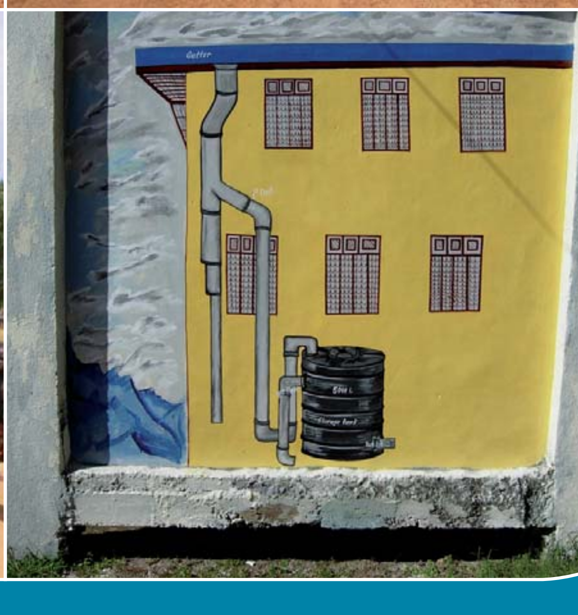
Roofwater Harvesting

A Handbook for Practitioners



T.H. Thomas and D.B. Martinson

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Preface

The growing role of roofwater harvesting

Water professionals are becoming increasingly worried about water scarcity. The UN World Water Development Report of 2003 suggests that population growth, pollution and climate change are likely to produce a drastic decline in the amount of water available per person in many parts of the developing world. Domestic Roofwater Harvesting (DRWH) provides an additional source from which to meet local water needs. In recent years, DRWH systems have become cheaper and more predictable in performance. There is a better understanding of the way to mix DRWH with other water supply options, in which DRWH is usually used to provide full coverage in the wet season and partial coverage during the dry season as well as providing short-term security against the failure of other sources. Interest in DRWH technology is reflected in the water policies of many developing countries, where it is now cited as a possible source of household water.

Rainwater systems deliver water directly to the household, relieving the burden of water-carrying, particularly for women and children. This labour-saving feature is especially crucial in communities where households face acute labour shortages due to the prolonged sickness or death of key household members, increasingly as a result of HIV/AIDS, coupled with a reduction in the availability of labour due to education and migration.

There has been much recent activity concerning domestic roofwater harvesting in countries as far apart as Kenya, China, Brazil and Germany. Many countries now have Rainwater (Harvesting) Associations. The technique is approaching maturity and has found its major applications where:

- rival water technologies are facing difficulties (for example due to deterioration in groundwater sources)
- water collection drudgery is particularly severe (for example hilly areas of Africa).

In some locations, such as India, DRWH has been strongly linked with aquifer replenishment programmes. Elsewhere it is seen as an attractive technique, in part because it fits with the decentralisation of rural water supply and is suitable for household management.

Purpose of this handbook

This handbook has been written to assist NGO and government staff responsible for implementing domestic roofwater harvesting systems or programmes. It is also meant to serve as a source of material for rainwater harvesting associations preparing national design guidelines in local languages. Finally, it could be used by individual householders or masons literate in English to design single roofwater harvesting systems.

Part A (Chapters 1 to 4) is focused on answering the question "When should DRWH be considered as a water supply option for a specified location or country?" This entails addressing other questions, such as, "How might DRWH be combined with other water sources?" and "How can DRWH systems be delivered?" Thus, Part A is aimed at those with responsibility for choosing technology – for example managers of NGO and governmental water programmes.

The rest of the handbook, Part B, is aimed at those implementing DRWH programmes and concentrates on which of the many forms of DRWH should be used in particular circumstances.

The handbook is primarily focused on 'low-cost' DRWH in the 'humid tropics'. It is deliberately specialised in geographical scope and target group, and more prescriptive than the good review of rainwater harvesting practice contained in John Gould and Erik Nissen-Petersen's 1999 book: *Rainwater Catchment Systems* (See Chapter 11 for references and for sources of further information on domestic RWH).

By 'humid tropics' we mean areas close to the Equator where rainfall is at least 800 mm per year and where normally not more than three successive months per year have negligible rainfall. However many of the techniques described are also suitable for the Monsoon tropics where annual rainfall is over 1,000 mm but the dry season is long (up to five consecutive months with negligible rainfall).

The table below shows how typical water yields vary with climate (tropical locations are shown in bold). Note that the rain per month in the wet season does not vary greatly across the tropics.

'Low cost' is an inexact term: we essentially mean 'affordable in a developing country'. Providing domestic water in rural areas via 'point sources', such as protected shallow wells, springs, boreholes and gravity schemes, appears to cost at least US$ 50 per household. In many ways, DRWH gives a better water service than do point sources, because it entails no fetching or queuing. It would be attractive to define 'low-cost' as meaning 'costing not more than US$ 60 per household' (roughly the cost of a corrugated iron roof for a small house.) Unfortunately, this is too difficult a cost target for DRWH to reach except under especially favourable climatic conditions. The handbook has therefore been written using US$ 100 per household as a nominal cost ceiling for a system that will meet the bulk of a demand for 100 litres of clean water per household per day. Elaborate and high-performance DRWH systems costing over US$ 1,000 per household, which can be found in countries like USA, Australia and Germany, lie outside the scope of this handbook.

Climate	Examples	Annual rainfall mm	'Wet' months / year*	Mean daily yield over 12 months (large store RWH)	Mean daily yield in wet season(s) (low-cost RWH)
		mm		litre/person/ day	litre/person/ day
Arid	Khartoum Karachi	200	2	2.5	15
Semi-arid	Bulawayo N Peru	400	4	5	15
Summer rains	**Guayaquil** **S W China**	800	4	**10**	**25**
Humid coastal & Monsoon	**Chennai** **Beira**	**1,000**	**6**	**12.5**	**25**
Equatorial (2 wet seasons)	**Kampala** **Ibadan**	**1,500**	**9**	**18.5**	**25**
High rainfall every month	**Singapore** **Manaos**	**2,000**	**12**	**25**	**25**
V High rainfall seasonal	**Freetown** **Yangon**	**>2,500**	**7**	**>30**	**>50**

Table assumes 7 sq m of roofing per person; *'wet' = rainfall over 40 mm/month

As a short handbook rather than a lengthy research report, this publication offers only brief evidence to support its recommendations and suggestions. Much of that evidence has however been published elsewhere, for example at the biennial conferences of the International Rainwater Catchment Systems Association (IRCSA)

All the hardware recommended has been field-tested.

Background and acknowledgements

In 2000 the UK Government's Department for International Development (DIFD) granted a contract to the Development Technology Unit at Warwick University, UK to research low-cost domestic roofwater harvesting for application in poor households in tropical countries. The research was undertaken in collaboration with local NGO partners, namely Water Action in Ethiopia, Lanka Rain Water Harvesting Forum in Sri Lanka and ACORD in Uganda. The study centred on developing and field testing low-cost DRWH technologies in one urban/peri-urban and two rural communities in each country, (see www.eng.warwick.ac.uk/dtu/pubs/rwh.html for reports). The research

programme culminated in March 2003 with national workshops in all three countries, feedback from which has been incorporated in this handbook.

That work built upon other research into tropical roofwater harvesting undertaken from 1998-2001 with support from the European Union and involving a partnership of British, German (FAKT), Indian (IIT Delhi) and Sri Lankan (LRWHF) organisations. The geographical focus of both research programmes was on areas where DRWH is comparatively easy and hence cheap to practice, rather than the semi-arid areas hitherto targeted by most roofwater-harvesting programmes. Lessons learnt during two further studies in Uganda since March 2003, funded respectively by the Ugandan Directorate for Water Development (DWD) and the Southern & Eastern Africa Rainwater Network (SEARNET), have also been incorporated in the handbook.

As a result of these and other recent programmes, the art of DRWH has advanced considerably in recent years. It is the purpose of this handbook to communicate these advances in a form suitable for practitioners to apply directly. Of course, further improvements in DRWH technology, including cost reductions, can be expected in the coming decade.

The authors of this handbook are happy to acknowledge with thanks the financial support of DFID and the European Union. Helpful advice from many friends, students and rainwater harvesting specialists, especially those in Sri Lanka, India, Uganda and Ethiopia, has been incorporated.

PART A

When should DRWH be considered as a water supply option for a specified location or country?

Chapter 1. Introduction to Roofwater Harvesting

1.1 What is roofwater harvesting?

'Rainwater harvesting' is a widely used term covering all those techniques whereby rain is intercepted and used 'close' to where it first reaches the earth. The term has been applied to arrangements to cause rainfall to percolate the ground rather than run off its surface, to forms of flood control, to the construction of small reservoirs to capture run-off water so that it can be used for cattle or micro-irrigation and to the collection of run-off from roofs and other impermeable surfaces. Thus, *roof*water harvesting is a subset of *rain*water harvesting, albeit an important one. This handbook covers only roofwater harvesting.

1.1.1 The basic roofwater harvesting system

Rain falls onto roofs and then runs off. The run-off is extremely variable – for the typically 99% of each year that it is not raining, run-off flow is zero. However if the run-off is channelled into a tank or jar, water can be drawn from that store whenever it is needed, hours, days or even months after the last rainfall. Moreover as the jar is generally located immediately next to the building whose roof the rain fell on, roofwater harvesting is used to supply water to that very building, with no need for the water to be carried or piped from somewhere more distant.

The essential elements of a roofwater harvesting system, as shown in Figure 1.1, are a suitable roof, a water store and a means of leading run-off flow from the first to the second. In addition, some RWH systems have other components to make them easier to manage or to improve the quality of the water. These elements are described briefly here and analysed in detail later in this handbook.

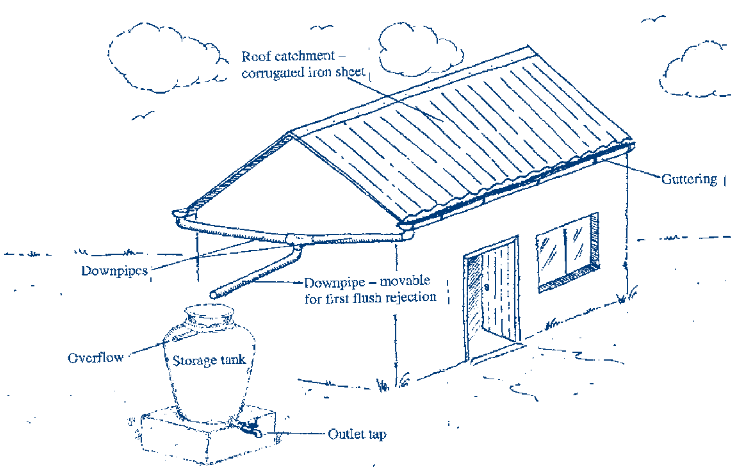


Figure 1.1. Picture of a simple domestic RWH system

The roof

To be 'suitable' the roof should be made of some hard material that does not absorb the rain or pollute the run-off. Thus, tiles, metal sheets and most plastics are suitable, while grass and palm-leaf roofs are generally not suitable.

The larger the roof, the bigger the run-off flow. The rainwater reaching a roof in a year can be estimated as the annual rainfall times the roof's plan area, but in the tropics only about 85% of this water runs *off* the roof. The remaining 15% is typically lost to evaporation and splashing. If the rain falls mainly as light drizzle, as in some more temperate countries, even more than 15% will be lost in this way through slow evaporation.

Often, and especially in areas of low annual rainfall, the available roof area is not big enough to capture enough water to meet all the water needs of people in the building. In this case, either the roof must be extended, or roofwater harvesting can only be one of a number of sources of water to meet need. In fact, getting water from more than one source is the usual practice in most rural areas of developing countries, and is reviving in popularity in richer countries.

The water-store

A RWH system with a large water store will perform better than one with a small store. A small store such as a 500 litre jar will often overflow in the wet season (because rainwater is flowing in faster than household water is being taken out), 'wasting' up to 70% of the annual run-off. It will also run dry before the end of the dry season. However, a small store is cheaper than a larger one and gives cheaper water (e.g. fewer cents per litre delivered). The designer of a system can choose the combination of cost and performance that best suits the user's needs and funds available. The figures in the box give a very rough guide as to how performance of a household system changes with store size. This shows that it takes a huge increase in store size to get a relatively small increase in performance.

Very cheap system (e.g. only 250 litre store)
Annual water yield in litres = 25% of annual rainfall (mm) x roof area (sq metres)

Cheap system (e.g. 1,000 litre store)
Annual water yield in litres = 45% of (annual rainfall x roof area)

Normal system (e.g. 5,000 litre store)
Annual water yield in litres = 65% of (annual rainfall x roof area)

Very expensive system (e.g. 16,000 litre store)
Annual water yield in litres = 85% of (annual rainfall x roof area)

Water stores are given various names, such as 'tank', 'jar', 'drum' and 'cistern', depending upon their size, shape or location. They can be above ground, underground or 'partly below ground' (i.e. set into the ground but with the top above the surface). Usually a RWH system uses only one water store, but there are situations where it is cheaper to use several different stores, placed round the rain-collecting roof.

Guttering

The arrangement for leading water from the roof to the water store is usually called 'guttering' or 'gutters and downpipes'. The gutters are open channels carrying water sideways under the edge of the roof to a point just above the water store; the downpipes are tubes leading water down from the gutters to the entrance of the water store. There are many ways of achieving the transfer of water from roof to store – for example in Northern China the run-off is allowed to fall from the roof edge onto a paved courtyard and there led towards an underground tank. However guttering is the most popular method because it helps keep run-off water clean.

Other components in a RWH system

Later in this handbook, we will discuss extra components found in some but not all RWH systems. These include screens and filters, overflow arrangements, level gauges and pumps (to lift water out of underground tanks).

1.1.2 The management of a RWH system

To get the best performance from a RWH system, water needs to be effectively managed by the user, to ensure that water is available in the dry season, when water has its highest value. Indeed one purpose of a water store is to transfer water from the wet season to the dry season. RWH systems are managed directly by householders rather than by government, water committees or water companies, a task that householders soon learn to do well. This style of management is often considered an advantage, since the management and maintenance of communal shared sources such as boreholes, has often proved problematic.

1.1.3 Institutional and domestic forms of RWH

Rainwater can be harvested from the roofs of individual houses, and that form of RWH is the main focus of this handbook. There is also widespread harvesting of roofwater in institutions such as schools. However this practice has often run into management problems, such as arguments about who 'owns' the water or who should maintain the system. For these reasons, many institutional RWH schemes have been failures. There is even interest in using institutional roofs to collect domestic water but, as discussed in Chapter 10, the total area of roofing on schools, churches and government offices is never large enough to supply all the houses in a settlement with water from the sky.

1.2 General character of roofwater harvesting

The general characteristic of harvested roofwater may be broken down into *convenience, quantity* and *quality*. This Introduction describes these properties in general terms, and each is explored in detail later in this handbook.

The most striking characteristic of DRWH is that it delivers 'water without walking'. In this sense, it offers users much greater *convenience* than do point water-sources like wells from which water has to be fetched, or even than public standpipes. This convenience is moreover available at every house on which rain falls, whether on a mountain top or on an island in salt water – the supply is not constrained by geology, hydrology or terrain. The convenience of DRWH is thus similar to that of a household piped connection except that the delivery from a RW tank is at very low pressure and needs a supplementary power source if it is to be lifted to a household header tank. Properly managed, a DRWH source is often more reliable than a piped water source in a tropical country (where many piped systems deliver water only intermittently), and management is wholly under the household's control.

The *quantity* of water obtainable from a typical house roof is not large. At high demand levels, such as 50 litres per person per day, DRWH will very rarely be able to meet all the household's water demands. However, at levels of 15 to 20 litres per person per day, DRWH *may* meet all of the demand. Annual output depends on the rainfall, the roof size and the complexity of the harvesting system. Expensive systems with large tanks deliver more water than cheaper systems with small tanks.

The *quality* of harvested rainwater varies with the seasons, the roof type and the complexity of the DRWH system. Elaborate RWH systems exist in rich countries that give the highest quality of water. Crude and informal RWH systems may be found in poor countries giving water that is green with algae and risky to drink. Between these extremes, good tropical-country DRWH practice gives water that is as safe as that obtainable from protected point sources such as wells, and often superior to them in taste.

> Roofwater harvesting provides a safe and convenient source of water of limited quantity, which is best used as a source of good quality water (e.g. for drinking and cooking) in a context where less convenient and/or dirtier sources are available to meet some of a household's other water demands.

1.3 Implementing domestic roofwater harvesting

1.3.1 Supply modes

Establishing a successful domestic RWH system entails a chain of actions, starting with the appraisal that DRWH is suitable technology for a particular situation and leading all the way through to system maintenance. Almost invariably it is members of the benefiting household who *operate* a DRWH system, because they are on site and because it is very awkward for an external agency to control how fast a household uses up its stored rainwater. However, some actions in some situations may be carried out by external agents such as government officers, voluntary organisations, artisans or private businesses. Table 1.1 shows some common combinations.

Table 1.1. Models and agents of DRWH supply and operation

	Models of RWH delivery					
	DIY / Self build	**Self-supply from market**	**Government rural water programme**	**NGO-aided**	**New middle-class estate**	**Service contract**
Full cost borne by user or subsidised?	Full cost	Full cost	Subsidised	Subsidised	Full cost	Full cost
Action	**Agents**					
Who decides if DRWH suitable?	Household	Household	Government	Household + NGO	Estate developer	Estate developer
Who selects/ designs a RWH system?	Household	Household / artisan	Government	Household + NGO	Estate developer	Service company
Who finances construction?	Household	Household/ micro-credit	Household+ government	Household + NGO	Household /developer	Service company
Who builds system?	Household	Artisanal installer	Contractor	Household + NGO	House builder	Service company
Who operates system?	Household	Household	Household	Household	Household	Household
Who maintains system?	Household	Household	Household	Household	Plumber	Service company

1.3.2 Self-supply

'Self-supply' DRWH is quite common in several countries. It normally takes one of two forms, namely 'informal' DRWH and 'suburban' DRWH, applied by respectively poorer and richer households.

Poor, especially rural, households, if they possess suitably hard roofing, often collect roofwater with a minimum of equipment. Bowls and buckets are placed under the eaves during rainfall. Those eaves may have very short and temporary gutters or no gutters at all, so run-off is usually intercepted only from a fraction of the roofing. The water may be transferred to some other container or used directly from the collecting vessel. By this informal means, some or all of a household's water needs can be met on rainy days. In the humid tropics there are typically around 100 rainy days per year, although on some of these only a millimetre or two of rain falls, insufficient to fill a set of bowls. A typical wet-day rainfall is 10 mm and the area of roof whose run-off is intercepted is typically only 3 to 6 square metres, so the average wet-day run-off that can be captured is less than 50 litres. However, fetching water from wells on cold, wet and slippery days is particularly unpleasant, so even this small yield is highly valued.

A few rural households have acquired larger receptacles such as 200 litre oil drums capable of holding two or three days water demand. Such receptacles need to be fed with the run-off from 2 or 3 metres of roof-edge, which requires an equivalent length of crude guttering to be fixed to the roof or to protrude from either side of the receptacle itself. These informal arrangements do not generally generate very clean water. Unless the receiving bowls are stood on chairs, water can be contaminated by ground splash. Water in oil drums is contaminated when cups are dipped in and, unless drums are covered, they grow algae and mosquitoes within a few days of being filled.

Figure 1.2. Informal roofwater harvesting (Picture: T.H. Thomas)

Any programme to mainstream formal DRWH can build upon householders' experiences with informal DRWH, because this leads to an appreciation of rain-harvesting possibilities, some skill in managing a very limited supply and often a desire to 'upgrade' to a larger and more reliable system.

Suburban or richer household DRWH in tropical countries has a very different character. It appears wherever the public or communal water supply is unattractive to the occupants of middle-class houses. Such houses almost always have hard, often quite large, roofs, while their occupants have relatively high water consumption and the wealth to make a significant investment in assuring a reliable, convenient and labour-saving supply. Occasionally such houses are rural, for example the retirement houses, rural retreats or family homes of successful professionals. More often, they are suburban, part of the urban economy not yet benefiting from reliable municipal piped water. In some landscapes, such houses use shallow on-site wells or even deep boreholes. In others, water is brought by bowser (tanker). DRWH is however an attractive option in the humid tropics and has led to the development of a supply chain for tanks (especially galvanised iron, high-density polyethylene (HDPE) and underground concrete tanks), and for gutters and such ancillaries as electric pumps to lift water to a header tank. Richer household self-supply may disappear once piped water reaches the relevant suburb or it may be retained as a cost-saving supplement to an often unreliable piped supply. Interestingly, DRWH has made recent advances in countries like Germany and Japan despite almost every house already having a piped water supply.

Richer household DRWH can be an important precursor to any form of publicly financed DRWH. It creates a market for both components and specialist installers and it offers a fashionable example for poorer householders to follow. In some cases, it is in the public interest actively to encourage this form of DRWH, for example because it relieves demand on urban water supplies nearing the limit of their natural capacity or because it offers some storm-water drainage benefits. There may also be need for public or state involvement in raising the quality of such private DRWH systems or in limiting the power of water companies to prohibit them.

1.3.3 Public supply

Mainstreaming DRWH as a normal option (often as an alternative to further developing groundwater sources) within public or communal water supply poses special problems for water authorities. DRWH is *not* in its essence a collective solution which can be centrally managed. Nor is it usually suitable as a sole supply, because there is not enough roof area per person to generate a generous annual flow. It is also not an option for some members of a community if they have poor homesteads with unsuitable roofs. So although DRWH may be cheaper per litre, more potable and more convenient than rival sources, it does not easily fit the practices or criteria of water authorities or water aiding charities.

Far more than point sources like springs, wells and tap-stands, DRWH requires the cooperation of individual households. Its equipment has to be located on private property; its management is household by household; it is not easy to monitor water quality or even the quality of installations. Unlike well-drilling or constructing gravity-fed systems, installing DRWH does not fit easily with the use of tendering (by contractors) for publicly-funded improvements in water supply. DRWH is generally so unattractive to the owners of private water companies that they have sometimes tried to get it prohibited!

For all these reasons, governments and charities cannot promote roofwater harvesting programmes simply by adding ‘DRWH’ to a list of approved technologies.

In general, a public-private cost-sharing approach is desirable, with households paying part of the cost of their own household systems. Indeed, it is an important attraction of DRWH that it empowers householders and encourages their investment in water infrastructure, putting their water supply on a similar footing to housing itself.

Because of this very distinctive character of DRWH, a governmental or NGO DRWH programme requires careful design. The details of such design are discussed in Chapter 4.

Many charities and NGOs have been down the road of delivering subsidised DRWH in the last decade, so the task can be achieved. Often the level of subsidy has been very high (as with drilled wells) but there are also examples of subsidy levels below 50%. There is less experience to date of government-financed DRWH and, for that reason, 'piloting' of both the technology and method of delivery is desirable before it is extended on a large geographical scale.

Chapter 2. The Advantages and Limitations of DRWH

2.1 DRWH compared with other forms of water supply

Almost all water used by human beings derives from rainfall. However, it is always necessary to store water, so that it can be used when rain is not actually falling, and it is often necessary to transport it from where it falls to where the user is located. Roofwater harvesting differs from other water supply modes in that there is no need to transport water, since it is used within a few metres of where it falls as rain. It does not use the soil as its storage medium, as is the case for almost all other modes.

Figure 2.1 below shows the main forms of rural water supply and marks by bold lines and arrows where water *carrying* occurs. Forms of lateral transport other than carrying are underground flow through an aquifer, surface flow along a river and gravity flow down a pipe. (This figure does not show the pumping of water from a well, spring or reservoir to a tap-stand or to a household tap.)

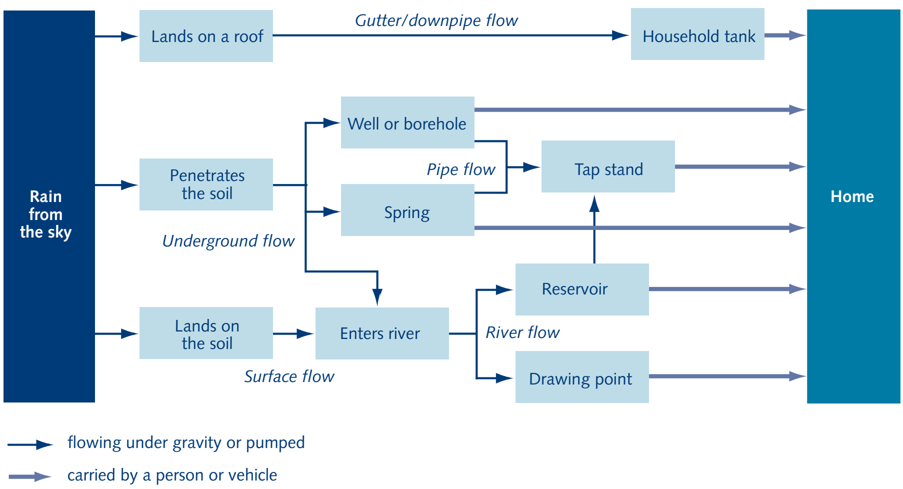


Figure 2.1. Common rural water supply techniques

The figure also shows the means of storing ('buffering') water from the point when it falls as rain until it is used in a household. In the case of DRWH systems, water is normally stored in 1,000 to 10,000 litre household tanks – also sometimes called 'jars' or 'cisterns' – and it is these tanks that dominate the cost of the system. In water supply other than DRWH, the cheapest and most common way of storing water is in the ground itself, in an aquifer whose top surface (water table) rises and falls with the seasons. However, there are often problems with aquifers. They may pollute the water they hold with such natural minerals as iron, fluorides or arsenic, with man-made nitrates derived from fertilisers or sometimes with pathogens from latrines. They may be too thin or too deep, and in areas of crystalline rock they can be impermeable, preventing water flowing through them. Aquifers are hard to 'manage' and in many countries the community finds it hard to prevent the water table dropping year by year due to excessive pumping. Often an aquifer is far below the settlement it serves, so that water must either be lifted from deep wells or carried uphill from valley springs.

We can broadly describe DRWH by its six main characteristics:

- collects only the rain falling on the available roofs (which occupy only a small fraction of the local land area on which rain falls)
- requires a suitable roof type (normally a 'hard' roof, such as iron sheets, tiles or asbestos) and on-site water storage (normally a tank)
- delivers water direct to the house without need for water-carrying
- does not require favourable local topography or suitable geology
- is a household technology, and therefore does not require communal or commercial management
- gives chemically clean and usually biologically low-risk water.

Table 2.1 compares DRWH with the common alternatives. Fully-shaded circles represent DRWH performing 'better' than the named competition. Empty circles show where it performs 'worse'. Semi shaded circles show where the performance is about the same.

Table 2.1. Rough comparison of DRWH with main competitor technologies

CRITERION OF COMPARISON, (assuming DRWH is feasible in terms of roofing and mean rainfall)	Assume competitor technologies are applied under conditions favourable to their use					
	Protected shallow well	Borehole	Protected spring	Prot spring + gravity pipeline to standpipe	Water collected from river or pond	Treated water pumped to standpipe
Is DRWH system cost per HH lower?	◐	●	○	●	○	●
Is DRWH system construction easier?	◐	●	◐	●	○	●
Is DRWH management simpler?	●	●	●	●	○	●
Is DRWH more convenient to use?	●	●	●	●	●	●
Is DRWH chemical quality better?	●	●	●	●	●	◐
Does DRWH depend less on favourable geology/topology?	●	●	●	●	●	●
Is DRWH biological[1] quality better?	◐	◐	◐	◐	●	○
Is DRWH drought[2] security better?	○	○	◐	◐	◐	○
Does DRWH give better water access[3] to poor households?	○	◐	○	○	○	◐

● Yes ◐ Similar ○ No

Notes on Table 2.1

1 The comparison of biological quality assumes (a) quality is measured in the house, not at source and (b) only the most basic water-quality design features are present in DRWH system. Addition of first-flush diversion, inlet filtering and floating off-take to the DRWH system would raise most comparisons of biological quality to 'better'.

2 Unless extremely large and expensive systems are used, the feature which DRWH performs worst is water security during a drought. This is partly compensated by the greater ease with which bowsered water can be distributed to households possessing (RWH) water tanks.

3 Comparison of access by the poorest in the community is strongly affected by whether full, partial or zero cost-recovery applies in the local water sector. In a 'gift economy' DRWH investment could be focused on the poorest households. However such households are likely to suffer the technical disadvantage of having small or otherwise unsuitable roofs.

2.2 Quantity: How much water can be harvested?

The quantity of water (Q) that runs off a roof into gutters, in litres per year, is fairly easy to calculate using the rough equation

$$Q = 0.85 \times R \times A$$

where:

R is the total rainfall in millimetres in that year

A is the guttered roof area in square metres

0.85 is a 'run-off coefficient'. It takes into account evaporation from the roof and losses between the roof & any storage tank; its value is around 0.85 for a hard roof in the humid tropics, where rain is often intense. It would be lower where rain falls as light drizzle and much lower for a thatch roof.

The amount of this run-off that can be actually delivered to a user by a RW system is *U* litres per year, where *U* is less than the run-off Q because the receiving tank sometimes overflows.

In fact

$$U = E \times Q$$

Where *E* is the 'storage efficiency' (a number never greater than 1) with which we use the water that reaches the tank. This efficiency *E* varies with:

- the tank size (bigger is better but also more expensive)
- the climate (equatorial is best, having a long-dry-season is worst)
- the way water is drawn: a higher rate of demand means higher storage efficiency E and so more litres in total but lower reliability (fewer days' supply per year).

There are different ways of employing DRWH, with names like 'sole source DRWH', 'main source DRWH', 'wet-season DRWH' and 'potable water DRWH'. These are examined in the following section. However, the storage efficiency (*E*) for all of them is usually between 0.4 and 0.8. Taking into account both the run-off coefficient and storage efficiency the water available to a household during a year is between one third and two-thirds of the rainwater falling onto the guttered part of the roof. How to select a tank size to get a desired efficiency or other performance is covered in more detail in Chapter 6 of this handbook.

In assessing the amount of water to expect from new DRWH systems it is therefore desirable to collect annual rainfall data and also to roughly survey the sizes of suitable (e.g. hard) roofs. Whilst the *fraction* of houses having hard roofs may be recorded in national household surveys, the distribution of roof *sizes* is unlikely to be recorded there. The median roof size and the size corresponding to the (lowest) 20^{th} percentile of house roofs should suffice to evaluate the scope for DRWH in any particular settlement.

Example based on a fixed storage efficiency:

Suppose rainfall is 1150 mm a year and the guttered-roof area is 4 m x 6 m. Then the expected roof run-off is 0.85 x 1150 x 4 x 6 = 23,460 litres per year. Assuming a storage efficiency of 70% the water drawn by the household would be 0.7 x 23,460 = 16,420 litres a year. The following examples illustrate user options:

- Employing a small tank, the water would all be used during the wet season of 20 weeks (**wet-season RWH**). The family could draw about 117 litres a day during that season but nothing for the rest of the year.
- By means of a medium-sized tank, the water could be spread over 40 weeks (**main source RWH**). the family could draw 59 litres per day for those 40 weeks.
- By means of a very large tank, the water could be used throughout the year as a **sole source**. The supply would only be around 45 litres per day for the whole year. (However, with a large tank, storage efficiency would rise above the 70% assumed above, so that 55 litres per day or more might be obtained).

2.3 Different ways a household can use DRWH

Domestic roofwater harvesting can yield adequate quantities of water throughout the humid tropics, but only low quantities in semi-arid zones. Unless the DRWH system includes a large and expensive storage tank, the availability of harvested water varies with the seasons. In light of these facts and the six characteristics listed in section 2.1, we have some choice in the way we use DRWH. We could aim at the highest level of delivery and accept the high system cost this incurs, or we could accept a lower service at a much lower cost. This is the basis of Table 2.2 below.

Table 2.2. Five styles of using domestic roofwater harvesting

1. As the sole source of water in situations where there is little seasonality in rainfall or where all other alternatives are impractical, unusually costly or socially unacceptable
2. As the main source of water, providing at least 70% of annual water use in situations where (usually higher cost) alternatives can be used to supplement it during dry periods
3. As only a wet-season source – whose benefit is greater convenience in water collection for a significant part of each year
4. As a potable water only source – providing 5 to 7 litres per person per day throughout the year
5. As an emergency source of water – to be kept for when all other sources have failed, or for fire-fighting and other emergencies.

