Chapter 8
Rainwater Harvesting for Domestic Supply

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Keywords Rainwater tank design · Rainwater demand · Rainwater supply · First flush devices

For most rainwater catchment systems, the storage tank represents the single greatest cost, especially for roof tanks where an existing roof structure in effect provides a free catchment area. The choice of a suitable tank design to match an existing catchment and local conditions is important, and careful consideration should be given to selecting the right one.

8.1 Types of Water Storage Structure

Rainwater storage reservoirs can be subdivided into three distinct categories:

- Surface or above-ground tanks which are common in the case of roof catchment systems, where the catchment surface is elevated, e.g., For roof catchments (Figs. 8.1 and 8.2);
- Sub-surface or underground tanks which are often associated with purpose-built ground catchment systems (Figs. 8.1 and 8.3); and

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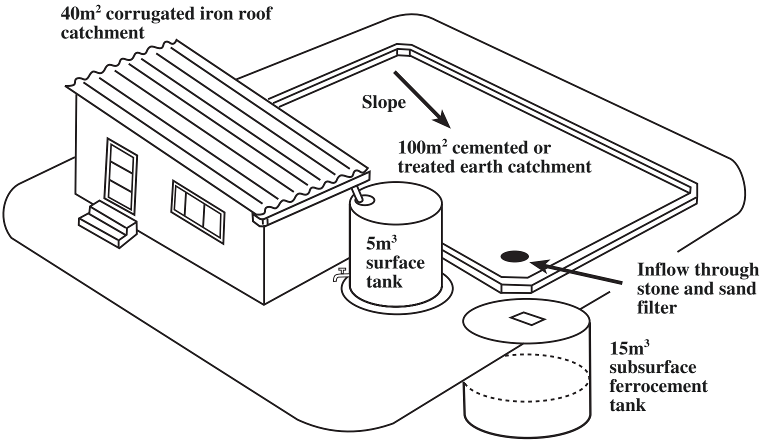


Fig. 8.1 Examples of surface (roof catchment) and sub-surface (ground catchment) rainwater tanks at rural households in Botswana

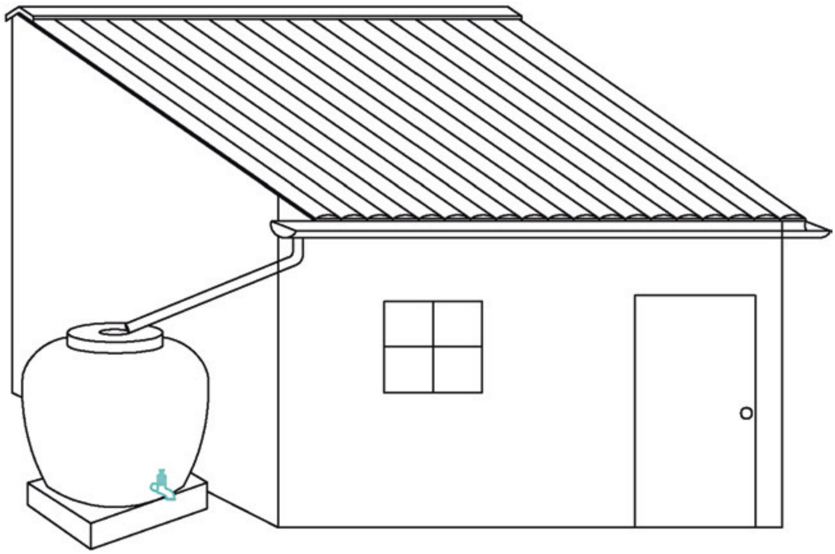


Fig. 8.2 2 m^3 'Thai Jar' ferrocement roof tank common in S.E. Asia (Gould and Nissen-Petersen 1999)

- Dams with reservoirs for larger catchment systems using natural catchments, e.g., Rock catchment dams, earth dams, and sub-surface or sand dams in sand rivers (Fig. 8.4). Examples and further information on these can be found at www.morewaterforaridlands.org

Since the water storage structure (tank or reservoir) is generally the most expensive part of the system, careful selection, design and construction are essential.

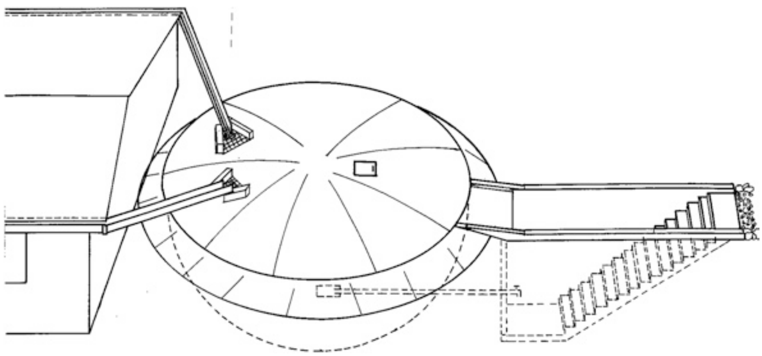


Fig. 8.3 80 m^3 hemispherical sub-surface tank from Kenya (Courtesy and permission from Nissen-Petersen)

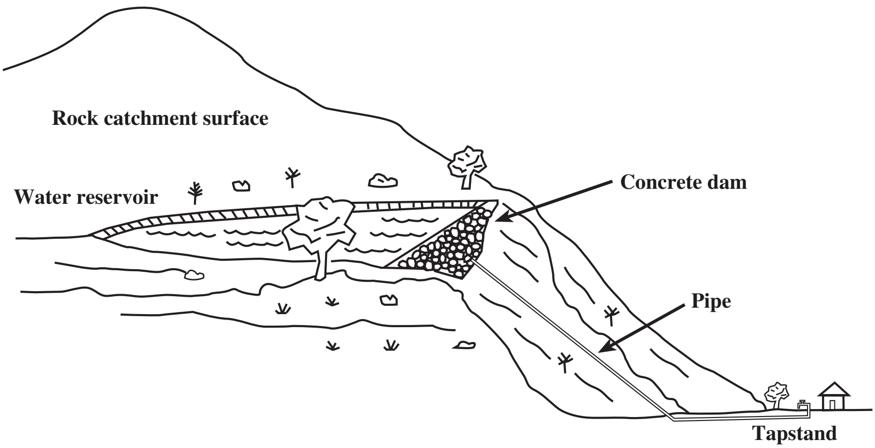


Fig. 8.4 Rock catchment dam common in East Africa

8.1.1 Surface Tanks

These can be constructed from a wide range of materials including

- Metal
- Wood
- Plastic
- Fiberglass
- Bricks
- Interlocking, compressed soil or stone blocks
- Ferrocement

- Concrete
- Rubber
- Others, e.g., ceramic

The key features of any tank are that it should be watertight, durable, affordable, and not contaminate the water in any way.

Surface tanks may vary in size from 1 m^3 to more than 40 m^3 for households and up to 100 m^3 or more for schools, hospitals, etc.

Smaller surface tanks can be made centrally and transported to site. It may be easier to ensure quality control in their construction. This is especially important for tanks which require a high level of workmanship, such as ferrocement. In Thailand, millions of 1–2 m^3 ferrocement jars have been constructed at small rural enterprises and delivered to households (Fig. 8.2).

A key advantage of surface tanks over sub-surface tanks is that water can be extracted simply and easily through a tap. If the tank is elevated, water can even be piped by gravity to where it is required. The main disadvantage of surface tanks is that they are relatively more expensive when compared with sub-surface storage.

Where roof catchment systems are incorporated in the initial plans and designs for houses, it is possible to make substantial cost savings by incorporating the rainwater storage reservoirs into the house structure itself, e.g., in the U.S. Virgin Islands, Bermuda, and parts of China, e.g., Zhejiang Province.

8.1.2 Sub-surface Tanks

Several of the techniques used for building surface tanks can also be used for sub-surface tanks with the soil being backfilled around the outside of the tank on completion. Where the soil is firm, some of the forces of the water against the side of the tank are absorbed by the soil and the walls do not have to be as strong as for an equivalent surface tank.

For ferrocement tanks, it is possible to line a carefully excavated hole with chicken wire and barbed wire reinforcement and plaster directly onto it. This dispenses with the need for a formwork for the walls of the main tank and helps reduce costs significantly.

Soil water and soil pressure will also exert external pressure on the tank walls. While this is counter-balanced by the internal water pressure when the tank is full, when the tank is empty this may produce substantial pressures and the walls must be strong enough to resist these. To overcome this, tanks must be cylindrical or hemi-spherical in shape.

