindrical tank, when the tank's depth equals its width.

However for certain sorts of cover it is difficult to span widths of more than say 7 feet (2.2 meters). The cistern we are about to describe has a rounded Cover and a rounded bottom and has an internal diameter of 2.2 meters. The depth of the straight part of its sides for different capacities is as follows:

usable capacity in litres	4,000	6,000	8,000	10,000
depth of cylindrical sides	0 meters	0.5 m	1.0 m	1.5 m
depth from dome to bottom	1.9 m	2.4 m	2.9 m	3.4 m

The Cover has to stop the water from evaporating, keep the water clean, prevent anyone falling into it and keep out light and mosquitoes. It has to be pierced by a big hole to let the rainwater in very rapidly and smaller hole through which water can be pumped out. These holes must also be mosquito and light proof, and at least one of them must be large enough for a man to squeeze through in order to inspect or replaster the inside of the tank. It is recommended that the Chamber is excavated through the main hole in the Cover. This method allows the cover to be cast easily in situ without the need for shuttering or special tools. An earth mound is constructed for this purpose below ground level, as shown in Figure XX. The Cover should be shaped so that it leads any run-off from nearby ground away from its inlet. It must be strong enough to bear the weight of many people, provided that it has been covered with earth so that only the top of the dome is above the ground.

The pump. Thomas and McGeever discuss the requirements of a handpump for poor rural communities in Uganda:
A pump for a household cistern should
be cheap (in Uganda a ceiling price of USh.15,000 = $US15 was chosen);
permit an adult to raise 10 litres per minute (a rate generally obtained from protected wells) from a depth of 4 meters without undue effort and also be usable by a child of 6 years;
be ‘self-priming’, delivering water within a few strokes of starting to pump even when the pump has been out of use for some days;
reach water within 20 cm of the bottom of a tank;
fit into the mortar plug in the cover (dome) of a cistern so that light, mosquitoes and surface water cannot enter, yet permit the riser pipe and foot valve to be withdrawn through that plug whenever they need any maintenance;
lift at least 100,000 litres under household conditions of use before requiring replacement;
lift at least 10,000 litres before requiring maintenance, all such maintenance being possible using skills and materials available in most African villages;
be economically manufacturable in each country of use;
discharge conveniently into a jerrycan or other collection vessel.

In addition it is desirable that

- the foot valve does not leak faster than 0.1 litre per minute, so that if the pump is used twice within say 10 minutes it does not have to be (self) re-primed for the second use;
- the intake is constrained to avoid drawing up sediment in the tank by being located say 10 cm above the tank bottom; however for cleaning purposes it is helpful if dirtied wash water can be lifted from as little as 2 cm from the tank bottom.

Some development of a handpump which aimed at achieving this specification was carried out, but the authors feel that it was far from ideal. We will not, therefore, consider this pump in this case study.

The Extras include some means of seeing the water level inside the tank without having to open the Cover, a coarse filter for water entering the tank and provision for safe disposal of any overflow water. There is some interest in putting a layer of sand at the bottom of the tank as an output filter, however this would require the pump intake to be connected to a perforated pipe running under the sand. (Experiments to test such a filter’s performance have yet to be done.)
During construction of any cistern, there are three choices in how one might combine the Cover and the Chamber. In some cistern designs, the Chamber is dug first and then the Cover built over the Chamber. In other designs the Cover and Chamber are made side-by-side and then the cover is lifted onto the top of the Chamber. For our design, we recommend a third method: the Cover is made first (in its final position at ground level) and then the Chamber is dug through an access hole in the Cover. It is not too difficult to do this if excavation is manual (although the procedure effectively excludes mechanical excavation and is therefore not recommended for high-wage countries) and it allows the use a cheaper dome-shaped Cover than if the cover had to be lifted. So the sequence for construction is as follows:

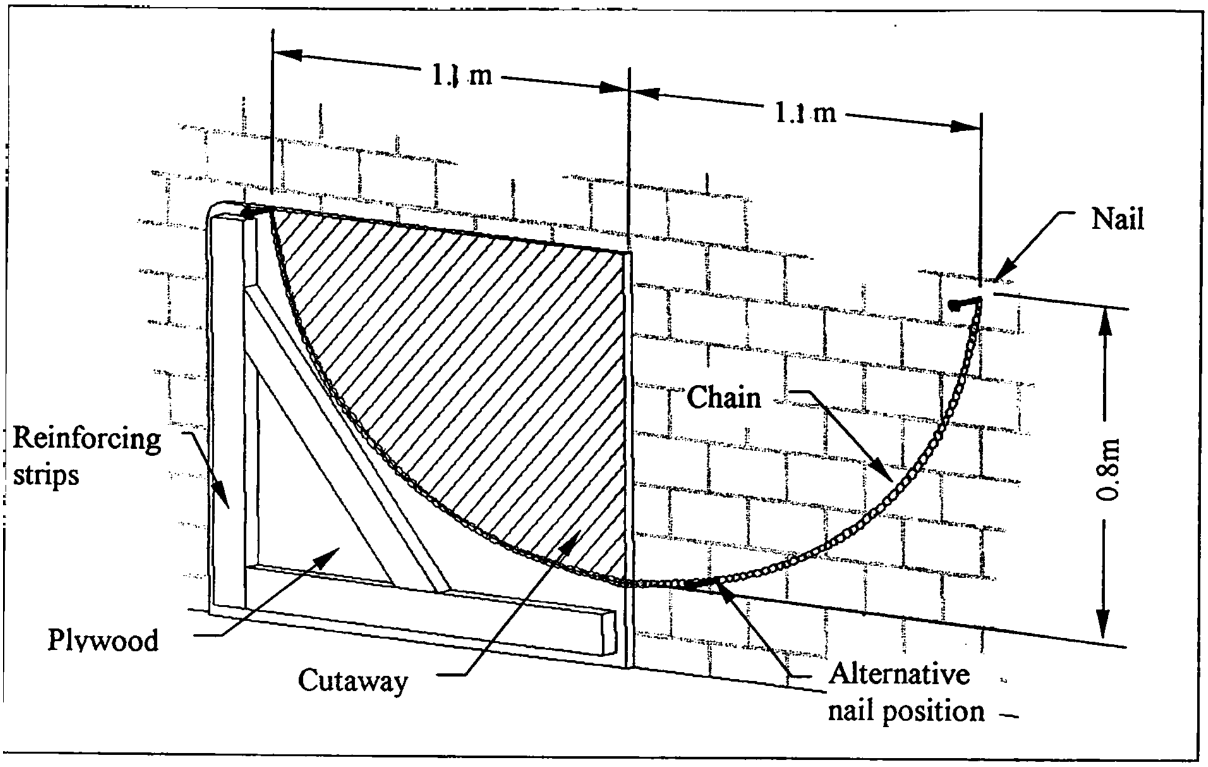


Figure 3 Making the template

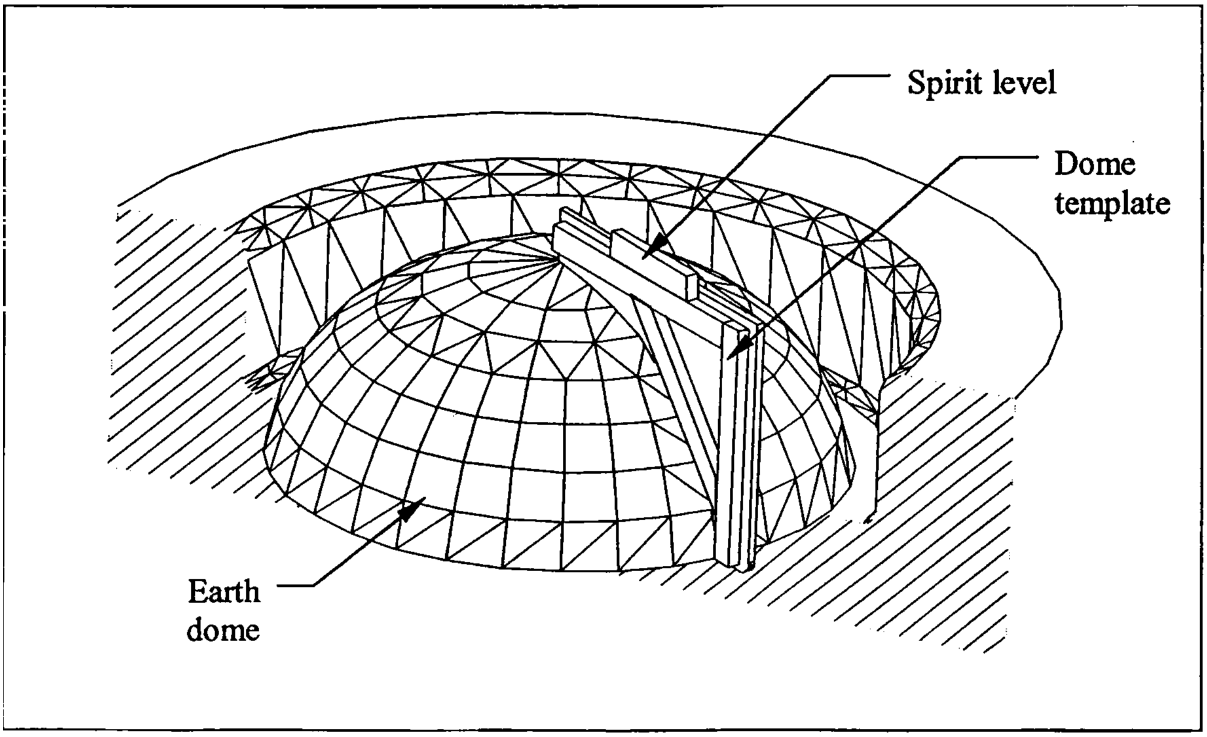


Figure 4 Forming the earth dome-mound

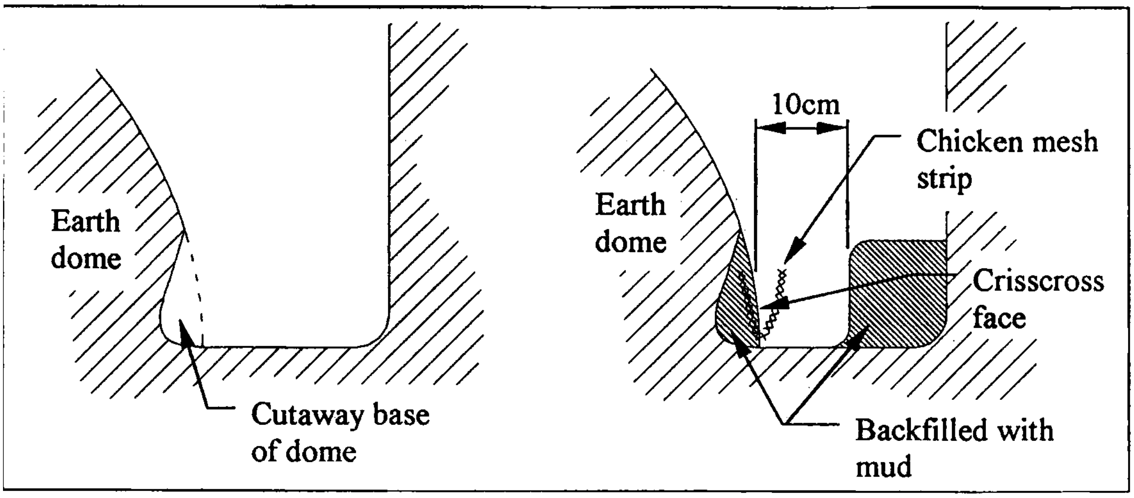


Figure 5 – Detail of joint between dome and wall

- Prepare reinforcing bar (and perhaps mesh) to place in the trench and round each hole in the dome
- Place mortar to form the ring beam and the dome with its two holes
- Cure the mortar then cover the dome with soil
- Through the larger hole dig out the Chamber
- Plaster the inside of the chamber and allow this plaster to cure
- Make the pump
- Set the pump into the dome
- Construct the tank inlet with its gravel filter