The first four styles listed in this table are described in the following paragraphs. Discussion of the fifth style (RWH as emergency water) may be found in Chapter 10, while the vulnerability of RWH systems to various disasters is covered in section 2.5 below.

2.3.1 Using DRWH as a sole source of water

RWH is not very suitable as a sole water source, because to achieve this requires such an expensive tank. Sole source RWH is used only if all alternatives to it are really difficult. Either water demand must be small, as in the example above, *or* the roof must be big *or* the annual rainfall must be high. Indeed, except in locations having a mean rainfall of over 2,000 mm/year, the main limitation on sole source RWH is roof area.

2.3.2 Using DRWH as a main source

If the RWH system is considered only as a main source, but does not have to meet full water demand during the driest months, its tank can be made considerably smaller than for sole source supply. A smaller tank is cheaper, but will often overflow during days of heavy rain and this will lower the efficiency with which roof run-off is captured to about 65%. The tank will also run dry during the driest months, although careful water management can reduce the length of these periods.

A humid household in the tropics will experience fairly generous RW availability during maybe 60% of each year (the wetter part), reduced availability for another 30% or so of each year and almost no availability for the remaining 10% of each year. During the period when no roofwater is available all household water must come from another source – the roofwater tank may prove useful for storing this 'other' water and even for improving its quality by sedimentation. This water from other sources may be relatively expensive per litre, whether measured in cash, in walking/queuing time or in sickness due to drinking poor quality water. For this reason meeting 80% of annual consumption by use of roofwater may reduce the total annual cost of water supply from other sources by only 60%.

It is very beneficial if during the drier months the household reduces its demand for water. For example 2 months with partial supply (50% of demand) is of greater benefit to residents than 1 month with full demand met followed by 1 month with no supply at all (empty tank). The simplest and generally most efficient way of rationing water from a tank is to vary withdrawals according to the level of the water left in the tank. We recommend an adaptive regime such as that in table 2.3:

Table 2.3. Adaptive demand strategy (for main source applications of DRWH)

Amount of water in tank	**Withdrawal** (litres/person/day)
Tank is over 2/3 full	20
Over 1/3 but under 2/3	15
Under 1/3	10

See 6.2.2 for explanation of adaptive demand strategy

2.3.3 Using DRWH as a wet season water source

Many households already collect roofwater on wet days. Unfortunately lack of guttering and storage vessels means they can only intercept a small fraction of the run-off. Wet season DRWH markedly increases this fraction using quite cheap equipment. With guttering, plus tanks or jars whose capacity is equal to 3 or 4 days consumption (say 400 litres), a household can meet all its water needs with roofwater throughout almost all of the wet season. This is particularly attractive where other sources are especially dirty at such times of year or if water fetching is especially unpleasant.

This wet season harvesting can become a nice precursor for more expensive main source harvesting, allowing households to get used to managing limited supplies and maintaining such hardware as gutters.

2.3.4 Using DRWH as a potable water source

In many rural situations and some urban ones, roof run-off water is cleaner than water from rival sources. One can therefore choose to operate potable water DRWH, drawing from the tank only water for drinking, cooking and basic hygiene, and using other sources for water uses such as laundry, house-cleaning, livestock and bathing. In some cases activities like bathing and laundry can take place at these other sources (e.g. at ponds in Southern Asia).

Because the requirement for potable water is not so high (say 30 to 40 litres per household per day), a medium-size tank may suffice to guarantee this quantity daily throughout the year. Although the RWH system may now be meeting only one third of total water-use volume, it is providing the most valuable part, worth probably more than half the annual total. Low rates of withdrawal result in the water staying a long time in the tank. This in itself improves water quality from a health point of view but may worsen the water's taste. So care must be taken both to make sure the tank materials do not give the water a bad taste and to apply additional cleansing measures to the inflow water immediately after rainfall.

2.4 Low-cost forms of DRWH

As the storage tank accounts for most of the cost of a RWH system, a low-cost system is one with a cheap tank. Chapters 6 and 7 and Appendix 2 of this handbook discuss tanks. A cheap tank is likely to have less than 2,000 litres storage for a household or less than 10,000 litres for a school.

The most obvious way of deciding whether a RWH is low cost would be to compare its cost with some upper acceptable limit. For example, a cost ceiling of US$ 100 investment per household might be chosen, (the actual figure should be based on conditions in the particular country where the RWH system is to be built). Alternatively, it is possible to work out the expected cost per litre of delivered water and check that it lies below some threshold such as 0.5 ¢/l.

Cost comparisons with other water technologies, should allow for the greater convenience of RWH than water fetched from a distant point source, but also for its failure to provide much dry season water.

Only under an exceptionally favourable equatorial climate, with rain expected every month, can 'low-cost' RWH act as a sole source of water. So we normally dismiss this possibility and concentrate instead on its use as main source, wet season source or potable water source.

Table 2.4. Low-cost DRWH in the tropics

1.	In an equatorial climate with short dry seasons, low-cost DRWH can be the **main source**.
2.	Throughout the humid tropics it can be used as a **wet season source** or as a **potable water source**.
3.	In a Monsoon climate with a 6-month dry season it is only feasible as a **wet season source**.
4.	In a semi-arid zone, low-cost RWH has little role unless highly integrated with other sources.

These four situations are discussed in more detail at the end of this chapter. In addition, there is also the informal (or 'opportunist**')** self-supply DRWH discussed in Chapter 1. Throughout the rural tropics one can also still find examples of the historic technique of collecting rainwater from trees – practitioners are usually old people. Informal DRWH is often a precursor to formal DRWH. The practice of the former creates demand for the latter and, as with other new techniques, staged upgrading is more likely to succeed than sudden wholesale promotion.

2.5 Risk and reliability

Roofwater harvesting, like all other sources of domestic water, carries the possibility of failure.

Drought

An obvious failure is when tanks run dry after a long period without rain. This feature of performance is expected and can to some extent be anticipated. For a known climate, we can design a roofwater harvesting system to give a known availability of water in an 'average' year – high if we are prepared to pay for a large tank, lower if we are not.

The science of weather forecasting is barely able to tell what will happen only one week ahead and so we cannot 'know' next year's rainfall. We usually assume it will be like past rainfall at the place we are building. However, there will always be years that are drier than usual. In such years even roofwater harvesting using big tanks may fail.

We must expect to reduce water consumption during droughts or to use water from other sources to refill roofwater tanks at such times. All water sources are at risk of failure during extreme droughts, but roofwater harvesting is generally *more* vulnerable than supplies that draw on ground water. However, supplies are also more under householder control.

Drought is not the only cause of water supply failure. There are many other causes, some of them sudden disasters and some of them gradual.

Sudden failures
Sudden failures are represented by earthquake, storm, breakages and cessation of management. Compared with most alternative sources, roofwater harvesting is robust in the face of disasters because its hardware is widely distributed and not interconnected. Few disasters can disable the bulk of its installed plant, although some individual households might lose their stored water and some entire buildings may be destroyed. There is no dependence upon uninterrupted electrical supply, unbroken main pipes or the good maintenance of components shared by many households. Indeed, in some earthquake-prone areas, roofwater harvesting has been promoted specifically because it alone can guarantee a supply of water for drinking or fire-fighting after an earthquake. It is also possible to design roofwater systems that continue to deliver clean water during floods or during periods of warfare.

Gradual changes
Gradual changes are a bigger threat to reliable water supplies than disasters. They include:

- exhaustion of 'fossil' water and depletion of aquifers
- decay or collapse of water management, especially where temporary 'outside' funding has created a water infrastructure but there is insufficient inside funding to fully sustain it
- poisoning of aquifers or rivers by natural processes or by human activities (arsenic, fluorides, nitrates and sewage are significant pollutants)
- population growth beyond the capacity of local groundwater or surface water sources
- infrastructure decay and mechanical breakdown.

Of all these gradual threats to water security, roofwater harvesting is only vulnerable to infrastructure decay. Its most vulnerable component is guttering, whose repair or replacement is usually within the competence and wealth of householders. Some roofing has a limited life, but its decay is readily visible and its maintenance is within local capabilities. The maintenance of tanks and filters is less simple because their deterioration is less visible to water users. Such deterioration (e.g. silting up, development of leaks) is fortunately usually slow with properly designed systems and the necessary repair/renewal can be assured via appropriate training.

In summary, roofwater harvesting is more vulnerable to drought but less vulnerable to other threats (sudden or slow-acting) than water supplies drawing on groundwater or rivers.

2.6 When *not* to use DRWH

Roofwater harvesting is not appropriate where normal conditions for its use cannot be met, where cheap, sustainable, plentiful alternative supplies have already been installed or where very high levels of water quantity and water quality must be provided.

'Normal conditions' may be taken as meaning that *all* the following conditions are satisfied:

- roofing is 'hard' rather than vegetative – this condition is met far more widely in the tropics today than it was 20 years ago, but there are still rural communities where only a few (richer) houses have hard roofs
- adequate annual rainfall per person reaches the guttered part of the roof – normally the captured run-off should equal at least the planned annual consumption per person; the trend towards multi-storey housing construction is unfavourable to DRWH because it reduces the area of roof per person
- there is space within the housing plot to construct a tank and permission for a householder to do so
- extreme air-pollution is absent.

Very high levels of demand or water quality that may exclude DRWH include:

- consumption exceeding 40 litres per person per day;
- a need to meet the full WHO 'zero risk' bacterial standards, as recommended for urban piped water.

2.7 Initial check list

To proceed with roofwater harvesting we need to answer 'YES' to each of these 3 questions:

Q1. Is current water provision thought by some householders to be seriously inadequate in quantity, cleanliness, reliability or convenience?

Q2. Is there an existing capacity to specify and install DRWH systems in the area, or could one be created in a suitable time?

Q3. Is there adequate hard roofing area per inhabitant, at least the figures given in Table 3.5 below? This table assumes that 20 litres per capita per day (lcd) is the normal supply but that this may drop to 14 lcd in the drier months. For potable water only, the requirement is assumed to be only 7 lcd.

Table 2.5. Roof area required (m^2 / person) for different styles of DRWH and different rainfalls

Type of RWH		700 mm rainfall	1000 mm	1500 mm	2000 mm	>2500 mm
		Roof area needed (m^2/ person)				
Sole source of water	**Large tank**	**14.5**	**10**	**6.5**	**5**	**4**
annually supplies 95% or more of a 'demand' of 20 lcd	*V Large tank*	*12*	*8*	*5.5*	*4*	*3*
Main source	**Medium tank**	**11.5**	**8.5**	**5.5**	**4**	**3**
supplies 70% of demand of 20 lcd in wet season, 14 lcd in dry season	*Large tank*	*9*	*6*	*3.5*	*3*	*2*
Wet season only source	**Small tank**	**8**	**5.5**	**4**	**3**	**2.5**
supplies 95% of wet-season de-mand	*Medium tank*	*6*	*4*	*2.5*	*2*	*1.5*
Potable water only source	**Small tank**	**6.5**	**4.5**	**3.5**	**2.5**	**2**
supplies 95% of 7 lcd demand throughout year	*Medium tank*	*5*	*3.5*	*2.5*	*1.5*	*1*

Notes: For each type of DRWH, roof areas needed for two tank sizes are shown
Bold type indicates the tank size normally used for that style of RWH and the corresponding roof area needed (we assume about 35% of the roof run-off is spilt due to tank overflow.)
Italic type shows a larger tank size (giving only 10% spillage) and the smaller corresponding roof area needed
'lcd' = litres per capita per day

2.8 The main applications of domestic roofwater harvesting

There are a number of situations that particularly favour adopting some form of DRWH. The principal of these are as follows.

1. *Improving user convenience (and increasing water use)*
   The most obvious role of DRWH is to reduce the drudgery of water fetching. Thus we might emphasise its installation in households more than, say, 500 metres from a reliable clean point source, or located high uphill from the nearest source. In many rural areas in the tropics, over half of households are in this situation, requiring more than two minutes to collect each litre of water they consume. Studies have shown that where protected sources are currently too widely spaced

(i.e. over 2 square kilometres per working source), to achieve a good access standard it is much cheaper to install main source or even wet-season DRWH than to greatly increase the density of protected point sources. Access standards are discussed in section 2.9 below. Households currently located far from protected sources either keep their water consumption below the WHO recommended 20 litres per person per day or use a mix of clean water fetched from afar and dirty water from polluted local sources. Introducing DRWH is therefore likely not only to reduce fetching time but also to increase water consumption and water quality.

2. *Compensating for low water quality or other problems at existing point sources*
   In a number of geographical locations there is no possibility of cheaply providing safe water within a reasonable distance of homes, because the ground conditions are unsuitable and surface waters are polluted or absent. The ground may be impermeable (e.g. North Eastern Brazil), groundwater may be over-mineralised by fluorides, iron or even heavy metals (Vietnam, India, Bangladesh, Southern Uganda), or the aquifer may be too deep to reach (Northern China). In these situations, using DRWH at least for potable water is likely to be safer than using raw groundwater and cheaper than treating groundwater (or bringing in fresh water by bowser). Extreme instances of this scenario are low tropical islands with neither sweet water aquifers nor surface streams. It is not surprising to find that DRWH is practiced in Bermuda, the Seychelles, the Maldives and some Pacific islands.

3. *Improving the water supply to particular households*
   Because DRWH is applied one house at a time, it is popular with richer rural households willing to invest in water supply improvement to their house alone. In this context, DRWH is in competition with the services of water carriers who are most used by such households and by rural businesses. There has also been recent discussion of the application of DRWH to relieve targeted households where the residents are unable to engage in normal water fetching. Households with too few adults, households with chronic illness such as TB and AIDS (which in themselves increase water demand for laundry) and households where there is age-infirmity or physical disability (e.g. landmine victims in Cambodia) are all possible candidates for targeted DRWH intervention.

4. *Where other sources cannot be further expanded*
   In urban rather than rural areas, rapid population growth may collide with constraints on expanding water supplies from traditional sources. Thus, the large Indian city of Bangalore is banned from increasing the flow it pumps from its main current source (the Cauvery River in a neighbouring state) and is looking to various forms of RWH and to water recycling. Another high altitude city, Nairobi in Kenya, is similarly reaching the limit of economically accessible water sources. In the longer term, water conservation and grey-water recycling may be the key technologies for such situations. In the shorter term RWH has the bigger role.

5. *Where householder investment in water infrastructure is needed*
   Many tropical countries striving to reach water supply and sanitation targets, lack the funds to achieve them. Finance for water improvements can come from governments, from aid agencies and from private investors (via private water companies). Each of these agents has advantages and disadvantages. Some mix is needed and in urban areas there has been some recent shift from the first to the last agents in this list. DRWH enables and encourages householders to invest in water infrastructure directly: it is as applicable to rural areas as to urban ones.

2.9 Water-access distances

Water carrying, even over flat ground, is a chore that increases with the distance from house to water source. If that distance is 500 metres then to collect 20 lcd (a WHO recommended minimum) takes around two hours per typical household per day – and much more for very large households or where the terrain is steep. There is often queuing time at the water point, occasionally for many hours a day. In theory, most tropical countries have some official maximum for access distance to a protected source beyond which a household would be classified as 'unserved'. This maximum was '1 mile' in much colonial legislation and the corresponding distance of 1,500 metres may still be found in official documents in countries like Uganda and India. In other countries, a shorter distance like 500 m is now used. In practice, the difficulties of measuring such distances result in distance limits being largely disregarded when national 'safe water coverage' statistics are calculated. In Africa in particular, very much time is spent in carrying water and this is becoming increasingly politically unacceptable.

Access distance standards are particularly important for DRWH policy, because installing DRWH dramatically reduces annual (or average) water collection time, although it may not reduce the maximum collection time per litre in the driest months. DRWH protagonists therefore need to challenge unrealistic distance standards (e.g. over 500 m) and ensure that average rather than maximum daily distance is stated in design specifications. Indeed they might best press for a ceiling on *annual mean collection time per litre* to be incorporated in water policies (as this would allow for both steep gradients and queuing times) and concentrate on serving with DRWH those households currently so far from point sources of safe and reliable water that they exceed this ceiling.

2.10 Economic viability

There are two main economic tests one might apply to a proposed DRWH investment. One is from the viewpoint of the user – "Is the payback from investing in DRWH good enough?" The other is from a water service provider – "In this location, is DRWH a cheaper way of achieving a particular level of service than any of the alternatives? This topic is covered in more detail in Appendix I: here we will just mention the main issues.

Payback

Constructing a DRWH system costs money, although once constructed the running costs are often negligibly small. The simplest of the many tests economists might use to see if the benefit from having a DRWH system is greater than its construction costs is the 'payback-time test'. To apply this we have to (i) put a value on the *annual benefit* that comes from possessing a DRWH system, (ii) estimate the *cost* of building the system and (iii) divide the system cost by the annual benefit to get a payback time (PBT) in years. Lastly we have to decide whether the PBT is short enough, for example we might choose 2 years as the *maximum acceptable PBT*.

For item (ii) we get a builder's quotation or we look at similar systems that have recently been built. For item (iii) we need to hold discussions with householders to see what payback time they are effectively using for their other decisions. It is item (i), *annual* benefit, that is hardest to assess.

Annual benefit of having a DRWH system is made up two elements: the annual saving (costs avoided) by having DRWH plus the value of any extra water the household uses as a result of having it. This second element – extra water – is very difficult to assess, so it is wisest to base the annual benefit and hence the calculated *PBT* just on the first element, namely the annual saving. For a few households, those who used to pay money for their water to be supplied and brought to the household, the annual saving is fairly easy to work out. For most households the main saving is in time, so we have to give a value to the time saved by no longer walking and queuing for the water now drawn from a rainwater tank. One method that has been used is to estimate how many hours a year the household has saved and then multiply that estimate by the value of one hour's time, pricing it for example at half the rate of paid unskilled labour.

Comparison of rival technologies

Here we have first to decide what service standard level to compare. An example of a service level might be "80 litres a day of potable water with a collection time of not more than 500 hours per year".

Then we have to design various options for delivering that service level and work out the investment cost of each. This design work may not be easy, as to do it well we need to know the location of every household and the constraints upon both well-sinking and on DRWH. The rival designs for a particular settlement of 140 houses round a single borehole might be:

Option 1 Drill five new boreholes so that all households can get the specified service level.

Option 2 Install DRWH systems in the 100 households who are far from existing sources and who therefore spend more than 500 hours a year fetching water.

Option 3 Drill one new borehole and install DRWH in all 70 households that are still too far from a protected source.

We choose the cheapest option. Sometimes it will be the DRWH option 2. Sometimes it will be the mixed option 3. Sometimes it will be option 1 and we can forget about DRWH at this site.

Despite this comparison being done very roughly and with poor data, it is worth doing. Very often DRWH options like 2 and 3 are much cheaper than non-DRWH options like 1. If they are not cheaper, it would be unwise to use them.

Chapter 3. Health Aspects of RWH

3.1 Water quality

Because some household water is drunk or swallowed with food, the quality of water drawn from RWH systems is very important. Rainwater itself is of excellent quality, only surpassed by distilled water – it has very little contamination, even in urban or industrial areas, so it is clear, soft and tastes good. Contaminants can however be introduced into the system after the water has fallen onto a surface. This handbook is focused on roofwater harvesting precisely because most hard roofs give much cleaner run-off water than can be obtained from ground level run-off. The run-off from thatch roofs is by contrast quite seriously contaminated. Where thatch water is harvested, it is commonly then improved by processes such as alum-accelerated sedimentation, boiling, SODIS (solar water disinfection) or other disinfection.

3.1.1 The path of contamination

When considering the water quality of a roofwater system, it is useful to observe the complex path a contaminant must follow in order to enter a human being. The usual paths are shown in Figure 3.1.

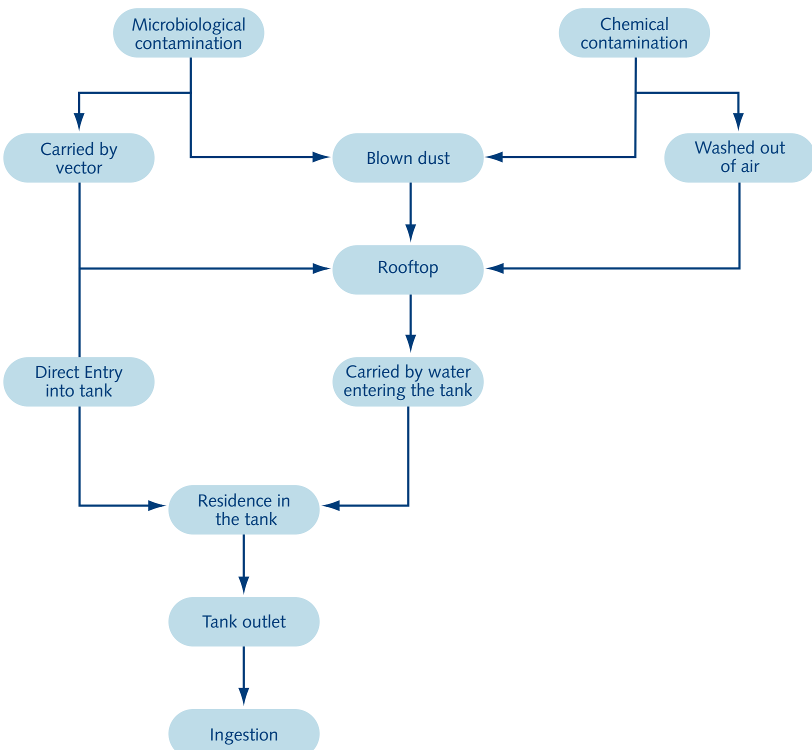


Figure 3.1. Contamination paths for roofwater harvesting

Roofwater harvesting generally represents a hostile environment for microbiological contaminants and presents a number of barriers to chemical contaminants. Means of enhancing these natural reduction processes are discussed in Chapter 9. The primary means of tank contamination is through water washed in from the roof, although the main reason for most outbreaks of reported disease is direct entry to water in the tank either via a vector, such as a rat, lizard or insect, or because of an accident.

Material washed in from the roof can come from several sources:

- By far the largest contribution will come from material that has accumulated on the roof or is blown onto the roof during a storm. Accumulated material may have been blown onto the roof by the wind, stirred up by passing vehicles, dropped from overhanging trees or deposited by an animal (or person) with access to the roof.
- If the roof is made of decayed materials, the roof itself can contribute to the dirt load. This is particularly true of low-quality roof materials such as thatch or tar sheets, though asbestos sheeting and galvanised iron (particularly if it is rusty) can also add material to incoming water.
- Passage of water along unclean gutters may add further debris.

The time that water spends in the tank provides opportunities for purifying processes such as sedimentation and bacterial die-off to take place, increasing water quality over time. If, however, the tank is poorly designed, built or maintained, storage may conversely provide further opportunities for pollution. If light is allowed to enter the tank, (particularly if it is open-topped) an active ecosystem may develop in the tank resulting in stagnant water of very poor quality.

Once the water has resided in a well designed tank for some time, it should be safe for drinking without further treatment, although some feel safer if the water is further treated. Rainwater is soft and has a very low turbidity so it makes an excellent candidate for many household treatment processes such as boiling, SODIS or biosand filters.

3.1.2 Reported illnesses associated with rainwater harvesting

There are only a handful of reported cases of illness associated with RWH systems. This is because well-maintained RWH systems tend to give fairly clean water and because outbreaks are confined to one system (household) and do not become widespread as with centralised water supply. Outbreaks tend not to be reported unless they involve a large number of people or take place on commercial premises.

Those cases that are reported tend to cite poor RWH practice, accidental contamination or immuno-compromised subjects or are cases where rainwater consumption is only one of a number of possible causes of the outbreak.

Most reported cases are of salmonella, delivered via the faeces of a bird or small mammals with access to the roof surface or to the tank, and tend to result from bad practice, e.g. roofs covered with dried and fresh bird droppings or frogs found in the tanks. None of the cases were fatal.

There are a few reports of gastroenteritis associated with *Campylobacter*, which is carried by birds, however the cases reported are either in immuno-compromised subjects (such as a chemotherapy patient) or have rainwater listed alongside several other possible causes (such as the consumption of poultry).

One outbreak of *Giardia/Campylobacter* has been reported. This was the result of poor sanitation practice where the outfall from a leaking septic tank entered an underground rainwater tank.

There have been a small number of epidemiological studies involving households using RWH systems. They show that households drinking rainwater have no greater risk of gastrointestinal illness than those drinking from groundwater sources or, in one study, than those using chlorinated public mains water.

The lessons that can be drawn from these cases is that good practice is essential in maintaining good health when using rainwater for drinking. However if good practice as described in Chapter 9 is observed, systems should provide good quality water. Special arrangements such as boiling, SODIS or biosand filtering may be appropriate for the very young, the very old or those whose immune system is reduced (e.g. by AIDS).

3.1.3 Microbiological contamination

A large number of studies measure indicator bacteria, such as total or thermo-tolerant coliforms, in rainwater systems. Most have shown indicator bacteria in rainwater tanks in some quantity but that this quantity has large variations both from system-to-system and over time, with readings changing several orders of magnitude within a few days. The reason for this is that the water becomes contaminated though the addition of material washed in from the roof, but over time contamination levels reduce due to settlement and die off within the tank. This can be seen in Figure 3.2 where the levels of indicator bacteria rise after rains and then fall over time until the next rain. Reductions of 90% have been noted after about 3 days, though this will change somewhat with local conditions.

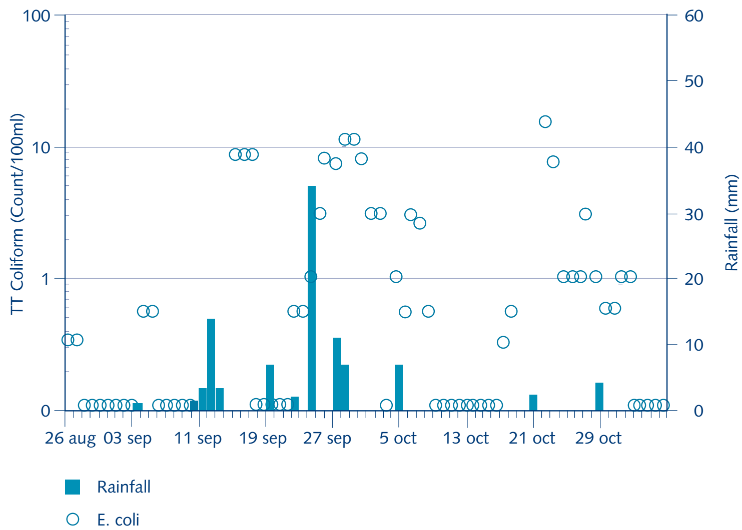


Figure 3.2. Episodes of rainfall and average of indicator bacteria taken from tanks in one location

There is a growing body of evidence, that the number of detected indicator bacteria is not correlated with pathogens but merely indicates the presence of opportunistic environmental bacteria. These environmental bacteria are not considered dangerous and there is even some evidence that they form an important part of the beneficial biofilms that line the walls of rainwater tanks.

Investigation of the path that a pathogen must follow gives some idea of the likelihood of contamination of a roofwater tank with a human pathogen. Human defecation on sloping roofs is uncommon and even on flat roofs is unusual. However, there are extreme circumstances in which human faeces are actually thrown onto roofs – roofwater harvesting is not viable in the land of the 'flying toilet'. Where open defecation is practiced, a possible path is via faecally contaminated dust blown onto roofs; however it is unlikely that live bacteria will survive the faeces drying out before it is light enough to be blown by wind. A more likely path is through deposition of animal faeces on the roof – this is borne out by the few illnesses associated with rainwater tanks being mainly salmonella-related as opposed to illnesses such as hepatitis, dysentery, cholera etc. which are transmitted via *human* faecal matter and have never been associated with roofwater harvesting systems.

The roof itself (particularly if it is made from steel) is an extremely hostile environment for human pathogens, which have evolved to live in a warm, wet, low-oxygen environment. The dry heat typical of a metal roof under bright sunlight will effectively kill many of these pathogens. This effect is borne out by the usually lower microbiological indicator levels from metal roofs as compared to other roof types.

Gutters, particularly if they have not been cleaned for a time, may contain a large amount of organic material. If allowed to enter the tank, this will form a good source of nutrition for bacteria and insects and may itself harbour some microbiological contamination. The processes of die-off and desiccation will also not be as effective in gutters as on roofs.

The tank itself is also a target for the direct entry of pollutants either through animals drowning in it, children swimming or through accidents such as spillage of raw sewerage into the tank. Despite such gross, direct contamination routes being the easiest to avoid, they form the largest cause of reported illness, mainly because they 'short circuit' the path usually followed by incoming contaminants.

Monitoring the bacterial quality of roofwater

As the bacteria contaminating harvested rainwater are generally of animal rather than human origin, indicators of human faecal contamination are not ideal surrogates for health risk in RWH systems. However it is unlikely that separate indicators just for RWH will ever be used.

The large variations in roofwater quality over time have implications for monitoring water from RWH systems:

- it is impossible to determine the typical bacteriological quality of the system from a single reading
- the wide variation makes normal averaging (the use of an arithmetic mean) inappropriate, as it will be dominated by high readings that only exist for a very short length of time.

These factors can be compensated for by following the guidelines used in monitoring environmental waters (which show similar changes over time). These guidelines recommend:

- That water is sampled several times over a period (e.g. the USEPA recommends five samples taken over one month)
- The *geometric* mean of the samples is calculated and used as the basis for water quality measurement.
  Note: samples from rainwater tanks can often yield a result of zero colonies. As it is impossible to calculate a geometric mean of any set of data that contains zeros, use a value of 0.5 for the zero readings.

This will, of course, put an additional burden on the monitoring programme. However if resources are limited, it is more accurate to perform at least three readings over a period of at least two weeks on a few systems rather than taking a single reading in many systems.

3.1.4 Chemical and physical contaminants

As rainwater is the result of a natural distillation process, the chemical quality of rainwater is good. It contains very little in the way of dissolved minerals and suspended solids. As in the case of microbiological contamination, the risk of chemical contamination comes after the rain has hit the roof. However, there are several barriers in the path of contaminants and other barriers can be installed cheaply and simply. Many of these are discussed in Chapter 9

Acidity

As the rain has fallen through the atmosphere it is usually saturated with oxygen and with carbon dioxide. The first is beneficial and improves taste, the second makes rainwater slightly acid at around pH6 in rural areas. Pollution in urban areas can lower the pH to 4-5, but roof run-off that is more acid than this is rare. The pH of rainwater tends to change with storage in cement-based tanks as clean, acidic rainwater reacts with the cement and absorbs calcium, making the water more alkaline in the range of pH8-9.

Heavy metals and urban pollutants

Particularly in urban areas, pollutants such as heavy metals and sulphates can enter the water and these materials have been found in several studies in urban roof run-off. These materials are found in the rainwater itself, in deposits on the roof, and sometimes leached out of the roof itself (particularly zinc and lead). While it is often not practical to filter these minerals, it has been found that these pollutants decrease over the length of a rainstorm i.e. the first mm will be much more laden with pollution than the second and so on. This is the 'first flush' effect and the introduction of first-flush mechanisms can substantially reduce the pollutant load delivered to the tank. Such mechanisms are discussed in section 9.2.3. Suspended metals are also very dense and so descend quickly to the bottom of the tank and resist being re-suspended. This effect has been demonstrated in several studies where the heavy metal content of the output from the tank has been much reduced from that of the incoming water. Investigation reveals that the sludge is high in these materials.

Suspended sediment

The largest component of roofwater pollution will be in the form of particles washed from the roof. Such sediment is suspended in the water and is measured by assessing turbidity, a measure of how cloudy the water is. Usually, suspended material is non-toxic (unless there are significant industrial pollutants in the area) but it can carry microorganisms and organic material and presents an aesthetic problem. High levels of turbidity can also protect microorganisms from light-based disinfection such as UV lamps or SODIS and can absorb chlorine.

Rainwater tends to produce water with a low turbidity, as most suspended matter settles in the still water of the tank. The incoming stream of suspended matter is also higher in the first flush and can be significantly reduced by first flush devices.

Filtering can be effective in removing larger material which includes most organic matter such as pollen leaves and buds. It is, however less effective in removing very fine mineral material blown onto the roof, which is very small at around 20-40 µm. However, 90% of this material will settle within 24 hours and form a sludge at the bottom of the tank that may be periodically removed if it becomes problematic.

Asbestos

Asbestos roofing is a common material in some countries and asbestos gutters can sometimes be found, so there are concerns about the risk of health problems from drinking water that has run-off via such materials.