Seasonal rises in groundwater levels may also create a situation where an empty tank can float like a boat. Care, therefore, has to be taken when siting the tanks! Raising the sides of the tanks above ground level and ensuring the tanks are never completely empty can also help counter this problem. Surface water should also be diverted away from the tanks by raising the ground around them.

Where impervious soils exist such as clay, it is often possible to construct unlined sub-surface reservoirs. Invariably, these suffer from problems of seepage, evaporation, and poor water quality.

The main advantage with sub-surface tanks is that they are generally cheaper per unit volume than surface tanks and use less space. The main disadvantage is that to access the water, some form of pump or other extraction method is required unless steps and a tap-stand are constructed from where the water can be extracted by gravity. Although, sub-surface tanks are quite common in some regions such as East Africa where they provide supplies for schools or small scale irrigation, nowhere are they as numerous as in China. In Gansu and neighboring provinces in China, over 2.4 million upgraded *Shuijiao* (sub-surface tanks) have been constructed since 1990. These are based on the traditional bottle shaped water cellars which have been used for centuries and were dug into loess soils and lined with clay. The upgraded *Shuijiao* are lined with cement mortar and have a concrete base and cover.

8.1.3 Dams and Sub-surface Storage

There are several different types of dams (rock catchments, earth dams, sub-surface dams, concrete dams, etc.) used for storing direct surface runoff.

(1) **Rock Catchment Dams**

Rock catchment dams are one of the cheapest and most effective types of rainwater storage system in areas with suitable sites (Fig. 8.4). Where impermeable exposed disjointed bedrock exists, potential dam sites can normally be found in natural valleys or hollows which can easily be converted into storage reservoirs by constructing rubble stone-masonry dams. Granitic inselbergs common in Africa and other parts of the tropics are ideal locations for rock catchments which normally vary from 500 to 10,000 m^3 in volume. Water can be piped by gravity to tap stands or storage tanks at the base of the outcrops or to nearby villages to improve accessibility.

(2) **Earth dams**

Earth dams consist of raised banks of compacted earth and can be constructed to retain water where it regularly flows into small valleys, depressions or on hillsides. The dam wall is normally 2–5 m in height and has a clay core and stone aprons and spillways to discharge excess runoff. Storage volumes can range from hundreds to tens of thousands of cubic meters.

(3) **Hafirs**

Hafirs are excavated reservoirs normally 500–10,000 m^3 in volume. Originating in Sudan, these sources still provide important traditional water supplies in many parts of semi-arid Africa for both people and livestock. Hafirs are located in natural depressions, and the excavated soil is used to form banks around the reservoir to increase its capacity. Bunds and improvements to the catchment apron may help increase runoff into the reservoir, but seepage and evaporation often result in drying out late in the dry season.

(4) **Sand River Storage Systems**

These are found mainly in semi-arid regions where most rivers are ephemeral and surface water flow may only be visible for a few weeks a year. Once the water subsides, the sandy river bed is exposed but while the river may appear dry, water is normally found flowing very slowly under the sand. These sand rivers provide important traditional water sources in many semi-arid parts of the developing world. To increase the upstream storage capacity in the river bed, a sub-surface dam can be built across the river channel using earth or stone-masonry with its top level with the sandy river bed. Sand dams are similar to sub-surface dams except that the top of the dam wall exceeds the level of the sandy river bed. These dams are built in stages with the dam wall height being increased by 0.3 m after floods have deposited sand to the level of the spillway. This allows sand to be trapped upstream of the dam wall, thus increasing the overall storage capacity of the river bed. Coarse river sand provides the best and greatest storage potential which often amounts to several thousand cubic meters for a single dam. The advantage with sand river storage is that it normally represents an upgrading of a traditional and hence socially acceptable water source. Since the water is stored under the sand, it is protected from significant evaporation losses and also less liable to be contaminated. The construction of river-intakes and hand-dug wells with hand pumps on the river bank can further help improve water quality.

(5) **Groundwater Recharge**

Groundwater recharge can be enhanced by rainwater harvesting where local conditions permit. This can sometimes result as a by-product due to downstream seepage from reservoirs following earth dam construction. In other places, runoff is deliberately diverted to recharge or maintain groundwater levels to ensure existing wells do not dry up.

8.2 Selection of Water Storage System

The most appropriate choice of storage system in any situation will depend on local conditions.

Several factors influence the choice of rainwater tank or reservoir, and these include:

- The amount of water storage required
  Is it for main or only supplementary supply?
  For single family, school, or whole community?
- Type and size of catchment
  Small fixed sized roof or expansive ground or rock catchment surface
- Rainfall amount and distribution
  Semi-arid low-rainfall or humid high-rainfall climate
  Seasonal climate with wet/dry season or rainfall all year

- Soil type and permeability
  Impermeable soils in arid areas may favor constructing sub-surface tanks
- Availability and cost of construction materials
  Cheap or freely available river sand, hard core, or rocks may make certain designs more affordable than others
- Availability and cost of off-the-shelf tank designs
  The cost and advantages with constructing storage tanks/reservoirs on site need to be balanced against the cost of off-the-shelf tank designs
- Affordability
  The high cost of rainwater storage tanks relative to incomes is often a key limiting factor
- Local skills and experience
  If local skills and experience are absent, a significant investment in training may be needed
- Availability of other water sources
  The quality, accessibility, and cost of development of other water sources

The comparative costs of locally available alternatives will also be a key factor in choosing the most appropriate tank or reservoir option.

Various environmental factors may preclude certain types of tank. For example, metal tanks are not suitable in areas of saline soils and coastal areas.

8.3 Determining Demand, Runoff Coefficient, and Supply

In this section, we will examine various ways of sizing a household rainwater catchment tank in order to endeavor to meet household water demand while minimizing system cost.

Usually, the main calculation when designing a domestic rainwater catchment system will be to size the 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 depending on roof material and slope)
- User numbers and consumption rates

Whether rainwater harvesting is done to meet occasional, intermittent, partial, or full household water supply requirements will also play an important part in determining the storage size.

8.3.1 Determination of Demand

Estimating household annual water demand may, at first, seem straightforward, i.e., multiplying mean daily water use per person by the number of household members by 365 days. For example, if household water use is 20 L of water per person per day for a family of 5, an annual household water demand of $100 \times 365 = 36{,}500$ L (36.5 m^3) might be expected.

In reality, it is more complex because adults and children use different amounts of water and seasonal water use varies significantly. For example, more water is used in the hottest and/or driest seasons. The number of family members staying at home may also vary at different times of the year. To try to take into account all such variables, household surveys need to be designed very carefully and detailed information sought.

Where demand estimates are being used as the basis for designing rainwater systems, they should therefore be treated with great caution, especially if the rainwater systems are the major or only source of supply. In such situations, adding a 20 % or more "safety margin" is appropriate.

Another factor is that people will tend to use rainwater more sparingly when water levels in household tanks get low. This informal rationing process is very important as it can significantly reduce the likelihood of the tank becoming completely empty and reduce the time period of any such system failures when they occur.

8.3.2 Runoff Coefficient

The runoff coefficient[1] (C) for any catchment is the ratio of the volume of water which runs off a surface to the volume of rainfall which falls on the surface.

$$C = \frac{\text{Volume of runoff}}{\text{Volume of rainwater}} \tag{8.1}$$

All calculations relating to the performance of rainwater catchment systems involve the use of a runoff coefficient to account for losses due to spillage, leakage, infiltration, catchment surface wetting, and evaporation which will all contribute to reducing the amount of rainwater which actually enters the storage reservoir.

For a well-constructed roof catchment, especially one made from corrugated iron sheets or tiles, the runoff coefficient for individual rainfall events may often be over 0.9, i.e., >90 % of rainfall collected (Ree 1976).

The long-term runoff coefficient for the system will, however, probably be less due to occasional, but substantial losses, resulting from gutter overflows during torrential storms (or temporary blockages by debris such as leaves), and the collection efficiency of both roof and ground catchment systems may be reduced when precipitation occurs as snow or hail or is affected by very strong winds. For this reason, it is appropriate to use a runoff coefficient of 0.8 as standard when

[1] Runoff coefficient may also referred to as the Rainwater Collection Efficiency (RCE).

Table 8.1 Runoff coefficients for different catchments in Gansu Province, China

Roof catchment		Ground catchment	
Clay tile (hand-made)	0.24–0.31	Concrete lined	0.73–0.76
Clay tile (machine made)	0.30–0.39	Cement soil mix	0.33–0.42
Cement tile	0.62–0.69	Buried plastic sheet	0.28–0.36
		Compacted loess soil	0.13–0.19
Corrugated iron[a]	0.8–0.85		

Source of data from Zhu and Liu (1998)
[a]Estimate for comparison and not included in the study

designing roof catchment systems. This figure is also recommended in a guide on the use of rainwater tanks produced in Australia (Cuncliffe 1998). Runoff coefficients for traditional roofing materials such as grass thatch and local clay tiles are generally lower than this as are those for most ground catchment systems.