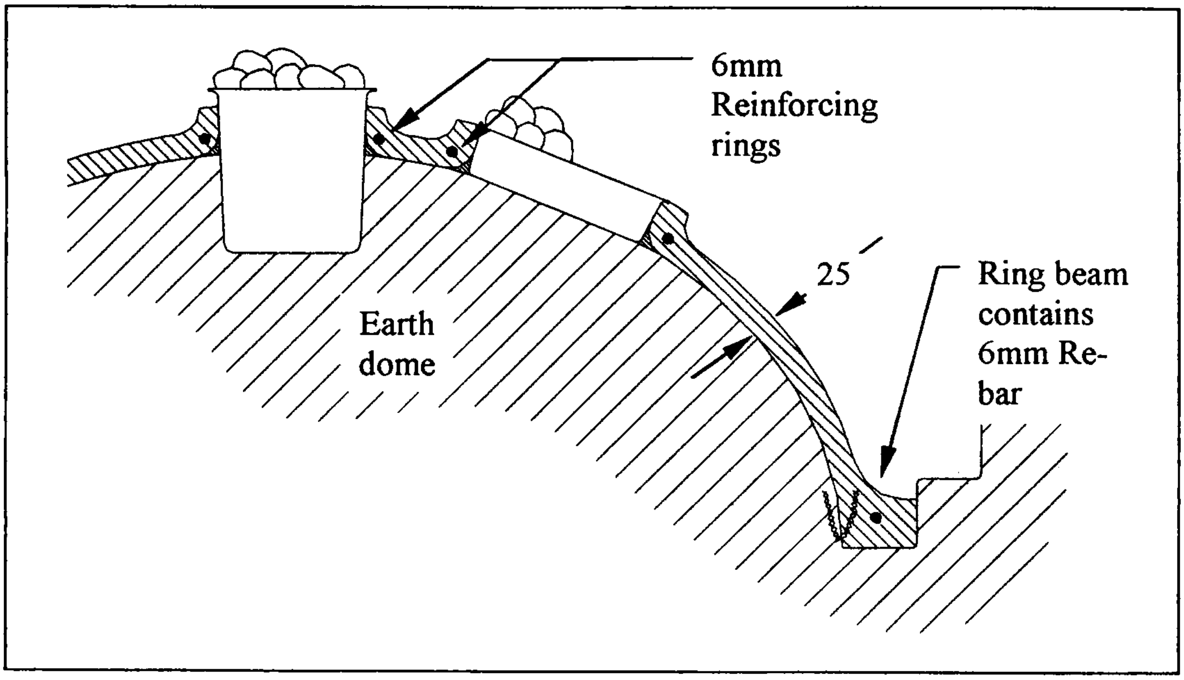


Figure 6 - Water inlet with coarse gravel filter

Provide drainage and arrange the hard-standing for pumper and water containers

The tank takes about 24 ‘man-days’ to construct. However the mortar dome and later the plaster in the chamber should each be left to cure for 2 weeks, so it needs a minimum of 6 weeks from when construction starts to when the tank can be used. Most of the work is digging but for 2 days an experienced plasterer is required. The pump can be made in a few hours.

Further work and field trials

Three tanks of 8000 litres were built and tested in the town of Kagadi. Tests on dome strength, leakage and chamber integrity and flexure were carried out and the results were very reassuring. Tests were also carried out a very low-cost pump design which proved to be unreliable and has therefore not been included in this Case Study.

Tank costs

Cistern costs (8,000 litre capacity with 20 mm dome and 2-coat chamber lining)

Item	*Quantity*	*Cost (US$)*
Cement/lime (including transport)	250 kg	65
Sand (assumed from a nearby source)	18 wheel-barrows	3
6 mm reinforcing bar	12m	5
Chicken mesh	3 m^2	4
PVC Bucket + 0.5 m of 50 mm piping		3
Unskilled labour for digging (9 m^3) etc.	20 person days	40
Plasterer	2 person days	8
Supervisor + say 25 km travel	1 person day	10
Tools (say)		5
	Total	143

Design variants

Some design variations have been discussed in this paper.

The dome of the tanks built in 1996 were 25 to 30 mm thick. Those recently tested for strength were 20 mm thick and performed well. 20 mm will be used henceforth as a norm. Moreover both mortar and concrete have been used for the dome. Concrete uses less cement, but requires fine aggregate (which is not widely available in rural areas) and is much harder to work smoothly as a plaster. There is some danger that these workability problems could lead to serious cracks in inexperienced hands. The mortar dome looks better. Mortar is more vulnerable than concrete to shrinkage during curing, but this should not matter in a largely unconstrained dome. On balance we recommend mortar despite the 33% higher cement requirement.

The chambers of the 1996 cisterns were single plastered to a thickness of 30 mm. The later tanks are using 20 mm applied as two layers (e.g. 15 mm plus 5 mm) rather than one. The tank most in danger of earth tremors has just been plastered with a 2-layer lime-cement mortar; it may take some years before the benefits of using this slower curing but more flexible plaster can be assessed.

Case study 7 – 10m^3 ferrocement water tank using former

Introduction

This example has been taken from ‘Ferrocement water tanks and their construction’ by S. B. Watt and published by Intermediate Technology Publications (more information about this book and this publisher is given in the information section later in this document). All figures in the Case Study are taken from this book.

Watt states that these tanks have been used for many years in parts of Africa and have been designed to be as simple as possible to build in self-help programmes. The users, who are at first unskilled in this sort of construction, can contribute their time and efforts in collecting sand and water, digging the foundations and preparing the mortar under the general guidance of a trained builder. With experience they quickly learn how to make the tanks without further guidance.