There have been a number of epidemiological and animal-based studies of asbestos in drinking water distribution pipes in centralised water supply systems. The animal studies involved dosing them with large amounts of asbestos and results were mainly negative, although some inconclusive results have also been obtained. Epidemiological studies have found little to no evidence of a correlation between ingestion of asbestos and gastrointestinal cancers.

Advice from the World Health Organisation and others is that while it is dangerous to breathe in asbestos dust, for example while cutting asbestos materials, there is no known danger from drinking water containing asbestos fibres. Asbestos is strongly associated with lung cancer, not stomach cancer. Asbestos pipes continue to be used in many countries for drinking water distribution with no ill effects.

3.2 Mosquito breeding

Mosquito breeding in roofwater harvesting systems has been associated with reported outbreaks of malaria and dengue in several locations. However, storage systems have usually been described as poorly designed and maintained, particularly in the case of unscreened and open-topped tanks. Gutters are also quoted as an important breeding site, particularly if they are incorrectly installed or installed with a low gradient so they do not drain properly, allowing water to pool in the gutter and/or debris to build-up.

The 'out of sight out of mind' nature of many parts of a rainwater catchment system is seen as a particular problem. Many parts of the systems are above eye-level and do not receive the attention they need – gutters are not cleaned and screens and covers are not checked regularly. This is further discussed in Chapter 8 and section 9.5.2.

Even a well screened tank will often allow insects to enter, mainly as "tight fitting lids" tend not to be as tight fitting as they appear. It is not uncommon to find adult mosquitoes in rainwater tanks. Mosquito eggs are also found as they can be laid by the adult directly in the tank or in the gutters and then washed into the tank with the next rains. A fair proportion of these eggs will hatch out to become larvae, which present an aesthetic problem as finding "wrigglers" in one's drinking water is off-putting. However, the main issue from a public health viewpoint is whether adult mosquitoes emerge from tanks and represent an increase in the total population.

Mosquito larvae go through four stages (called instars) before they pupate and emerge as adults. Larvae eat bacteria and protozoans but as discussed in section 3.1, these organisms are rare in well designed rainwater tanks that don't allow the entry of light. Laboratory studies have found that in the absence of nutrients, larvae don't develop beyond the third instar and therefore adult mosquitoes don't develop under those conditions. Field surveys have found that at one extreme there are open-topped tanks with a high load of washed-in organic material – where tiny worms and mosquito larvae and pupae abound. At the other extreme, tanks which are covered so that no light enters and are well screened against the entry of leaves and twigs – may contain a few larvae but do not contain pupae. These studies are preliminary but do indicate that a well-designed and maintained tank will not encourage the spread of mosquitoes.

RWH systems are also reported to be only a fraction of the available breeding sites for mosquitoes and so should be considered as a part of a larger effort to mitigate their breeding.

3.3 Special risks peculiar to RWH systems

There are a few special health risks associated with RWH, though these are rare and are generally lower than the risks of collecting and carrying water from other sources.

Digging underground tanks can be hazardous in certain soil conditions. Local experience with latrine digging should therefore be noted. Fortunately, tank excavation is not very deep or narrow, therefore avoiding some of the hazards of well digging.

Householders sometimes express the fear that having an outdoor water store makes them vulnerable to malicious poisoning. However, no instances of this occur in the literature and there are few poisons that would be effective when diluted by a large amount of rainwater.

Underground tanks with missing covers, like open wells, are an obvious hazard to small children or to night walkers. For this reason some above ground walling or fencing is desirable on such tanks. Even above-ground tanks need to be properly covered to discourage children from swimming in them.

There have been occasional reports of builders or cleaners being asphyxiated after entering a tank, and it is good practice to have someone outside the tank when anyone enters.

Building and maintaining RWH guttering without scaffolding involves the risk of falling.

3.4 Health benefits

Properly performed, DRWH delivers safe drinking-quality water. Where this replaces water from unsafe sources, significant health benefits can, of course, be expected.

Introducing DRWH where formerly there was none will increase household water consumption and thereby should improve hygiene. Some experts argue that good health depends more on having plentiful water than having a little very clean water.

Reducing the effort spent in fetching water (by installing DRWH) has a variety of benefits, some health-related and others not. Back strain and injury are often caused by water-fetching, falling while carrying water up steep paths is not uncommon and accidents to children left behind in a house also occur. In a few locations water fetchers are in danger from snakes or larger animals, and even of rape where women have to set out for water points before dawn.

Where the time released from fetching water is used for food-growing, some nutritional improvement will result.

Standing in long queues near shallow wells or springs close to swamps may significantly expose people to mosquito bites and hence malaria or dengue: installing DRWH should reduce this risk.

Chapter 4. Delivering DRWH Systems

In Chapter 1, six modes of DRWH delivery were mentioned (Table 1.1). In this chapter, some of these are discussed in more detail.

4.1 The special problems of subsidised DRWH

'Self-supply' DRWH (as discussed in section 1.3.2) places key responsibility for technology choice and for financing with the individual household. Such a household might well, for example, choose to start with a very cheap low-performance variant of DRWH. Government's involvement in that process is either negligible or limited to some aspect of public education, quality control or provision of credit.

By contrast, the use of DRWH to achieve a governmental aim of better water coverage may require some form of subsidy, and any such subsidy is in turn likely to require public accountability, some element of equity and hopefully transparency too. (A discussion of the actual delivery follows in section 4.5 below). In many countries, the delivery (as opposed to the design) of water infrastructure has recently been transferred to the private sector via some form of contract tendering.

In Chapter 1, the special features of DRWH were identified, as was their consequent conflict with government delivery procedures originally designed to generate only 'communal' water sources. Almost all government or NGO programmes to deliver DRWH systems entail cost-sharing – the household is expected to contribute part of the cost and a governmental or aid-funded subsidy will pay the rest. In the case of NGO programmes, there may also be other objectives (such as the empowerment of women) that justify a high level of costly interaction with households and communities or even a 100% subsidy.

To succeed, any programme of subsidised DRWH needs to include the following activities:

1. A study to establish that DRWH *is* economically viable in the target area – i.e. is likely to supply water to a defined level of convenience more cheaply than by increasing the number of point sources.
2. A popularisation process in which householders are taught the benefits and limitations of the technology they are being encouraged to invest in – perhaps encouraged by seeing suitable local demonstrations.
3. The agreement of a subsidy policy – for example that outside funds will pay only for a partial DRWH system per household and that the cost of any excess over that minimum has to be borne by the benefiting household.
4. A household selection process that identifies which houses are physically capable of installing DRWH, financially capable of paying a share of its cost and are 'deserving of subsidy'. Deserving might mean they are located far from existing point sources or they are particularly water-stressed for social reasons. Clearly the interests of those unable to benefit must be covered by some political or community process.

5. A supply chain for key components like gutters, tanks (if not built on-site), taps, inlet filters etc and materials like cement and suitable sand.
6. An installation/construction process which may use actual household labour (for which training must be provided) or more usually artisanal labour (for which training may still be needed). Installation also needs some form of quality control.

4.2 The supply chain for DRWH components

Any new technology requires the development in parallel of (i) a supply chain for materials and components, (ii) demand from the final user or some agency representing the final user and (iii) local stockists/installers/repairers. Fortunately, the 'self-supply' activities of richer households and the demands of other parts of the water economy often result in a DRWH supply chain forming in towns. Institutional and self-help RWH may result in the local manufacture of gutters and metal water tanks. Unreliable municipal water supplies usually create a market for large-capacity HDPE header tanks amongst richer households. However, these are urban developments that rarely extend to small towns or villages.

There are two extremes between which we may place any particular DRWH supply chain.

One extreme is the centralised manufacture of fairly high-tech components, such as PVC interlocking guttering, by a large (often multinational) company. The company will be well placed to bid to supply large DRWH programmes and its products will generally be of proven quality. However, delivery costs may be high and the company is unlikely to appoint distribution agents at village level. The bulkiness of most DRWH components means they do not lend themselves to international trading. However, certain specialist components of more advanced DRWH systems may only be currently available from countries like Australia, Germany or USA. Such components are unlikely to be used in low-cost tropical DRWH. The more common small components like taps, level gauges and low-lift pumps may be more cheaply available as imports – from countries like China – than from artisanal workshops or capital-city factories.

The opposite extreme is to use components made on site – for example mortar-lined underground tanks rather than factory-made plastic ones. On-site production may even be done by householders under suitable supervision. Materials like cement are of course usually mass-produced, but that poses no problem as they serve a large enough general market to have developed a good distribution network. Other materials, like sand and timber will be locally generated. Informal DRWH systems may be made entirely on site from very local materials. However, simple formal DRWH systems are usually made locally, employing mass-produced materials. As in the case of drilling wells, when control over tendering is passed from central to local government there is often a swing towards production techniques that maximise the fraction of expenditure that is retained in the local economy. Many NGO programmes have sought to make 'income generation' a key objective of their

DRWH activities or to reduce the cash cost of DRWH systems by using household labour as much as possible.

Between these extremes are production processes that mix mass-produced components with on-site construction or that employ components made in small local workshops. The oldest of the large DRWH programmes, in North East Thailand, employs mortar jars made in local workshops and the same approach has spread to Indochina. By contrast the big North Eastern Brazilian '1 Million Tanks' programme emphasises on-site construction.

In choosing which form of supply chain to promote and after assessing what is already available, government and other agencies need to weigh up the relative importance of:

- simplicity of contract (large contracts with a single supplier are easiest to organise; they may however be most prone to corrupt practices)
- potential for local income generation (highest with workshop/artisanal supply)
- need to minimise cash contribution by households (favours self-build programmes)
- lowest cost (production + delivery + supervision + training)
- national modernisation/industrialisation policy (and enhancing linkages within the economy)
- sustainability (in terms of any limited local resources and import capacity)
- replicability in new districts
- performance (durability, ease of correct installation, reliability)
- competition (avoidance of over-dependence on a single local or national enterprise).

4.3 Small rainwater supply companies

At the village level, a householder needs a string of services before she/he can prudently install 'self-supply' DRWH. These are

- advice about viability, cost and likely water yield
- design of a system (especially the sizing of components)
- procurement of components
- installation and any on-site construction
- advice about how to operate the system once built
- maintenance services and repairs.

It is unlikely the householder can reach one of a country's few DRWH experts, and these services are beyond the experience of most local jobbing builders. There is therefore a strong case for the development, through example, training and perhaps the placing of initial orders, of rainwater harvesting companies located in small trading centres, each serving 1,000 to 10,000 households. A typical such company, employing three people, will:

- stock and sell a small range of DRWH system components like gutters
- know where to obtain the materials and tooling needed to build new DRWH systems

- have the skill to install/build simple systems
- be able to interpret design guides (e.g. those prepared by a national rainwater association) and then recommend a range of viable designs to customers.

Although the initial business of such companies is likely to be 'self-supply' DRWH, they are suitable to be sub-contractors to NGOs running subsidised DRWH programmes and in due course to tender for local government contracts too. Such companies have in the past often grown out of NGO programmes. Any government DRWH programme would be strengthened by the existence of such companies and therefore their establishment is a proper part of any strategy to mainstream DRWH.

4.4 Delivery of DRWH by NGOs

Non-government organisations, both national and international, have been in the forefront of DRWH promotion. They have identified or developed suitable designs, sometimes importing them from other countries. They have trained practitioners. They have been able, by virtue of their close contacts with communities and community-based organisations (CBOs), to engage communities with such difficult issues as the selection of households to benefit from outside subsidy. They have engaged in familiarising communities with the possibility of DRWH alongside other educational activities relating to health and hygiene. They have also used DRWH as a means of achieving goals other than improved water supply, such as the strengthening of civil society, the relief of poverty and the emancipation of women. In many countries, NGOs have been formed specifically to promote or install DRWH. In some countries, for example Sri Lanka and Uganda, government agencies exploring the possibilities of DRWH have been happy to employ NGOs to implement pilot programmes.

It seems unlikely, however, that NGOs will continue to have a major role once DRWH is more securely established. Their statutes and traditions make them rather weak contractors. They are under pressure from both clients and funders not to 'fail' and therefore to prefer expensive but safe solutions rather than take an appropriate level of risk. In many countries, DRWH suffers from excessive costs and it is not usual for NGOs to emphasise cost reduction. Indeed, in some NGO programmes, such thorough and frequent community and household consultations are made that each 'US$ 150' DRWH installation has to carry the cost of several motorised visits to remote homesteads by NGO staff.

However, DRWH is such a decentralised technology that the ability of NGOs to penetrate deeply into rural society is particularly valuable. We may therefore look to NGOs to specialise in:

- pioneering/piloting DRWH delivery in new districts under contracts that allow for a high level of uncertainty in outcome
- delivery of DRWH to very remote communities or to selected marginalised households

- advocacy for RWH in general and its more radical versions in particular
- using DRWH alongside other techniques in social uplift and rural income-generation programmes.

A weakness of some NGO programmes has been an unwillingness to promote sustainable forms of DRWH. Some NGOs see themselves as essential, long-term intermediaries between aid agencies and households, and have therefore been reluctant to accept the commercialisation of services such as the supply of water systems, or to reduce 'standards' in order to achieve system affordability. Thus, many NGO DRWH programmes have unfortunately been as 'start-stop' as government programmes, with activity wholly regulated by the availability of new funding.

4.5 DRWH in government water programmes

DRWH is slowly becoming a technology acceptable within government water programmes, especially for rural areas, and the phrase 'mainstreaming rainwater harvesting' is increasingly heard. In many tropical countries, foreign governments have a significant influence over national water supply strategies via official aid, so *their* growing interest in DRWH is also affecting its status with governments and civil servants.

Unlike NGOs, however, government water agencies are more regulators than implementers of programmes, more susceptible to political pressures and probably even more wary of risky innovation. Until the late 1990s, government agencies in tropical countries had direct experience of delivering water infrastructure and hence receiving feedback concerning technological changes. Today the assumption is that technical innovations should originate either in the private sector or perhaps in NGOs. It is not clear how either of these can afford the prior investment to be able to deliver 'proven' new technologies for public use.

4.5.1 Relieving water stress

The most obvious entry point for DRWH in governmental water programmes is the servicing of 'water-stressed' communities. These are settlements where, for one reason or another, water supply is inadequate and conventional technologies are too difficult to use to improve it. In some countries, like India, national technical criteria have been developed for assessing which communities are, or are not, water stressed. In other countries the process is more informal or purely political. Growing decentralisation of political decision-making offers a mechanism for a water-stressed area to give a high priority to improving water supply, even if that prioritisation still needs to be expressed as a request for funding from a central budget. Some water-stressed communities are simply starved of investment or are socially marginalised. Others suffer deteriorating water supply due to bad technical practices, like groundwater pollution or over-pumping of aquifers, or to loss of control of resources to more powerful neighbours. A third group suffer from essentially geological problems: the water to which they have access is barely potable yet would be very difficult to purify. Where these local problems are severe, government must face the difficult step of moving from funding *communal* water sources to funding *household* ones. For example, how bad must local conditions be before a government agency would agree to pay for changes to domestic roofs to make them suitable for DRWH in a settlement where all other supply options were impractical and yet most roofs were still grass?

Where such significant procedural changes are required, it is attractive to pilot them in an area of dire necessity before applying them where DRWH has a smaller economic advantage.

4.5.2 Modernisation

The next entry point is 'modernisation' – which in the context of rural water supply might simply mean reduction in drudgery. Water supply policy has for several decades been mainly driven by health concerns, especially favouring the replacement of dirty water sources by safer ones. Often public officials and NGO staff have been patronising – 'educating' communities about the importance of clean water, hygiene and good sanitation using their superior scientific knowledge. However whereas a householder's commitment to cleaner water may depend on believing medical explanations about how diseases are transmitted, the same householder needs no expert to explain that water-carrying is laborious. DRWH matches to some extent a change in emphasis from 'improving heath' to 'making life easier' and from telling people what is good for them to letting them decide their own priorities. It also feeds into any cultural strategy to increase the rights or influence of women and children.

The usually-assumed 'modern' approach to water supply is to deliver plentiful clean water by pipe to every household. In the short term, this is known to be far too costly and perhaps too hard to manage for poor countries, but it remains a longer-term target. However such centralised delivery of water, and even the practice of only delivering a single (i.e. potable) quality of water is coming under question worldwide even in rich countries that have depended on treated piped water for decades. DRWH could be regarded as a stepping stone towards the modernisation of water supply – a technology to be used for the time being until something better can be afforded. However, DRWH is also a candidate 'post-modern' technology, something that the whole world may be moving towards to achieve greater environmental sustainability. Thus, a poor country deploying roofwater harvesting may be 'leading' rather than 'catching up'. DRWH can be viewed as a pioneering technique similar to eco-sanitation and water recycling.

4.5.3 Attracting private investment

A third motive for promoting DRWH is desire by government to attract private investment in water infrastructure. In cities, non-government investment in water supply can be sought from financial institutions mediated by large, even international, water companies. The model of the public-private (actually public-commercial) partnership (PPP) is well established, although its achievements in the water sector are not impressive. However for the supply of water to poor and scattered rural households in the tropics, this model seems unsuitable, because it is unlikely to generate good operating profits for commercial companies. Instead, it looks more attractive to engage rural beneficiaries directly and entice householders to invest something in their own water supply.

Operating programmes that match this motive of encouraging investment can conflict with ideals of equity, since to concentrate public resources on those most able to make a matching contribution clearly militates against the poorest households. It is generally accepted that water, at least at some very basic level of supply, should not be treated as an openly tradable commodity to be assigned only to those who can afford it. So perhaps 'water as a right' is being replaced not by 'water as a commodity' but by 'some water as a right, more water as a commodity'. There are ways of matching a DRWH programme to such ideas, freely offering a minimum of water to all (using very small and cheap systems) but requiring beneficiaries to fund any supply above that minimum. Choosing that minimum (at for example 5, 10, 20 or 40 lcd) is of course, ultimately a political decision.

4.5.4 Water equity

A fourth objective of a governmental DRWH programme may be 'geographical equity'. Indeed this is the driving force of most recent government investment in rural water infrastructure and has recently been associated with the slogan *"Some water for all, not all water for some"*. DRWH is a good tool for meeting this objective, since it can be applied household by household. Using 'walking time to the nearest protected source' as a measure, one can readily target DRWH to have the greatest effect on balancing hitherto unequal water access. With community assistance and acceptance, DRWH can also be targeted at other categories of disadvantaged household, for example at the poorest of the poor. In practice, it may be necessary to set aside a small part of the funds for a part-subsidised DRWH programme to cover a total subsidy for exceptionally needy households.

4.5.5 DRWH for households of people with disabilities

Households where people have disabilities may be particularly limited in how much water they can fetch, whether their disability is injury (e.g. from landmines in Cambodia), chronic illness (e.g. AIDS/TB in Africa), old age or a shortage of adults in the household. Programmes to deliver DRWH specifically to such households are discussed in Chapter 10.

4.5.6 DRWH for refugees and internally-displaced persons (IDPs)

People displaced from their homes, of which the world holds at least 30 million, generally become very poor and have little political leverage to obtain services like water. Their homes are small and often made of temporary materials: they rarely have good roofs. There may even be a government policy of discouraging temporary homes (camps) from taking root and becoming more permanent through the delivery of better services. Camp dwellers often live at a higher density than their settlement area can support and may be located on marginal land away from existing services. They may be at special risk from such threats as fire – which every year destroys several African refugee/IDP settlements.

It seems unlikely that DRWH has a major role to play during the 'crisis' (new arrival) phase of a refugee camp: it may have some contribution to make in the longer term. The use of DRWH for reducing water stress after disasters like war or earthquake is discussed in Chapter 10.

4.5.7 Delivering a public subsidy

Tendering is at the heart of proper allocation of publicly funded work to private contractors. However tendering requires the job to be clearly defined in terms of both quantity and quality. To tender for the delivery of defined components, such as plastic water tanks of a defined size and durability, to a government depot is straightforward. By contrast, to sensitise a community to the possibility of a new technology and then, with the participation of beneficiaries, to deliver a predetermined number of part-subsidised domestic systems is much less amenable to tender. Not only does the contractor require an unusual range of skills – for example in community mobilisation, training, materials procurement and construction quality control – but the outcome of the programme depends in part on factors outside the contractor's control. At the very least, there is a problem of transition when community DRWH programmes are first introduced in a country or area, because it is unsatisfactory for contractors to learn solely on-the-job. At the worst, DRWH might prove impossible to deliver using conventional tendering procedures.

As well as 'start-small' pilots, other options employed in other areas than DRWH to address such difficulties include:

- to precede open tendering with a training and qualifying programme for interested contractors
- to separate social activities like community sensitisation and micro-credit allocation from technical activities like procurement, building and inspection and treat them under separate contracts
- to operate construction subsidies by giving householders credits to obtain selected components or services themselves from authorised suppliers – backed by a process of confirming actual construction of approved DRWH systems
- to operate construction subsidies via suppliers in the form of a process by which approved suppliers (competitively selected by the householders) are reimbursed for part of the cost of the components and services they supply. Similar systems are used by Northern governments to promote investment in domestic energy conservation, pollution control etc.

4.6 Increasing the demand for and understanding of DRWH

Activities listed in section 4.1 started with *a study of viability* and (assuming the viability test is passed) *popularisation*.

The operation of DRWH systems, and usually also their financing, requires householder commitment. So it is hardly possible to mount a part-subsidised DRWH programme without first undertaking popularisation whose purpose is to create some local demand for DRWH systems. There is very frequently a strong demand for water itself, but that demand may not yet be expressed as any interest in roofwater harvesting.

Many people are ignorant of the potential of DRWH to supply domestic water. However, DRWH is also vulnerable to excessive expectations. Few householders, or even water professionals, seem aware of its limitations. Nor can they forecast, even very roughly, the likely yield of any particular combination of system and roofing. Moreover, a DRWH programme may be given political objectives that it cannot physically meet – such as providing a household with more water than falls on its roof as rain.

There is also an issue of the trade-offs between performance and cost. Beyond a certain point, increasing the annual yield of a DRWH system by only 10% may require a redesign that doubles its cost. Both the government agency authorising a DRWH programme and the receiving householder need to understand this. The dry season performance of a DRWH system in a particular year depends not just on that year's weather pattern but also rests heavily on how the household chooses to operate their system. The main source, potable only and wet season only forms of DRWH listed in Chapter 2 are but three of the options available to a householder.

Agricultural extension and public-health programmes have long engaged in sensitising communities to new techniques – their advantages and their limitations. In order to be more credible, they have often operated from 'field stations' where the techniques have been tested and refined before being promoted. The literature has for decades addressed how to avoid promoting non-viable innovations, how to identify lead adopters of new technology in a target community and how to interact cheaply with many people in rural areas. Promoters of DRWH would do well to discuss their proposed actions with extension workers from these two fields.

Fortunately, the performance and costs of DRWH may be easier for a citizen to observe and assess than the corresponding aspects of say crop-rotation or using mosquito nets. In many cases simple physical demonstration, preferably in a frequently visited location like a market or school, may suffice, provided that the demonstration system is properly operated by its beneficiaries. This proviso may be difficult to meet in an institution like a school.

The management style chosen by a DRWH system owner is not observable to a passer-by. Physical demonstrations need to be backed by some organised exchange of experiences between early operators and those who might follow them. This poses a major problem of timing, since unless carefully coached by an expert, early adopters will usually need two or more dry seasons before they have optimised their water management strategies – careful tank management is rarely practised during the first year after a DRWH system is installed.

A sensitisation programme therefore needs the demonstration of physical systems and the encouragement of early adopters, but this is not enough. Some more interactive forms of promotion are also desirable. An ideal sensitisation programme would fast, cheap and testable.

Speed in demonstration can usually be increased by applying 100% subsidy to demonstration hardware, usually in return for the willingness of its recipient to allow the public to inspect it and to share (verbally) their experiences in using it. However, it is important to ensure that the technology is actually ready for such demonstrations, (including having the constructors trained *out* of the public eye), that the demonstrations are actually wanted by their operators and that they are helpfully labelled. Thus, the following message might be painted onto a water tank.

> This is a system for harvesting water from a house's roof: it was completed in June 2006 by (named builder).
>
> It can give about 5 jerrycans of water a day in wet months, 2 jerrycans a day in most dry months, but nothing in August.
>
> A system like this costs ZZZ, towards which the District Water Programme may pay YYY during 2007
>
> Please take a pamphlet from the tray below.

Other forms of popularisation include posters, pamphlets, interviews on local radio, meetings and mobile (perhaps scale-model) displays. Potential adopters like to see photos of hardware and lists of possible suppliers, and need to be told where and when to apply for any subsidies.

'Sensitisation', especially when it is performed under contract, should include some test of its effectiveness – both how many people were reached and how their understanding changed. As *outreach* is very hard to measure, the testing of *changed understanding* may have to serve for both the nature and the extent of the impact. For this reason, good sensitisation should always start with some survey of existing awareness and understanding. This (sample) survey makes a good base from which to design a post-sensitisation survey. Obviously good sensitisation should produce a measurable change between 'before' and 'after'.

PART B

Implementation Guide

Chapter 5. DRWH Configurations and Requirements

5.1 Components of domestic roofwater harvesting systems

The main parts of a DRWH system were named in Chapter 1. In this chapter we go into more detail about what we *require* of each part and in Chapters 6 to 9 we describe ways of meeting those requirements.

Rainwater harvesting systems can roughly be broken down into four primary processes and three treatment processes. These are outlined in Figure 5.1.

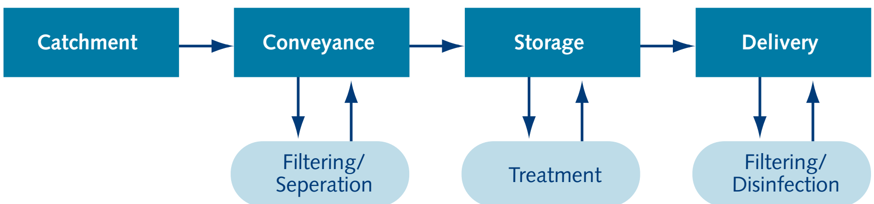


Figure 5.1. Process diagram of domestic rainwater harvesting systems

A typical low-cost roofwater harvesting system in a developing country was shown in Figure 1.1. In that figure the catchment is a roof, the water is conveyed by guttering and downpipe to a storage tank, and delivery is by a tap connected to the tank. Treatment includes a manual 'first flush' system and a before-tank filter/screen. A number of processes automatically occur within the tank itself such as settlement, flotation and pathogen die-off. Finally, the household may employ some technique of disinfection (such as chlorination, solar disinfection or use of a ceramic filter) to the water *after* it is drawn from the tank.

5.2 Roofing requirements

The two basic requirements for a roof to be used for roofwater harvesting are:

- most of it (e.g. over 80%) must be easy to connect to gutters and there should be some method of fixing those gutters under the roof
- the water that comes from the roof must be free of serious or poisonous contamination, especially by dissolved material.

For a roof to yield good quality water, the roofing material must be impermeable. As can be seen in Table 5.1, organic roofs (e.g. thatch) have only a very small run-off coefficient (the fraction of water that falls of a roof that is conveyed to the gutters) and produce poor quality water. Organic roofs are also sometimes round in shape and have a high slope, making guttering difficult to apply.

Table 5.1. Characteristics of roof types

Type	Run-off coefficient	Notes
Galvanised Iron Sheets	>0.9	• Excellent quality water. Surface is smooth and high temperatures help to sterilise bacteria
Tile (glazed)	0.6 – 0.9	• Good quality water from glazed tiles. • Unglazed tile can harbour mould • Contamination can exist in tile joints
Asbestos Sheets	0.8 – 0.9	• New sheets give good quality water • No evidence of carcinogenic effects by ingestion • Slightly porous so reduced run-off coefficient and older roofs harbour moulds and even moss
Organic (Thatch, Palm)	0.2	• Poor quality water (>200 FC/100 ml) • Little first-flush effect • High turbidity due to dissolved organic material which cannot easily be filtered or settled out

If an impermeable roof is not available, one can sometimes be built in the compound just for rain harvesting. Either a galvanised iron (GI) sheet roof can be built on a frame (possibly doubling as a shed or even the cover for a water tank) or a less permanent structure can be made of polythene sheet or a tarpaulin, anchored against being blown away in high winds. If plastic materials are used, they should be demountable so they can be sheltered from wind-borne dust and sunlight in weeks when the rain isn't falling. Generally, covering an organic roof with plastic sheeting is not advisable: the sheeting will prevent natural ventilation through the roof, so trapping moisture under it and causing the organic material to rot.

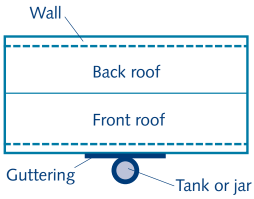
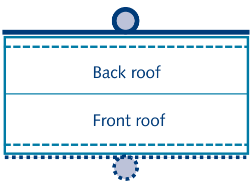
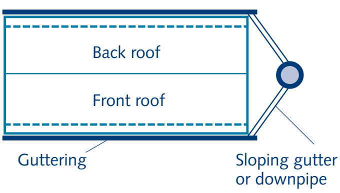
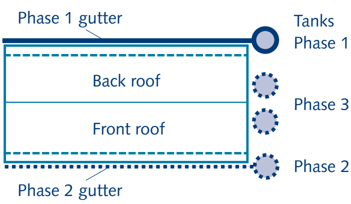
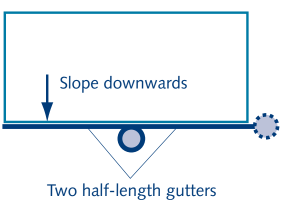
5.3 Layout and guttering requirements

Run-off water is carried to the tank usually by way of gutters and a downpipe. Sometimes there is no separate downpipe and the gutters themselves are extended to finish directly above the tank. Guttering must be capable of first *catching* the run-off from a roof and then *carrying* it to the storage. Guttering is described in Chapter 8

The layout of the system can have a strong effect on the guttering requirements. If the layout of the plot permits tanks to be located anywhere on it, then one can choose tank sites that minimise the size of guttering. Table 5.2 shows different DRWH layouts.

Thus if the roof has a single slope (no peak – layout E in Table 5.2), the tank is best located midway along the roof's lower edge. If however the roof has a double slope (either side of a central ridge – layouts A to D), thus needing separate gutters along the front and the back of the house, the tank is most easily placed at the end of the house where both gutters can access it. Alternatively, using *two* tanks, one at the front and one at the back, may give a neater and sometimes cheaper system.

Table 5.2. Some common DRWH system layouts

Plan of house with DRWH System	Name and Notes
	**A Simple 'Informal' DRWH System** • Very cheap • Collecting run-off from only 1/5 of the roof
	**B Front-and-back DRWH System** • Minimises size and cost of guttering • Two small tanks cost more than one big one • Can be built in two phases – phase 2 is shown dotted
	**C Single-tank DRWH System** • Economises on tank cost • Tank does not obstruct windows • Tank may be far from kitchen & bathing place • Gutters have to be large • System is often rather ugly
	**D Phased installation** • Jars are installed as funds become available, phase 1 then phase 2 then phase 3. • Phase 3 jars take overflows from phase 1 and 2 jars and hence hold cleaner water • A common form of DRWH in SE Asia
	**E DRWH on Single-pitch roof** • Economical in guttering and tank • Suitable for buildings in trading centres • An alternative tank position is shown dotted

5.4 Filtering and separation

Some degree of first-flush diversion, filtering or separation is required, particularly if the water will be used for drinking. *Diversion* means throwing away the roof run-off water whenever it is particularly dirty – like in the first minutes of a storm after several dry dusty days. *Filtering* and *screening* mean 'holding back' solid debris on a surface but letting the water pass through. Solid debris therefore builds up on the filter and periodically has to be removed, perhaps by the filter surface being washed. *Flow separation* means splitting the flow into two streams, one containing most of the water, the other containing most of any debris. The first stream goes to the tank; the second stream is thrown away. Self-cleaning filters are effectively a type of flow separator. (Water quality and water treatment are covered in Chapter 9.)

Filtering the water before it enters a tank has several advantages over filtering it as it leaves the tank. It prevents most of the nutrients that breeding insects and bacteria need from ever reaching the tank. Pre-filtration also means the tank will rarely or ever need cleaning. Combined with good tank ventilation, it stops the tank water from going anaerobic and smelling.