Natural land surfaces will normally have runoff coefficients below 0.3 and even as low as zero. Massive rock outcrops used for rock catchment systems are the one exception and may have runoff coefficients of as much as 0.8 according to Lee and Visscher (1992).

A major study in Gansu Province in China (Zhu and Liu 1998) to determine the runoff coefficients of different local roof and ground catchment surfaces in areas with mean annual rainfall varying from 200–500 mm came up with the following results, Table 8.1.

These figures show the runoff coefficient for the particular catchment type which could be expected 95 % of the time (it may be less in occasional extreme drought years). The higher figure in the range relates to catchments in areas with mean annual rainfall of 400–500 mm, while the lower figure is for areas receiving just 200–300 mm. The long-term estimate of the runoff coefficient for corrugated iron roofs is included for comparison and was not part of the study. Due to their higher cost, metal roofs and gutters were not present in the study area at that time.

8.4 Determining the Rainwater Supply

The actual amount of rainwater which can be supplied varies greatly, as it depends on the quantity and distribution of rainfall, the size of existing or affordable catchment surfaces, and the volume of the storage tank. In situations where existing roofs are to be used, the catchment area is fixed, and for a particular location, the amount of rainfall cannot be changed. In these instances, the only variable the designer can use to influence the available rainwater supply is the volume of the storage tank.

Rainfall Data

Rainfall data can normally be obtained from National Meteorological Departments, the Ministry of Agriculture, Universities, and Research stations, and may be obtainable directly through the Internet. Care should be taken when selecting the best rainfall data source station, as in some areas, mean rainfall may vary markedly over short distances, especially in mountainous terrain.

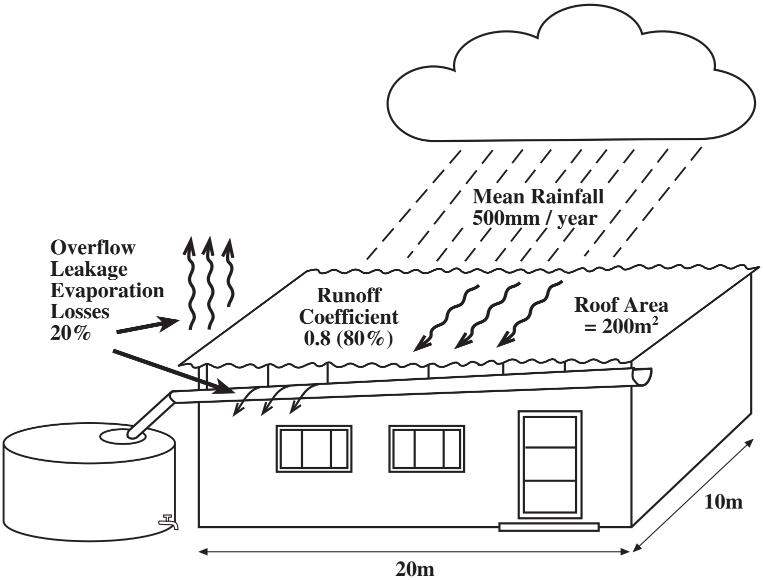


Fig. 8.5 Typical roof catchment system (used in sample calculation)

Rainfall is very variable, especially where annual precipitation is less than 500 mm. It also varies with location, so that data from a weather station 20 km away may be misleading when applied to the site of the rainwater harvesting system (see Fig. 8.5).

To determine the potential rainwater supply for a given catchment, reliable rainfall data for a period of at least 10 years are required. In drought prone climates, a longer historic rainfall record is preferable and a 20-year series is ideal. A longer rainfall data series may give a false picture of current rainfall conditions if regional climatic changes have occurred.

8.5 Calculating Potential Rainwater Supply from a Simple Roof Catchment

The size of the supply of rainwater depends on the amount of rainfall, the area of the catchment, and its runoff coefficient. For a roof or sloping catchment, it is the horizontal plan area which should be taken (see Fig. 8.5). The runoff coefficient takes into account any losses due to leakage, evaporation, and overflow and is normally taken as 0.8 for a well-constructed roof catchment system. Rainfall is the most unpredictable variable in the calculation since in many areas, there is considerable variation from one year to the next. An estimate of the approximate mean annual runoff from a given catchment can be obtained using the following Eq. (8.2).

$$S = R \times A \times C_{\mathrm{r}}, \tag{8.2}$$

where
S = Mean rainwater supply in cubic meters (m^3)
R = Mean annual rainfall in millimeters (mm/a)
A = Catchment area in square meters (m^2)
C_{r} = Runoff coefficient

For example,

$$\begin{aligned} S &= 500 \text{ mm/a} \times 200 \text{ m}^2 \times 0.8 \\ &= 0.5 \text{ m/a} \times 200 \text{ m}^2 \times 0.8 \\ &= 80 \text{ m}^3/\text{a} = 80,000 \text{ L/a} \\ &= 219 \text{ L/day.} \end{aligned}$$

8.6 Sizing the Water Storage Structures

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 (e.g., Computers)
- The skill and education levels of the practitioner/designer

The actual amount of rainwater supplied may vary greatly from year to year and also depends on the volume of the storage tank and the rate of water use.

8.6.1 Methods for Sizing Rainwater Tanks

Below three different methods for determining, the required storage volume is outlined.[2]

[2]The examples shown here are adapted from the Domestic Roofwater Harvesting Research Program part of the Development Research Unit at the University of Warwick UK. The website at: www2.warwick.ac.uk/fac/sci/eng/research/civil/crg/dtu-old/rwh/ is an excellent resource for finding out information on domestic rainwater collection and has many links to other useful websites.

(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:

$$\text{Consumption per capita per day} - C = 20\ \text{L}$$

$$\text{Number of people per household} - n = 5$$

$$\text{Longest average dry period} = 100\ \text{days}$$

$$\text{Annual consumption} = C \times n \times 365 = 36{,}500\ \text{L}\left(36.5\ \text{m}^3\right)$$

$$\text{Storage requirement} = C \times n \times 100\ \text{days} = 20 \times 5 \times 100 = 10{,}000\ \text{L}\left(10\ \text{m}^3\right).$$

This simple method assumes sufficient rainfall and adequate catchment area, and is therefore only applicable in these situations. It is a method for acquiring rough estimates of tank size.

If good quality data are available on household water consumption and the maximum length of any dry periods, this method can be very useful. It has the advantage of not requiring accurate rainfall data or sophisticated modeling tools.

(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 Fig. 8.6). 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 rainwater harvesting storage sizing.

Demand:

- Number of staff: 7
- Staff consumption: 45 L per day $\times$ 7 = 315 L per day
- Patients: 40
- Patient consumption: 10 L per day $\times$ 40 = 400 L per day

Total demand: Staff consumption + Patient consumption = 715 L/day or 21:75 m^3/month

Mean annual rainfall = 1056 mm

Example Medical dispensary, Ruganzu, Biharamulo District, Kagera, Tanzania 1997 Supply:

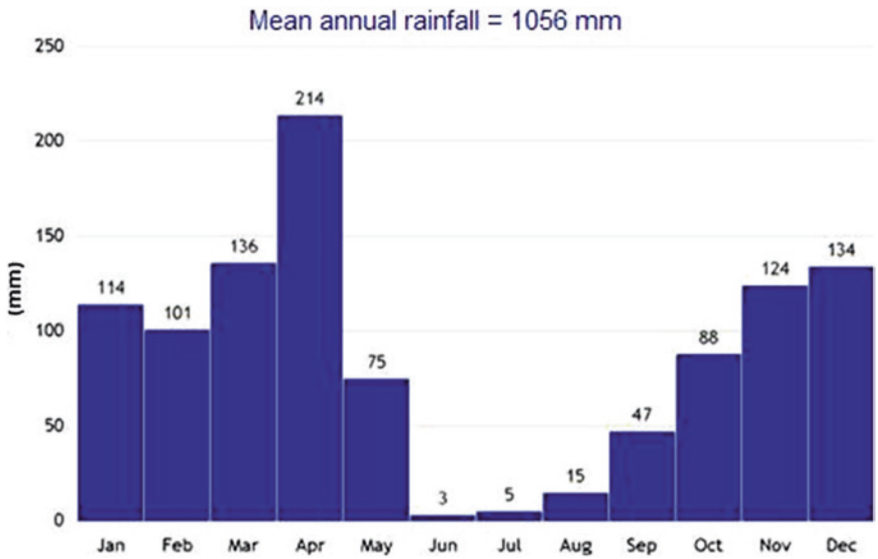


Fig. 8.6 Mean monthly rainfall for Biharamulo District

- Roof area: 190 m^2
- Runoff coefficient (for new corrugated GI roof): 0.9
- Average annual rainfall: 1056 mm per year
- Annual available water (assuming all is collected) $= 190 \times 1.056 \times 0.9 = 180.58\ m^3$

$$\begin{aligned}\text{Daily supply available} &= 180.58/365\\ &= 0.4947\ m^3/\text{day}\\ &= 495\ \text{L per day}\\ &\quad \text{or } 15.05\ m^3\ \text{per mean month}\end{aligned}$$

So, if we want to supply water all the year to meet the needs of the dispensary, the demand cannot exceed 495 L per day. The expected demand cannot be met by the available harvested water. Careful water management will therefore be required.