A trained builder with 5 helpers takes approximately 3 days to complete the tank. The users often contribute some money towards the cost of the tank, which helps to cover the builders’ wages, the cement, reinforcement and the hire of the formwork.

Design

The tanks have been designed for construction by relatively unskilled workers. They have a diameter of 2.5m, a height of 2m, giving a capacity of 10cubic metres. The final wall thickness will be about 4cms. The tanks are built on site and should not be moved.

Formwork

The 2m high formwork is made from 16 sheets of standard galvanised roofing iron, 0.6mm thick with 7.5cm corrugations rolled into a cylinder with a radius of 1.25m. Steel angle iron (40 x 40 x 5mm) is bolted vertically on the inside face at the ends of each set of 4 sheets – this allows the sheets to be bolted together to form a circle. Between the edge of each section is placed a wedge which is pulled out to allow the formwork to be dismantled (see Figure1).

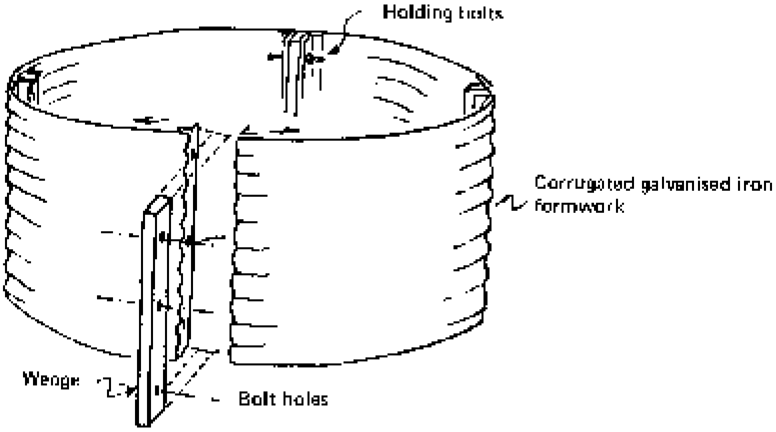


Figure 1 – Assembling the formwork

Construction

A circular area 2.8m in diameter is cleared at the required site for the tank and excavated down through the loose topsoil. A 10cm layer of sand is laid evenly over the excavation and a 7.5cm layer of concrete mix of 1:2:4 (cement:sand:gravel by volume) will form the foundation slab under the tank. Into this concrete foundation is cast a 1m length of 20mm bore steel water pipe with a tap on the outside end. The pipe is curved so that it projects 10cm above the floor of the tank; a piece of wire is threaded through the pipe to act as a pull through after the tank has been built (see Figure 2).

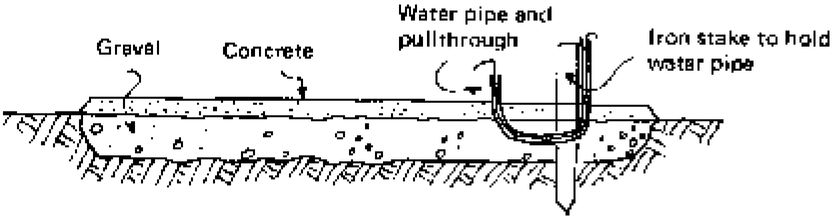


Figure 2 – Foundation of tank

When this concrete slab has hardened the formwork of the tank is erected. The bolts passing through the angle iron and wedges are tightened to provide a rigid cylindrical form. This is cleaned free of cement and dirt, oiled and the wire netting wrapped around it to a single thickness and tucked under the forms. The netting has a 50mm mesh, and is made from 1.0mm wire.

To form the hoop reinforcements, the straight galvanised iron wire, 2.5mm diameter, is wound tightly around the tank from the base at the following spaces:

2 wires in each corrugation for the first eight corrugations
1 wire in each corrugation for the remaining corrugations
2 wires in the top corrugation

About 200m of 2.5mm diameter wire will be needed, weight 8 kg. The netting provides vertical reinforcement to the tank and also holds the hoop wire out of the corrugations. The outside is then plastered with a layer of mortar made from a mix of 1:3 (cement : sand by volume)and as soon as this has begun to stiffen a second layer of mortar is trowelled on to cover the reinforcing wire to a depth of 15mm. The surface is finished smooth with a wooden float.

After a day or so the formwork is dismantled by removing the holding bolts and by pulling out the wedges which will leave the shuttering free to be stripped away from the inside mortar wall. The sections are lifted clear of the tank to be thoroughly cleaned of any mortar or cement. A 20cm length of 8cm diameter downpipe is built into the wall at the top of the tank to act as an overflow and the inside of the tank of plastered with mortatr to fill up the corrugations. When this has hardened sufficiently, a second final coat is trowelled onto the inside and finished with a wooden float.

A 5cm thick layer of mortar is next laid onto the floor of the tank and the junction of the floor with the walls built into a coving. The floors are not reinforced and so the tank wold fracture if it were moved. Take care that the mortar does not fill up the outlet pipe. Before the mortar on the floor has stiffened, form a shallow depression in the middle; this will allow the tank to be cleaned at a later date – the sediment can be brushed to the hole and cupped out (see Figure 3).