Criteria that should be met for inlet filters or separators are set out below:

- they should be capable of dealing with the flows associated with high rainfall intensities (e.g. a 2 mm / minute downpour onto a 50 m^2 roof causes a flow rate of 1.7 l/s): high flow rates require large filter areas
- they should be easy to clean or largely self-cleaning
- they should not block easily (if at all) and blockages should be easy to see
- they should not become a source of additional contamination if left uncleaned
- the cost of the inlet filter should not be too high (10% of the tank cost should be considered a maximum)
- the amount of water lost by diversion or for washing the filter should be only a small part of the total flow.

Inlet filters can be located anywhere along the water-flow path from the roof to the tank inlet.

The pros and cons of different positions are shown in Table 5.3.

Table 5.3. Pros and cons of different filter positions

Location	Advantages	Disadvantages
In-the roof before the gutter	Prevents leaf build-up in gutter and so: ● removes fire hazard ● reduces mosquito breeding ● avoids chore of cleaning gutters	Expensive due to the large areas to be covered.
At the entry to the down-pipe	Can be combined with a drop to increase its flow rate Can replace gutter-downpipe connections such as gutter boxes Can be self cleaning (to some extent)	Difficult to inspect or to clean due to its height. May cause some water to remain in the gutter after rainfall has ceased, allowing mosquito breeding.
In downpipe (not possible where the tank entry has to be close under the gutter)	A long downpipe means the filter can have a large surface area Low space requirement Some designs also act as first flush diverters.	Requires more complex design Poor design can lead to excessive water loss: may use (waste) more than 10% of water flow for its self cleaning action: Difficult to access for cleaning Blockages not visible to users
In-line (underground)	No mounting problems Easily accessed for cleaning	Only useful for underground tanks Poor design can lead to ingress of dirty groundwater into the tank
At the entrance of an above-ground tank	Simple and inexpensive - can be as simple as a cloth over the tank inlet Very visible (unless the tank is over 180 cm tall)	Entrance to tank is accessible to accidental (or deliberate) contamination

5.5 Tank requirements

The store of water in a roofwater harvesting systems is usually a closed tank of one design or another. The basic requirements for such tanks or jars are that they should:

- not have excessive loss through seepage or evaporation – as compared to the water demand (less than 5% of daily demand)
- not present an excessive danger to users falling in or by the tank failing in a dangerous way

- provide water of a quality commensurate with its intended use – water that is used for drinking requires particular care:
  – the tank should be covered to prevent entry of light, and sealed against intrusion by mosquitoes and small creatures
  – the tank should be ventilated to prevent anaerobic decomposition of any matter that is washed in.

Ideally, it should also:
- be affordable
- be durable (or easy and cheap to maintain in good condition)
- have a means by which water can easily enter and easily be withdrawn (into the normal household receptacle used in the area)
- have some arrangement to satisfactorily handle tank overflow
- be easy to clean or 'self-cleaning'
- look attractive.

To reduce guttering costs and complications, the tank should be sited as close to the house as is possible without undermining the foundations of the dwelling. If an underground design is used it should be placed more than 15m uphill from any pit latrine. The selection of tank type is covered in Chapter 7. The sizing of tanks is covered in Chapter 6.

5.6 Special requirements for urban areas

Urban environments have many constraints of their own. They are much more crowded than rural areas and space (land) is expensive. Roof sizes can be quite small (as low as 2 m^2 per person); the materials they are made from are sometimes scavenged and less than ideal. Tenure is often uncertain with many people living as tenants and others 'squatting'.

The solution to the space problem is to build tanks which have a small footprint or that protrude from the building as little as possible. In the case of a squatter or temporary settlement, the structures should also be portable. An example of a water store specifically designed for use in a crowded settlement is the drum tank described Appendix 2. The capacity of such a tank will, by necessity, be small (less than 1,000 litres), however this is an economically sensible size given the availability of alternative water sources and the small roof sizes.

Figure 5.2. Rainwater harvesting in a Colombo shanty community next to a railway (the rail can be seen on the bottom left) (Picture: T. Ariyananda)

Demands placed on the system are often higher than in rural areas as the rainwater is expected to perform functions such as laundry that might take place at a point water source in a rural area

Pollution from automotive exhausts and industrial activity can be high and there is the possibility of blown (or even thrown!) human faecal matter from unhygienic toilet practices. Where the alternative source to rainwater harvesting is treated piped water, rainwater is mostly used as for secondary purposes like laundry and cleaning, quite the opposite of rural DRWH practice. However, where (as is often the case in slums) alternative sources are badly polluted springs, streams or shallow wells, the DRWH water will usually be cleaner and therefore might be reserved for potable purposes.

Chapter 6. Tank sizing

6.1 Introduction to sizing

The tank or jar used to store water in a roofwater harvesting system is usually its most expensive component. If we choose to make it very large, the system will make the best use of the water running off the roof but will incur a high cost. If we choose a very small tank, the system will be cheap but will waste quite a lot of the available water because the tank will sometimes overflow. So 'sizing a tank' means choosing the best compromise between good performance and low cost. Often there are only a few tank sizes available, so sizing means choosing which of these offers the best value.

Sizing can be done by custom (use the size everyone else in the district has been using for years), or by price alone (use the biggest tank you can afford) or by some sort of calculation. This chapter presents ways of calculating what size is best for in a particular house. That 'best size' is not the same for all houses, but depends upon the climate, the roof size, the number of people living in the house, the way the household manages its rainwater supply and the household's wealth.

For example, here is a list of factors that favour a household buying a *big* DRWH tank
- the cost of water (from other sources) is high
- the dry season is long and the cost of water in the dry season is much higher than in the wet season
- the roof is large and so is the family size
- the household is rich, or can borrow money at a low rate of interest
- the household is not willing to reduce its water consumption in the drier months.

For an agency providing highly subsidised DRWH, a big tank is justified where
- the house is in a 'water-stressed' area or is very far from any other water source
- people in the household are too disabled to fetch water
- there is political willingness to provide a large subsidy in order to give a high level of service.

The opposite of the conditions listed above would justify buying (or supplying) only a small DRWH tank.

In sections 6.2, 6.3 and 6.4 below we discuss these factors and how they influence tank sizing. section 6.5 describes a very basic procedure for choosing a tank size. section 6.6 covers more complex (advanced) tank sizing techniques.

6.2 Water availability, water demand and DRWH 'performance'

6.2.1 Water availability and need

The water available in an average year, as run-off from a hard roof, is typically 85% of (roof area in square metres) x (annual rainfall in mm). We will call this Annual Run-off (ARO). In rural areas of the tropics, ARO is typically 20,000 to 60,000 litres a year. Of course, the amount varies from year to year and run-off mostly occurs in the wet season. (Close to the Equator there are often two wet and two dry seasons per year, further from the Equator there is only one of each per year.). As mentioned in Chapter 1, only a fraction of this ARO can be used by the household. That fraction varies from under 10% for an informal DRWH system with little guttering and little storage, to over 90% for a system with full guttering and a very big tank. However a tank doesn't *make* water, it only stores it, so there is no way of harvesting in a year *more* water than runs off the roof in that year. Thus if the roof is small, the water harvested from it is unlikely to meet all the household's water needs, no matter how big the tank.

The amount of water a household 'needs' is very hard to decide. If water were cheap and plentifully available day and night, a household might use 1,000 litres a day – as is common in countries like the USA. If water were very scarce and expensive, it might use as little as 12 litres a day. Each person needs at least 2 litres per day to stay alive in a warm climate and at least 7 litres per day to stay healthy and practice good hygiene. The World Health Organisation recommends 20 litres per person per day as a minimum, but there are many rural communities in the tropics where water consumption is well below this figure.

6.2.2 Demand strategies

We are more interested in the demand a household places on its DRWH system – how much it tries to draw from it each day – than actual 'need'. Householders with a new DRWH system usually draw a lot of water from it and discover that their tank gets empty early in the dry season. In their second dry season they usually lower their demand, so that they get a higher level of water security. They also may discover that they can combine a high water supply in wet months with reasonable water security in dry months by varying their demand either according to the season or according to how much water is left in the tank.

In calculating the performance of a DRWH system (and how it varies with size of tank), we need to first decide what demand is going to be put on the system. The three most common demand strategies are

Constant demand – a fixed amount, which we can call 'standard' demand, is drawn each day until the tank runs dry

Adaptive demand – a fixed ('standard') amount is drawn whenever the tank is between 1/3 and 2/3 full. This demand is increased by (for example) one third whenever the tank is more than 2/3 full, but is reduced by (for example) one third whenever the tank is less than 1/3 full.

Seasonally-varied demand – a larger amount might be withdrawn in traditionally wet months and a lower amount in traditionally dry months.

Of these three demand patterns, the second ('adaptive') is usually the best from an economic point of view.

6.2.3 Choosing a 'standard' demand

Very few DRWH systems give too much water – more water than the household could make use of. So even the 'standard' demand is likely to be less than need. It is sensible to choose a standard daily demand that matches the annual water (*A x R*) expected to fall on the roof.

As there are 365 days in a year, a sensible daily demand would be *A x R* / 540 (that is 80% of average daily run-off where run-off itself is 85% of water reaching the roof). As will be shown later, higher demands result in poorer system performance.

6.2.4 Describing the performance of a DRWH system

In order to choose which of several possible tank sizes to use, we need to understand their different performances.

The simplest measure of DRWH system performance is *efficiency*; that is the fraction of the roof run-off water that reaches the household. Thus if 40,000 litres a year runs off the roof into the gutters and the household only draws 30,000 litres a year from its RW tank, we would say the system efficiency was 30,000/40,000 = 0.75 (i.e. 75%). *Efficiency = 100%* represents technical perfection but is never realisable or affordable. *Efficiency = 25%* shows that most of the run-off is being wasted and there is much scope for improvement.

However, we can think also think of performance as 'how well the roofwater system does what we have asked it to do', and we choose some measure of that performance. The most obvious such measure is *demand satisfaction*, which is the fraction of the annual demand (in litres) the system manages to deliver. Another such measure is *reliability* which is the fraction of days in a typical year that the tank has not run dry.

An economic measure of performance is the annual *value of water delivered.* This could be combined with the cost of the system to generate some standard economic ratio such as the system's payback time (capital cost of system / annual value of the water it delivers).

Table 6.1 summarises the various possible performance measures. The most common ones are shown **bold.**

Table 6.1. Roofwater harvesting system performance measures

Measure	Formula	Units	Of special interest to
Annual water delivered	W_a	litres	
Efficiency	$E = 100x\ W_a/ARO$	%	System designer
Demand satisfaction	$S = 100x\ W_a/demand$	%	Householder
Tank empty days per year	T_e	days	Householder
Reliability of supply	100 x (365-*Te*)/365	%	Householder
Value of water delivered in year	$\$_{water}$	money	
Payback time	$\$_{water}/\$_{system\ cost}$	years	Investor/Govt/ NGO

All these measures are affected by tank size and in particular the ratio of tank volume *V* to average daily run-off *(ADR = ARO/365)*. This ratio is measured in days (since *V* is in litres and *ADR* is in litres per day) so it is convenient in this handbook for us to describe tank sizes in days. Thus a '7-day' tank has a volume equal to 7 times the average daily roof run-off.

6.3 The ideas behind tank sizing

The performance of a RWH system thus depends upon both supply and demand factors, in particular:

- the local climate
- the area of guttered roof
- the capacity *V* (in litres) of the RWH storage tank
- the strategy the household members use to draw water from their tank
- the 'standard' daily household demand.

The system designer can't change the climate and probably can't afford to increase the roof size to a larger one, so tank capacity (*V*) is the main design variable. Making the tank bigger will improve performance but will strongly increase overall cost, because tanks account for up to 90% of RWH system costs. As said above, we are seeking to find what size gives the best trade-off between performance and cost.

In the past very large tanks were often built, so large that they sometimes cost more than the house they served. These gave good water supply performance but at an unaffordable price. In fact the most 'economical' size (that which gives the shortest payback time) is usually very small – typically of a volume equal to only about three day's water consumption.

6.3.1 Meeting a defined 'measure of performance'

The first step in tank sizing is to decide which performance measure (of those in Table 6.1) to use. Each of them is useful; none is perfect. Having chosen both a performance measure and what value we want it to have, we could investigate different sized tanks and choose the one that is just big enough to give the required performance. For example, we might size the tank to give a demand satisfaction of 85%. To do the investigation we will need to know all the other factors – climate, roof size, standard demand and tank water-management strategy.

This approach takes no account of costs or ability to pay. We could call it the 'performance-at-any-cost' approach. It is the opposite of a 'what-we-can-afford-regardless-of-performance' approach. More commonly we use neither of these approaches but seek to balance performance against cost.

6.3.2 The cost of a RWH system and its economic performance

The cost of a RW tank depends on its design, on where and how it is built and on its volume. Here we are looking particularly at *tank volume*, *V*. Tanks of any given design usually show strong 'economies of scale', meaning that their cost per litre of capacity goes down as their volume goes up. Suppose a RW tank is to be built in an Indian village. The following costs illustrate the economy of scale (Rs = Rupee):

> 1 small (1,000 litre) tank costs Rs.1,000/-, giving *unit cost* of Rs.1.0 per litre of tank volume,
>
> 2 small (1,000 litre) tanks cost Rs.2,000/-, giving the same *unit cost* of Rs.1.0 per litre,

but

> 1 big (2,000 litre) tank costs only Rs.1,400/-, giving a lower *unit cost* of only Rs.0.7 per litre.

Generally one big tank will be about 30% cheaper than two smaller ones that together match its capacity.

System costs are dominated by tank costs, except when the tank is very small. Table 6.2 shows how overall system cost typically rises with increasing tank volume, but system cost per litre of storage falls. It also shows how, from knowing the cost of one system, you can forecast the cost of another system with a larger or smaller tank. This economy of scale is discussed further in section 7.5.

Table 6.2. Typical variation of system cost with tank size

Tank volume in 1,000 litres	0.6	**1.0**	1.5	2	3	4	5	7.5	10	15	20
Cost relative to 1,000 litre tank	0.7	**1.0**	1.4	1.7	2.3	2.8	3.3	4.5	5.6	7.6	9.5
Relative system cost *per litre of tank capacity*	1.14	**1.00**	0.90	0.84	0.76	0.71	0.67	0.60	0.56	0.51	0.47

Note: This table assumes *system* cost rises by 0.75% for every 1% increase in *tank* volume.

Example:
Suppose a roofwater harvesting system containing a 1,500 litre tank costs US$ 50. What will a system with a 7,500 litre tank (of the same type) cost?
From Table 6.2, a 5-fold increase in tank volume from 1,500 to 7,500 litres implies that system cost rises by 4.5/1.4 = 3.3, i.e. a 3.3-fold increase). Thus system with the 7,500 litre tank will cost 3.3 x US$ 50 = US$ 165.

Of course there will be an upper limit to tank size, set perhaps by transport restrictions or the availability of moulds, but up to that limit it seems that it would always be more economical to go for a larger tank. Unfortunately, when we double the size of a tank, we do not double the performance of the DRWH system. *Efficiency, demand satisfaction, reliability* and *value of water delivered* may all go up, but by less than the cost of the system. For example if we were to calculate the tank cost per litre per year delivered by the system, we would probably find it higher (worse) for the 7,500 litre tank than for the 1,500 litre one.

If – with difficulty – we could work out the *annual value of water delivered* by a DRWH system, we could fairly easily combine it with the system's construction cost to calculate an economic measure like *payback time*. We would then be left with the final design choice, namely what payback time is acceptable. For example, we might choose "the biggest tank to give a payback time of less than two years".

In practice it is very hard to convert the performance measures of efficiency, demand satisfaction or reliability directly into money. So if we employ such measures, we must be prepared to somehow compare the costs of different systems with their respective performances and make our tank size choice accordingly.

6.4 Effect of tank size on performance in representative climates

6.4.1 Various climates

No two locations have identical rainfall. Moreover, good local rainfall records are not normally available to a tropical DRWH system designer. Even if they are available, they describe the past, not the future. For this reason, sizing RW tanks is always a rough process, with uncertainty of up to plus or minus 30%. We can consider three climate zones as being representative of much of the humid tropics, each having annual rainfall *R* of at least 800 mm. The zones are:

Zone A - uniform rainfall zone (Cuba, Indonesia), no month's average rainfall is under 20 mm

Zone B - bimodal rainfall zone (Lake Victoria, Venezuela, Sri Lankan Wet Zone) – there are 2 wet seasons each year and no two successive 'dry' months have under 20 mm rainfall

Zone C - unimodal rainfall zone (Ethiopian Highlands, Liberia, Panama, Philippines) – one wet and one dry season each year and not more than three successive dry months

In addition to these three zones, a fourth is just outside the 'humid' tropics proper and is less suited to *low-cost* DRWH.

Zone D - Monsoon zone (e.g. Abuja, San Salvador, Delhi) – up to 6 successive dry months.

In the Introduction, we said that DRWH is mainly for use in the *humid tropics,* essentially zones A to C above. Most sites more than 15 degrees from the Equator are in zone D which is outside the true humid tropics and where very low cost DRWH performs poorly. An expanded list of countries and their climate zones is shown below in Table 6.10

6.4.2 Performance under constant 'demand'

The simplest water demand strategy described in section 6.1 is one of 'constant demand'. Every day the household attempts to draw the same 'standard' amount from their RWH system. Some days however this demand will not be fully met and some days the tank will be empty and demand won't be met at all. We will now look at what level of *demand satisfaction* we can expect, when using this strategy. (*Demand satisfaction* = litres of water delivered / litres demanded) We can work out an average level over an average year. However during the year this *satisfaction* will vary – from near 100% during the wettest months to as low as 10% during the driest month.

Actual rainfall records have been used to calculate Table 6.3 and Table 6.4.

Table 6.3 shows that the demand satisfaction (for which the higher the value the better) that we can expect from any particular tank size gets markedly worse as we move from Zone A to Zone D.

Table 6.4 uses the same data to calculate payback time which also gets worse as we go from climate Zone A to Zone D. (A low value payback time is good; a high value is bad.)

However when we look at the effect of tank size on performance within any one climate zone, we find that increasing tank size improves demand satisfaction but makes payback time worse.

For a given desired performance (such as *demand satisfaction* = 80%) we need bigger tanks in places where the rainfall is less uniform.
However bigger tanks mean a longer payback time.
Also for given total investment, building small tanks at many houses gives more water in total, and a better financial return, than building one big tank at one house.

Table 6.3. Demand satisfaction for different tank sizes and different climates (daily demand D = constant = 80% of average daily run-off ADR)

Tank size in days (*V / ADR*)	**5 days**	**10 days**	**20 days**	**40 days**	**80 days**	**160 days**
Climate	**Performance: *demand satisfaction* (%)**					
Zone A Uniform humid	76	89	97	99	100**	100
Zone B Two short dry seasons	53	67	79	87	95	100
Zone C One dry season	50	62	71	76	82	95
Zone D Monsoon One long dry season	44	53	60	66	74	88

* The four climate zones are described above in 6.4.1.

** 100 indicates complete demand satisfaction

Table 6.4. System payback time for different tank sizes and climates (daily demand D = constant = 80% of ADR)

Tank size (*V* / *ADR*)	5 days	10 days	20 days	40 days	80 days	160 days
Climate	**Performance: *payback time* (in months)**					
Zone A Uniform humid	6*	8	11.5	18	27.5	43
Zone B Two short dry seasons	8.5	10.5	14	20	29	43
Zone C One dry season	9	11.5	16	23	33.5	47
Zone D Monsoon	10.5	13.5	18.5	26.5	37.5	49

* As a basis for all the other values of payback, Payback Time for 5-day tank in Zone A has been taken as 6 months.

Table 6.5 is similar to Table 6.3 except that the daily demand has been increased from 80% to 100% of average daily run-off. The *satisfaction* is now poorer, even when the tank is made as large as 100 days, showing that it is unwise to apply a demand as high as this (1.0 x *ADR*).

Table 6.5. Demand satisfaction with higher demand (constant daily demand D raised from 80% to 100% of ADR)

Tank size (*V* / *ADR*)	5 days	10 days	20 days	40 days	80 days	160 days
Climate	**Performance: *demand satisfaction* (%)**					
Zone A Uniform humid	65	79	88	93	96	99
Zone B Two short dry seasons	44	58	70	77	85	93
Zone C One dry season	43	55	65	71	76	85
Zone D Monsoon	38	48	55	61	69	80

6.4.3 Performance under adaptive demand

So far we have assumed a constant daily demand (e.g. *D* = 80% of *ADR*). Instead we might employ an *adaptive demand* like that described in section 6.2.2. Now the daily demand will vary between 4/3 of 80% of *ADR* (consumption raised) down to only 2/3 of 80% of *ADR* (consumption cut), according to how much water is left in the tank. We now get a better performance as shown in Table 6.6. Compared with constant demand, satisfaction is up by 20% for very small tanks, but the improvement is negligible for very large tanks. If instead of calculating *satisfaction* as the fraction of demanded water that was delivered, we had calculated the fraction of *days* for which demand was satisfied, we would have found an even bigger improvement from using this 'adaptive demand'.

Note that demand satisfaction is measured against a particular demand pattern and by adopting adaptive demand instead of fixed demand, we have changed this demand pattern. Thus it may be feared we are obtaining greater reliability at the expense of less water overall. However, were we to measure total water delivered by a DRWH system in a year (or efficiency, which is total delivery / total run-off), we would find that changing from fixed to adaptive demand does indeed also increase the total water delivered and hence capture efficiency. This is because under adaptive demand less water is lost per year through tank overflow during heavy rains.

Table 6.6. 'Demand satisfaction' as in Table 6.3 but with adaptive demand (demand is variable but based on a 'standard demand' of 80% of ADR)

Tank size (*V / ADR*) =	**5 days**	**10 days**	**20 days**	**40 days**	**80 days**	**160 days**
Climate	**Performance: *demand satisfaction* (%)**					
Zone A Uniform humid	85	95	99	100	100	100
Zone B Two short dry seasons	65	79	89	95	99	100
Zone C One dry season	62	74	82	85	90	98
Zone D Monsoon	57	67	74	79	85	94

6.4.4 Effect of operating choices on performance – and recommendations

There are two main operating choices open to a household using DRWH. These are the level at which it sets 'standard' demand and whether it uses constant demand (throughout the year) or adaptive demand (draws more water in wet months and less in dry months).

Table 6.7. Effect of operating choices

Operating choice	**Demand satisfaction**	**Reliability**	**Efficiency & annual yield**	**Payback time**
Increase the 'standard' demand	Gets worse	Gets much worse	Improves	Improves
Change from fixed demand to adaptive demand	Improves	Improves strongly	Improves	Improves slightly

Recommendation
The setting of standard daily water demand should be at about 80% of average daily roof run-off (i.e. at *roof area* x *annual rainfall* / 540) and households should adopt adaptive daily demand rather than fixed daily demand.

6.5 Suggested (basic) tank sizing method

The following **suggested method for tank sizing** is based on following a five-step procedure. (We assume that users manage their water with an adaptive strategy, drawing more when the tank is nearly full than when it is nearly empty.)

Table 6.8. Five-step basic procedure for choosing tank size

1. Calculate the average daily run-off (*ADR*).
   ADR in litres/day = (roof area in m^2) x (local annual rainfall in mm) / 430 (the number 430 expresses both days in year and 0.85 roof run-off coefficient).
2. Select a climate Zone (A to D) with the aid of Table 6.10 below.
3. Decide your design objective (I, II, III or IV) from the four listed under in Table 6.9 below. Most people use either Objective II (= using a small tank to keep costs low and accepting that user 'demand' cannot always be met) or Objective IV (= using a large and expensive tank to make sure that demand can be met in all but the very driest week in a typical year). Objective I, the cheapest, is for where roofwater harvesting is used only to save water-collection time during the wet season.
4. From Table 6.9, read off a recommended tank size *N* (which is listed in 'days'). Work out the tank size *V* (in litres) as *ADR x N*.
5. Work out a suitable 'standard' daily demand (= 80% of *ADR* expressed in litres per day) and tell the user this is what you have designed for. Also tell them that it is OK to use 1/3 more per day when the tank is nearly full but that they should use 1/3 less when it is getting empty. (This is the adaptive demand strategy).

Table 6.9. Recommended tank size N in 'days' (Tank volume V = ADR x N)

Climate Zone (as Table 6.10)	**Objective of Design**			
	I Shortest payback	II Low cost satisfaction = 70%	III Medium cost Satis. = 85%	IV High cost Satis. = 97%
Zone A Uniform humid	N <5 days	N <5 days	N = 5 days	N = 15 days
Zone B Two dry seasons	N <5 days	N = 6 days	N = 14 days	N = 60 days
Zone C One dry season	N <5 days	N = 8 days	N = 40 days	N = 160 days
Zone D Monsoon	N <5 days	N =13 days	N = 80 days	N = 220 days

The basis of design in column I is to get the highest satisfaction per dollar spent. This corresponds to using a very cheap small tank or jar and therefore getting a poor satisfaction and a low annual volume of water.

The basis of design in columns II to IV is to achieve some particular level of demand satisfaction. This is the fraction (of the water the user chose to demand of the roofwater system) that he/she actually gets in an average year.

Note that with climate Zones C or D the tanks become big and expensive if they are to give even 85% demand satisfaction, and very big indeed if the user requires say 97% satisfaction.

The climate Zones (all with annual rainfall over 800 mm) used for Table 6.10 are those listed at the start of section 6.4 above.

Table 6.10. Approximate climate Zones (A to D): selected countries in the humid tropics

Africa	Zone		Asia	Zone		Latin America	Zone
Burundi / Rwanda	B		Bangladesh	C		Amazon (Brazil/ Ecuador/Peru)	A
Cameroon	B		Cambodia	D		Andes (Colombia/ Ecuador/Peru)	C
Congo (DRC & CR)	B		China S	C		Brazil (coast/ plateau)	C/D
Côte Ivoire (South/ North)	B/D		India Deccan/NE	C/D		Belize	A
Ethiopia	D		Indonesia	A		Caribbean (South)	C
Gabon / Equat'l Guinea	C		Malaysia	A		Costa Rica / El Salvador	D
Ghana & Togo (South/ North)	B/D		Myanmar (S/N)	C/D		Cuba & North Jamaica	A
Guinea	D		Philippines (South/ North)	C/A		Dominica / Haiti	A
Kenya	B		PNG/ Solomons	A/C		Guatemala / S Mexico	D
Liberia	C		Singapore	A		Guyana / Surinam	A
Mozambique & Angola	C		Sri Lanka (wet/dry)	B/C		Hispaniola/ Puerto Rico	A/C
Nigeria/ Benin (South/ North)	B/C		Thailand (South/ North)	C/D		Honduras	B
Sierra Leone	C		Vietnam & Laos	C		Nicaragua	C
Tanzania (North/rest)	B/D					Panama & N Colombia	C
Uganda	B					Venezuela (South/North)	B/C

6.6 More advanced tank sizing procedures

6.6.1 Using a computer programme to predict system performance

In selecting the sizing methods described in section 6.5 above, you are relying on other people's judgement of what to design for. If however you are ready to choose a tank size that takes into account both cost and performance, you may decide to use a performance simulation programme like the rainwater tank performance calculator, available at the web site www.eng.warwick.ac.uk/dtu/rwh/model.

The procedure to use is

1. Gather rainfall data for your area (ideally *actual* monthly data for 10 years, otherwise just use *mean* monthly data for all 10 years).
2. Log onto the site and follow the instructions. It will enable you to compare the performances of various tank sizes for your particular rainfall and building. It gives you a choice of assumptions to work to about user behaviour and a choice of performance measure – reliability, satisfaction or efficiency.
3. Choose the tank size that will just give the performance you have decided you need.
4. Check whether the cost of this size of tank is affordable – you can assume system cost varies with tank size according to Table 6.2. If it is not affordable then choose a lower level of performance. Remember that the smaller the tank, the better is the economic return – i.e. the shorter the payback time.

6.6.2 Tank sizing for semi-arid zones

The trade-offs discussed above, and the tank sizing recommendations that follow from them, do not fit semi-arid zones – i.e. zones with dry seasons longer than 6 months. In such zones all dry season water sources may be unreliable. In such situations, a popular strategy is to try to fill a tank during the short rainy season and then use that one tankful of water over the rest of the year. Such tanks are likely to be even bigger than the largest sizes shown in Table 6.9.

The tank designer has to choose whether to make its volume 'large' (namely equal in volume to an average year's roof run-off) or 'very large' (equal to run-off in a year of unusually good rainfall). To make this choice, it is desirable to know the annual rainfall for the last 15 or more years. To assist tank sizing in this context, a well-established computer programme called SIMTANKA2 can be found at the Ajit Foundation web site: http://homepage.mac.com/vsvyas/science.html#simtanka. After using the programme to estimate the performance of the system with the tank size you propose, compare that performance with that tank's cost to decide whether the combination is acceptable.

Chapter 7. Selecting the Tank Type

7.1 Introduction

The tank represents the largest single cost in a roofwater system: in higher capacity systems it can account for 90% of the total system cost. Even in smaller capacity low-cost systems, the tank represents about 70% of the system cost. It is therefore vital to get this component right.

The selection of the right tank involves a number of variables, some easily measured and others more difficult to quantify. Some important factors are:

- Cost
  - up-front cost (in cash and time)
  - maintenance cost
- Direct benefits
  - amount of water delivered
  - number of months per year the system is in operation
  - longest period the system will be dry
  - water quality
- Indirect benefits
  - time saved not fetching water from other sources
  - health benefits accrued from increased water use
- Prestige value
  - tank size
  - quality of construction
- Other factors
  - local knowledge of designs and techniques
  - is it desirable to build (and pay for) the system in stages?

To a water supply organisation, the most important factors are cost (primarily up-front cost, since maintenance is typically done by the household), and the direct benefit in the water collected by the system (and the knock-on benefit in saved time, and/or additional water use in the home). The benefit side of the equation itself has two components: how much each household can gain from its DRWH system and how many households can be provided with systems. The second of these will depend on the cost of each system of the chosen design and the total amount of money available to build systems.

To a householder, the priorities may be different. Up-front cost is important where there is a significant household contribution or the tank is bought outright by the household. However, in recent years many tropical DRWH systems have been so heavily subsidised that beneficiaries have had little interest in the cost. The amount of water that can be delivered by the system is important to the householder. The actual amount is difficult to predict and is usually unknown to the householder, who will probably use the tank size to judge this. Prestige is also important to householders – a visible water tank can be a considerable household asset and a large, high-quality tank can enhance the householders' standing in their community. However, householders often fail to realise that doubling the size of a tank does not double the water it can deliver in a year.

While there is considerable crossover in these goals, the community should be exposed to information on:

- how much water can be gained from a range of system sizes and how this water will be distributed over the year
- the effects of different water management strategies on the water gained from the system
- a range of designs of different quality
- the trade-off between tank cost and system coverage or household contribution
- any cash or labour contribution expected from the household.

A range of designs of different quality and size should therefore be presented along with the quantity of water they can be expected to deliver, when in the year water will be available, the outlay of householder's time and money, and the need for upkeep and maintenance. Different options should be illustrated with pictures of the tanks. This 'catalogue' approach has been common in sanitation projects (where it is called 'the sanitation ladder') and is particularly suited to rainwater harvesting. Such a catalogue is shown in Figure 7.1, on the assumption that a water provider has a fixed budget for DRWH systems and that the community is unable to provide any cash contributions. Different scenarios will need some modification. Increasingly DRWH is moving from something donated to households to something they buy – perhaps with the aid of small loans. For such an open market setting, the 'number of systems that can be built' row would be irrelevant, but information on any necessary deposits and the repayment schedule should be included.