Figure 8.7 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 as shown in Fig. 8.8.

Table 8.2 shows the spreadsheet calculation for sizing the storage tank. It takes into consideration the accumulated inflow and outflow from the tank, and the

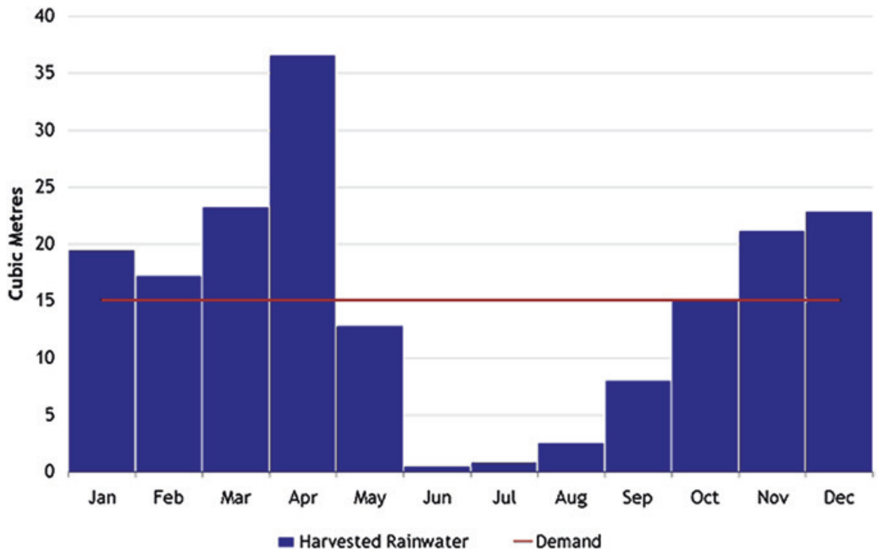


Fig. 8.7 Comparison of the harvestable water and demand each month

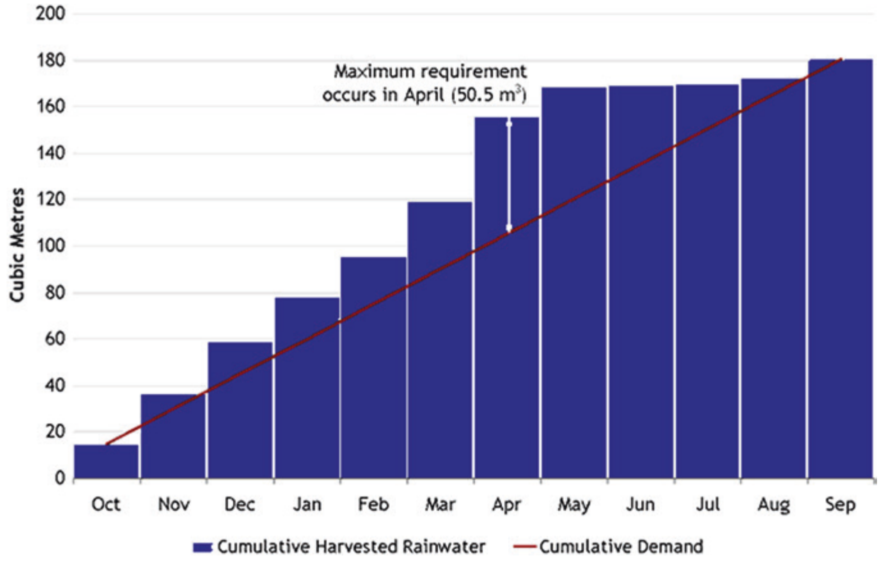


Fig. 8.8 Predicted cumulative inflow and outflow from the tank (*Note* The maximum storage requirement occurs in April)

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 m^3. All this water will have to be stored to cover the shortfall during the dry period.

Table 8.2 Spreadsheet calculation for sizing the storage tank

Private month	Rainfall (mm)	Rainfall harvested (m^3)	Cumulative rainfall harvested (m^3)	Demand (based on total utilization)	Cumulative demand (m^3)	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	15.03	180.58	0.00
Totals		180.58		180.58		

8.6.2 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.

$$\text{Storage efficiency } (\%) = 100 \times \left(1 - \text{overflow}/\text{inflow}\right)$$

$$\text{Provided that inflow} < \text{demand}$$

$$\text{System efficiency } (\%) = 100 \times \text{water used}/\text{water falling on the roof}$$

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 rainwater harvesting system may show unreliability not only because storage is small, but because the roof area is insufficient. Figure 8.9 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

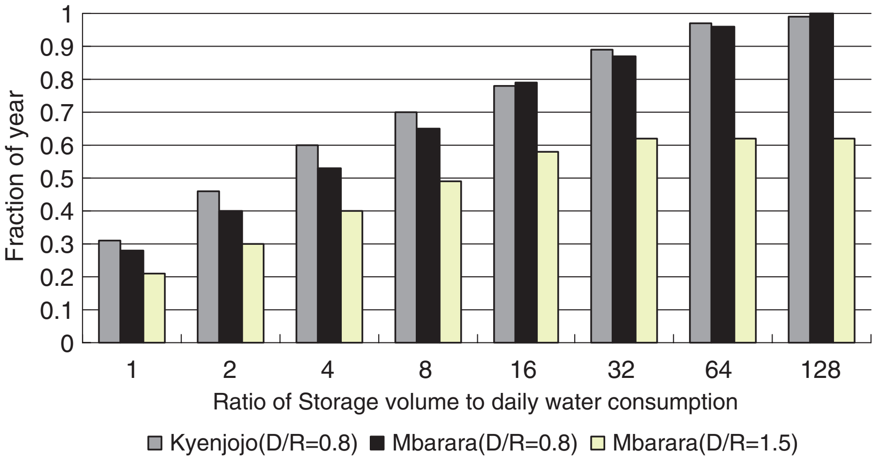


Fig. 8.9 Availability of rainwater supply as a fraction of the year

80 % of average annual roof runoff). Assuming a say 100 L 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 rainwater harvesting system in a poor country. In any case, as we shall see below, users may change behavior so as to reduce the effective unreliability of their systems.

8.6.3 System Features that Affect Tank Sizing

- An oversized roof slightly compensates for an undersized tank.
- 'Partial' rainwater harvesting systems, either where it is accepted that rainwater 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 rainwater harvesting system rises with the cost (in money, effort, or even ill-health) of the alternative source that is used when the tank runs dry.
- If users are able and willing to adjust their consumption downwards during the dry season, or when they find water levels in their tank lower than average, tanks can be sized smaller. A simple but effective approach to such rationing is shown in Box 8.1 below.

8.6.4 Rationing

Whether carefully controlled and executed or simply carried out as a natural reaction to the tank becoming empty and a looming water shortage some form of water rationing is almost inevitable in situations where a given water demand cannot always be met by any particular rainwater collection system.

In areas where seasonal water shortages are common, it therefore makes sense to incorporate a systematic and carefully planned rationing system. A rationing schedule can be very simple and need not be hard to execute as the example in the box below illustrates where simply reducing a standard abstraction rate of 3 large buckets (60 L) to 2 (40 L) when the level of water in the tank fall below a third full can greatly increase the time period that the system can continue supplying water. When the tank is more than two-thirds full, the daily water allowance can be increased to 4 buckets (as this will ensure less water is lost due to tank overflow in periods of higher rainfall). In periods of severe drought or at the end of the dry season, an emergency rationing measure of taking just 1 bucket could be introduced when the tank is less than 1/10 full to further extend the period during which water can be abstracted.