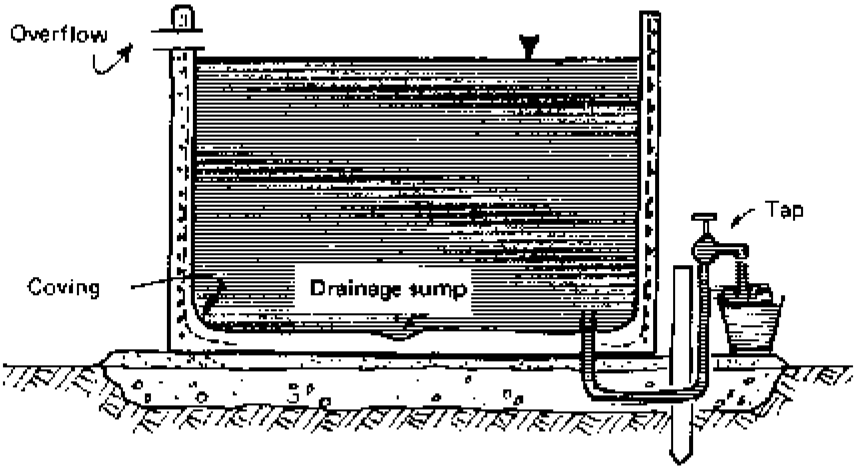


Figure 3 – The completed tank

The inside of the tank is painted with a thick cement slurry to seal the inside of the tank the a small of water is allowed to stand in the bottom of the tank and the tank is covered and cured for seven days.

Roof

The tank is covered with sheets of 0.5mm galvanised sheeting supported on two lengths of angle iron. Alternatively, a reinforced mortar roof may be built in the way described in Case Study 8 (Factory Made Tanks – New Zealand). Building a mortar roof is not difficult but does require more formwork.

Materials

Materials required for a $10m^3$ tank with galvanised iron roof.

Cement	600 kg
Plain wire 2.5mm diameter	200m
Chicken mesh – 1m wide	16m
Water pipe – 20mm bore	1m
Water tap	1 No
Overflow pipe – 8cm bore iron or concrete	0.2m
Sand	$1.0m^3$
Gravel	$0.5m^3$
Galvanised iron sheet and angle iron	

Case study 8 – Factory made tanks, 1 to 25m^3, New Zealand

This example has been taken from 'Ferrocement water tanks and their construction' by S. B. Watt and published by Intermediate Technology Publications (http://www.oneworld.org/itdg/publications.html). All figures taken from this publication also.

Introduction

Ferrocement tanks have been made commercially in New Zealand for many years and have now largely replaced the traditional corrugated galvanised iron tanks. They are used mainly to store water for domestic and dairy purposes on the farm but they are also winning acceptance for industrial liquid storage. The cost of the smaller tanks is comparable with that of tanks made from other materials such as galvanised iron; the cost per unit volume decreases rapidly with increase in size.

Tank sizes

The tanks are constructed in various sizes, with capacities from 1m^3 to 25m^3, diameters from 1m to 3.6m, and heights from 1.3m to 2.9m. With specially built formwork and machine mortar mixers each tank takes 2 – 5 person days to build. There are several manufacturers producing such tanks in New Zealand. The high wage costs in New Zealand are reflected in the prices of the tanks.

Design

The water pressure in a tank full of water generates stresses in a tank that are difficult to calculate structurally. The tanks have been designed to resist only hoop stresses and a layer of woven netting is included as nominal reinforcement; this netting in fact provides the only reinforcement at the base of the wall where it joins with the floor – the point of greatest stress. This section is thickened during construction and from information given by the manufacturers there is no evidence that cracks appear under normal loads. The only causes of failure have resulted from damage during delivery.
All the tanks are built with an integral roof and a covered access hatch.

Capacity (m^3)	Diameter (m)	Height (m)	Weight (tonne)
0.9	1.2	1.3	0.25
1.8	1.55	1.3	0.3
2.7	1.85	1.3	0.45
3.6	2.0	1.45	0.8
4.5	2.0	1.95	1.25
9.0	2.9	1.95	2.1
13.5	2.9	2.6	3.0
18.0	3.65	2.6	4.0
22.5	3.65	2.9	5.0

Table 1 – Size and weight of New Zealand tanks

Cement	740 kg
Sand	1.0m^3
Plain wire – 4mm diameter	330m
Wire mesh – 1m wide	28m
Weld mesh for slab	7m^2

Table 2 – Materials needed to make a 9m^3 tank

The quantities shown in Table 2 are higher than a comparable tank, which would be built in situ. The tanks described here have to be stronger than the self-help tanks to be able to withstand the extra stresses during transportation

Construction

The tanks are constructed on special fabricated steel formwork which is quickly erected (see fig 1), or on a temporary timber formwork. Usually, the floor of the tank is cast first; this is reinforced with welded steel mesh made from 8mm diameter rods at 20cm centres with a floor thickness between 6cm and 10cm, depending on the size of the tank. Loops of 8mm steel are allowed to project from the base to allow for easy handling; this also reduces the stresses that will be set up in the tanks as they are being lifted or winched. A strip of chicken wire is also cast into the sides of the floor and is bent up into the walls.