	Tank size	**1,000 litre**	**2,000 litre**	**5,000 litre**	**10,000 litre**
Based on constant demand (40 litres per day)	**Fraction of HH water provided by tank**	61%	68%	79%	94%
	Max dry period	163 days	151 days	113 days	51 days
Based on variable demand (tank is more than 2/3 full, 70 litres/day; if it is less than 1/3 full, 30 litres per day; otherwise, 50 litres per day.)	**Demand satisfaction**	60%	66%	74%	86%
	Max dry period	135 days	112 days	37 days	0 days
	Max low-use period	83 days	98 days	159 days	147 days

	Tank size	1,000 litre	2,000 litre	5,000 litre	10,000 litre
Design 1: Pumpkin tank					
	Number of tanks that can be built	1,000	680	410	280
	Unskilled labour content (per tank)	6 days	8 days	13 days	19 days
	HH contribution (other than labour)	0	0	0	0
Design 2: Dome tank					
	Number of tanks that can be built	2,000	1,360	820	560
	Unskilled labour content (per tank)	6 days	8 days	13 days	19 days
	HH contribution (other than labour)	0	0	0	0
Design 3: Mud tank					
	Number of tanks that can be built	3,000	2,040	1,230	840
	Unskilled labour content (per tank)	9 days	14 days	24 days	35 days
	HH contribution (other than labour)	0	0	0	0

Figure 7.1. An example of a tank selection matrix (Pictures: D.Rees and D.B. Martinson)

7.2 Cost

Selecting a tank design with too high a cost will have several drawbacks:

- roofwater harvesting will be seen as an expensive option
- there will be a low service coverage for a given programme budget; a few households will get a big improvement in their water supply but most will get none
- the technology will not be replicated, as it is unaffordable (In recent surveys, almost all householders cite lack of resources as the main reason they have not taken up domestic roofwater harvesting.)
- cost-recovery will prove impossible.

Tanks can be made cheaper by reducing the size of the tank or the quality of materials used or by increasing the household contribution (in either money or time). Reducing size can provide large savings, as shown in Chapter 6. However, householders often demand larger tanks for reasons beyond their need for a water supply, associating larger tanks with better security and status. Other options may therefore be appropriate to reduce the cost per unit size. (Due to economies of scale, this is more correctly described in terms of an *equivalent unit cost* – see section 7.5).

7.2.1 Strategies for cost reduction

Shape optimisation

Savings in materials can be made by optimising the geometry of water tanks so as to minimise the ratio of surface area to volume. For example a spherical tank has only 87% of the surface area of a cylindrical tank holding the same amount of water, and a tank whose walls are thicker at the bottom than at the top uses less material than one whose wall are of a constant thickness. Using highly optimised shapes should, however be balanced against the additional skill required to form them – for example a spherical tank with tapered walls is very hard to make and requires complex formwork (formwork is a temporary frame used to hold wet concrete in a particular shape until it sets). If skilled labour is inexpensive, considerable savings can be made by changing from a simple to a complex shape, as the amount of material to make the tank can be reduced by up to a third. By contrast, where labour is expensive, it may be better to use a simpler shape such as a cylinder since that is quicker to manufacture.

Optimised shapes also tend to need specialised moulds that should be factored into any cost calculation. These moulds however can usually be used many times and so are extremely useful when a large number of tanks is required. The 'Thai jar' is a good example of shape optimisation and reusable moulds. Many millions have been made and this is widely recognised as one of the cheapest designs – although this is for a number of reasons of which the shape is only one (see Box 7.1). The larger Sri Lankan 'pumpkin' tank has a partially optimised shape and is constructed on an open frame.

Each material favours particular shapes. Bricks, concrete and sheets of waterproof fabric are all easier to form into rectangular shapes than into circular ones. The top of a tank is cheaper to build as a sloping or conical roof than as a flat slab.

Workshop production

Production in an indoor workshop is an important part of the reason for the low-cost of the Thai jar. Significant savings in material and labour can be made if products are manufactured in quantity and under closely controlled 'factory' conditions. The buying power of the manufacturer increases and proper workshop practices such as batching and sub-assembly can be incorporated to reduce labour cost. High-performance manufacturing practices such as vibrating tables and underwater curing can also be incorporated into workshop-produced tanks increasing their strength without increasing material use. Production is also unaffected by bad weather.

A factory-made jar cannot be larger than can be transported from factory to the customer's home. However, tanks can also be made in factory-produced sections which are later assembled on site. The 'cement plate cistern' from Brazil and the 'segmental shell' developed by SERC in India are examples of workshop-produced segmented tanks. Both these designs are described in Appendix 2,

Components such as filters or tank covers can also be mass-produced. In order to benefit from centralised workshop production, sections and components need to be of a manageable size and appropriate transport is needed.

Box 7.1. The Thai jar – an example of workshop-based optimisation

The 1980s was the Water and Sanitation Decade but by the end of a decade of extended effort most countries were little better off. Not Thailand, however. By the end of the decade, Thailand could boast almost 100% water supply coverage. The development of rainwater harvesting technologies and particularly the Thai jar played no small part in this

The jar began as a community-made item using a mould made from sacking filled with sand or sawdust. The jars soon reduced in price to about US$ 20 largely through commercial manufacture. The price today is less than US$ 15 and the jars are almost universal in rural homes in Northern Thailand, and are also found in neighbouring countries such as Cambodia where they sell for less than US$ 10. This price makes the jars affordable by all but the poorest and has caused DRWH to become widespread without further input from any institution.

The secret of the low cost is not necessarily mass manufacture in the traditional sense as Thai jars are often made by part-time farmers in small batch quantities, but is due to the optimised shape, the quality and availability of tooling and the quality control available by making them in a workshop rather than on site. Each jar is made on a cement brick mould, coated with mud as a mould release. The mould sets themselves are also made locally, so a factory may have several for simultaneous use. The steel formers for making the moulds, however, are made centrally ensuring tight quality control of size and shape. The high quality solid mould allows a very uniform and thin coating of mortar to be applied, resulting in a highly optimised product.

Attempts have been made to transfer the jar to other countries, notably in Africa. However while the basic design of a small jar has been maintained, the workshop practice has not, most jars being made using filled sacks as formwork. This has resulted in a product that, while cheap compared to larger tanks, is much more expensive (and less well finished) than jars made in Thailand. More recently, there has been a move toward using workshops and wooden moulds which has yielded a more economical product.
Photographs of Thai jars are in Appendix 2.

Underground construction

A large number of lower-cost tanks are built underground as the earth itself can be used to support part of the water pressure load. Underground tanks are better able to approach certain ideal shapes such as reverse-domed bottoms, as they are not constrained to have a flat bottom for stability. In addition, the ground itself can be used as the construction formwork. Where the soil is suitable and the water table is never near the surface, these advantages can result in material reductions in the order of 50%. Moreover, the tanks have a high unskilled labour content that can be supplied directly by the household or by a labourer. Examples of successful underground tanks include the DTU Dome tank and the Brazilian brick & lime cistern which use the ground for partial support. These tanks are described in Appendix 2.

The relative merits of underground and above ground tanks are shown in Table 7.1. As a general rule people prefer an above ground over a below ground design. However, there is an even stronger user preference for larger tanks over smaller ones, and that often favours a below ground option. Householders need to be aware of the difference styles, costs and benefits to be able to make a reasoned choice.

Table 7.1. Relative merits of above ground and underground tanks

	Pros	Cons
Above ground	• Allows for easy inspection for cracks or leakage • Water extraction can be by gravity and by tap • Can be raised above ground level to increase water pressure	• Require space • Generally more expensive • More easily damaged by accidents • Prone to attack from weather • Failure can be dangerous
Underground	• Surrounding ground gives support allowing lower wall thickness and thus lower costs • Difficult to empty accidentally by leaving tap on • Requires little or no space above ground • Unobtrusive • Water is cooler • Some users prefer it because "it's like a well"	• Water extraction is more problematic – often requiring a pump, a long pipe to a downhill location or steps • Leaks or failures are difficult to detect • Possible contamination of the tank from groundwater or floodwaters • The structure can be damaged by tree roots or rising groundwater • If tank is left uncovered, children (and careless adults) can fall in, possibly drowning • Heavy vehicles can drive over a cistern causing damage • Cannot be easily drained for cleaning • Unsuitable for areas where the water table rises above the bottom of the tank • Usually unsuitable when soils are loose

Some of these disadvantages can be alleviated by putting the tanks 80% below and 20% above ground. The Brazilian plate cistern and the DTU dome tank are made this way.

Reducing construction and material quality

Construction quality affects such features as longevity, ease of use, appearance and potential to generate pride in ownership and to satisfy the builder's desire to do a proper job. However, construction quality does *not* necessarily equate to water quality. A good example of deliberately lowering construction quality to achieve affordability is the Tarpaulin tank, designed by ACORD for refugees in Southern Uganda. The tank (see Box 7.2 below) uses a plastic tarpaulin in a pit to hold the water while the above-ground structure is wattle and daub. Large savings were made by exchanging expensive materials such as ferrocement for lower quality materials that could simply be gathered.

Figure 7.2 schematically shows the relationship between tank size, construction quality and cost. Generally, rainwater harvesting projects in developing countries have operated at the 'medium quality' level, using materials such as bricks and cement and techniques taken from the formal housing sector. However many houses, especially those of the poor, use much cheaper (often free) materials. As a result, rainwater cisterns are often of an inappropriately higher quality and higher cost than the houses they serve, as can clearly be seen in Figure 7.3.

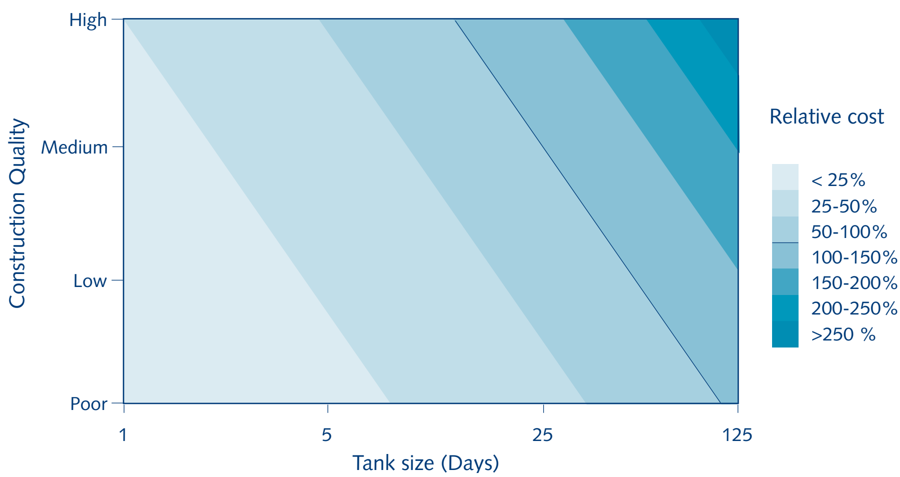


Figure 7.2. Schematic graph of cistern cost versus size and construction quality. (A 'medium quality 25-day tank' is assumed to cost "100%").

Figure 7.3.Typical rural building in Ethiopia with an unsustainably costly ferrocement tank
(Picture: B. Woldemariam)

The quality of *informal* RWH systems commonly found in poor households (using oil drums and kitchen utensils) is generally lower than the DRWH systems installed by water providers.

Lowering construction quality from a high standard mainly affects appearance. The next parameter to suffer is durability – cheap materials like wattle and daub walls do not have the durability of mortar and need more frequent renewal. Finally, the point is reached where water quality itself is degraded, for example by omitting the cistern's cover. A domestic RWH system should not be made to such low quality, unless perhaps it is cascaded to give two outputs – of non-potable and potable quality, matching different applications.

A number of critical features should be regarded as a minimum specification for any domestic rainwater harvesting system:

- the tank should not have excessive loss through seepage or evaporation
- the tank should not endanger its users, either by their falling in or by the tank failing violently
- the water must be of a quality suited to its intended use
- drinking water in particular requires that:
  - the inlet water be filtered to remove gross impurities or the first-flush run-off be removed
  - the tank be covered to prevent the entry of light, and sealed against intrusion by small animals
  - the tank be ventilated to prevent anaerobic decomposition of any washed-in matter.

Land use and height-to-width aspect ratio

If land shortage is a problem, as it often is in urban or peri-urban locations, tall thin tanks are recommended because they take up less ground space. Such shapes do not suffer from serious diseconomies due to their shape unless their height is more than three times their width. Tanks of this shape can continue upwards until gutter level is reached. Very shallow, wide shapes by contrast tend to use a lot of land and are therefore unpopular. They also suffer from strong material diseconomies, mainly due to their large floor and roof area.

Box 7.2. The tarpaulin tank – self-help innovation

The tarpaulin tank is an excellent example of what can be achieved if a strict eye is kept on the costs while maintaining the bare essentials of function.

The civil war in Rwanda brought large numbers of refugees into Southern Uganda, many of whom settled in the mountains near the town of Mbarara. In places such as the Orikinga valley the water table lies well below the surface and may be contaminated with unacceptable levels of iron and manganese.

The refugees had little capital to buy equipment but the UNHCR supplied several tarpaulins to be used as shelter. On finding these tarpaulins to be waterproof, a number of families lined holes with them and successfully used them to collect rainwater. However the lined pits were vulnerable to foreign matter getting in and, being open to the sky, allowed algae to develop, resulting in a reduction in water quality.

ACORD Uganda worked with the households to develop an improved design that would allow for increased water quality but retain the low-cost nature of the tank. The improved design featured an enclosure made from wattle and daub with a galvanised steel roof. The enclosure meant that light and foreign matter were kept out of the tank improving water quality. The top edge of the tarpaulin could be raised about 10cm to keep ground run-off out of the tank, an overflow arrangement could be introduced and access to the water was by dipping a half-jerrycan through a wooden door.

The tarpaulin tank is however, not a durable solution in all cases. The problems are primarily location related. If the design works in one part of a location, it should work everywhere. If it fails in one spot, it will generally not be suitable across the whole location. Problems include:

- termites eating the wattle and daub frame – this can be dealt with using similar methods as to protect housing
- The tarpaulin can rot – it is unclear whether this is due to insects or fungal activity, but it does seem to be correlated to soil type
- roofing sheets can rust.

Photographs of Tarpaulin tanks are in Appendix 2.

7.3 Other factors affecting technology choice

7.3.1 Labour content

Generally, the labour used in building tanks will be local, so tank-making will generate local employment and money will go into the local economy. Using designs whose construction has a high labour content will therefore usually be good for the community as a whole. Labour time varies with tank size in much the same way as overall cost, so the easiest way of expressing labour cost is as a *fraction of total cost*. This fraction will stay fairly constant throughout changes in tank size but will vary strongly from design to design and country to country, as the relative costs of labour and materials change. Some labour cost fractions for production of tanks are given in Table 7.2. The same figures can also be used to estimate the labour fraction of tank maintenance costs.

Table 7.2. Labour cost as a fraction of the total cost, for selected rainwater tanks

Tank type	Ethiopia (variable material cost & low labour cost)	Uganda (high material cost & low labour cost)	Sri Lanka (low material cost & medium labour cost)
Mud tank	63%	55%	80%
Thatch tank	40%	45%	70%
Dome tank	35%	35%	60%
Pumpkin tank	35%	25%	50%
Open frame ferrocement	25%	25%	35%
Drum tank	20%	25%	60%
Tube tank	20%	30%	50%
Tarpaulin tank	20%	20%	33%
Plate tank (Brazil)	15%	15%	30%
Thai jar	10%	20%	30%
Moulded plastic	<5%	<5%	10%

7.3.2 Potential for householder contributions in kind

Unskilled labour content

Often, beneficiaries who are very poor are expected to contribute to costs in the form of labour. If householders are willing to provide this, then choosing a design with a high unskilled labour content will allow them to install a larger system than they could otherwise afford. This, of course only holds true up to the point where householders consider that the level of labour and organisation required is a burden. This issue should therefore be discussed with the community at the technology-selection stage. The household labour cost is best expressed as a fraction of the total labour cost – but it can also be presented to householders as the time commitment they are required to make, and can be also used by a DRWH system provider in budgeting.

Table 7.3. Household labour fractions

Tank type	Unskilled household labour (as a fraction of total cost)	Unskilled household labour (as a fraction of total labour)
Thatch tank	20%	80%
Open frame ferrocement	14%	60%
Tube tank	9%	80%
Dome tank	9%	65%
Drum tank	9%	30%
Pumpkin tank	6%	65%
Thai jar	4%	50%
Tarpaulin tank	4%	70%
Mud tank	3%	85%
Plate tank	2%	50%
Moulded plastic	1%	50%

Local materials

Another contribution in kind is the provision or gathering of local materials. Building materials such as sand and gravel make up 3-6% of the cost of most cement-based designs, while for other designs thatch and poles are needed. Such contributions reduce the total cost to the provider and the savings can again be put towards offering the community more or larger systems. This increase in householders' time contribution should also be an explicit part of the technology choice discussion with the community.

7.3.3 Ease of implementation

One of the main reasons that agencies use expensive plastic tanks is their ease of implementation – just 'deliver and connect'. Other designs, particularly those with a high householder labour content, require close supervision throughout the building process. The cost of this management may be significant and should again be explicitly included in the selection exercise.

7.4 Tank materials and techniques

7.4.1 Precast Concrete

A pair of precast tanks in rural Australia
(Picture: Economy Tanks Pty. Ltd.)

A precast concrete tank being buried in urban Germany
(Picture: Mall GmbH)

Precast plates being placed on a ferrocement tank in Brazil
(Picture: Johann Gnadlinger)

In high-income countries such as Australia and Germany, pre-cast concrete tanks form a large part of the DRWH market. The tanks are cast in sizes up to 35m^3 under controlled factory conditions, delivered to the site by truck and installed by crane. The economies inherent in this strategy revolve around the ability for the factory to specialise in this type of construction, the use of appropriate jigs and the ease of installation which reduces on-site labour costs. In Germany most tanks are sited underground to reduce space requirements.

There have been several attempts to build such tanks in low-income countries such as Brazil and Kenya, using shuttering with corrugated iron, but the technology has generally proven too expensive to be widely replicated. Pre-cast rings, already produced in quantity for well lining, have been used successfully in Bangladesh for DRWH tanks. This ability to mass-produce items gives the technique some promise in the field of tank components such as segmented covers and filter boxes. Concrete is also used for ancillary work around tanks such as foundations, drainage and soakaways.

7.4.2 Steel

A large steel tank in rural Australia
(Picture: Pioneer Tanks Pty. Ltd.)

A corrugated steel tank in rural Uganda. Note the darker ring at the bottom of the tank – a concrete repair that is often needed
(Picture: D. Rees)

An oil drum tank in rural Uganda
(Picture: D. Rees)

Steel tanks of various sizes have been used throughout the world for many years and are still popular today. They range from the steel drums often found outside houses in East Africa to gigantic 1.5 million litre structures used to supply remote communities in Australia. The tanks can be delivered to a site and installed in a short time by a skilled person, often without the need for an extremely firm foundation as the steel structure will 'give' a little to accommodate any settling.

Problems with corrosion at the bottom of the tank have been observed after about two years. Building a concrete ring around the base of the tank can effect a repair, but such failures in the field have limited the steel tank's acceptance and wider application. The problem does not generally appear in tanks in high-income countries where steel tanks are generally coated inside or lined with plastic. Placing a lump of limestone in the tank has been recommended as a way to reduce the acidity of the stored rainwater and hence extend tank life.

Oil drums are one of the most widely dispersed water containment stores in the world. However, a number of unique problems affect water quality:

- most drums have previously contained chemicals, often toxic ones
- drums have usually been opened in such a way that they are uncovered and thus present an ideal environment for mosquito breeding and algal growth
- water extraction can be a problem – dipping with a cup can introduce contamination.

If these problems can be solved inexpensively, then drums offer a readily available supply of small storage units. However, the cost per litre is often high.

7.4.3 Plastic

Plastic tank intended for underground installation in Germany
(Picture: Roth GmbH)

Plastic tanks in Uganda
(Photo D. Ddamulira)

Tarpaulin lined underground tank in rural Uganda
(Photo D. Rees)

Plastic tanks, usually made from HDPE or glass reinforced plastic (GRP), form the fastest growing segment of the market. They are popular in high-income countries where they compete directly with older technologies such as steel or concrete on a direct price basis. In low and medium-income countries, these tanks are generally more expensive by a factor of three to five, which has slowed their adoption. However, this is changing – in Sri Lanka the price penalty of a plastic tank is down to about +70% while in South Africa the differential is even less.

Even in countries where there is a price premium for plastic tanks, they are often employed by water supply organisations, as they are quick to install and are known to work reliably (usually backed by a 25-year manufacturer's guarantee). Consumers also like the tanks and see them as the most up-to-date method of storing water, although there are some problems in cleaning the tanks and their characteristic black colour means that water heats up inside.

At the lower-cost end of water storage, the use of plastic lining materials in combination with non-plastic local materials is highly cost-effective.

7.4.4 Ferrocement

Household ferrocement tank in Ethiopia
(Picture: S. Akhter)

Mass produced cement jars for sale by the side of the road in Thailand
(Picture: R. Ariyabandu)

Ferrocement "pumpkin" tank in Sri Lanka
(Photo T. Ariyananda)

Ferrocement is the technology of choice for many rainwater harvesting programmes, the tanks are relatively inexpensive and, with a little maintenance, last indefinitely. The material lends itself to almost any shape (it used for boat building and even sculpture). Ferrocement construction, which is described on the next page, has several advantages over conventionally reinforced concrete, principally because the reinforcement is well distributed throughout the material and has a high surface area to volume ratio. In particular:

- cracks are arrested quickly and are usually very thin resulting in a reliably watertight structure
- it has a high tensile strength (in the region of 3 MPa before cracking)
- within reasonable limits, the material behaves like a homogeneous, elastic material
- no shuttering or moulds or vibrator are needed.

The technique was developed in France in mid 19th century and was initially used for pots and tubs and even boats, but was however displaced by less labour-intensive reinforcement methods. Water tank construction with ferrocement has been ongoing since the early 1970s, was popularised in Thailand and has since spread to Africa, South America, Sri Lanka and elsewhere.

Tank construction using ferrocement involves the plastering of a thin layer of cement mortar (typically 1 part cement to 3 parts sand mixed with about 0.5 parts water) onto a steel mesh (typically chicken mesh though weld-mesh is also popular). Despite being described as a 'low skill' technique, workmanship is an important issue. The thickness of mortar is sometime as little as 5 mm giving little room for error when covering the mesh. Formwork can be used to support the mesh before it is plastered or alternatively a self-supporting mesh can be used. A solid formwork reduces error and permits the application of thinner plaster, and is often behind successful designs. Increasingly though, formwork is being abandoned due to its high cost and to gain flexibility in size.

The most popular ferrocement tank design continues to be the straight cylinder. Formworks are easy to construct using sheet metal or BRC mesh, and there are usually no foundation problems as the base is very wide. There can be some problems of cracking at the wall-base joint if the stress concentrations there are not accounted for in the design. There have been some reports of cracking at the lid-wall interface. Several designs such as the Sri Lanka pumpkin tank have been produced with a rounded shape to avoid breaks at junctions.

Even more popular than cylinders, but not technically 'ferrocement' are the Thai jars (Box 7.1 above). There are more than 14 million of these jars throughout Thailand with capacities ranging from 0.5m^3 to 3m^3.

Another method of employing mass-production techniques is to make the ferrocement tank in sections. The Structural Engineering Research Centre in India makes tanks in full height or half height segments which are shipped out by truck and joined together on site in a single day. The segments have a much-reduced thickness as they can be made horizontally at a comfortable height on well-designed jigs. Segmented techniques have also been tried in Brazil with the segments made on site. The material cost is similar to same-size ferrocement tanks made on a formwork, but the tanks are quicker to build.

Several attempts have been made to reduce costs by replacing the metal reinforcement in ferrocement with other materials such as bamboo and hessian. There have been some successes, but also a number of notable, large-scale failures. In Thailand, more than 50,000 bamboo-cement tanks had been built before a study revealed that fungi and bacteria were decomposing the bamboo. Within a year, the strength of the reinforcement had reduced to less than 10% and some bamboo had rotted away altogether. The study concluded that the majority of bamboo cement tanks would fail, some suddenly and dangerously. Another programme in East Africa by UNICEF and Action Aid in the 1970s developed the 'ghala basket' an adaptation of a traditional grain basket made waterproof by the addition of mortar. By the mid 1980s, it was becoming clear that these baskets were susceptible to rotting and termite attack and the design was abandoned.

7.4.5 Bricks

Burned brick tank in rural Uganda
(Picture: V. Whitehead)

Tank made from stabilised soil blocks in urban Uganda
(Picture: T. Thomas)

A communal masonry tank in Rural Ethiopia
(Picture Water Action)

A plastered rectangular brick tank in rural Sri Lanka
(Picture: D. Rees)

Bricks and blocks of various types are widely used for wall-building. Materials are found locally and local people prepare the bricks themselves, so keeping the cost low and retaining money in the local economy. Bricks can be made from a number of materials such as burned clay, cut stone, soil stabilised with a small amount of cement or even concrete. Unfortunately, while bricks are useful for ordinary walling they less well suited to tank construction because tank walls are subject to tension. The tensile forces are usually taken up by the mortar and by adhesion between the mortar and bricks, which is usually fairly low. Brick tanks can also suffer a cost disadvantage as the thickness of the tank is set by the width of the bricks. If the bricks are poorly fitting, such as in a cylinder with a small diameter, they can actually require more cement than an equivalent ferrocement tank.

Interlocking and curved bricks, usually using stabilised soil, have been tried in several places including Thailand and Uganda. A machine for making interlocking mortar blocks is also available. Most of these designs interlock only vertically, but rely on shear forces between the mortar and block to take the big horizontal stresses. A more satisfactory solution would be to interlock blocks horizontally on their top and bottom surfaces. However, this does not appear to have been investigated.

7.5 Comparing costs of different technologies

As discussed in section 6.3, water tanks exhibit strong economies of scale, so that larger structures cost less per litre of storage than smaller structures. This does not however mean that water delivered by a larger system will always be cheaper than water from a smaller tank. It does mean that comparing tank technologies is a more complex task than simply dividing the cost by the capacity and revealing a storage-cost-per-litre. Costs should only be compared within one country, as material and labour costs vary markedly across the world. Figure 7.4 shows a number of tank costs in three countries. For international comparisons, the bill of materials for each design should be obtained and re-costed for construction in the target country.

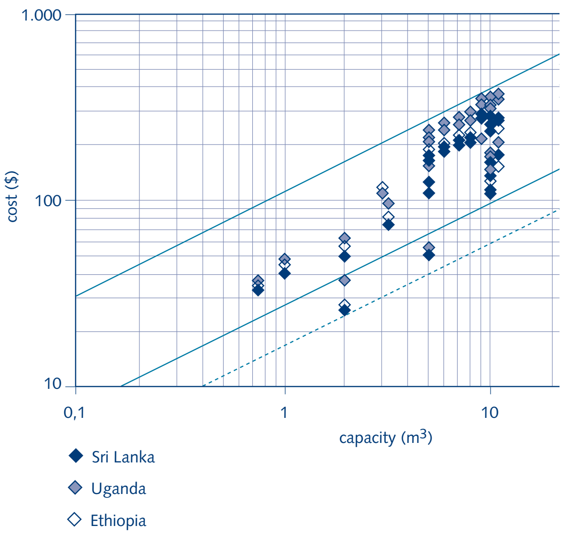


Figure 7.4.Tank costs (based on bills of materials in three countries)

The cost-capacity lines follow a predictable pattern, particularly for a similar design. The increase in cost with tank size is roughly equivalent to the square root of the increase in volume[1]. In other words if a tank doubles in size, the cost should only increase by a factor of close to 1.4 ($\approx \sqrt{2}$). It takes a fourfold increase in volume size to double the price of a tank!

1 The rise is more accurately described by the formula $\frac{C_a}{V_a^{0,55}} = \frac{C_b}{V_b^{0,55}}$, where C is cost and V is volume. Square root is an easily applied approximation, i.e. using SQRT(V_a) instead of $V_a^{0.55}$

A useful concept is the *equivalent unit cost* (EUC), which is a more accurate way of describing the unit cost of as tank than simple using cost per litre. The EUC is what a tank using a particular technology would cost if it were scaled down to 1m³ (1000 litres) capacity. It can simply be calculated by dividing the cost of any tank by the square root of its volume in cubic metres.

$$EUC = \frac{C}{\sqrt{V}}$$

Where:

EUC is the equivalent unit cost

C is the cost of a tank of volume *V*

V is the tank volume (in m^3)

Some typical equivalent unit costs are given in Table 7.4.

Table 7.4. Equivalent unit costs of rain-tanks (based on Ugandan material and labour costs)

Tank type	Tank cost	Tank capacity (m^3)	Simple Cost per m^3	Equivalent unit cost
Thatch tank	$61	5	$12	**$25**
Tarpaulin tank	$62	5	$12	**$26**
Tube tank	$29	1	$29	**$27**
Mud tank	$44	2	$22	**$30**
Dome tank	$80	5	$16	**$33**
Thai jar	$44	2	$22	**$36**
Plate tank	$150	10	$15	**$42**
Pumpkin tank	$160	5	$32	**$67**
Open frame ferrocement	$350	10	$32	**$96**
Drum tank	$115	0.5	$230	**$140**
Moulded plastic	$750	25	$30	**$150**

7.5.1 Maintenance

Maintenance costs for tanks tend to be quite low, depending on the choice of design. A lower quality design costs less initially but needs more maintenance to stop it deteriorating over time. Some parts, such as screens or linings, may need periodic replacement. A larger tank presents a larger maintenance job and the cost of maintenance rises with tank size in much the same way as up-front costs rise. Thus, the simplest way to describe annual maintenance cost is as a fraction of capital costs. Table 7.5 estimates this maintenance-cost fraction for several designs of tank. The actual cost-fraction will vary from site to site but the values presented below should be useful for planning. Some of this cost will be in the form of labour (cleaning etc.) and some in the form of materials.

Table 7.5. Maintenance fraction for rainwater tanks (cost in maintenance each year as a fraction of total investment cost) – based on Ugandan data)

Tank type	Maintenance fraction
Drum tank	2%
Moulded plastic	2%
Thai jar	5%
Open frame ferrocement	7%
Plate tank	7%
Pumpkin tank	7%
Dome tank	10%
Tarpaulin tank	10%
Thatch tank	15%
Tube tank	20%
Mud tank	25%

7.6 Summary

There are many possible tank types. A choice must be made of one that is the right balance of cheap, available, attractive and durable. Designs are often chosen that are 'too good' – they give good performance but at such a high cost that in poor tropical countries they can only be used if a high subsidy is available. Generally, mortar jars, ferrocement or brick tanks or simply-lined underground cisterns are most appropriate in poor communities, whereas metal, plastic and concrete tanks are usually only a sustainable option for better-off households or in rich countries.

Bigger tanks of course cost more than smaller ones, although usually they are cheaper 'per litre'. For this reason, it is wise to convert any actual tank cost into the equivalent unit cost (per 1,000 litre tank) before comparing one tank type with another.

If householders are to contribute their labour to the production of DRWH systems, then one should look for tank types that require a lot of unskilled labour in their production.

Although DRWH systems are usually built on-site by masons, there are often big cost-savings to be made by manufacturing tanks in factories or in workshops and then transporting the finished tanks to the homestead where they are to be used. In a few cases, it is cheapest to make tank components, such as panels, in a factory, then carry them to site for assembly into the final DRWH system.

Chapter 8. Guttering

8.1 Introduction to guttering

8.1.1 Guttering in the tropics

In rich and temperate countries it is normal to fix gutters to every roof to prevent water running down the walls, causing erosion or stains. As rainfall intensities in these countries are not high, gutters are for aesthetic reasons laid *horizontally* (that is, with no slope) and very close to the roof edge. They are usually fixed to a wooden or plastic fascia board. Horizontal laying requires gutters to be quite large or downpipes to be quite close together.

In poorer tropical countries, such guttering would be a luxury. Tropical roof overhang is often 600 mm or more, to shade the walls from the high-angle sun, so roof run-off is thrown clear of the walls, although it may create an erosion channel in the ground next to the building. Even if walls are wetted by rain, they soon dry in a hot climate. Adding guttering is only justified if it can 'earn' its cost by collecting roofwater. Moreover, to keep size and cost down, it is normal to slope gutters rather than laying them horizontal.

8.1.2 Guttering failures

Good guttering matters. Failure of guttering is the commonest cause of failure in established RWH systems and sometimes prevents new systems from ever functioning. It is common to see gutters that are twisted, bent, leak at the joints or fail to properly catch (intercept) the roof run-off. Many gutters are never cleaned – especially if they are higher than two metres off the ground – and therefore become blocked with soil or vegetation. Installation faults include having the gutter slope the wrong way, failing to seal the gutter to the downpipe, sagging (offering permanent water pools for mosquitoes to breed in) and placing the tank too far from the building. We might also count as an installation fault placing a tank at the end of a long building, like a school, (requiring very large gutters) when placing it in the middle of the building would permit much smaller gutters to be used.

A 'failure' of a different kind is to use gutters and downpipes that are unnecessarily large and expensive.