Box 8.1: Simple and effective Approach to Rationing Water Supply

Rainwater Tank showing suggested daily abstraction rates to extend the period which the tank can supply water.
Daily water supply

When tank >2/3 full	4 buckets
	3 buckets
When tank <1/3 full	2 buckets

Rationing schedules of this type may only be needed in situations where no other water sources are available, or during the dry season or drought periods. In situations where a household is entirely dependent on a rainwater tank as its sole water supply, it would be prudent to introduce even more stringent 'emergency rationing' when the tank becomes less than 10 % full. Some computer models available free online such as the rainwater tank performance calculator discussed below include options for incorporating rationing into the analysis.

8.7 Computer Models

There are several computer-based programs for calculating tank size quite accurately.

8.7.1 SimTanka

One such program, known as SimTanka, has been written by an Indian organization and is available free of charge on the World Wide Web. The Ajit Foundation is a registered non-profit voluntary organization with its main office in Jaipur and its community resource center in Bikaner, India.

SimTanka is a software program 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 meager 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. Alternatively, 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, Rain Recorder, 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 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 www.indev.nic.in/ajit/Water.htm (Source: the information given here is taken from this website).

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

8.7.2 Rainwater Tank Performance Calculator

Another excellent such program which is available free online can be found at www2.warwick.ac.uk/fac/sci/eng/research/civil/crg/dtu-old/rwh/model and provides a simple yet powerful design tool. This tank performance calculator provides a simple, easy to follow, step by step approach to assess tank performance.

As the cost of a domestic rainwater harvesting system depends mainly on the size of the tank, it is important to design the tank to ensure optimum performance at tolerable cost.

This program calculates the approximate system reliability and efficiency for a selection of tank sizes including one that you can define, using your monthly rainfall data and roof area.

The user also defines how the rainwater will be used by giving a nominal daily demand and choosing between three water management strategies:

- Constant demand.
- Varies with tank volume.
- Varies with season.

The program requires the following data: nominal daily demand, roof area, and tank volume. Ten years of monthly rainfall data (in mm) need to be entered in the following format. Each number has to be followed by a comma (e.g., 74, 58, 106, 195, 164, 103, 104, 104, 128, 127, 120, 67).

8.7.3 Points to Bear in Mind Regarding Computer Models

The use of computer based models allows great flexibility when producing output for system design since the model can be tailored for any particular system under given rainfall conditions. The format of the output can also be customized to requirements and the performance of specific designs simulated under various demand scenarios. For example, the implications of introducing a dry season rationing schedule on storage requirements could easily be tested using a long rainfall record.

Due to their speed and flexibility, computers provide a powerful tool when simulating future rainwater supplies and anticipated storage requirements on the basis of past rainfall data. While computer models are becoming increasingly capable of mimicking the performance of real systems, they are only as good as the data used. Obtaining good quality rainfall data in a format that can readily be used in any model will greatly reduce the time, effort, and cost of any computer-based modeling exercise. As with other methods, an accurate and lengthy rainfall record is essential. A minimum of 20 years of rainfall data is preferable especially in drought prone areas. While mean monthly data can be used, weekly or daily records will give a more accurate prediction of system performance.

Where feasible, these should be used, especially if they are available in digital format that can be readily fed into a computer program. Normally, the data will need to be reformatted to meet the specifications of any particular program. Care should be taken to check the data carefully, so that account can be taken of any missing or spurious values.

Where rainfall records are short, it is possible to use computers for data simulation to extend the record. This may be convenient but the resulting data will be no more accurate than the historical data on which it is based. For those who really like to do their own thing, there is even advice on how to use common computer packages or write your own program to determine the performance of any roof catchment system.

It should be borne in mind, however, that the tidy and uncomplicated world of the computer simulation can turn out to be very different from reality, where leaks or the pranks of small children can play havoc with the neat predictions of the most sophisticated computer model.

8.8 Structural Design of Water Storage

8.8.1 Selecting an Appropriate Tank Design

Ideally, a tank as well as having the appropriate volume with respect to the catchment area, rainfall conditions and demand, should have a functional, durable, and cost-effective design. Field experience has shown that a universally ideal tank design does not exist. Local materials, skills and costs, personal preference, and other external factors may favor one design over another.

(i) Key requirements common to all effective tank designs[3]

- A functional and water tight design.
- A solid secure cover to keep out insects, dirt, and sunshine.
- A screened inlet filter.
- A screened overflow pipe.
- A manhole (and ideally a ladder) to allow access for cleaning.
- An extraction system that does not contaminate the water, e.g., tap/pump.
- A soak-away to prevent spilt water forming puddles near the tank.
- A maximum height of 2 m to prevent high water pressures (unless additional reinforcement is used in the walls and foundations).

(ii) Other features might include:

- A device to indicate the amount of water in the tank.
- A first flush mechanism.
- A lock on the tap.
- A second sub-surface overflow tank to provide water for livestock.

[3] List adapted from Latham and Gould (1986).

If rainwater catchment systems already exist in an area, it is important to take time to visit and inspect a few systems. The owners or users of the systems should be questioned regarding their assessment of their own tank designs. This process allows the advantages and disadvantages of different locally produced designs to be compared and weighed against the sales pitch given by manufacturers of commercial systems. The exercise will also provide some useful lessons, which may help avoid potential future problems that might result from the selection of an inappropriate design.

8.8.2 Deciding on Most Suitable Type of Tank

Having established the required volume for the storage reservoir, it is also necessary to decide whether to opt for buying an "off the shelf" commercially available tank or to construct the system on site.

A number of factors are likely to influence this decision. These include the cost, durability, acceptability, and appropriateness.

Transport costs can also be high, especially where distances are large and roads are poor. Practical considerations are also important. For example, in many circumstances, such as in remote rural locations, 10 m^3 usually represents the upper limit for tanks which can be constructed at central locations and transported in one piece to the location required.

Plastic and fiber glass tanks although expensive in some countries are light and relatively easy to transport. Metal tanks are also commonly delivered by road, where delivery to remote locations is required, such as in Australia. Costs can sometimes be reduced by nesting several progressively smaller tanks together, if covers can be detached. Delivery of small ferrocement tanks is possible if care is taken and road conditions permit.

There are some advantages to buying ready-made commercial tanks. They can be quickly erected at the site and be operational within days of the decision to install them, compared to weeks or months for tanks requiring construction on site. Because commercial tanks are normally built in large numbers, they are subject to economies of scale and quality control. This can, in some cases, make them more durable and cost-effective than tanks built on site especially if poor levels of workmanship are suspected.

Commercially available tanks do not require the availability of skilled labor, construction materials, and an appropriate design. Since commercially made tanks, especially those requiring special equipment, such as for molding plastic, are often produced only at major centers, transport costs to remote rural locations are often high. The other main disadvantage with commercial ready-made tanks is that they are normally more expensive than tanks constructed on site. This is especially the case in situations where free or low-cost labor and local building materials are available. The free collection of river sand and aggregate, for example, is common practice in many community self-help projects in developing countries.

Systems designed and constructed by an individual householder or community can also be tailor-made to meet the specific local requirements. In the context of a community project, there are several other benefits to be derived from constructing systems on site. While unskilled voluntary labor may help bring down system costs, the utilization of skilled paid labor from the community will provide employment. The involvement of the community in the construction of any water systems helps develop skills and self-reliance. This also ensures the community is more likely to be able to properly operate, maintain, and repair the systems in the future.

8.8.3 Tank Shape, Dimensions, and Type

As a general rule, water tanks should ideally be cylindrical or spherical in shape. This is because cylindrical or spherical shapes optimize the use of materials and increase the wall strength. Spherical tanks are difficult to construct and require some sort of stand for support. A good compromise shape for strength and cost-effectiveness is the Thai jar (Fig. 8.10). The jar shape gives maximum strength since the walls are curved in both vertical and horizontal directions yet it requires no special stand. Although, "jumbo jars" up to 6 m^3 have been built, to construct larger surface tanks in this way would be very difficult so for practical purposes, a cylindrical shape is the best compromise. This does lead to comparatively large stresses along the joint between the wall and the base which must be strong enough to withstand this (Watt 1978).