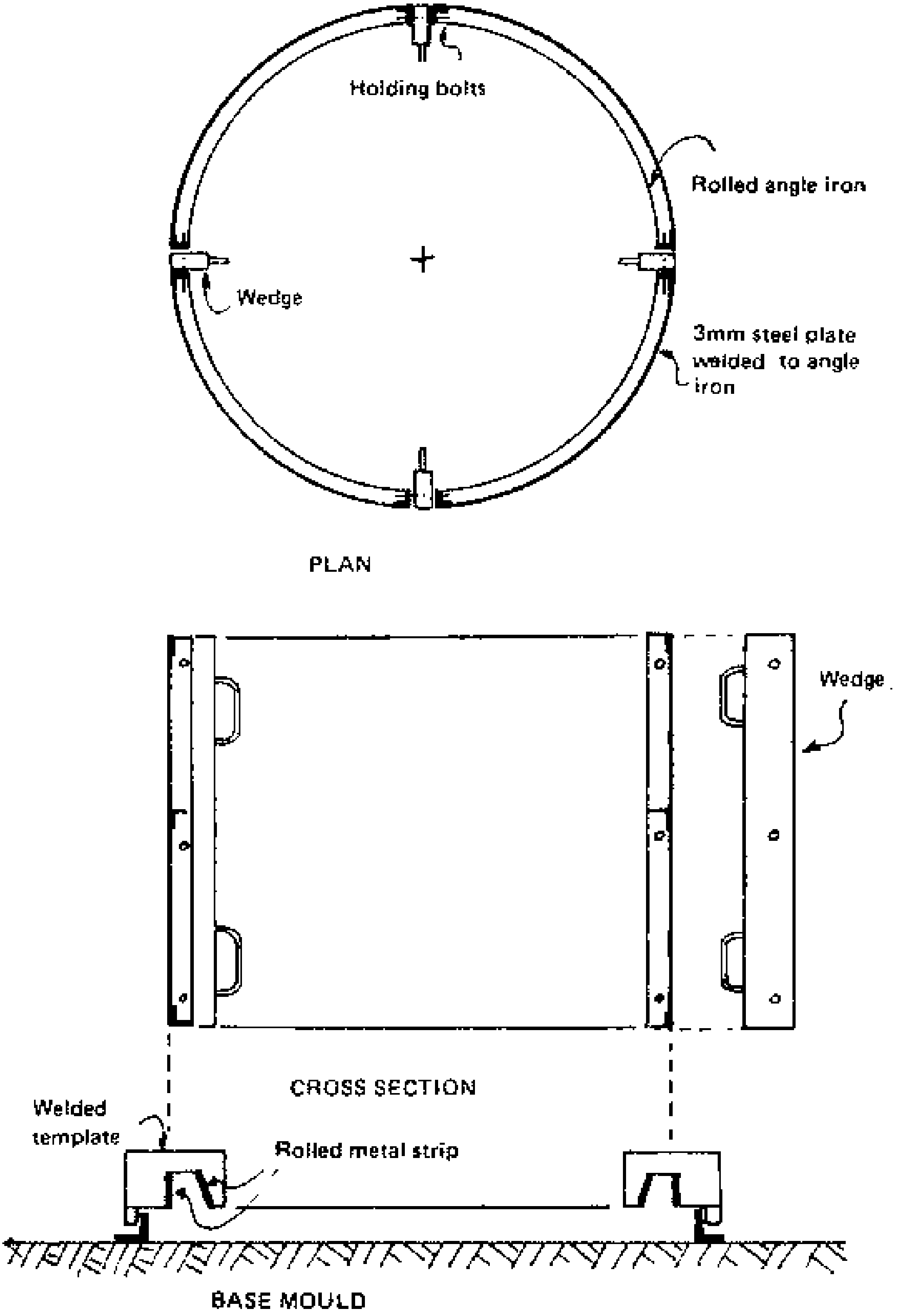
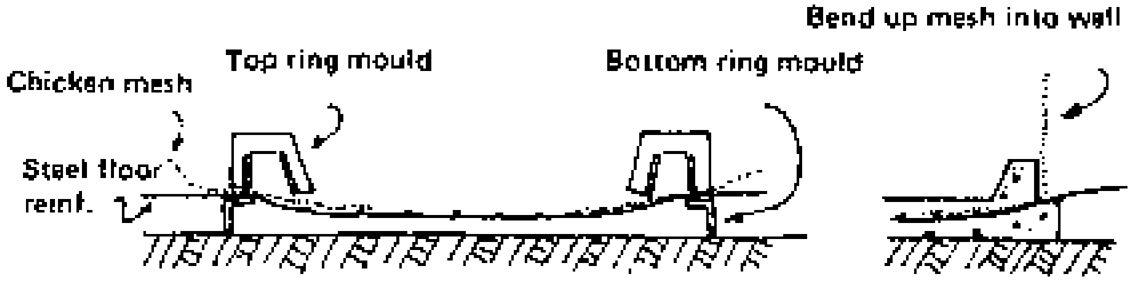


Figure 1 – formwork used for tank construction



Ring moulds and reinforcement

Poured floor

Figure 2 – Casting the base slab

When the floor slab has been cast, the formwork is erected and the chicken wire folded up against the shuttering. A layer of chicken wire or weld mesh made from 2mm wire at 5cm centres is wrapped around the tank to cover the shuttering from top to bottom (see Figure 3).

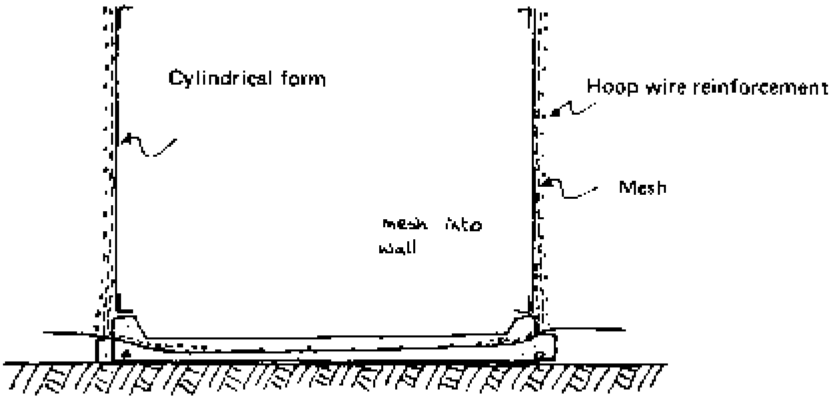


Figure 3 – Assembling the formwork and reinforcement

The main reinforcement, 4mm diameter straight wire, is wrapped tightly around the tank in a spiral with a 5cm gap between the wires. Theoretically this gap should be much smaller at the bottom of the tank than at the top to take the extra stresses, but in practice the spacing is left constant. This prevents mistakes during construction and does not add appreciably to the overall cost. The same spacing is often used on all of the tanks, both small and large.

The first mortar layer (1:3 cement:sand by volume)is trowelled onto the tank 1cm thick and given 24hrs to harden. A second layer of mortar is then trowelled on and finished smooth with a plasterer’s float; this is also given 24hrs to harden.

The formwork is now carefully stripped and removed from inside the tank and a third layer of mortar is trowelled onto the inside of the tank to completely cover up the reinforcement. A thick un-reinforced coving is added to strengthen the joint between the floor and the tank.