Poor guttering is often the result of the way RWH is implemented. It is common for an outside agency to specify and subsidise tanks but leave the guttering to the householder's discretion – and probably ignorance. Thus one meets schemes where the tanks are 'professional' but the gutters are 'amateur'. At the very least, householders or local builders need guidance on how to select and fix their gutters.

8.1.3 Good guttering

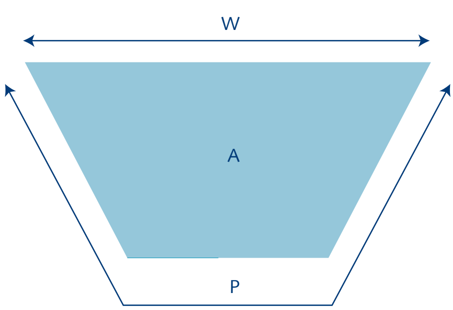
To work well, guttering should:

- perform well at catching water as it runs off the roof
- carry water towards a downpipe or outlet without overflowing
- be cheap
- be durable and resistant to 'normal abuse'
- be of an economic size, neither too small nor too large (in practice, sized to capture about 95% of run-off)
- be laid at the proper slope and at the proper distance from the house wall / roof edge
- have effective joints between sections and to the 'downpipe' (which may itself be a steep gutter).

8.2 Choosing the gutter shape

The size and shape of a gutter affect both its ability to catch run-off and what it can carry without overflowing at its lower end. An ideal gutter would be very wide (big value for *W* in Fig. 8.1) and also have a large cross-sectional area (*A*) for the water to flow through. However the amount of material in a gutter, and thus its cost, depends mainly on its perimeter (*P* in Figure 8.1), so we would like this perimeter length to be not very large. Thus we are looking for a shape that *for a given perimeter P* makes width *W* and area *A* as big as possible.

Other factors affecting gutter shape are ease of manufacture, ease of cleaning (including self-cleaning) and ease of hanging. The two shapes that best combine all the various requirements are a trapezium (as shown in Figure 8.1, with equal-sized bottom and sides) and a semi-circle. The semi-circle is cheapest to make by plastic extrusion or by cutting a tube (even a bamboo) in half, and is also easiest to clean. The trapezium is easier to make if folding metal sheet, but a little prone to silting. An even easier shape to fold would be a 'V', but this doesn't make good use of material and is easily blocked by twigs and leaves.



W width
P perimeter
A water-carrying area

Figure 8.1. Typical gutter cross-section (trapezoidal gutter)

8.3 Choosing the slope of the guttering

Gutters normally slope downwards towards the point where they connect to a downpipe. This makes the water flow faster and hence gives the gutter extra water-carrying capacity where it is most needed. For a given roof and rainfall, increasing the gutter slope means that a smaller and cheaper gutter can be used. (To double the capacity, the slope has to be increased fourfold.) The slope may be uniform or it may increase towards the outlet. For example, it would be good to hang a 3-section gutter so that the first two sections were sloped at ½% and the last section at 1%, as explained below. A ½% slope drops 5 mm per metre; a 1% slope drops 10 mm per metre.

Usually the roof edge is meant to be horizontal – in practice the builder may have let it slope up or down a bit. The gap between a sloping gutter and a horizontal roof-edge will get bigger towards the discharge (downpipe) end of the gutter. The steeper the slope, the bigger the gap, and an over-large gap is bad, because the discharge end of the gutter will not catch all the roof run-off water. For most gutter sizes, we would like to keep this gap less than the width of the gutter itself. So for a house the gap should be less than 60 mm (2½"), whereas for a long school building it might be as big as 150 mm (6").

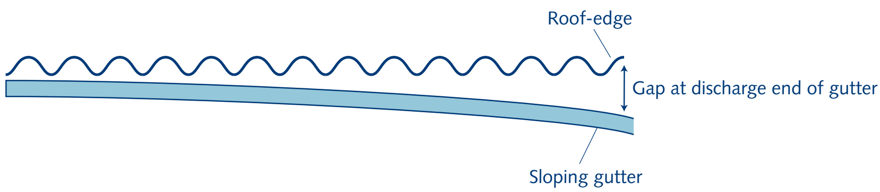


Figure 8.2. Effect of slope on the gap between roof and gutter

If we make the gap at the *top end* of the gutter as small as possible, then we find the gap at the *discharge end* will be according to Table 8.1 below. Arrangements C and D, the "½% & 1%" combination of slopes shown in **bold,** is what we would generally recommend. The flow capacity (maximum flow-rate the gutter can carry) for arrangements C or D we call **Q.** The max flowrates of arrangements A, B, E and F are shown as multiples of **Q**.

Arrangement A is also quite good: it is also the easiest to implement because the first half can be laid using a spirit level. However, any sagging on the flat section will cause tiny pools to remain after the rain ceases, which encourages mosquito breeding. For this reason, arrangements A and C should not be used where malaria, dengue, elephantiasis or yellow fever are rife. In such areas it may be advisable to use steeper slopes (like arrangement F), sacrificing some run-off-interception for a health-safety gain.

Table 8.1. Effect of gutter length (L) and slope on the roof-to-gutter gap

Slope arrangement	Flow Capacity	House L = 4m	House L = 8m	School L = 15m	School L = 25m
		Gap at discharge end (in mm)			
A - First half of gutter is flat, last half slopes at 1%	0.9xQ	20	40	75	125
B - ½% for whole length	0.7xQ	20	40	75	125
C First one-third, slope is 0%; next one-third, slope is ½%; last one third, slope = 1%.	**Q**	**20**	**40**	**75**	**125**
D First two-thirds, slope is ½%; last one third, slope = 1%.	**Q**	**27**	**53**	**100**	**167**
E - 1% for whole length	Q	40	80	150	250
F - First two-thirds slopes = 1%, last one third slopes = 2%	1.4xQ	54	106	200	333

Table 8.1 assumes that gutter sections are too rigid to bend. However, gutters made of plastic may bend quite easily. In such cases, the gutter trajectory can be a smoothly changing slope like that in Figure 8.2, starting almost flat and reaching the slopes shown at the transition points in the table. Thus for recommended arrangement D, the slope is increased from ½% to 1% over the last 1/3 of the gutter's run.

8.4 Choosing the gutter size

During light rainfall and no wind, even a small gutter will intercept and carry all the roof run-off. Under intense rain, especially with corrugated roofing, there is some risk that run-off will be lost either by overshooting the gutter or by making the gutter overflow. In the tropics about 10% of all rainfall arrives at a rate of 2 mm per minute or more. In fact, 2 mm per minute is a good choice for sizing gutters. When rainfall intensity exceeds 2 mm/min, such a gutter will spill the excess. However, over a year such overspill will account for only 2 or 3% of total run-off. On this basis, and assuming the gutter is sloped according to arrangement **C** in Table 8.1, we recommend the following gutter sizes.

Table 8.2. Recommended gutter sizes

Area of roof served by one gutter (m^2)	10	13	17	21	29	34	40	46	66
Semi-circular or trapezoidal gutter: recommended width in mm	50	55	60	65	75	80	85	90	100
Recommended down-pipe size (outside diameter in mm)	15	20	25	25	32	32	40	40	40

Note that where a gutter only drains a small roof area (for example when a water-jar is fed by a short gutter from either side), a very small gutter size can be used. In such situations a PVC pipe as small as 50 mm outside diameter (2″ pipe) can be sawn longwise, and each half used as a gutter.

8.5 Choosing how far out to hang the guttering

On a roof made of tiles, run-off water has very little speed and on a windless day will drop straight down from the roof edge, (path A in Figure 8.3). Sometimes it sticks to the roof edge a little and so falls *inside* that path, (path B). With a corrugated roof, of galvanised iron (GI) or asbestos sheeting, the run-off gets up a certain speed, so it follows a path like C in the figure. When there is strong wind, the run-off water will be blown around, sometimes inside and sometimes outside path A.

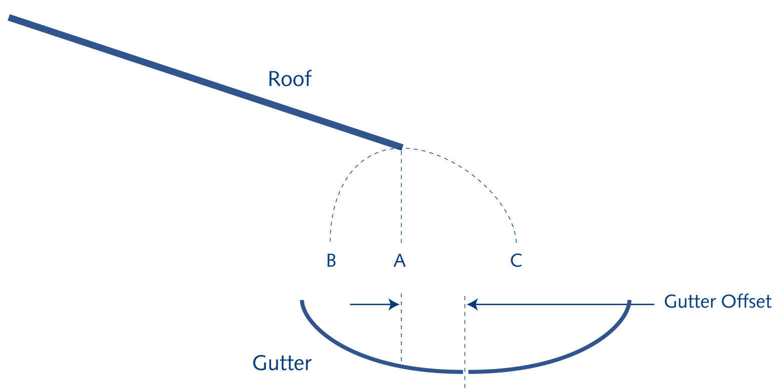


Figure 8.3. Run-off patterns

Fixing the centre of the guttering directly under the roof edge ('offset' is zero) is best for tile roofs and fixing it further out (with offset equal to about 20 mm) better suits a corrugated roof. 'Offset' is the horizontal distance outwards from the edge of the roof to the centre of the gutter.

8.6 Downpipes

The tank inlet must be lower than the lowest part of the guttering if water is to flow from the gutter to the tank. (Sometimes tanks are mistakenly built so high that inflow is impossible!).

The simplest way to connect the guttering to a storage tank is to place the tank beyond the gable-end of the building, with its centre in line with the guttering. In this case, it is only necessary to extend the guttering, at a slope of about 2%, until it is above the tank inlet. The guttering extension has to be supported at both its ends and may need a centre prop as well. If however the jar/tank inlet can be put directly under the gap between *two* gutter ends – one coming from the left and the other from the right, as in arrangements **A, B** and **E** in Table 5.2 – then the two gutter discharge jets will hit each other and conveniently fall straight down into the jar.

The next simplest way is to extend guttering just a little beyond the end of the building and provide a hole in its bottom to let the water drop downwards. This water can be intercepted by a separate open-channel (same size and shape as guttering) that carries it at a slope of about 2% to a point above the tank inlet. Because the tank no longer needs to be in line with the roof edge, it is now possible to feed water from two gutters into a single tank. This arrangement is widely used to connect both the front roof and the back roof of a house to a single tank placed near the line of the roof's ridge (arrangement **C** in Table 5.2 in Chapter 5).

Finally, a pipe may be run from a funnel below the gutter end to the tank input by whatever route causes the least obstruction. Pipes are usually much neater than channels and are less easily disturbed. They can be routed so that they can be fixed to the walls of the building or even run underground. They may be joined by tight fittings, for example 'elbows' made to fit exactly over their outside surface. These fittings may be held in place by friction ('push fit'), by plastic solvent cement or by rubber 'O' rings. There are also watertight 'Tee' fittings for connecting down-pipes directly to the underside of gutters. Unfortunately, in many countries such fittings are more expensive than the pipes.

Suggested sizes for downpipes are given in the bottom row of Table 8.2 against the roof area feeding the downpipe. These sizes are big enough for a downpipe whose length is not more than three times its 'drop' (where 'drop' is the change in height from the pipe entry to the pipe exit). For downpipes laid at very 'shallow' slopes, i.e. whose length is more than three times their drop, the next larger size is recommended. If a tank inlet filter is provided, then the drop should be measured to the top of the filter.

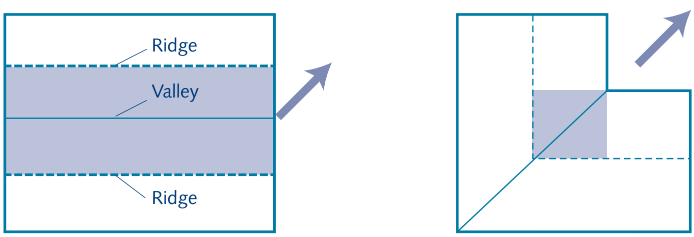
In any case, it is wise to provide a coarse screen above the pipe entry to prevent large twigs and leaves from entering. If there is a first flush device (to divert the dirty run-off water that comes at the beginning of the first rainfall after a long dry period) it may come *before* the downpipe or be combined with the downpipe.

8.7 Alternatives to guttering

There are alternatives to guttering for capturing run-off water, but they are usually either inefficient at catching run-off or work only on certain types of roof. Common examples are glides, troughs, spouts and roof valleys.

A glide is a low ridge built at a slight angle across a sloping roof near its lower edge. Water running down the roof hits the glide and is diverted sideways, so that most of the roof's run-off arrives at one point where it pours into a funnel and downpipe. Unfortunately glides only work well with plane roofs rather than ridged or corrugated ones, the roof must have a good slope and no gaps in it, and the glide's bond with the roof must be watertight and permanent, despite any roof movement. Any rainfall hitting the roof below the glide will be lost, so the glide should be set low on the roof and at a slope of under say 2^0 to the horizontal.

A trough is in effect a ground-level gutter lying underneath the roof edge. To catch water efficiently and to reduce wall damage due to splashing, a trough needs to be much wider than a gutter. Another variant is to have short lengths of gutter sticking out sideways from the top of a tank such as an oil drum, so that they are above the ground but well below the roof edge.



a. Parallel roof *b. L shaped roof*
Figure 8.4. Draining a roof using 'valleys'

Roof valleys can be found where a house is covered by two parallel roofs or where the roof plan is 'L' shaped. However unless the roof is single-sloped, only a part of the roof's run-off reaches a valley. Generally gutters catch run-off from a larger part of the roof than valleys do.

8.8 Installing gutters

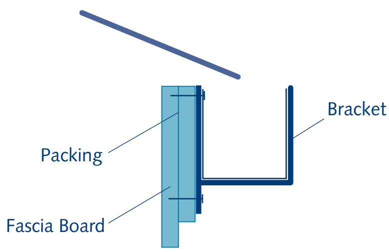
Mounting gutters onto roofs in developing countries presents particular problems. The roof edge is very often not level, fascia boards are frequently missing and rafters end at a varying distance from the edge of the roof. When installing gutters it is important to make sure the gutter slopes downwards in the way described in section 8.3, even where the roof edge itself has not been built straight and horizontal. The gutter's slope should be set relative to a horizontal line and not relative to the roof edge.

8.8.1 Mounting onto a fascia board

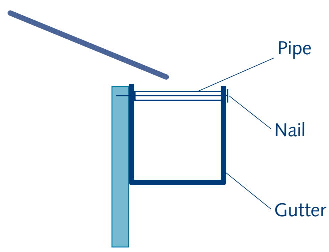
The easiest method of gutter mounting is to use a fascia board. A fascia is a plank set on its edge and attached to the ends of the rafters, just inside the edge of a roof. Brackets can be mounted to this board to hold up the gutter or nails can simply be put through the top of the gutter into the board. In the latter case it is common to use a short length of small-diameter pipe as a 'stand-off' – the pipe around the part of the nail inside the gutter allows the nail to be hammered in without squashing the gutter itself. See Figure 8.5b.

Brackets to fix to fascia boards are usually available for factory-made plastic gutters, and feature clip-on mouldings or easy-to-bend fixings. Locally made metal gutters are sometimes supplied with bent-steel brackets, but these are usually not very rigid. Once a gutter has been mounted, the brackets ought to be rigid enough not to bend when, for example, someone steps on the gutter while climbing onto the roof.

Often a bracket will need 'packing out' so that the gutter has the right offset – this packing is achieved by putting a short piece of wood between the bracket and the fascia board as shown in Figure 8.5a.



a. Bracket-mounted gutter

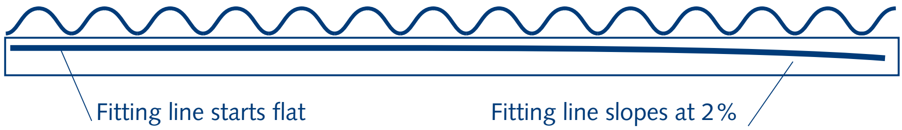


b. Gutter nailed to fascia board

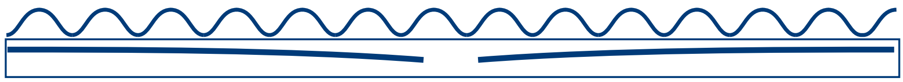
Figure 8.5. Fascia board mountings

Before fixing brackets to a fascia board, we need to draw a horizontal line along the board close to its top, using some form of level (perhaps a spirit level or a hosepipe water-level). Below this horizontal line we can then draw another line (the *fitting line*) to show exactly where the top of the gutter should be placed. Starting at the end of the roof furthest from the down-pipe, the fitting line would follow the pattern of slope that you have selected from Table 8.1: the slope always increases towards the outlet end.

The brackets are then mounted so that the top of the gutter follows the fitting line. The addition of slotted screw holes will allow finer height adjustment. No adjustment is, however, possible for distance from the roof edge unless packing material is used, so a wider gutter may be necessary to accommodate variations along the roof edge.



a. Discharge at the end of the facia board



b. Discharge at the centre of the facia board
Figure 8.6. Marking out a 'fitting line' onto a fascia board

8.8.2 Mounting a gutter onto the rafters or purlin

The fascia board is often missing, so brackets can be mounted instead on the top or side of the sloping rafters as shown in Figure 8.7. The bracket can be moved along the rafter for horizontal adjustment and bent to give height control. When adjusting for slope, it is also worth bearing in mind that the adjustment will take place on an empty gutter whereas a full gutter will flex the brackets downwards, somewhat altering their position. This change will tend to make the gutter hang lower and increase the slope.

A cheaper version of a fascia board (if there is not one present already) is to attach a gutter-mounting bar of timber, e.g. 1″(25mm) x 2″ (50 mm) in section, onto the purlin or the rafter ends. This bar should be mounted via spacer pieces cut so that the outside face of the bar is about 1cm inside the roof edge. Once mounted, the fitting line is then marked onto it and the gutter fixed to it.

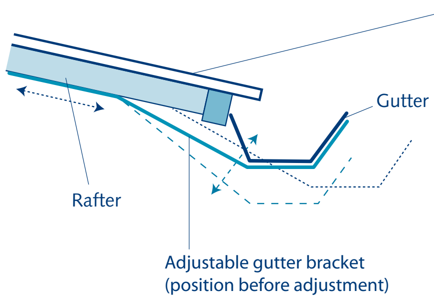


Figure 8.7a. Rafter mounting

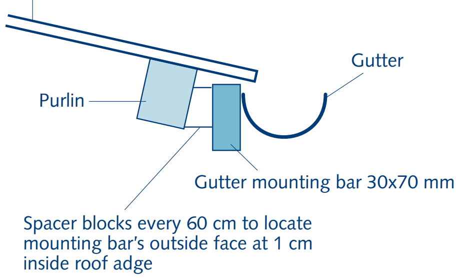
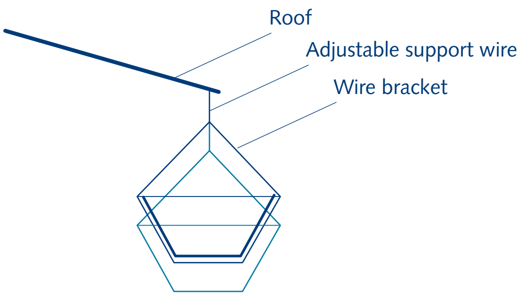


Figure 8.7b. Purlin mounting

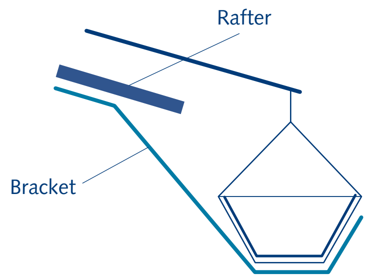
8.3.3 Suspending a gutter directly from an iron roof

The roof edge itself seems an attractive place to mount the gutter. The gutter will automatically follow any lateral movement of the roof and the length of the mountings can be adjusted to give fine control of the drop as shown in Figure 8.8a. The mounting is also very cheap as only wire is required. It does however, place the centre of the gutter under the roof edge and so will not allow optimal interception. The wires themselves are an obstruction when cleaning the gutter, as a brush cannot simply be swept along the length of the gutter.

If a suspended roof edge mounting is chosen, a mounting every metre or so is required. The wires themselves should be tied to the top of any corrugations and as near to the rafter as practical. Their distance from the roof edge should be about 1cm.



a. Usual suspended mounting method



b. Suspended plus supporting bracket

Figure 8.8. Suspended mountings

It can be difficult to mount the gutter firmly enough. Most suspended systems use wires to tie the gutter under the roof edge. This unfortunately allows the gutter to be blown from side-to-side during strong winds. The addition of a supporting bracket, such as that shown in Figure 8.8b, every two metres will significantly reduce this problem.

8.9 Making gutters

Almost all gutters in formal DRWH systems today are made of plastic or metal, although other materials have been occasionally used, including wood and bamboo. In informal systems, by contrast, organic components like lengths of banana culm are widely used for short gutters. In Sri Lanka and Zimbabwe asbestos cement gutters are also used, but in most other countries this material is banned for health reasons (danger of inhaling dust when cutting).

In richer countries, PVC or other plastic gutters are the norm and are sold with fittings allowing watertight joints to be made between gutter and gutter or gutter and downpipe. However in many less economically development countries (LEDCs), purpose-made plastic guttering is hard to find or too expensive. Here, the main options are gutters made of galvanised iron or from reformed plastic piping. PVC and sometimes ABS piping is quite widely available in length up to 6 metres and in wall thicknesses from 1mm to 3 mm. This can be adapted for guttering by sawing it longitudinally into two halves. The problems with this material are:

- inadequate stiffness if thickness is only 1mm as in cheaper piping
- difficulty in joining unless the join can use the socket normally available at one end of each length
- brittleness after extended exposure to tropical sunshine and liability to crack at imperfectly formed holes
- high cost of fittings such as elbows and tees.

However PVC is fairly easy to heat and form into gutter end-stops, for example. It may be readily adapted to accept nails if holes are first made with a hot metal spike. Plastic piping may therefore be directly used for down-pipes and may form the raw material for forming gutters. Presumably, manufacturers of these extruded pipes will add gutters to their sales range when market demand justifies.

Galvanised iron roof sheeting can be cut and bent unto a 'U' to form a gutter. A more popular shape, though not one to make best use of the metal area, is a cut-strip folded to give a trapezoidal gutter with a vertical back face to fit against the fascia board and an outwards-angled front face intended to intercept even the most intense run-off. Unfortunately, the cutting of both curved and of folded gutters leaves a dangerously sharp edge, which is also prone to rusting. Normal tinsmith practice would be to fold over such edges and this is widely done. However, roofing-grade GI sheeting is too hard for this operation and softer metal (milder steel) sheet must be used, which is normally more expensive. Metal gutters made in this way are not easy to support or to join. The gutter-to-gutter joint often leaks unless sealed with some sort of mastic (e.g. bitumen) and taped firmly together (e.g. with rubber strips cut from car or lorry inner tubes). Soldering is another widely used process to join GI gutter lengths, attach end plates or, more commonly, attach metal downpipes to gutters. Such rigid gutter-to-downpipe connections are a source of weakness and one often sees gutters badly twisted because the attached downpipe has moved.

Chapter 9. Designing Systems to Reduce Health Risks

9.1 The path of contamination

To decide on the best strategy to reduce human infection from roofwater systems, it is useful to revisit the path a contaminant must follow in order to enter a potential host. The usual paths available are shown diagrammatically in Figure 9.1 along with the processes and strategies available to reduce the contaminant flow.

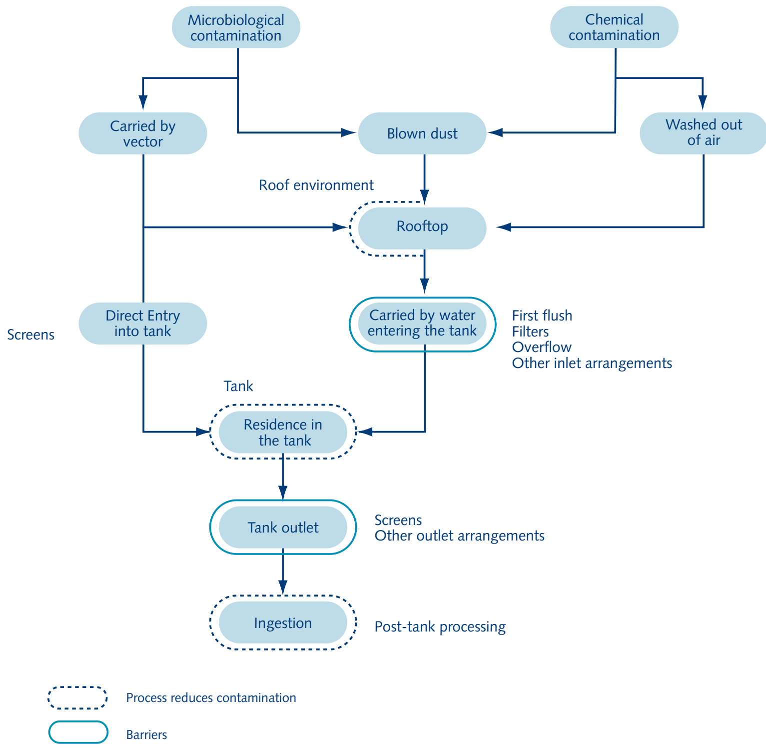


Figure 9.1. Contamination paths for roofwater harvesting

Of the available paths, the direct entry of contamination is seemingly the simplest route to block. However, it can prove very difficult in practice to totally eradicate all possible disease vectors, since the smallest of creatures such as insects will find *any* hole in the tank's defences. Larger animals, particularly mammals and birds that represent the highest disease risk to humans, can however be excluded by ensuring that all inlets and outlets are screened.

The remaining paths rely on the contaminants being washed in from the roof. Contaminants that enter the tank this way follow a complex path past a number of barriers which can be enhanced by appropriate system design.

9.2 Inlet screens

As the water must pass from the roof to the tank inlet, the conveyance is a good place to put a filter to block any contamination from entering the tank. The vast majority of chemical and microbiological contaminants will be stuck to debris from the roof so removing the debris will also remove the contaminant. Removing debris also reduces the level of nutrient reaching the tank and thereby impedes mosquito larvae development and long-term survival of bacteria.

The filter can be anywhere along the conveyance path from the gutter entrance to the tank inlet, and should be capable of dealing with the high flows associated with high rainfall intensities (a 2mm/min peak intensity translates into a 1.7 l/s flow on a 50 m^2 roof).

Criteria that should be met for inlet filters are:

- filters should be easy to clean or largely self-cleaning
- filters should not block easily (if at all) and blockages should be obvious and easy to rectify
- filters should not provide an entrance for additional contamination, even if the filter is left uncleaned
- the total cost should not be out of proportion with the rest of the system (5-10% of the tank cost should be considered a maximum)

To counter problems of blocking and self-cleaning, in several countries the inlet filter is split into two – a course leaf filter and a fine filter.

9.2.1 Coarse leaf filters

The first line of defence is a coarse leaf filter installed anywhere from the gutter to the entrance to the tank (see section 5.4). It need not be especially fine (a 5 mm grid is sufficient), so that no problems should be encountered with flow rate through the filter. The filter itself can be removable for cleaning.

9.2.2 Fine filters

Most fine filters used in developing countries are based on sand or gravel. These filters can be used for roofwater harvesting systems, however there can be problems with upkeep as householders often dispose of filter media when it becomes blocked, replacing it with courser media or nothing at all. In developed countries, self-cleaning filters are available with a fine mesh screen (typically 0.4 mm). These screens use the first flow of water from a storm to flush the filter of debris or have a continual washing action using about 10% of the water. In smaller, low-cost roofwater systems there is usually significantly more water available from the roof than the tank can contain, so self washing filters may be viable if suitable filter mesh or cloth is available locally. Experiments have shown that a muslin cloth with a 1mm weave over a welded steel frame such as shown in Figure 9.2 is effective in reducing particles as small as 0.1mm in rainwater, while spilling only about 3% of the annual water flow.

Figure 9.2. Self cleaning cloth filter
(Picture: D.B. Martinson)

9.2.3 First flush

Contaminants washed from a roof are usually concentrated in the first part of the run-off. After this initial run-off has washed the roof the water is considerably safer, so a useful alternative to fine filtering is to remove the first part of the rainfall. This process is called *first flush diversion*.

At the most extreme, all water from the first storm or two of the new wet season should be thrown away as the roof will be very dirty after a long dry season. Alternatively, a number of devices will divert just the first part of each storm. There has been much speculation about how much should be thrown away from each storm. Recent research suggests a rule of thumb that *for each mm of first flush the contaminate load will halve*. From this, the following method has been derived to decide on the best amount of water to divert.

1. Measure initial run-off turbidity on a wet day following at least 3 dry days (turbidity is measured in units known as NTU).
2. Select a target maximum turbidity at which to allow water to enter the main tank – 20 NTU is usually sufficient.
3. Employ Table 9.1 to decide how many millimetres of rainfall to divert
4. Divert that amount (= mm x roof area) of water whenever at least 3 dry days precedes rain.

Table 9.1. Recommended first-flush amounts (in mm rainfall)

Initial run-off turbidity (NTU)	Target turbidity (NTU)			
	50	**20**	**10**	**5**
50	0	1.5	2.5	3.5
100	1	2.5	3.5	4.5
200	2	3.5	4.5	5.5
500	3.5	4.5	5.5	6.5
1,000	4.5	5.5	6.5	7.5
2,000	5.5	6.5	7.5	8.5

Several arrangements have been used for first-flush diversion. The simplest is to move the downpipe to one side at the start of a rain episode so that it spills water onto the ground instead of into the tank. This manual arrangement relies on the user being at home when it starts raining and prepared to go out in the rain to operate it.

An automatic diverter is one that without any human intervention throws away (or diverts) run-off corresponding some volume of rainfall on a roof; it then slowly resets itself. A simple automatic method is to add an extra closed off section of downpipe before the tank inlet as shown in Figure 9.3. The volume of water diverted *V* will be the capacity of the pipe: divide this volume by roof area to get the equivalent rainfall in mm .

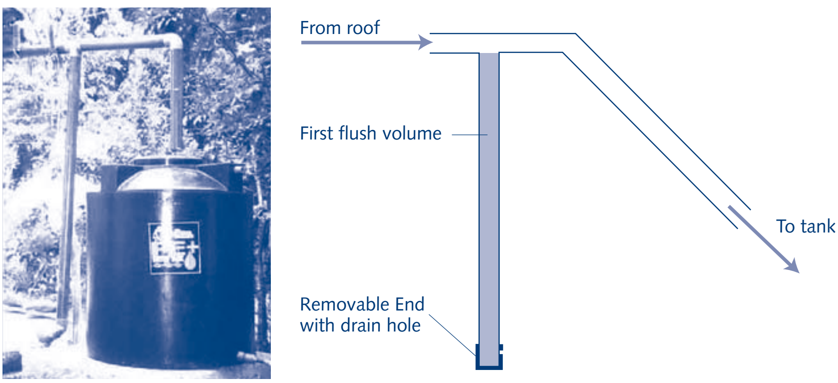


Figure 9.3. Pipe first flush arrangement (Picture: T. Ariyananda; diagram: D.B. Martinson)

The cap at the end of the pipe must be removable to facilitate cleaning.

We want the water in the first-flush pipe to drain away slowly so that by the time the roof gets dirty again it is ready to divert another volume *V*. However if it drains away too fast and more rain comes soon, before the roof has had time to accumulate much dirt, unnecessary diversion will take place, wasting water. The small hole in the cap will allow the pipe to empty over a period, gradually resetting the system. If this hole is not added, the system must be drained down manually. Failure to do this will result in a pipe full of contaminated water that will not only fail to work for the next storm, but can cause additional pollutants to be washed in to the tank from the first-flush device itself.

The hole is thus a critical component. If it is too large, the first-flush pipe will empty too quickly; if it is too small it will be liable to block. The position of the hole should be slightly *above* the bottom so any sludge in the bottom of the pipe will not quickly block it.

Unfortunately, even a large upright pipe only holds a few litres, whereas many roofs, particularly those near to dirt roads, may need 100 or more litres to be diverted. Moreover, to empty a pipe in three days (a typical time) through a small hole means the hole must be tiny and therefore very likely to block. So, another technique is to place a larger buffer jar (say 100 to 1,000 litres) between the gutter and main storage tank, and provide the buffer with an outlet near its bottom, as in the photo below. Water from this buffer outlet will be of a low quality and should not be used for cooking or drinking. It should, however be used regularly (e.g. for washing or bathing) or there will be no first-flush benefit. Note that the top of this buffer jar needs to be higher than the entry to the main water store, which is easy to arrange if the main store is underground but not if it is above-ground. If a household has been using a water jar and later buys an underground tank or a second jar, then the first jar can be used as a first-flush buffer and as a laundry water supply.