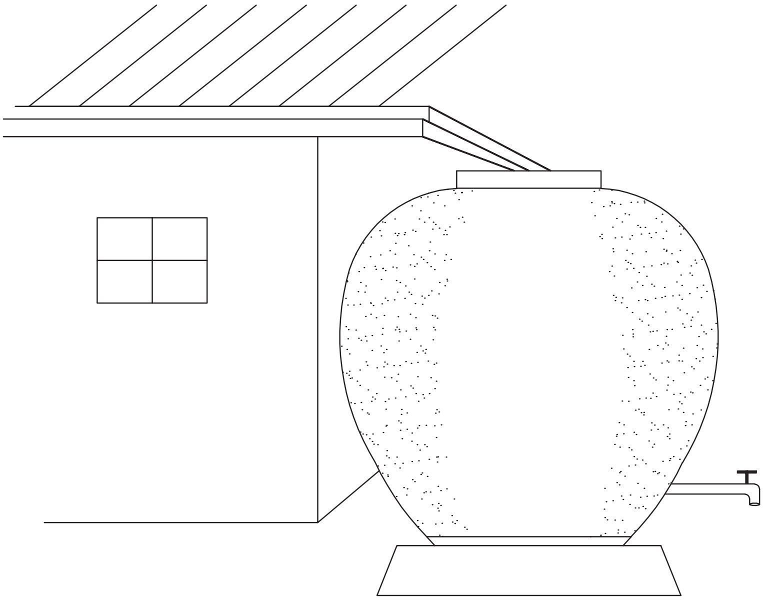


Fig. 8.10 Thai Jar—the *curved shape* gives it strength and cost efficiency

For surface tanks, the cylindrical shape is by far the most common. To maximize the storage volume while minimizing the cost, the tank should be reasonably evenly proportioned. Tall tanks with narrow widths and very low tanks with large diameters require more materials and cost more per unit volume. There are, nevertheless, a number of other factors which need to be considered. Unless additional reinforcement is added, the height of water tanks for roof catchment systems should not exceed 2 m.

This is because the internal force of water against the tank walls increases with the depth of the water. If the height of a tank is increased, then the reinforcement must be increased accordingly to prevent collapse of the tank. Where tanks exceed 2 m in height, special attention should be paid to reinforcing the lower sections adequately and if in doubt, expert advice should be sought (Fig. 8.11).

When deciding on whether a surface or sub-surface tank is more appropriate, the following points should be considered. Although underground storage reservoirs are generally cheaper, some form of pump or gravity-flow connection to an excavated or lower level tap stand is generally required to extract water. While substantial cost savings may be possible particularly in the case of larger excavated tanks, other factors such as local soil conditions need to be considered. Where the sub-soil is rocky, excavation may not be feasible and where it becomes waterlogged, there is a risk that a nearly empty sub-surface tank could start to float and rise out of the ground.

The decision regarding the final choice of storage tank will depend on a wide range of factors including the availability of materials and locally available labor skilled in tank construction.

8.8.4 Cost-Effectiveness

The cost-effectiveness is often the determining factor when deciding to choose a particular technology or design. The high initial capital costs required for rainwater catchment systems, particularly in more arid and seasonal climates where large

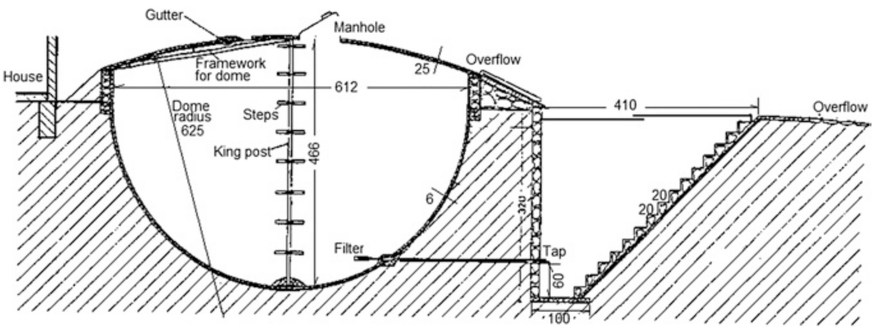


Fig. 8.11 Hemispherical 90 m^3 sub-surface ferrocement tank design from Kenya (Permission and courtesy from Erik Nissen-Petersen)

storage reservoirs are required, further increase the need to ensure cost efficiency. Tank sizing and the selection of a tank with suitable shape and dimensions are crucial in optimizing cost-effectiveness. The choice of a durable design with a long life expectancy and low maintenance costs is also critical.

While a \$1000 tank may initially appear a much cheaper alternative than a \$2000 tank, if the more expensive one has a life expectancy of 25 years compared with 10 years for the cheaper one, the costs should be reassessed in terms of \$2000/25 = \$80/year versus \$1000/10 = \$100/year, respectively. In this case, the more expensive tank would seem to be cheaper over the long term.

The use of discount rates which involve making assumptions regarding the declining future value of current funds upsets such simplistic analysis, as do uncertainties surrounding the actual life expectancies of different designs. Nevertheless, it is clear that two different designs cannot simply be compared at face value without taking other factors into account.

8.8.5 Availability and Suitability of Materials and Skilled Labor

The availability of different raw materials is crucial to the decision regarding the eventual choice of tank design. If key materials are not locally and cheaply available, it may be worth considering a commercially available design, rather than substitute a critical building material with something less suitable.

The availability of suitably experienced and qualified labor for tank construction is vital if a project involves tank construction on site. Certain designs, such as ferrocement require particular care and attention to detail, which, if ignored, could eventually jeopardize a project. If the necessary skills are not available in the project area, it is sometimes possible to develop the necessary skills through training courses.

Unless large numbers of tanks are going to be built, it may be difficult to justify any such major investment. It should nevertheless be recognized that investment in training and skills development may have many positive spin-offs for a community in a variety of areas unrelated to the project itself.

8.8.6 Siting of Tanks

Key issues to be considered when siting a rainwater tank or reservoir:

- Avoidance of any potential health hazards, e.g., never locate tanks near toilets/pit latrines, waste disposal facility, or other source of pollution.
- Avoid sites where surface runoff is evident due to the risk from soil erosion, which could cause damage to poorly sited tanks (if such sites have to be used, bunds and/or cut-off drains should be constructed to divert flood waters away from the base of the tank).

- Tanks should generally be located so they can collect water from as large a roof/catchment area as possible. This will often be the determining factor regarding the siting of the tank, e.g., between two buildings.

8.8.7 Design Flaws, Implementation, and Operation

To ensure the success of any rainwater harvesting project, it is essential to take time to design systems carefully and in a way appropriate to the local conditions. This process should involve the community in all aspects of planning, project design, implementation, operation, and maintenance.

Experience has shown that simply providing rural communities with the necessary "hardware," however, technically sound it may be, is not enough to ensure projects will succeed. In the case of jointly owned and operated communal projects, particular care and attention is needed to make sure procedures are in place to guarantee systems will be operated and maintained properly and projects will be sustainable. This will ensure that clear lines of responsibility and accountability are established and that resources both in terms of trained personnel and finance are available to guarantee regular maintenance and timely minor repair work is done before major system failures occur.

Encouraging the proper operation and maintenance of individual household systems such as roof catchments is generally much more straightforward than for communal systems since it is in the householders' own personal interest to maintain their own systems properly and since all the benefits of the system accrue to the household, most are highly motivated with respect to proper system upkeep.

The best way to minimize potential problems is to ensure that any design used has been thoroughly field tested. If a new design is being implemented, it should undergo field trials through a pilot project phase and any necessary modifications or improvements to the design made before wider replication take place. Many projects in the past have also failed because of unrealistic expectations of the willingness of communities and individuals to provide free or cheap labor.

8.8.8 Importance of Field Testing New Designs

The adoption and widespread replication of new designs, however, promising they may seem at the development and demonstration phase, is extremely risky if they are not first subjected to thorough field testing through carefully monitored pilot projects.

The failure of various low-cost cement tank designs using organic reinforcement (bamboo, sisal, and basketwork) in both east Africa and southeast Asia during the early 1980s provides an important lesson in this respect. The development and hasty promotion of low-cost bamboo and basketwork reinforced tanks designs, in Thailand and Kenya, respectively, and their widespread adoption resulted in one of the most serious failures of rainwater tank technology to date (Latham and Gould 1986).

In the case of the bamboo reinforced tank, insufficient field testing and premature promotion of the design resulted in extensive replication in Indonesia and Thailand (where as many as 50,000 were constructed). Unfortunately, after a couple of years, many instances of tank failure were reported due to damage of the bamboo reinforcement, resulting from termite, bacterial, or fungal attack. Apart from the problem of cracking and leakage of the 5–12 m^3 tanks, the risk and related danger of a tank bursting and causing injury, or even death, had to be taken seriously.

As for the basketwork reinforced 'Ghala basket' tanks widely promoted in Kenya in the early 1980s, several thousand of these were constructed, but within a couple of years, most tanks suffered failure due to rotting or termite attack of the organic "reinforcement." The lessons in both these instances are clear. It is vital that new designs are thoroughly field tested before widespread promotion and replication of the technology. This is not always easy to ensure in practice due to the urgent need to find solutions to pressing water problems, especially when an apparently appropriate solution is found.