Finally, the roof is built onto the tank y laying mortar onto shaped formwork which is propped from underneath. the roof is reinforced with two layers of wire mesh, which is tied onto the mesh protruding up from the walls (see Figure 4).

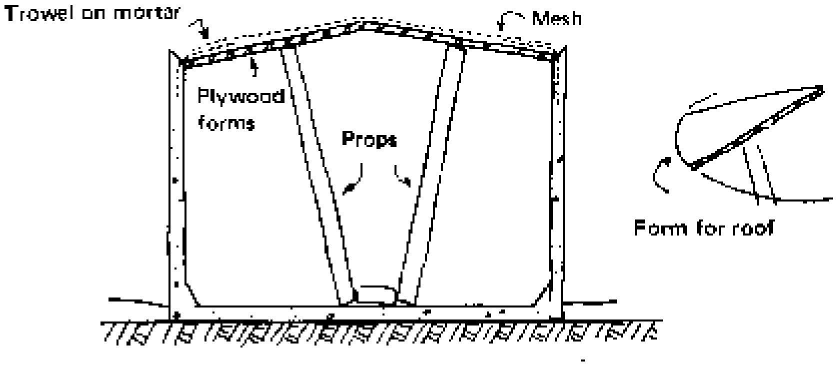


Figure 4 – Constructing the roof

A prefabricated angle iron frame is set into the wire mesh to provide formwork for an access hatch into the finished tank. This is removed after the mortar has set (see Figure XX5). Mortar is trowelled on in a 3cm layer and allowed to cue for 3 days. When it is strong enough the roof and access hatch formwork is stripped and a layer of mortar trowelled onto the inside of tank roof.

The tank is finally painted on the inside with a coat of cement and water slurry, a small volume of water is allowed to sit in the bottom of the tank and the tank is covered and cured for at least 7 days.

Transporting the tanks

The factory tanks of less than 25m^3 capacity are light enough to be carried by lorry. They are taken to the prepared site and joined directly to the necessary pipe connections; tanks of larger capacity are usually built on site.

The smaller, lighter tanks are lifted onto and off of the lorry with a truck-mounted hoist. The larger tanks are winched onto the truck with a sling. The first step is to jack one edge of the tank clear of the ground. The truck is then so positioned so that a pair of steel runners resting on its carrying platform can be placed under the tank to form a ramp. A wire rope sling is fitted around the tank, which is then drawn up the ramp by a winch mounted on the truck. Steel pipes are used as rollers when moving the tank.

For unloading the platform of the truck is raised slightly and the tank slides down the ramp. The steel pipes are again used as rollers and the downward movement is controlled by the winch.

Case study 9 – RWH in the barrios of Tegucigalpa

Introduction

This case study is drawn for a report produced by UNICEF in 1991. The ‘Barrios’ of Tegucigalpa, Honduras, are the low-income urban settlements that have developed around the city as tens of thousands of people move, each year, to the city from rural areas. They come in search of better living conditions but often end up in these barrios, where public services and amenities are poor or non-existent. Health statistics show that the residents of the barrios are suffering from a number of water related diseases that could easily be avoided with provision of a reliable, clean water supply. Unfortunately, more than 150,000 residents have to find their own water.

Water vendors sell water at extortionate prices, some families having to spend 30 or 40% of their income on water alone. In 1987, UNICEF, SANAA (National Water and Sewage Service) and UEBM (Unit for Marginal Barrios) started work on an integrated water supply project that would help the residents to direct their money into providing themselves with clean water. The programme studies several water supply options, including piped networks, groundwater wells, trucking of water and rainwater harvesting.

The report from which this Case Study is drawn studies the indigenous RWH systems in use in two barrios - Israel Norte and Villa Vueva. Although technically unsophisticated and lacking good health practice, the systems described here show what urban settlement have done to improve their own lot. Many of the systems make use of recycled or scavenged materials and some examples show high levels of initiative.

Water use

In the two barrios mentioned above, about 90% of the families collect rainwater. The quantity of rainwater collected varies from home to home. Figure 1 shows the percentage of needs met by rainwater in the barrio of Israel Norte.

Figure 2 shows the various uses of rainwater and the percentage of people who use the rainwater for a particular application.

Fig. 1 -Percentage of water needs met by Rainwater in the barrio of Israel Norte

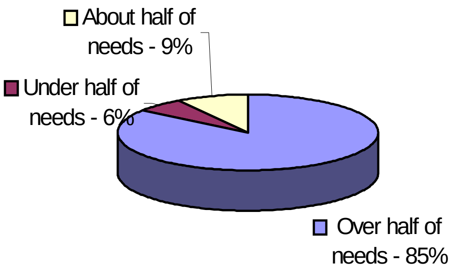
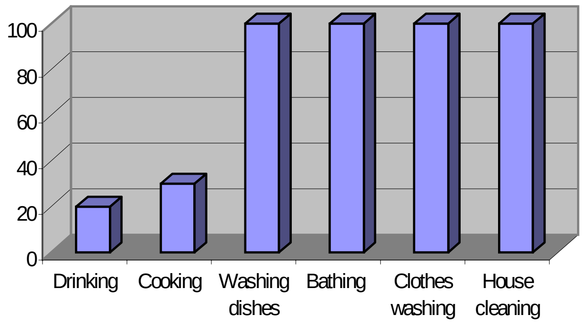


Fig. 2 - Rainwater uses in Israel Norte - %age of residents using rainwater for the following applications



The deficit in drinking and cooking water is usually met by water which is purchased form vendors or from nearby standpipes in middle class residential areas. The rainwater is not seen as being a high-quality source of water.

Rainwater harvesting is popular as there is a direct saving for every litre of water saved. For a household with a 45m^2 collection surface (the average roof area) the saving is over US$100 annually.