1,600 litre mortar rain-jars transported to site by handcart and installed in cascade. The right hand jar gives washing water and the left-hand jar gives potable water. Note the narrow (50 mm) guttering and the cheap hosepipe used instead of a tap.

Figure 9.4. Buffer tank arrangement (Picture: T.H. Thomas)

A newer first-flush concept balances the rate of water intake into a suspended hollow ball against its leakage, raising its weight and stretching its suspension until it descends into a recess, blocking the opening and allowing water into the tank. The system has the advantage of being self-cleaning and removes the need for any storage of the first-flush water (and its subsequent drainage). The system is available in products in Australia and the USA but has not seen service in low-income countries yet. Some products are under development such as the one shown in Figure 9.5 which sit in a PVC tee and use a clay disc to control the drainage over several days without risk of blockage.

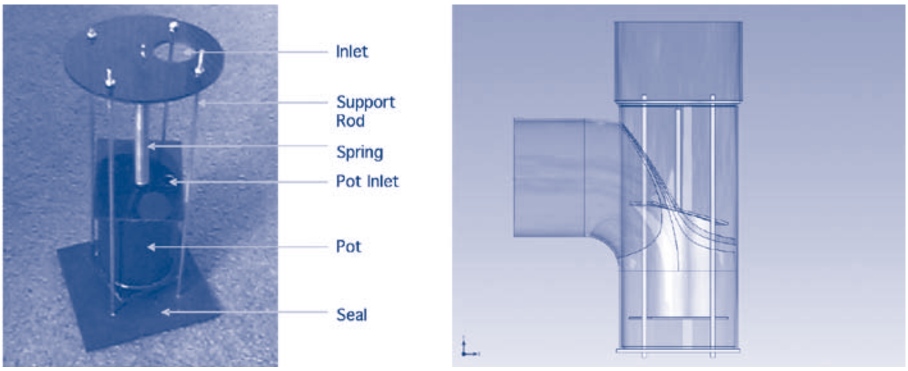
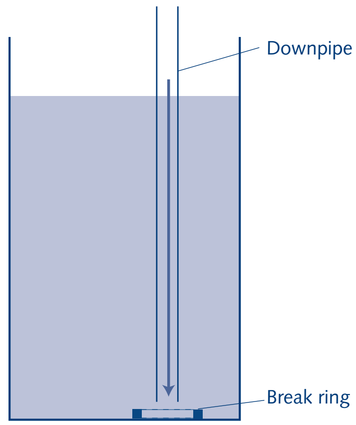


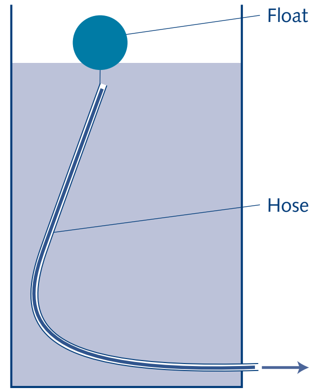
Figure 9.5. Experimental first flush device (Picture: M. Knight)

9.3 Inlet and outlet arrangements

The quality of water stored in a tank improves with time. Small particles sediment out and bacteria die off. Water entering the tank tends to be both colder and of a lower quality than the stored water in the tank and it is desirable that the new water should not mix with the older water. The best way to do this is by arranging the inlet so that it goes all the way to the bottom of the tank as shown in Figure 9.6a. A ring of material surrounding the inlet will break the downward flow and prevent it from disturbing any settled material. With this arrangement, the incoming water will remain in a zone on the bottom of the tank and will not disturb the cleaner water above it.

The outlet to the tank is similarly important. As the dirtiest water is at the bottom of the tank, it is best to take the water from near the top. To do this the outlet must be on a flexible hose with a float at the top as shown in Figure 9.6b. The float can be anything that floats; successful examples have been made from discarded mineral water bottles. To prevent entry of floating matter and aerobic bacteria that may swim to the surface, the entrance to the hose should be about 100 mm below the surface of the water.





a. Inlet

b. Outlet

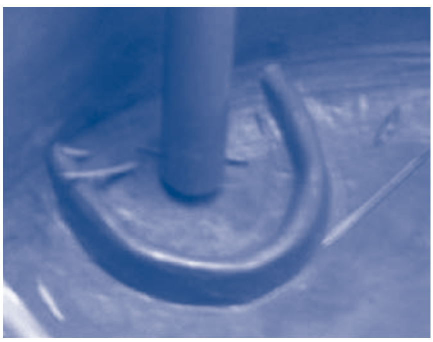
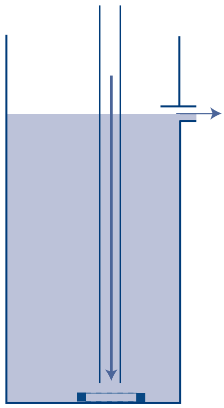


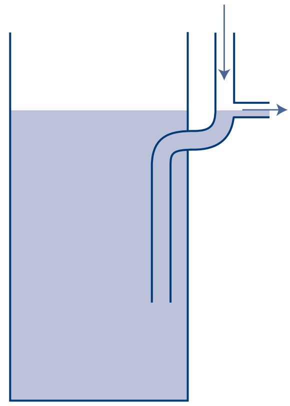
Figure 9.6. Ideal inlet and outlet arrangements (bottom-in top-out)
(Diagrams: D.B. Martinson; pictures: D.B. Martinson and V. Whitehead)

9.3.1 Overflow arrangements

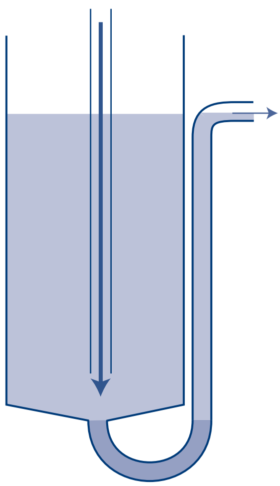
The overflow from the tank can improve or protect water quality. The standard overflow shown in Figure 9.7a simply throws water from the top of the tank. This arrangement unfortunately jettisons the cleanest water (if the bottom-in / top-out arrangement is adopted), and replaces it with dirtier water from the roof. A better arrangement is shown in Figure 9.7b where the entrance / overflow pipe blocks incoming water from mixing with the water stored in the top of the tank and channels it to the overflow exit if the tank is full. This is probably the best arrangement for tanks of less than 2 m^3.



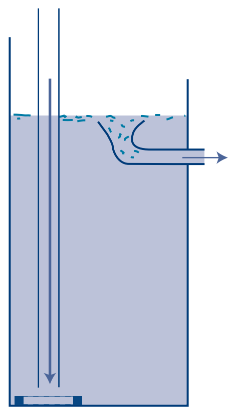
a. Standard arrangement



b. Inflow exclusion



c. Desludging bottom exit



d. Top cleaning syphonic action

Figure 9.7. Overflow arrangements

For larger tanks with well-designed inlets, the inlet water will have a lower impact and can therefore be used to perform cleaning tasks to improve the quality of water in the tank. Figure 9.7c shows an arrangement where the overflow water is taken from the bottom of the tank. This means that the overflow water will be the dirtiest water and will also carry any settled matter with it. A tank with an overflow of this design will have a reduced need for desludging but may need to have any floating matter skimmed from the water surface periodically, particularly if vegetable matter is allowed to wash into the tank. In an area where most material entering the tank floats to the top, the arrangement shown in Figure 9.7d may be preferable. In this configuration the overflow acts as a suction pump as the water must accelerate to fall into the overflow pipe. This tends to suck any floating matter into the overflow, cleaning the top of the tank.

9.4 Post tank processing

Stored roofwater should require no further processing to be safe, however it does not always conform to the strictest WHO standards (e.g. zero occurrences of *E.coli*). If water of such high quality is needed, most standard household treatment processes work well with rainwater drawn from storage. As settled tank water is very clear, this is particularly true of treatments that rely on light penetration such as SODIS, UV sterilisation or very fine filtration such as Biosand.

9.5 System maintenance

9.5.1 Roofs

The roof is the largest single source of contamination in a roofwater harvesting system. As seen above, householders are usually recommended to throw away the dust-laden run-off water from the first shower after a long dry spell. However this can be avoided if the roof itself is cleaned of dust and debris just before the rains start. Considerably less water is used in this cleaning than would otherwise be thrown away. Cleaning the roof is clearly only practical if the roof is not very steep: fortunately tropical roofs are rarely steep. The main problem is to judge when a dry spell is about to end.

9.5.2 Gutters

Gutters seem to be the forgotten children of rainwater harvesting systems. Many a user will fastidiously clean the tank, carefully throw the first rains away but never even look at the gutters. Out of sight it seems is out of mind. A gutter full of debris will taint the water and the debris will eventually prevent the roof run-off from flowing towards the tank. A great deal of dry vegetable matter so close to the dwelling may also present a fire hazard. Gutters eventually capture enough dust to develop an ecology; even trees can be found growing from gutters. They are also a prime breeding ground for mosquitoes if water is allowed to stand or form pools behind blockages. It is essential that gutters are cleaned out periodically.

Gutters can simply be swept out with a brush from time to time: certainly before the rains start and preferably again a few times during the rainy season. The frequency of cleaning should depend on the levels of blown dust, the presence of overhanging trees and the propensity of the gutters themselves to block.

9.5.3 Filters

Dirty filters will not pass water efficiently and may themselves become a source of contamination. Unless filters are self-cleaning they will need inspection and occasional washing. Even a self-cleaning design should be inspected periodically to ensure it is working correctly.

As gravel and sand filters become dirty, they increasingly impede the flow of water. When this happens, the filters need to be emptied and the filter media thoroughly rinsed before being put back.

Cloth filters also become dirty over time. They will not impede the flow of water like a sand filter, but will allow dirt to be washed through the filter into the tank. They should be washed with the household laundry whenever they look dirty.

Filters made from mesh may catch larger debris such as sticks. As they become blocked, they impede water flow and provide a home for wildlife, even rats. They can be brushed or (if removable) simply tapped out.

First-flush systems should be self-emptying so that they automatically reset. However, they too should be cleared of accumulated sludge at least every third storm or they will also become a source of contamination

9.5.4 Tanks

The cleaning of the tank is probably the most common action taken by a householder in the maintenance of a domestic roofwater harvesting system. It is also the least important! Excessive cleaning of a tank actually destroys the layer of beneficial bacteria that forms a film on the walls and aids the killing of pathogenic bacteria. Moreover, the act of entering a tank in order to clean it introduces new contamination and may result in the tank cover being damaged or left off. An uncovered tank is more likely to become polluted than one that has not been cleaned.

Cleaning tanks should be limited to the scooping or washing out any settled matter and performed only when the sludge level is approaching the level of the outlet connection or when the water smells. Scrubbing the walls of a tank should be discouraged.

Chapter 10. DRWH Systems for Specific Scenarios

The purpose of this Chapter is to pull together, and revise, the material in the rest of the handbook by looking at five common scenarios. For each one, the main requirements and constraints are identified and suitable designs are suggested.

10.1 Rural self-supply DRWH using a commercial supply chain

'Self-supply' is a term growing in popularity in water-supply circles to denote the situation where householders provide their own water infrastructure. Shallow ('garden') wells and roofwater harvesting are the favoured technologies, since neither requires negotiating agreements with neighbours or officials. As mentioned earlier in this handbook, self-supply ranges from informal DRWH using temporary materials to 'middle-class' DRWH using plastic and concrete components.

For *rural* self-supply in the tropics, the overriding requirement is usually that cost should be very low. Most rural households obtain water from more than one source, and the poor dry-season performance of small (low-cost) DRWH systems may therefore be tolerated provided they relieve the drudgery of fetching water for the bulk of each year.

The possibility of installing DRWH capacity in easy stages is also important. Economies of scale that often come from installing all the storage capacity at one time are of little interest to families who cannot save over several years to buy a large tank. Therefore, we need to look at variants of DRWH that are:

- cheap (e.g. under $US 60) for the first and each subsequent phase of installation.
- simple enough to be stocked, built or installed by an artisan without great skill or significant investment (do not have to rely on an NGO promotion programme)
- are actually available in the district
- are suitable for use with quite small roofs – say 25-50 square metres in area
- give water as clean as that fetched from wells (not necessarily as clean as urban piped water)

For this scenario there appear to be three options – to upgrade an informal existing system, to install a small but high quality DRWH system or to obtain a large, cheap but not very durable tank.

Upgrading an informal system
Where a hard roof is already used for water collection during rainstorms the quantity and quality of the water can be increased by installing short, small gutters and up to 400 litres of storage.

The gutters can be 2-metre lengths of 2" (50 mm) half-pipe or of half-bamboo or a single furrow of GI roofing sheet tied to the ends of the roof poles. Alternatively double furrows of corrugated GI sheet can be lodged in the mouth of the storage vessel so that they extend out either side under the roof edge – of course these 'wings' must slope down into the vessel.

Storage can be a set of pottery jars, a washed-out oil-drum (fitted with a wooden cover and a tap) or a 400 litre mortar jar built on site. The storage vessel should be raised off the ground to reduce the drop-distance from the roof and to ease later transfer of water to household containers.

Water quality is increased by placing a cloth to act as filter, light-excluder and vermin excluder over the top of each storage vessel. Cleaning out the gutters and sweeping down the roof regularly will also much improve water quality.

Small high-quality DRWH system

Here the intention is to build up the DRWH system over some years, so even the first instalment should be of durable design. Only a part of the roof will be guttered – two short gutters will probably suffice to lead run-off from 18 square metres of roof into a single jar that could be of mass-produced HDPE plastic. However, nothing bigger than a 400 litre jar is likely to be affordable and this is barely sufficient to guarantee 40 litres a day of water in the wet season (and none in the dry season). If available in the area, Thai-type mortar jars of 1,200-1,600 litres could be used which should yield 60-80 litres a day in wet months and drinking water only during dry months.

Provided the storage jar is located midway along a roof edge, 50 mm or 75 mm wide guttering will suffice. This is best mounted upon a long batten nailed to the rafter ends. No downpipe is essential but a chain, stick or short length of gutter may be used to guide the water down towards the jar's mouth. That mouth should be closed with a perforated bowl containing gravel or (better) covered by a stretched, elastic-edged cloth. The jar should be on a 40 cm plinth to allow jerrycans or jugs to be filled from its tap or hose outlet. Alternatively, when there is no plinth, a small pit can be dug under the tap to allow a container to sit underneath the tap. Such pits need good drainage to avoid becoming full of spilled water.

Expansion over future years can take one of two forms. One is to duplicate the original system on the other side of the house. The other is to add an adjacent jar(s) so that the old one overflows into the new (as described in section 9.2.3).

Big cheap tanks

If the size of the storage tank can be raised to 5,000 litres and water from the whole roof can be captured, then a good wet-season and a limited dry season supply is possible. Unfortunately $US 60 will not usually buy such a large tank, unless durability is sacrificed. Guttering will need to be of organic materials or perhaps scrap metal/ plastic. The tank will need to be partly underground – for example, the tarpaulin-lined pit with a mud and corrugated iron superstructure described in Box 7.2. A handpump would aid water quality but for a low cost initial installation a dip-jar will probably have to be used.

10.2 Subsidised DRWH to improve 'water coverage'

'Safe water coverage' has become a politically important statistic. It purports to measure the fraction of a country's (or district's) population with domestic access to adequate volumes of clean water. The measure is calculated in various ways, but sometimes barely acknowledges that if a water source is very inconvenient, the daily quantities fetched from it will be low. In effect, using a remote source AND achieving the WHO recommended water consumption of 20 litres/person/day are incompatible. However, if coverage is calculated only by multiplying source numbers by a nominal users-per-source and then dividing by the population, then convenience is effectively ignored. And if convenience is unimportant, the main virtue of DRWH is disregarded. However, if coverage criteria also include a convenience test – such as only households within 500 m of a clean source qualify to be counted, then it will often be attractive to water authorities to promote DRWH in those households that are a long distance from existing wells.

Because the household use of multiple sources, or water of more than one quality, confuses the calculation of water coverage, government agencies generally prefer to assume only one source is used by each household. This implies that if DRWH is to be used to improve water coverage, the DRWH system must be at least of 'main source' type if not actually of 'sole source' type. Unlike the self-supply context examined above, this context demands relatively large and therefore expensive systems.

A further requirement may be that the supply of DRWH systems must be awarded by a bulk tendering process that excludes participation by rural micro-enterprises. Indeed the requirements of funders, the self-interest of politicians and the inability of civil servants to supervise widely scattered construction may all favour the awarding of orders to large national contractors, such as the manufacturers of lightweight plastic tanks.

So in these circumstances, it seems we must restrict DRWH designs to those that:

- are standardised so that only one model needs testing
- are able to supply 20 lcd for most of each year (typically storage capacities of 6,000 to 10,000 litres)
- can be quickly delivered and assembled at very scattered locations, without site pre-survey or much inspection during construction
- give demonstrably clean water for many years
- do not give rise to demands on government for maintenance services (some agencies rule out any design that includes a hand-pump because experience with pump maintenance at wells has proved so negative).

If this specification is to be strictly followed, only large above-ground tanks will be acceptable. These may be concrete, reinforced brick, factory-made plastic or metal. Galvanised iron tanks are unlikely to meet the criteria, since 10,000 litre GI tanks are hard to deliver undamaged and only have a 15-year life. If guttering is not excluded, (it is usually seen as the household's responsibility), it would probably have to comprise imported PVC gutters bracketed to a fascia board. If left to householder supply, gutters are likely to be metal unless PVC gutters are available in local markets.

This list is very restrictive. It results in a high system cost and minimises the scope for local employment in supply or maintenance. The high cost makes extracting a significant user contribution very difficult. Some experts argue that DRWH is fundamentally unsuited to contractor supply, because its success depends in part on the participation of individual householders in siting, maintaining and even in supervising construction.

During or prior to any supply contract, there must be a stage of identifying beneficiaries. Even where allocation is by formula (e.g. "only houses more than 700 metres from a borehole") the allocation process may be politically contentious. There was a mass movement in NE Brazil to challenge the tradition of awarding water tanks for votes.

If the further criterion of requiring some involvement of the community in construction is added to the list, then 6,000-litre ferrocement jars become eligible, as represented by the Sri Lankan pumpkin tank design. The plate tank from Brazil and some interlocking brick tanks might also be considered. With such technology, the role of the contractor becomes one of supplying materials and of training and inspection.

To really reduce costs in this context, and where ground conditions permit, it is attractive to go partly underground (see Appendix 2 for suitable tank designs). As underground storage requires a pump, a cheap reliable and user-maintainable pump must also be identified. There are several candidates, including mass-produced metal Chinese piston pumps and locally made tube-in-tube plastic pumps.

10.3 Subsidised DRWH for people with disabilities

A programme, to relieve water stress in households where responsible adult(s) are restricted in their ability to collect water because of disability, has to identify and reach a small fraction of the total households in any settlement. Beneficiaries are likely to be even more scattered than in the scenario in section 10.2 above. However, the selection of these beneficiaries may be less contentious. Moreover, no technique other than RWH is easy to apply to a sub-set of homesteads.

Many people have difficulty in fetching water due for example, to sickness, limblessness, paralysis or age, but may need more laundry/bathing water than average because of sickness. People with AIDS and / or TB have a low immunity to infections, which creates a greater need for potable water to be clean.

DRWH programmes for people with disabilities require systems that:

- provide water throughout the year, implying large and costly designs
- can be delivered to widely-spaced households

- give safe water
- can be maintained by neighbours
- are tailored to a particular disability (e.g. in the design of water outlet).

Like other beneficiaries, people with disabilities prefer some relief to none. For a given total budget, more benefit can be given (more fetching-hours saved per year) if the first criterion above is relaxed and many cheap small DRWH systems are supplied instead of a few large ones.

If this relaxation is acceptable, so that the designs built within a disability programme are also compatible with unsubsidised self-supply in the rest of the community, then disability DRWH donation programmes can have wider community benefit, since the systems become demonstrations for the rest of the community and learning opportunities for local suppliers.

10.4 DRWH in emergencies

Roofwater harvesting has a possible role both in disaster preparedness and in disaster relief.

The storage of significant quantities of water at the household level is a suitable preparation for disasters that interrupt other supplies, such as:

- typhoons/hurricanes that knock out piped systems and pumping stations
- floods that pollute, silt-up or prevent access to wells
- earthquakes that damage all infrastructure and start fires needing water to extinguish (some tanks will survive a quake, whereas a centralised water system will probably fail entirely)
- war or civil unrest which damages pumping stations and reservoirs and may remove operating staff
- oil-spills, river pollution and toxins that render surface sources unusable and sometimes also poison groundwater.

Some local authorities, in regions particularly prone to natural disasters such as earthquakes or floods, require buildings to have such water storage.

Having emergency water storage does not always mean practising roofwater harvesting – a store could be kept topped-up with piped water or groundwater. However, emergency stores that are accessed perhaps once in 10 years are unlikely to be well-managed or fully maintained, whereas stores that are part of a system in regular use are less likely to suffer neglect.

There is no single RWH design that best fits disaster preparedness, although some designs do not match some emergencies. Underground tanks are inappropriate in the context of flooding and in some flood plains where houses are built on stilts, tethered floating jars have been recommended.

For disaster *relief,* DRWH is not appropriate for deployment during the first week or two of an emergency, since it is too bulky and costly. In a few cases, such as toxic spills in a high-rainfall zone, it may later be employed for lack of any alternative. However, there is certainly opportunity in refugee camps for DRWH to supplement bowsered supplies and there is scope for modifying the design of emergency tents to facilitate the collection of run-off from their roofs. Such modifications include hemming up the edges of tarpaulin roofs to form pseudo-guttering and issuing funnels to assist the direction of run-off into containers.

10.5 Institutional RWH

This book is about domestic rather than institutional RWH. However, there is some overlap because small buildings such as staff-houses may be included in institutional systems or because institutional systems may be used to supplement domestic ones. Rarely does institutional roof area represent more than 10% of total roof area in a settlement. However, institutions are sometimes the only buildings with hard roofs.

Institutional RWH has a poor record, mainly because of management difficulties. Many systems, especially rural school systems, have failed. Sometimes this is because of poor technology (bad design, poor construction, gutter lower than tank entry, insufficient taps). More commonly it fails because there has not been prior agreement about *who* the water is for (children, teachers, neighbours), who supplies missing components like gutters, who is responsible for maintenance and repairs, who rations limited water, and what happens in school holidays etc. Resentment about water allocation may lead to vandalism.

A common institutional RWH design is to place a very large concrete tank at the end of a long building. This is rarely ideal. The guttering has to be long, large and drooping. The single tap is inadequate for many users and has to be frequently locked because the potential for water loss (were it left running) is so high. Moreover, the water is nowhere near latrines, where its contribution to hygiene is most needed, while any filter is located too high to be visible and therefore is never cleaned.

Figure 10.1. Unworkable school system in NW Uganda (Note entrance to the plastic tank is above *gutter level)*

Certainly, such a centralised design should have some piping to a set of taps, which therefore need to be located below (e.g. downhill of) the tank bottom unless a pump and header tank are added. Such pumping has the advantage of controlling wastage. For schools an alternative to a centralised system using a single large tank is a classroom-by-classroom system whereby each classroom manages its own tank or jar, typically of volume 1,500–5,000 litres, centred along 5-10 metres of guttering. There is then also some scope for using the systems for educational purposes, such as pupils practicing the management of a limited resource, performing geometry, measuring rainfall or even constructing the jar.

For more enclosed and disciplined premises like hospitals and barracks, the centralised arrangement is less problematic and may indeed facilitate the combining of RWH, water treatment and a piped supply. It is financially attractive to the institution (although not to the local water company), to use RWH in the wet months and piped or pumped water during the dry season.

Chapter 11. Sources of Further Information

11.1 Books & Guides

Gould, John and Nissen-Petersen, Erik (1999). *Rainwater Catchment Systems for Domestic Security*. London, UK, Intermediate Technology Pubs (ISBN 1853394564)

Macomber, Patricia (2001). *Guidelines on Rainwater Catchment Systems for Hawaii*, ISBN 1929325118, available from: http://www.ctahr.hawaii.edu/oc/freepubs/pdf/RM-12.pdf

enHealth Council (2004). *Guidance on use of rainwater tanks,* Australian Government ISBN 0642824436, available from http://enhealth.nphp.gov.au/council/pubs/pdf/rainwater_tanks.pdf

11.2 Web sites

The Development Technology Unity rainwater pages carry notes, project reports, links and the 'rainwater tank performance calculator' mentioned in section 6.6 above.
www.eng.warwick.ac.uk/dtu/rwh

Working Papers, Technical Releases and many other reports can be found at:
www.eng.warwick.ac.uk/dtu/pubs/rwh.html

The International Rainwater Catchment Systems Association (IRCSA) has been running conferences every two years since 1980. Conference proceedings are available at:
www.ircsa.org

The Centre for Science and Environment, Delhi. CSE focuses on India and especially on RWH for aquifer replenishment:
www.rainwaterharvesting.org

The World Health Organisation Guidelines for Drinking Water Quality are at:
www.who.int/water_sanitation_health/dwq/gdwq3rev/en/index.html

Post-Tank Processing
SODIS: www.sodis.ch/

Biosand filter: http://www.jalmandir.com/filtration/biosand/biosand-filters.html

Rainfall data
Some useful datasets of varying quality but for many locations can be found at:
hydrolab.arsusda.gov/nicks/nicks.htm

APPENDICES

Appendix 1: Economic Viability and Contribution to Safe Water Coverage

Both of the topics covered by this Appendix are specialised and less likely to be of interest to the general reader. The first two sections are relevant to those who have to provide an economic justification for a DRWH programme. In section 2.10 it was claimed that there are two main economic tests one might apply to a proposed DRWH investment. One is from the viewpoint of the user – "Is the payback from investing in DRWH good enough?" The other is from a water service provider – "In this location, is DRWH a cheaper way of achieving a particular level of service than any of the alternatives?" These two questions are addressed by the sections entitled 'Calculation of payback time' and 'Economic comparison of DRWH with rival technologies' respectively. The third section of this Appendix discusses ways in which the contribution of RWH to national or local 'safe water coverage' statistics can be calculated.

Calculation of payback time

It was argued in section 2.10 that DRWH lends itself to the use of payback time as a measure of user viability and that we therefore need to:

- put a value on the annual benefit that comes from possessing a DRWH system
- estimate the cost of building the system
- divide the system cost by the annual benefit to get a payback time (PBT) in years
- decide whether the PBT is short enough.

Annual benefit

Installation of DRWH may increase water consumption but the main change is that the time spent obtaining water drops sharply. So the conservative estimate of the benefit is simply the value of 'time saved', converted from hours to money in order to calculate a payback time. As time savings usually vary by season, it is sensible to calculate *annual* savings not daily ones.

Of many possible valuations for time, one of the more attractive is to use 2/3 the local rate per hour for unskilled labour. Collecting water is self-employment performed at a time convenient to the householder, with no 'overheads' like searching for work or travelling to a workplace, and is available to most family members. It therefore seems reasonable to value it using an hourly rate lower than that for outside employment. After discussion with householders in a target area, one might come up with a different fraction from 2/3. However, hypothetical wages are not easy to discuss meaningfully! Often the time saved is used for alternative self-employment such as agriculture, but this benefit would be extremely difficult to value.

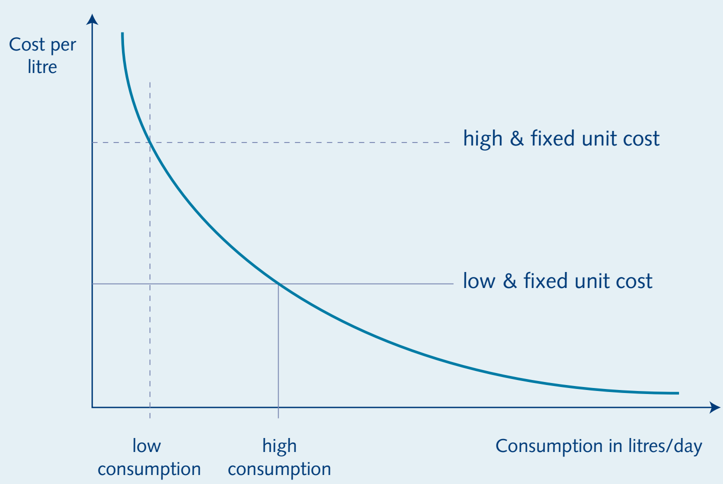
There are other ways we might value the time saved, for example by valuing health benefits, food calories 'saved' or the supposed market value of water itself. A skilled NGO with adequate resources for surveys might be able to use this last valuation, which incidentally is likely to vary by season.

The benefit in hours varies with the design of the DRWH system – a large system (big store, big roof etc) will save more hours than a small one, especially in the drier months when water may have a higher time value (more minutes spent fetching each per litre). It is prudent therefore to calculate the benefits for more than one design, for example for both a small 'potable only' system (option 4 in Table 2.2) and a larger 'main source' system (option 2), and relate these benefits to the respective costs of the two systems.

If we decide also to include the value of *extra* water consumed, we should value it at a lower rate than we value the water now drawn from a RW tank that used to be fetched from far off. A 50% valuation per litre might be a reasonable estimate.

Valuation of water

The valuation of water consumed is inherently complex and we can only approximate it. For any given household the first say 20 litres per day are critical for good health or even for survival, and are therefore very valuable. By contrast, extra litres after the first 200 per day have almost no value. In deciding how much water to obtain, a household is in some way determining at what level of consumption having 'one more litre' has less value than the cost of getting it. Although the immediate cost of drawing that 'one more litre' from a rainwater tank is almost zero, householders know that its replacement cost might be quite high, especially in a dry month, and so learn not to use such tank water too lavishly. Water from vendors, water fetched from point sources and some piped water has a cost-per-litre that does not vary greatly with how many litres are taken – so the level of consumption of such water is quite a good guide to how highly a household values successive litres. For the purpose of estimating the benefit of a DRWH installation, we normally use the apparent cost per litre to that household before the system was installed.



Cost of building

The cost of a DRWH system is generally easier to evaluate than its benefit. We might get a builder's quotation or we look at similar systems that have recently been built. For each of the RWH design options just considered for benefit, we need a corresponding system construction cost. Generally, system cost is dominated by storage cost and as a rough approximation we can adjust the system cost to allow for a larger *size* of storage tank according to the formula:

$$\frac{\text{Cost of system with storage capacity } V_2}{\text{Cost of system with storage capacity } V_1} = \left(\frac{V_2}{V_1}\right)^{0.55}$$

If however the greater storage in a large system is obtained by simple increasing the *number* of storage containers (e.g. of fixed-size jars) then the savings from 'economies of scale' are much less, and a more accurate formula would be

$$\frac{\text{Cost of system with storage capacity } V_2}{\text{Cost of system with storage capacity } V_1} = \left(\frac{V_2}{V_1}\right)^{0.9}$$

Evaluating the payback time

This requires first its calculation (probably in months as PBT = *12 x building cost / annual benefit*) and then the making of a decision whether the value obtained is acceptable. Payback time is not an everyday concept for most householders, although their decision-making for other large items (such as a better roof or a bicycle) may indicate some implicit maximum payback time criterion. In the absence of any standard, a maximum of 18 months might serve as a guide to DRWH viability. Almost always, smaller systems have a *lower* (i.e. better) payback time than bigger systems. Another expression of this is that (for a given total investment), installing many small (i.e. partial supply) DRWH systems will yield a greater annual benefit than installing a few large (i.e. main supply or sole supply) systems.

Economic comparison of DRWH with rival technologies

Defining a service standard

In section 2.10 it was noted that to make a meaningful comparison of the costs of different supply options (including some entailing DRWH) we must first declare a service level (service standard). It is usual to define such standards only in terms of quantity and quality: convenience is often neglected although it is a major concern for householders and strongly influences consumption quantity. As the major advantage of using DRWH is increased convenience, any comparison of rival water supply technologies which does not include a convenience standard is more or less meaningless. Moreover using an inappropriate convenience standard also gives biased results.

If a *maximum daily value* of collection time per household, or per litre, is set (a fairly simple alias for convenience), then the only qualifying technologies are likely to be closely spaced point sources and sole source DRWH. Both of these options are expensive – usually too expensive for consideration. More sensible is to set a maximum *annual* collection time per household. This allows cheaper options to be considered, such as partial DRWH, or mechanising water transport from distant sources for the few months per year that such sources are needed.