8.8.9 Training, Quality Control, and Good Management

While many projects fail as a result of the use of inappropriate technologies and designs, frequently the technology may be sound but failure is due to a lack of training, quality control, or poor management. Specific problems stemming from this include poor workmanship, inadequate maintenance, and lack of the necessary skills, training, and supervision to ensure high-quality construction. Use of inappropriate materials, such as saline water or poorly graded sand cause structural weaknesses in the tank which may well act as obstacles to long-term project success.

In one major project in Kenya, for example, widespread tank cracking and failure resulted after a few years due to the "disappearance" of cement during construction, resulting in inadequate quantities being used in the building of large ferrocement tanks. It is probably fair to say that the checkered history of ferrocement tanks in Africa, and particularly problems with the construction of larger rainwater tanks in Botswana and Namibia stem mainly from insufficient attention having been given to thorough training, careful quality control, and project management.

8.8.10 Importance of Proper Operation and Maintenance

Manuals and literature relating to rainwater catchment system operation and maintenance generally recommend that regular system maintenance should be carried out. In reality, it seems, based on field observations, that regular cleaning of systems tends to be the exception rather than the rule.

Maintenance is also frequently neglected, often to the detriment of the system's life span.

The diagrams in Box 8.2 compare a good and bad roof catchment system. The poorly designed system is probably only about 10 % efficient. Less than a quarter of the roof area is being effectively utilized and only half of the storage capacity. Unfortunately, this is based on a real example observed in 1991 in Masunga, Botswana.

Leaking taps, blocked or broken gutters, and downpipes are very simple to maintain and repair but if left unattended, these frequently result in total system failure. Even such obvious measures, like closing a dripping tap properly so water loss is avoided, are sometimes not done, especially in the case of communal tanks. Unless specific training is provided and responsibilities allocated, it is probably safest to assume that very little effort will be made regarding operation and maintenance, particularly with communal systems, at least until they fail or breakdown completely. The situation regarding privately owned systems is somewhat better, but even here it sometimes helps raise awareness amongst system owners about the necessity and benefits to be derived from regular system cleaning and maintenance.

8.9 Gutters and Downpipes

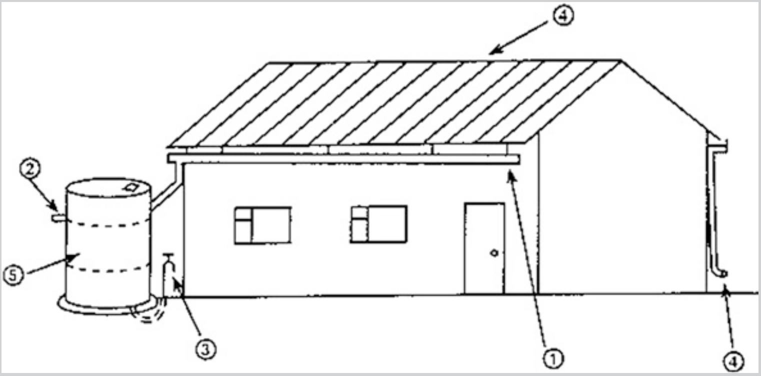
Although gutters and downpipes are not the only method for delivering water from the catchment to the storage tank, they are by far the most common. Other methods used include the use of roof "glides" as in Bermuda, and cement channels are common in parts of rural China. Simple gutter troughs made of wood or sheet metal are also a common technique used for simple informal home-made systems at millions of poorer households across the developing world.

A carefully designed and constructed gutter system is essential for any roof catchment system to operate effectively. A properly fitted and maintained gutter–downpipe system is capable of diverting more than 90 % of all rainwater runoff into the storage tank (Ree 1976) even though the long-term collection efficiency is usually between 80 and 90 %.

Gutters and downpipes can be made of a variety of materials: metal, plastic, cement, wood, and bamboo. Typically, conventional 'off the shelf' metal or plastic gutters and downpipes will cost between 5 and 15 % of the total system cost, depending on local prices and conditions. All too often, both individuals and projects overlook the importance of guttering. This frequently results in only the runoff from part of the roof area being utilized.

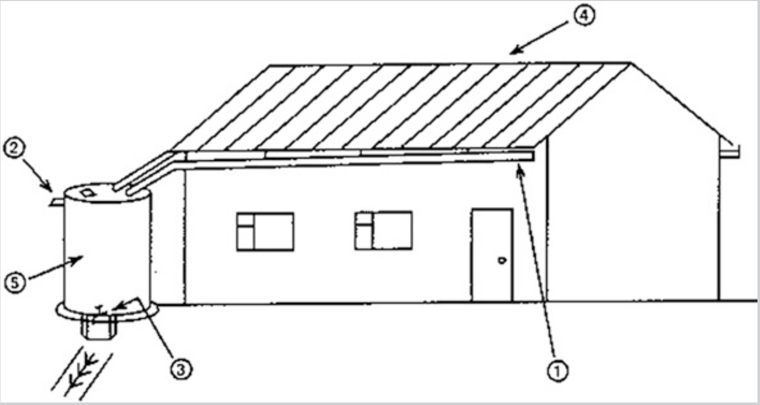
The gutter and downpipe systems are crucial to any rainwater catchment system yet they are frequently the weak link, which result in poor system efficiency. Broken gutters often lead to little or no water reaching the tank. Regular gutter maintenance is, therefore, essential. Leaves and other debris in the gutter must be cleaned out and overhanging branches should be removed.

Box 8.2: Common problems with roof catchment design



Example of poor system design
Many roof catchment systems are poorly designed. Common mistakes include:

1. Gutters which are horizontal or sloping away from the tanks
2. Overflow pipes placed well below the top of the tank
3. Outlet taps high above the base of the tank
4. Down pipes leading to waste
5. Only part of the roof area being used



Example of good system design
Note Differences:

1. Gutter Slope
2. Height of Overflow
3. Height of Tap
4. Total Catchment Area Used
5. All Storage Volume Used.

8.9.1 Gutter and Downpipe Sizing

Gutter and downpipe sizing is a crucial element of the design of any system. Large quantities of runoff may be lost during heavy storms if gutters are too small and overflow. As a general guide to gutter dimensions for catchment areas of different sizes, a useful rule of thumb is to make sure that there is at least 1 cm^2 of gutter cross section for every 1 m^2 of roof area (Hasse 1989). See Sect. 9.8 in Chap. 9 for further guidance on sizing and types of guttering.

To avoid overflow during torrential downpours, it makes sense to provide a greater gutter capacity. The gutter must be of a sufficient size, in order to discharge water to the tank without any overflow in the gutter. The usual 10-cm (4″)-wide half-round gutter is generally not big enough for roofs larger than about 70 m^2. A 10 cm × 10 cm^2 gutter with a cross-sectional area of 100 cm^2 can be used for roof areas up to about 100 m^2 under most rainfall regimes.

For large roofs, such as at schools, the 14 cm × 14 cm V-shaped design described below, which has a cross-sectional area of 98 cm^2, is suitable for roof sections up to 50 m in length by 8 m in width (Fig. 8.12). When installed with a steeper gradient than 1:100 and used in conjunction with splash-guards, V-shaped gutters can cope with heavy downpours without large and unnecessary losses due to gutter overflow, splash, and spillage. A gradient of 1:100 also ensures less chance of gutter blockage from leaves or other debris as these are more easily flushed out. Under ideal conditions, a properly designed and installed gutter and downpipe system with splash guards can have a runoff coefficient in excess of 0.9 (90 %).

Downpipe cross sections are sometimes smaller than those of gutters as it is assumed that since they are normally vertical, water will pass through them faster than through gutters. In roof catchment systems, however, downpipes should have similar dimensions to gutters. This is because the downpipes are often not vertical and usually act as channels to convey water from the end of the gutter into the tank.