Technical detail

The RWCS’s used in the barrios are rudimentary. The basic system usually has the following components:

Roof – collection surface

The average roof area in the Villa Nueva barrio is 45m^2, with typically half of this area being used for collecting water. The recommended roof area to provide adequate collection area for total rainwater harvesting is 100m^2. The average rainfall in the area is 788mm, which is quite low and hence the large collection area requirement. The majority of the rainfall (as shown in Figure 3) falls between April and November with two peaks, one in June and one in September.

Roofing material varies, but by far the most commonly used material is iron sheet. Other materials used are asbestos/cement sheets, clay tiles, *techon* (a locally produced asphalt treated pressed paper sheet) and a variety of discarded plastics and sheet materials.

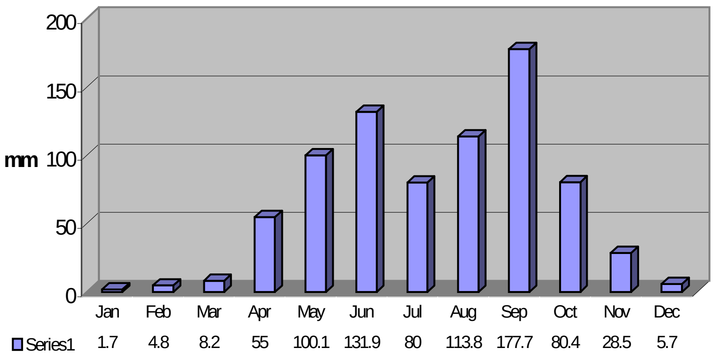


Fig. 3 - Average monthly rainfall in Tegucigalpa (1985 - 1989)

Gutters to collect the water from the roof

Again, a variety of materials have been used to make gutters. In the barrio of Villa Norte 75% of the gutters are made from sheet steel. The fabrication technique of steel gutters varies also – some have been made from scraps of steel sheet or old, flattened steel drums. Pre-fabricated gutters are also seen - these are rolled to give a semi-circular trough, and are fitted with a neck to attach the downpipe (where fitted), which can be of PVC. The authors state that the cost of these gutters was US$36 for a 20 foot length (1991). There are a number of different methods for fixing the gutters, but where high quality gutters are used the quality of the bracket is usually better also, being formed of wood or bent reinforcing bar. Some gutters were poorly mounted with depressions which allows water to stand and corrode the steel. Gutters are typically fitted to one side of the building only.

PVC gutters are formed from 8” PVC pipe which has been cut in half. The cost of a 20 foot length of PVC pipe is US$38 which provides 2 lengths of guttering when split. The PVC guttering is preferred because it is cheaper and lighter. Many other scavenged materials are used for guttering, including wood and asbestos sheeting.

Downpipe

In Israel Norte barrio, 90% of the systems have no downpipe. The water runs from the gutter directly into the storage vessel. The remainder used either plastic hose, PVC pipe or sheet metal to transport the water to a remote water storage container.

None of the systems studies were fitted with any kind of screen, filter or first flush mechanism.

Storage

Water storage facilities at the barrios are, again, basic. The majority are old 200 litre steel barrels. These are bought (the average price is US$13) or scavenged and most contained pesticides, chemicals or toxic materials – so are not well-suited to water storage. The second most common type of storage is the *pila, a* concrete water tanks of about 500 litre capacity which has an integrated washing board (see Figure 4). These are built by local masons and cost approximately of US$25. The tanks can be sized to suit the needs and means of the user. Fifteen to 30 % of the residents of the barrios have these pilas.

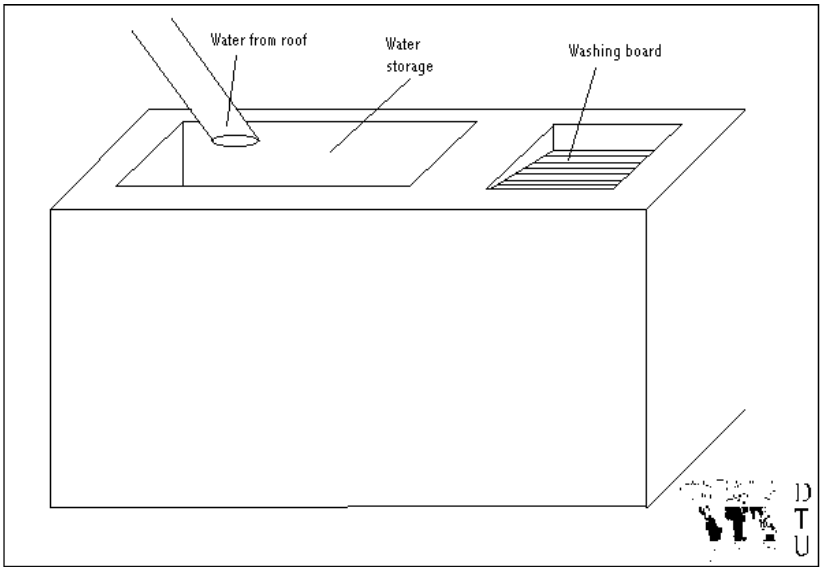


Figure 4 – The brick and mortar *pila*, as found in the barrios of Tegucigalpa

Some people have also acquired plastic barrels which may have contained paint, oil or other substance. Only very few of the systems studied had a cover fitted.

Water quality and alternative sources of water

The study team sampled the stored rainwater to find the level of bacteriological contamination present. It was found that where the water was used for drinking, 63% of the water samples taken contained E.Coli. Where the water was used for other domestic purposes only, 71% of the samples were contaminated. All sample were taken from the storage vessels.

The study team also sampled the alternative sources of water for the two barrios included in the study. Table 1 below shows the results.

Source	Number of Coliforms present (WHO guidelines recommend 0 coliforms in drinking water)
SANAA / UNICEF public taps	0 coliforms
Private water vedors – sample taken from hose	Uncountable
Unprotected superficial cells	varies between 650 and uncountable
Store reportedly selling water bought from SANNA truck	0 coliforms

Table 1 – Alternative water sources and their quality – Villa Nueva barrio