Having once set a convenience standard (like a maximum annual fetching time) it becomes necessary to identify which households generally do not currently meet it. In an area with a few perennial protected point sources, these will be the households far from such a source (say over 500 m – as are probably 2/3 of rural households in Africa). In an area like Bangladesh or the Mekong delta they may be low-lying, seasonally cut-off or non boat-owning households. In an area with plentiful local dirty water, they may be the households that cannot afford to treat it and therefore have to fetch potable water from a distant source. More difficult to identify by a time-based accessibility measure are households with people with disabilities who have limited ability to fetch water and therefore a severe trade-off between collection time and consumption quality. Such households can only economically be served by some household-specific technology such as DRWH or the provision of a handcart. Where such households are numerous, as in areas affected by war or major out-migration of youth, they may affect the choice of water supply for the whole community. Usually, however, they will not have much influence on a purely economic evaluation of alternatives for the community.

The cost of actually surveying the fraction *F* of households currently exceeding a chosen annual water-fetching time could be high. Techniques like participatory rapid assessment (PRA) or satellite-image interpretation might be used. However, a reasonable estimate might be obtained for a target district by combining

- an upper limit on annual water collection time *T* (e.g. 400 hours),
- the mean geographical area *A* per working protected source (e.g. 6 km^2),
- annual water consumption (e.g. *Q* = 20,000 litres/household),
- estimated water-carrying speed (e.g. S = 50 litre-km per hour),
- a correction factor *C* (e.g. C = 2) to reflect that household density may be higher near water sources

The actual population density does not affect the outcome – other than one might expect a higher density of sources wherever the population density is higher since many water authorities try to set upper limits on habitants per protected source.

Example of calculation of fraction F of households not meeting the access-time standard

Combining the suggested values for *Q*, *T* and *S* listed above, we get a maximum allowable distance *r* from household to source (if that household is not to exceed the set annual time limit *T*)

$r = S \times T / 2Q = 0.5$ km,

where the factor 2 reflects the need to make return trips.

The area within a circle radius $r = 0.5$ km is 0.785 km^2, so one protected source per 0.785 km^2 would meet the access standard. However currently there is only 1 source per 6 km^2, so it would require an 8-fold (i.e. 6 / 0.785) increase in the number of such sources to achieve the chosen access standard.

Allowing for the two-times higher ($C = 2$) settlement density close to the source, the fraction *F* of homesteads needing a more convenient supply in this example is

$F = 1 - (2 \times 0.785) / 6.785 = 0.77$ (i.e. 77%).

It can be shown that about half of these 77%, i.e. those living over 1 km from the source at present, exceed the allowed time by a factor of more than 2, and the very furthest households need a three-fold time-reduction. These different degrees of improvement needed are of interest because using DRWH for 6 months a year (or to meet 50% of water demand) gives a 2-fold reduction in annual fetching time but to get a 3-fold reduction requires 2/3 of water demand to be met from rain harvesting.

Identifying sensible options for improved supplies

This is the next step after identifying *which* households need improvement. We may assume that protected sources of water do exist but that the service they offer to some households is inadequate, because they are too distant or too congested. There may or may not be local unprotected sources. The main options for improvement are:

i. installing DRWH (only in inadequately-served households and only to the degree needed to bring those households up to the access standard)
ii. increasing the density of protected point sources (e.g. by drilling more wells)
iii. treating unsafe water to bring at least 7 lcd up to potable standard (assuming dirty water is readily available)
iv. transporting potable water to the settlement
v. some combination of two or more of the above.

The first two options are capital intensive, the next two have lower capital costs but higher running and management costs. Our purpose in this Appendix is to show how to compare options (i) and (ii). The 'fraction of households needing better supply' (*F*) is an important parameter because crudely:

- option (i) requires DRWH be installed in fraction *F* of households
- option (ii) requires point-source numbers be increased by a factor of $1/(1-F)$ and so the ratio of new sources to existing sources is $R = 1/(1-F) - 1 = F/(1-F)$

The cost of option (i) is therefore

the cost per DRWH system (C_{RWH}) x F x number of households (N_H),

while the cost of option (ii) is

the cost per new point source (C_{SOURCE}) x R x number of existing sources (N_S).

We can immediately identify the point where the options have the same overall cost, namely when:

$\boldsymbol{TC_{(i)}}$ (= C_{RWH} x F x N_H) **=** $\boldsymbol{TC_{(ii)}}$ (= C_{SOURCE} x R x N_S)

and rearranging gives, *for equality of total cost,* that each new point source should cost:

Break-even source cost $C'_{SOURCE} = C_{RWH} \times N_H / N_S \times (1 - F)$

(note: N_H/N_S is 'households per existing source').

Thus if the actual cost per new point source C_{SOURCE} is indeed less than the break-even source cost C'_{SOURCE} just calculated, then choose option (ii) and install more point sources. (The most favourable scenario for building new point sources is when $F = 0.5$, i.e. 50% of households need upgraded service. Lower and higher fractions give extra advantage to DRWH).

If, on the contrary, the actual cost C_{SOURCE} is greater than the break-even value C'_{SOURCE}, then go for the option (i), DRWH. In practice we often find that C_{SOURCE} is many times greater than C'_{SOURCE}, so that the RWH option is much cheaper than creating new point sources.

Safe water coverage

Water ministries in many countries, as well as some UN agencies, are strongly interested in measuring 'safe water coverage', namely the fraction of the population who are said to have access to sufficient 'clean and safe' water. Values for such coverage often appear in national statistics and in water plans. So the question naturally arises, "How much does DRWH contribute towards Water Coverage?" Unfortunately there is no easy answer, mainly because of the issue of measurement.

A person should properly be counted as served with water if she/he has access to

- enough water (say 20 litres/day)
- clean water (say in the WHO "low risk" class)
- reliable water (say for 360 days a year)
- convenient water (say within 500 m of the house)

In practice water coverage statistics are generally prepared without the survey effort necessary to check any of the four conditions above and in particular the last two conditions. Sometimes coverage is derived from sample household surveys, but more commonly it is inferred by counting sources and multiplying each source by the number of people it is assumed to serve.

This supply-based calculation could be extended to include DRWH by estimating the annual water yield of a typical RWH system and dividing it by the required consumption per person (e.g. 7,300 litres/year) to obtain a number of persons supplied per system N_{Syst}. The DRWH contribution to coverage, N_{RWH} persons, would then be the product of the number of DRWH systems and this N_{Syst}. Unfortunately this takes no account of the general scarcity and higher costs of water during the dryer months of the year.

A variant on this approach would be to classify DRWH systems as either 'partial supply' or 'sole supply' and to add to coverage statistics either XX% or 100% of the population of households having that particular system variant. XX might be 50% or the value assigned to it could be adjusted to reflect the lower value of the wet-season water that partial DRWH mainly delivers.

Another variant – recently recommended to the Ugandan Directorate of Water Development – is to identify how much RW storage volume Q is required to give a satisfactory water supply for 1 person. This value Q (storage-litres per person) varies with local climate and therefore needs calculating for each district. After deciding a value for Q, then the procedure for estimating N_{RWH} (the RWH contribution to safe water coverage) is as follows:

1. estimate the total storage volume V_{RWH} of all qualifying RWH containers in that area, including both domestic and institutional RWH systems, (very small or unprotected containers would not qualify)
2. divide this volume by Q, thus the number of persons covered is $N_{RWH} = V_{RWH} / Q$.

The technique is fairly easy to apply. V_{RWH} for a particular area can usually be estimated on the basis of discussion with local government officers for a few 'typical' locations within that area and then extrapolated according to relative populations. Values for Q can be calculated using local rainfall records and a RWH system performance simulator such as that found at www.eng.warwick.ac.uk/dtu/rwh. However as RWH performance depends not only on storage volume and rainfall but also on roof area, assumed water demand and RWH system management, typical values for these factors have to be chosen before Q can be calculated. Alternatively, a crude value for Q can be obtained by multiplying the assumed length of the dry season (in days) by required dry-season supply (e.g. 12 lcd); this crude procedure is likely to give a higher value for Q than a more careful estimate based on actual monthly rainfall records.

Since DRWH has 'convenience' as its main virtue – lack of which from rival sources often translates into reduced water usage – any measure that disregards convenience will overestimate the contribution of other sources. There is also a problem with double counting – which can give a falsely high estimate for water coverage. Those living far from a point source (e.g. a well) but having DRWH may fairly be assumed to be supplied only by rainwater, even if that nearest point source is underused. But those with DRWH systems who live close to a point source might be assumed to use water from both. So we might wrongly count these households twice unless perhaps the arrival of the DRWH released the well water to new users. Double counting is also a danger whenever two point sources are close to each other, but it does not happen when adjacent houses install DRWH. In the short term the only practical option seems to be to add the number 'N_{RWH}', as described above, to any national or district safe water coverage count based just on point sources. Such a total count is likely to be a biased one, but at least the bias is consistent from one year to the next, so that upwards or downwards trends in coverage can safely be inferred. In the longer term, a household survey with carefully designed questions is the only safe way to measure which households do and do not have enough safe and convenient water.

Appendix 2: Tank Designs

Several designs discussed earlier in the Handbook are brought together here. To avoid repetition, descriptions sometimes refer back to text in Chapter 7.

Moulded plastic

Mass-produced commercial-quality tank

Description
Plastic tanks are used worldwide, and are usually made from high-density polyethylene (HDPE) or glass reinforced plastic (GRP) by urban factories using complex machinery. Their general characteristics are discussed in Section 7.4.3. They form the fastest growing segment of water-storage provision and compete directly steel or concrete on a price basis. In developing countries, these tanks are generally more expensive by a factor of 3-5 than the cheapest alternatives but this is changing. Even where they are markedly more expensive, they are often employed by water supply organisations, as they are light to transport, quick to install and are believed to work reliably (usually backed by a manufacturers guarantee).

Plastic tanks in Uganda
(Picture D. Ddamulira)

Plastic tank in Sri Lanka
(Picture T. Ariyananda)

Further information
These are commercial products so contact your local supplier.

Drum tank

Small footprint tank with workshop production and use of mass-produced parts

Description
The drum tank, tested in Sri Lanka, Ethiopia and Uganda, uses two vertically stacked drums with welded seams to prevent leakage and an internal sand filter. As the slow flow through the filter could reduce storage, particularly in heavy storms, an optional

separate tank has been added to catch this overflow. The design is robust and can be made in a central location and installed in a short time. It is also extremely portable. Where height is limited, the drums can be configured horizontally.

Pipe arrangement for sand filter

Being trucked out to site

Configuration of drums (Pictures: B. Woldemarium)

Further information

Construction details can be found in DTU Technical Release TR-RWH 15 available from www.eng.warwick.ac.uk/dtu/

Open-frame ferrocement tank

Flexible sized tank with low tooling costs

Description

Developed slightly later than the closed-form ferrocement tank, the open-frame tank, used throughout Asia and Africa, is more expensive overall, but much more flexible in size. It has now become the most popular form of ferrocement tank made in Africa and Asia. A cylinder made from BRC mesh or a network of reinforcing bars replaces the role of the solid form, which means that there are no additional mould costs and any size can be made. The bars also form part of the overall structure resulting in a stronger overall tank (although the square mesh will also tend to concentrate stresses somewhat).

The downside to this design is that the mould is included in the tank structure and therefore not reusable and the formwork is not very rigid resulting in a thicker and less controlled wall section. This has resulted in a tank that generally costs more than the closed-form structure.

Moving the mould into place

Partially rendered tank

Note: pictures taken from "*Rainwater Catchment: Status and Research Priorities in the South-eastern Asian Region*"

Further information

Detailed instructions for several sizes are given in; J Gould and E. Nissen Petersen, "Rainwater Catchment for Domestic Supply" IT Publications 1999

Closed-mould ferrocement tank

Formwork used to reduce cost

Description

The closed-mould ferrocement tank has been used since the mid 1970s in many countries in Africa, Asia and the Americas. Early versions used a corrugated iron lid that proved unreliable. These days, most ferrocement tanks have a domed cover also of ferrocement.

The tank is made, using a solid mould of either corrugated or flat galvanised steel sheet made in curved sections that bolt together forming a cylinder. Mesh is wrapped around this mould and galvanised wire wound in a spiral around the tank with smaller spacing at the bottom and larger spacing at the top. The mesh is then plastered over with mortar, which is left to cure overnight. The form is then dismantled and the inside plastered with mortar. Most of these tanks are then lined with cement slurry that renders them waterproof; others use a waterproofing agent in the main mortar coating.

Screwing together the steel sheet form

Steel sheet form, wrapped by wire mesh and galvanised wire

Application of the first layer of mortar on top of the wiring

Finished tank being painted

Note: pictures taken from "*Technical Presentation of Various Types of Cisterns Built in the Rural Communities of the Semiarid Region of Brazil*"

Further Information

It has been well described in; S.B. Watt, "Ferrocement Tanks and Their Construction", IT Publications, 1978

Details are also given in; J. Gnadlinger, "Technical presentation of various types of cistern built in the rural communities of the semi-arid region of Brazil", Paper presented to the 9th IRCSA conference held in Brazil can be found at www.ircsa.org.

Pumpkin tank

Ferrocement shape optimisation

Description
Ferrocement is a mouldable material and lends itself to the manufacture of a large number of different shapes. This has been exploited to make tanks approach the ideal spherical shape – maximising volume for surface area and reducing bending forces. Notable is the Sri Lankan pumpkin tank.

The pumpkin tank was developed as part of the Community Water Supply and Sanitation Programme in Sri Lanka in 1995 and since than several thousand have been built as part of water supply schemes in various parts of Sri Lanka. The design uses an open mould that is shaped to approximate a sphere by rounding the top and bottom. An advantage of this design is that there is no need for a large separate cover.

One of the mould legs

Partially rendered tank

Finished tank (Pictures D. Rees)

Further Information
Full construction details for the tank are available from the Lanka Rainwater Harvesting Forum at www.rainwaterharvesting.com.

Plate tank: Brazil

Modular construction for a large tank

Description

The plate tank was developed in North-eastern Brazil where it is now the most popular form of tank construction. It is made about 2/3 below ground and 1/3 above. The construction is of plated mortar or sometimes concrete 3-4 cm thick and about 50 cm square made in a steel form. The plates are placed together and fixed by winding wire around the construction. A layer of mortar is plastered inside and out to finish the tank. The roof is also made from pre-cast parts which are placed and plastered over to produce the final tank.

Making the plates

Fixing the plates

Plastering the outside

Installing the roof

Note: pictures taken from Haury, S "*The Plate Cistern: Project Management and Construction Manual*" and from Gnadlinger, J "*Technical Presentation of Various Types of Cisterns Built in the Rural Communities of the Semiarid Region of Brazil*".

Further Information

Details are given in Gnadlinger, J., "Technical presentation of various types of cistern built in the rural communities of the semi-arid region of Brazil", A paper presented to the 9th IRCSA conference held in Brazil can be found at www.ircsa.org.

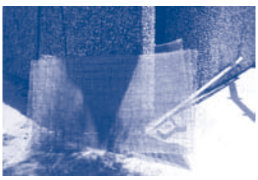
Detailed instruction can be found in Haury, S "*the Plate Cistern: Project Management and Construction Manual*" available from rainwater-toolkit.net.

Plate tank: India

Large mass-produced tank

Description

In response to the need for a mass produced tank that is quick to install, the Structural Engineering Research Centre (SERC) of Ghaziabad near Delhi developed a tank that can be made in sections, transported to a site and assembled. The sections are made on a rounded support resulting in a smooth cylindrical shape and reduced stress concentration at the join. The mould is either made on-site from sand or from other materials such as steel in a workshop. A panel of BRC mesh about 1m x 1.5m is bent over the base and mesh laid on top. Mortar is then pressed through the mesh against the curved surface of the base leaving a 10cm border around the outside and the panels are allowed to cure. The final assembly is achieved by binding the panels together with binding wire and plastering over the join.



Mesh

Laying mortar on mesh

Removing panels

Assembling panels

(Pictures: D.B. Martinson)

More Information

The technique is described in Sharma, P.C., "Ferrocement Water Storage Tanks for Rain Water Harvesting in Hills & Islands", A paper presented to the 12^{th} IRCSA conference held in India. IRCSA proceedings can be found at www.ircsa.org.

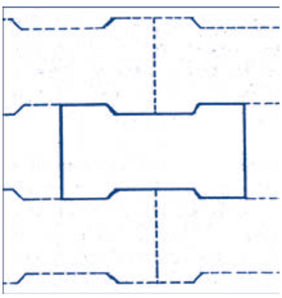
SERC are no longer providing technical support but the journal New Building Materials & Construction World published monthly from Delhi) will provide support to agencies. Tel.: 011-26841228, Fax: 26832424

Interlocking block tank: Thailand

Above ground material substitution with new jointing methods

Description

Several attempts were made to reduce costs in larger tanks in Thailand including bamboo cement and using various blocks. The blocks were designed to interlock, efficiently transferring the load between blocks and reducing mortar used for joining. The thickness of the blocks and the high level of compaction used in their manufacture results in a tank that can be made without reinforcement, although a ring of reinforcement was incorporated for safety. Problems came with aligning the blocks and ensuring a consistent layer of binding between the blocks. While not widely replicated due to its complexity this technique is instructive. If these problems can be overcome, the technique could conceivably be used with stabilised soil blocks or shaped burned bricks, dramatically reducing cement use.



Block configuration

Making blocks

Finished tank

Note: pictures taken from "*Rainwater Catchment: Status and Research Priorities in the South-eastern Asian Region*"

More information

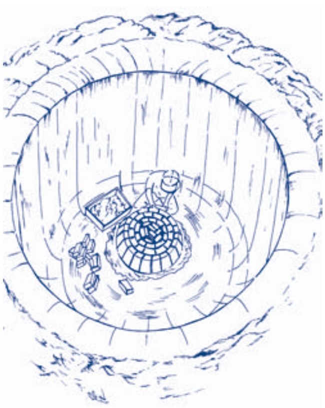
The tank is described in "Rainwater Catchment: Priorities in the South-eastern Asian Region" (Report No. IDRD-MR127e). IDRC, Canada.

Brick-lime cistern: Brazil

Underground functional separation

Description

When the ground can be relied on to take some of the load, tanks do not have to be so strong and materials that would otherwise be unusable can be employed. Such an underground design is the brick-lime cistern developed in the North-eastern Brazil and has been built for several years. The design is totally underground with only the dome protruding. Locally-made burned bricks are laid directly against the sides of an excavation and mortared together with lime, resulting in a slightly flexible structure that transfers a great deal of its load to the surrounding earth. The inside surface is sealed with a lime-cement mix and waterproofing is achieved by a cement slurry coating applied with a brush.



Beginning building the cistern

Making the brick dome

Finished tank

(Pictures: J. Gnadlinger)

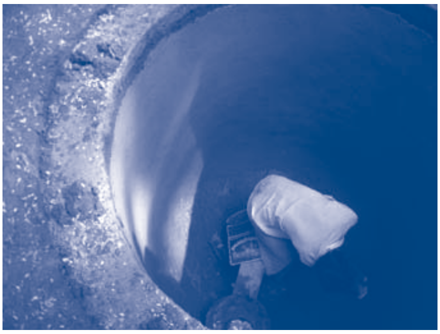
More information

Manufacture of the cistern is described in "Redescobrindo a cal para construir cisternas" (Using lime to construct cisterns) available from http://www.abcmac.org.br.

Dome tank

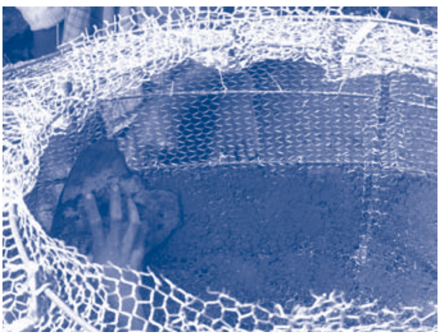
Description

The dome tank, tested in Sri Lanka, Ethiopia and Uganda, is a partially below ground tank with a ferrocement domed cover. The dome uses a removable frame that leaves behind only wire mesh as reinforcement. The mortar can either be applied without any other formwork, using one person outside to apply the mortar and one person inside to provide a backing (the addition of a small amount of sacking fibres to the mortar was found to help this process) or by making a temporary formwork from cardboard. The dome can be built when the tank is commissioned or added later when more funds are available, using a low cost roof in the mean time (see also thatch tank below).



Lining the pit

Fixing the frame for the dome



First layer of mortar for the dome

Finished tank

(Pictures: D.B. Martinson)

More information

Construction details can be found in DTU Technical Release TR-RWH 13
www.eng.warwick.ac.uk/dtu/

Thai jar

Workshop-based production using solid formwork and an optimised shape

The Thai jar was developed in the 1980s, since which many millions have been made, driving down the cost. It is described in Box 7.1. The price today is less than US$ 15 and the jars are almost universally found in rural homes in Northern Thailand and are also found in neighbouring countries such as Cambodia where they sell for less than US$ 10. This price makes the jars affordable by all but the poorest and has caused DRWH to become widespread without further input from any institution.

Each jar is made on a mould made of cement bricks, which are coated with mud as a mould release. The steel formers for making the moulds are made centrally ensuring tight quality control of the size and shape. The high quality solid mould allows a very uniform and thin coating of mortar to be applied resulting in a highly optimised product.

Attempts have been made to transfer the jar to other countries notably in Africa. This has resulted in a product that, is much more expensive (and less well finished) than jars made in Thailand. A move toward using workshops and wooden moulds has yielded a more economical product.

Jar factory with made jars

Mould pieces

Transporting jars by cart in Uganda

(Pictures of Jar factory and Mould pieces: R.de Ariyabandu)

Further information

The tank is extensively discussed in a number of books and publications. Construction details of a version being used in Uganda can be found in DTU Technical Release TR-RWH10
www.eng.warwick.ac.uk/dtu/

Tarpaulin tank

Ground support used by low-cost mass produced and gatherable materials

Description
The tarpaulin tank is an excellent example of what can be achieved if a strict eye is kept on costs while maintaining the bare essentials of function.

The civil war in Rwanda brought large numbers of refugees into Southern Uganda. UNHCR had supplied several waterproof tarpaulins to be used as shelter. A number of families lined holes with them and successfully used them to collect rainwater. ACORD Uganda worked with the households to develop an improved design that would prevent foreign matter and light getting in, to improve water quality and to prevent algae from developing. The improved design featured an enclosure made from wattle and daub with a galvanised steel roof. The top edge of the tarpaulin could be raised about 10cm to keep ground run-off out of the tank and an overflow arrangement could be introduced. Access was by dipping a half-jerrycan through a wooden door.

The tarpaulin tank is not a durable solution in all cases:
- termites eating the wattle and daub frame – this is can be dealt with using similar methods as used to protect local housing
- the tarpaulin can rot and this seems to be correlated to soil type
- roofing sheets can rust.

Frame

Daubing the walls

The tarpaulin

Completed tank (Pictures: D. Rees)

More information
More details about the tank can be found in DTU Technical Release TR-RWH05.
www.eng.warwick.ac.uk/dtu/

Tube tank

Ground support used by low-cost mass produced and workshop-based components

Details

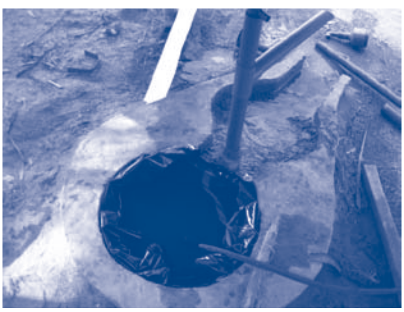
The tube tank, tested in Sri Lanka, Uganda and Ethiopia, is a small tank, stripped to the bare essentials. Water storage is in a plastic tube and extraction by a PVC pump. The slab can be precast in a steel mould either on site or in a central location.

The tank design is particularly suited to rapid implementation projects such as refugee camps where a quick solution is required for water provision ahead of more permanent measures. If householders do the excavation, an agency can simply transport a number of prefabricated parts and each tank can be assembled within an hour.

Tank size is determined by the depth of the hole, so the deeper a household digs, the larger the store. Extra storage is relatively cheap as the cost of the tank is dominated by the concrete slab. The longevity of the tube is variable, but it will normally need replacing every year or so.

General arrangement of tube tank

Retaining ring



Overflow

(Pictures: D.B. Martinson)

More information

Construction details can be found in DTU Technical Release TR-RWH 14
www.eng.warwick.ac.uk/dtu/

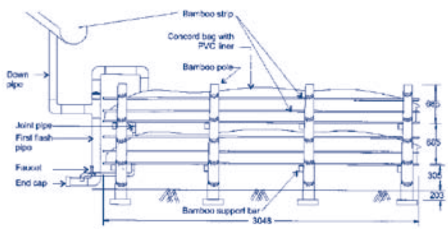
PVC lined concord cloth bag with bamboo frame

Above-ground quality reduction

Description

The PVC lined concord cloth bag is a recent innovation by International Development Enterprises (IDE) and is used in Bangladesh. As with the tarpaulin tank, the majority of the materials are gatherable or made locally. Only the PVC liner and plumbing need to be imported. The above ground design allows the water to be drawn without effort and also allows the tank to be monitored for damage.

The tank consists of two cloth bags waterproofed with a PVC liner. Each bag is laid horizontally in a bamboo frame and plumbed to a tap. The total capacity of the tank is about 3,000 litres and the total cost is about US$ 30.



General Assembly Diagram

Competed tank

(Picture and diagram: IDE)

More information

More information can be obtained from IDE in Bangladesh.
http://www.ide-bangladesh.org

Mud tank

Above ground structure using low-cost mass produced and gatherable materials

Description

The mud tank, as tested in Sri Lanka, is an above ground tank with much of the economy of a below ground tank. Wattle and daub is a widespread practice for building from earth, particularly when householders build their own homes. The technique uses unmodified mud to fill a frame structure made from roundwood. The materials necessary for this type of constructions are all gatherable, so cash costs are low, being limited to the liner and plumbing.

Bamboo frame

Detail of access to tank

Finished tank

(Pictures: D.B. Martinson)

More information

Construction details can be found in DTU Technical Release TR-RWH 11
www.eng.warwick.ac.uk/dtu/

Thatch tank

Description

The thatch tank tested in Ethiopia, Uganda and Sri Lanka uses organic material for the roof of the tank, reducing material and skilled labour costs. In fact, the roof needn't be made of thatch and tanks have been made with tar sheet or corrugated iron roofs.

The key features are a polyethylene liner to seal the tank against vermin intrusion and falling material and a trench around the tank to protect it against stormwater. The barrier must be done correctly or it will not work, and the tank must be inspected carefully before use. The thatch tank can also be used as an interim step to the Dome Tank described earlier.

Thatched tank in Ethiopia
Note: drainage to pit

Tar sheet cover in Sri Lanka

Underground tank with sloped ring beam

(Pictures: D.B. Martinson)

More information

Details can be found in DTU Technical Release TR-RWH 12
www.eng.warwick.ac.uk/dtu/

About the authors

Terry Thomas

Terry Thomas is a university teacher who runs the Development Technology Unit, a small research group at the Engineering School of Warwick University, UK, concerned with engineering and product design for rural development in tropical countries. The Unit has for more than two decades complemented an undergraduate degree programme in Engineering Design and Appropriate Technology. Terry is also Chair of Trustees for a spin-off charity in Cambodia, (DTW Ltd), that manufactures equipment for landmine clearance, WATSAN and to help people with disabilities. Terry has worked on roofwater harvesting issues for many years, in East Africa, South Asia and Mexico, and is a committee member of the International Rainwater Catchment Systems Association (IRCSA). Other current technical interests concern low-cost building materials, artisanal employment and rural energy supply. Previous research led him from electronics and automation in the 1960s, via driverless public transport in Europe and public transport in India in the 1970s, to hydropower and biomass conversion in the 1980s.

Terry has four daughters born in three continents, two still at school, cycles to work, reads novels, lives in the inner city but enjoys walking in the countryside. In recent years he has spent time in Uganda where he acts as part-time ‘research officer’ for the Uganda Rainwater Association, runs an annual field course for English and Ugandan engineering students and would like to build a house in the hills for his retirement.

Brett Martinson

Over the years, Brett has sold things, fixed things, built things and designed things. He now works as a teacher and researcher at the School of Engineering at the University of Warwick. He has been working in water supply for almost ten years and has concentrated on roofwater harvesting with the Development Technology Unit since 2000, concentrating on cost reduction and water quality enhancement. He has worked in India, Sri Lanka, Uganda and Ethiopia; and is an active member of the IRCSA.

Born in Australia, Brett came to England in his early 20s and never got around to going back home. He currently lives on a narrowboat, cruising the UK canal system with his wife and 1½ children. His interest in roofwater harvesting stems back to his days visiting his grandfather’s farm in rural Australia where he drank rainwater exclusively.

About IRC

IRC facilitates the sharing, promotion and use of knowledge so that governments, professionals and organisations can better support poor men, women and children in developing countries to obtain water and sanitation services they will use and maintain. It does this by improving the information and knowledge base of the sector and by strengthening sector resource centres in the South.

As a gateway to quality information, the IRC maintains a Documentation Unit and a web site with a weekly news service, and produces publications in English, French, Spanish and Portuguese both in print and electronically. It also offers training and experience-based learning activities, advisory and evaluation services, applied research and learning projects in Asia, Africa and Latin America; and conducts advocacy activities for the sector as a whole. Topics include community management, gender and equity, institutional development, integrated water resources management, school sanitation, and hygiene promotion.

IRC staff work as facilitators in helping people make their own decisions; are equal partners with sector professionals from the South; stimulate dialogue among all parties to create trust and promote change; and create a learning environment to develop better alternatives.

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Acronyms

ACORD	Agency for Co-operation and Research in Development (Uganda)
ADR	Average daily run-off
ARO	Annual run-off
CBO	Community based organisation
DFID	Department for International Development (UK)
DRWH	Domestic roofwater harvesting
DTU	Technical University of Denmark
DWD	Directorate for Water Development (Uganda)
EUC	Equivalent unit cost
FAKT	Finanzen, Analysen, Kommunikation und Technologie (German non-profit consultancy firm)
GI	Galvanised iron
GRP	Glass reinforced plastic
HDPE	High-density polythene
IDE	International Development Enterprises
IDP	Internally displaced persons
IIT	Indian Institute of Technology
IRC	IRC International Water and Sanitation Centre (Netherlands)
IRCSA	International Rainwater Catchment Systems Association
LRWHF	Lanka Rain Water Harvesting Forum (Sri Lanka)
NGO	Non-governmental organisation
NTU	Nephelometric turbidity units
PBT	Payback time
PNG	Papua New Guinea
PPP	Public-private partnership
PVC	Polyvinyl chloride
RWH	Roofwater harvesting
SEARNET	Southern and Eastern Africa Rainwater Network
SERC	Structural Engineering Research Centre (India)
SODIS	Solar water disinfection process
UNHCR	United Nations High Commissioner for Refugees (UN Refugee Agency)
UNICEF	United Nations Children's Fund
USEPA	US Environmental Protection Agency
WHO	World Health Organization

Roofwater Harvesting: A Handbook for Practitioners

With rising global concern over the shortage of clean water, the hunt for safe sources is being stepped up. Collecting the water that falls onto household roofs provides an attractive method of conserving water delivered directly to the home. "Water without walking" relieves families of much of the burden of water-carrying.

Investment in Domestic Roofwater Harvesting (DRWH) is growing in countries as diverse as Kenya, China, Brazil and Germany. However, the simplicity of the idea can be deceptive. Roofwater harvesting is not a panacea and has many complexities that can trip up policy makers.

In most tropical countries, DRWH can provide full coverage in the wet season but only partial coverage in the dry season. The right combination of roofing materials, guttering, collection and storage systems is needed to successfully collect even 80% of the water that falls onto a roof.

Roofwater Harvesting: A Handbook for Practitioners is a practical guide that distils the extensive experience of the two authors in this technology. It covers such issues as optimum tank size to meet different needs, methods to ensure that only clean water enters the tank, ways to protect against potential health hazards and factors that influence public and household investment.

Anyone interested in domestic roofwater harvesting as a policy or a technology will find this book, with illustrated practical examples from around the world, to be a mine of information. Those who are implementing such a policy will find detailed discussions of the contribution it can make to safe water coverage and the economics of installing and maintaining such a system.

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