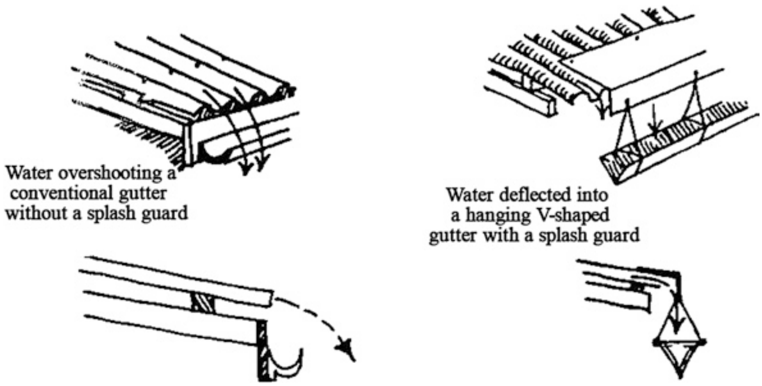


Fig. 8.12 Splash Guards—useful additions to use in conjunction with V-shaped gutters on long roofs to avoid water loss from over-shooting (Courtesy and adapted from Skinner 1990)

8.9.2 Splash Guards

During torrential downpours, large quantities of runoff can be lost due to gutter overflow and spillage (Fig. 8.12). This is particularly a problem on long roofs where, due to the slope of the gutter, it may hang many centimeters below the eaves of the roof. To overcome this problem, a device known as a splash guard, which was originally developed in Kenya, can be incorporated on corrugated iron roofs (Nissen-Petersen 1992). Splash guards consist of a long strip of sheet metal 30-cm wide, bent at an angle, and hung over the edge of the roof by 2–3 cm to ensure that all runoff from the roof enters the gutter. The splash-guard is nailed onto the roof and the lower half is hung vertically down from the edge of the roof. This simple device, which can be manufactured on site, serves two purposes:

(i) The gutter can be suspended from the splash-guard instead of being fitted in gutter-brackets nailed to a fascia-board, which becomes redundant.
(ii) The vertical flap of a splash-guard diverts all roof runoff into the V-shaped gutter hanging underneath it, preventing "over-shooting" or "under-cutting" of rainwater, which otherwise would lead to substantial losses.

An alternative way to deal with the problem of water over-shooting a conventional gutter is to use a specially designed extended V-shaped gutter or G-shaped gutter which wraps around the edge of the roof ensuring all runoff is directed into the gutter (diagrams of these designs can be seen in the next chapter Sect. 9.8).

8.10 Tank Inflow—with Self-Cleaning Mesh Screen

Coarse filters and screens are commonly used to exclude debris from entering storage tanks. A simple and appropriate design is the use of a self-cleaning screen. This consists of placing the end of the downpipe or down-gutter about 3 cm from the mesh screen in front of the inlet hole. The galvanized 5-mm mesh screen should slope at not less than 60° from the horizontal above the tank inlet.

Objects larger than 5 mm, such as stones, small branches, and leaves, are pushed down the gutter and downpipe by flowing water until they strike the mesh. Here the debris will be caught and roll downward off the screen while the water shoots through the mesh into the tank.

Any dust from a roof, which is finer than the mesh, will enter the tank along with the water and settle at the bottom of the tank. Since dust lying on roofs is sterilized by prolonged exposure to sunshine and it will settle on the tank floor below the draw-off pipe in-take, it should not adversely affect water quality once it has settled.

Guttersnipe

The guttersnipe or leaf-slide is another very simple device for removing leaves, insects, and other debris from entering the storage tank (Fig. 8.13) and works along the same principles as the self-cleaning tank inlet. The guttersnipe sits at

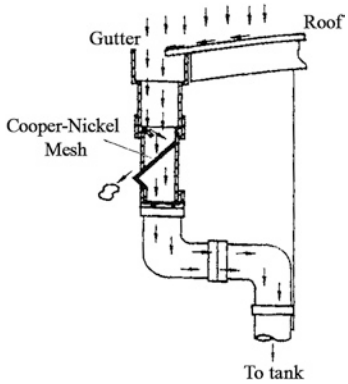


Fig. 8.13 Guttersnipe or Leafslide (Source and courtesy Finch 1994)

the top of the downpipe in PVC housing at least 15 cm below the gutter inlet, and consists of a stainless steel or copper-nickel mesh angled at 60° from the horizontal. This wire screen has 1-mm gaps between the wires, and has the size of about 18 cm by 9 cm for a standard gutter. The screen allows water to pass through it but excludes other material which is washed off in a self-cleaning mechanism. The maintenance required involves the cleaning of the screen once a month to remove any algae which may accumulate. Tests have revealed that use of guttersnipes may reduce bacteriological contamination of stored rainwater (Finch 1994).

8.11 Water Extraction Devices and Other Features

In order to withdraw water from the storage reservoir, some form of extraction device is needed. Normally this will be some form of water tap or pump and the extraction device is a vital link in the system. Broken or leaking taps, all too often, render systems useless for want of regular inspections and basic maintenance.

8.11.1 Taps

A properly functioning and well-maintained tap is a necessity for any surface catchment tank. A dripping or leaking tap can lose thousands of liters, quickly emptying most average sized rainwater tanks. Taps are most vulnerable to breakage on communal tanks particularly at schools where they are frequently used and occasionally abused by the children. Since a 20-year life expectancy is a reasonable assumption for a well-constructed and maintained water tank, a durable tap with a good life expectancy should be fitted, especially on communal tanks.

For communal tanks being used by large numbers of people, a lockable tap may be appropriate in order to control access and extraction rates from the tank. Sometimes tanks become empty simply because taps are left dripping or running.

Self-closing taps can help overcome this problem although they are more prone to breakage and maintenance problems. Privately owned household tanks generally suffer few problems with tap breakage and maintenance. While this is partly due to lower levels of usage, it is also an interesting reflection on human nature.

Often the water tap on a tank is built into the wall of a tank, where it is difficult to avoid seepage and impossible to draw water from that part of the tank situated below the level of the watertap—a wastage of storage capacity called "dead storage".

In other water tanks, the draw-off pipe is rightly placed in the concrete of the foundation but the tap is raised to about 60 cm above the floor of the tank to allow for a bucket to be placed under the tap. Again, this arrangement wastes a good portion of the tank volume on "dead storage" sometimes as much as 20 % of the tank volume. To avoid "dead storage" in the lower part of water tanks, the water tap must be positioned below the floor level of a tank. There are two ways of obtaining this: either the foundation of a tank can be elevated around 50 cm above the ground level by constructing a solid platform or the tap point can be situated below ground level.

8.12 Tank Overflow

Additional "dead storage" will be created at the top of water tanks, if the bottom of the overflow pipe is not placed at the maximum water level of a water tank. This means that in flat roofs made of reinforced concrete, the overflow pipe should be concreted into the base of the roof to avoid dead storage. In domes being used for storage, the overflow can either be placed at the level of the inlet for guttering, which determines the maximum water level or the gutter inlet can also be used as the overflow. In any case, the overflow should be situated vertically over the tap stand to force water overflowing to fall onto the concreted tap point excavation, from where it is drained to a soak-away pit without eroding the base of a water tank.

8.13 First Flush Systems

Although not absolutely essential for the provision of potable water in most circumstances, when effectively operated and maintained, first flush systems can significantly improve the quality of roof runoff.

If poorly operated and maintained, however, such systems may result in the loss of rainwater runoff, through unnecessary diversion or overflow and even the contamination of the supply.

In poor communities, where the provision of even a basic roof tank represents a substantial upgrading of the water supply, the addition of a first flush system will add some additional expense to the system and it may be worth considering it as a future upgrade.

In some locations, where roof surfaces are subjected to a significant amount of blown dirt and dust, or where particularly good quality water is required and proper operation and maintenance can be guaranteed, a first flush system can be very effective.

In a study by Yaziz et al. (1989), water quality analysis of the initial “foul flush” runoff from both a tile and galvanized iron roof in which the first, second, third, fourth, and fifth liter of runoff were sampled revealed high concentrations of most of the pollutants tested in the first liter with subsequent improvements in each of the following samples, with few exceptions. Fecal coliforms, for example, ranged from 4 to 41 per 100 mL in the first liter of runoff sampled but were absent entirely in samples of the fourth and fifth liters. The study also revealed that the rainfall intensity and number of dry days preceding a rainfall significantly affect runoff quality with higher pollution concentrations after long dry periods. Based on these findings, the minimum volume of foul flush (“first flush”) which should be diverted for an average sized ‘Australian’ house was recommended to be 20–25 L by Cunliffe (1998).

The most effective first flush devices are often the simplest such as those used in northeast has been fitted as standard to thousands of tanks. Nevertheless, regular cleaning of the devices is needed.

To avoid the need of the manual resetting, draining and cleaning of the first flush system various self-cleaning systems have now been developed.

Based on this experience, it is recommended that if any kind of first flush device is to be considered, it should be simple, and should not require regular attention regarding its operation and maintenance.

Examples of such devices include:

- Self-cleaning first flush device.
- Self-cleaning gutter snipes sold commercially (see Fig. 8.13).
- Self-cleaning inlet mesh.
- Sedimentation chambers requiring only occasional cleaning.
- Movable downpipes for diverting the runoff from the season’s first downpour.

The last device is appropriate in regions with distinct wet and dry seasons. This cleans the catchment and delivery system flushing away dust and other debris which may have accumulated in the dry season.

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