Domestic Roofwater Harvesting
Research Programme

VERY-LOW-COST DOMESTIC ROOFWATER HARVESTING IN THE HUMID TROPICS: EXISTING PRACTICE

DFID KAR Contract R7833

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CONTENTS

REPORTING CONVENTION, DEFINITIONS AND ABBREVIATIONS

The abbreviations RWH, DRWH and VLC DRWH used in this report denote respectively ‘roofwater harvesting’, ‘domestic roofwater harvesting’ and ‘very-low-cost domestic roofwater harvesting’.

Costs cited in the report are in UK pounds or pence; all physical units are metric.

The ‘humid’ tropics is taken to be that (primarily Equatorial) Zone in which mean annual rainfall exceeds 800 mm and not more than 3 consecutive months have less than 30 mm per month mean rainfall.

The Principal Investigator and two Research Associates are located in the ‘DTU’, the Development Technology Unit of the School of Engineering at Warwick University.

1. INTRODUCTION

This is the first output of the Main Phase of a 27 month research contract (R7833) for the Department for International Development, one of two reports due 8 months after the authorisation of commencement of that Phase. The subject matter of this report substantially overlaps that of the contract's Inception Phase Report rendered in March 2001 - which will not be repeated here. It extends that earlier Report by its tighter focus on 'very low cost' DRWH and on the 'humid' tropics, by its inclusion of material from household and community surveys undertaken in 8 low-income locations in 3 countries in the humid tropics during August-September 2001 and from a regional survey in Thailand in May 2001, and by developments in the theory of DRWH since March.

There is a substantial literature and an extensive practice of DRWH in the tropics. However neither has paid great attention to affordability and hence accessibility to poor households (except those covered by subsidy-intensive projects). One role for DRWH is as a supply of last resort in semi-arid regions – a role that dictates much of the content of such influential publications as Gould & Nissen-Petersen 1999 and Agarwal 2001. Generally however this role requires RWH systems to contain large and therefore costly water stores – tanks, cisterns or jars. DRWH in the *humid* tropics is practised but much less reported. By avoiding the onerous requirements of a supply of last resort (accepting instead the more common role of a supply satisfying 60 to 80% of a household's water needs) and by focussing on locations where the dry season is not long, one can employ DRW systems with small cheap water stores. Such locations in the tropics are the home to some 600 million people, some in medium-income countries but most in low-income countries, and are the focus of this Report.

What system cost we can deem 'affordable' is a function of average or of specific household income, and of the costs associated with rival water supply technologies. These latter costs depend strongly upon local geography. There is plentiful evidence that the high cost, in money or effort, of obtaining water results in most poor tropical households consuming less than 25 litres per capita per day (lcd) and under particularly unfavourable circumstances their consuming less than 10 lcd.

A RWH system capable of supplying say 5000 litres per capita per year in the humid tropics typically costs in the band £15 to £50. These costs however assume that a hard roof is already installed at the relevant house – a condition increasingly but still far from completely satisfied in the Equatorial Zone. Moreover it is in practice also necessary that the mean annual rain precipitation on that roof exceeds 7500 litres. How much storage capacity say $50 can buy, after subtracting the costs of such system components as guttering, varies (with local unit costs of labour or materials) between 500 and 5000 litres. One major objective of this research programme is, by design innovation, to reduce the cost of such storage.

Opportunist (or 'informal') DRWH we have found to be quite extensively practised in the humid tropics although it is rarely recorded in water statistics or noted by policy makers. By definition, it employs no permanent structures or equipment – only existing household vessels are used to collect roof run-off during storms. This, along with the collection of rainwater from leaves and trees, constitutes a traditional base of DRWH that however rarely satisfies more than 15% of a household's water needs. In terms of the number of households practising it, this informal version dominates other forms of DRWH in many locations and is therefore of considerable importance in its own right. It may also be an important precursor to the update of the VLC variant of DRWH that this Report analyses.

There is an important current, but so far incomplete, development in the RWH literature. The primary historical source of information on both theory and practice has been embodied in the pre-prints or proceedings of the 10 large biannual conferences of the International Rainwater Collection Systems Association. Unfortunately only a few of these documents are readily accessible, despite their being widely cited in key publications: those from the earlier meetings exist as only a few paper copies in the hands of long-term IRCSA Committee members. Until October 2001 the DTU itself only held 4 of the 10 sets. DTU staff are participating in a project to locate, scan and place on the Web the remaining proceedings (same hundreds of papers) that is now underway and should be completed by February 2001. From that time it should be possible to recapture important findings from the last two decades.

This Report focuses mainly on the *status quo* with respect to the technology, sociology and economics of roofwater harvesting and of rival water sources. Warwick University's three research partners are located in Ethiopia, Sri Lanka and Uganda, which have therefore been the venue for field surveys. However a separate tour of Thailand was organised to examine long-term RWH developments there, and through correspondence the situation in India, Cambodia and Brazil has been monitored.

2. TECHNOLOGY

2.1. Introduction to RWH Technology

Rainwater harvesting technology has been a traditional practice in some cultures for centuries and as such many technologies are the result of a long evolutionary process. Even the current resurgence of interest in rainwater harvesting as a source of water supply has been in existence for over twenty-five years (more in some countries such as Australia). As a result a number of technologies have become accepted into the norms of rainwater harvesting practice. Some of these are modifications of designs that go back into antiquity while others have been developed more recently.

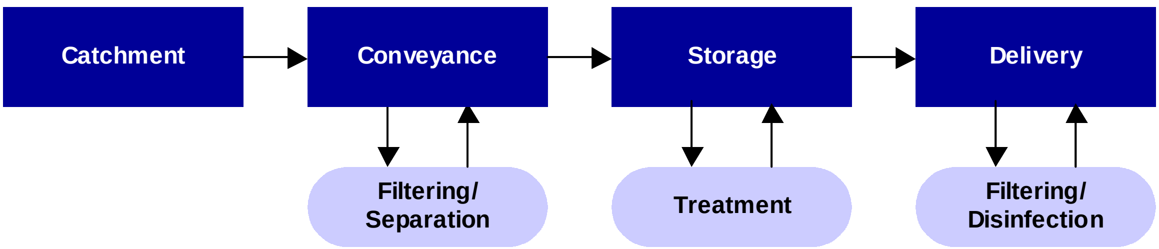
There is also a drive to improve and innovate. Developed countries such as Germany have recognised domestic rainwater harvesting as a solution to the problems of overexploitation of water resources and have been working apace to implement user-friendly, reliable and high quality systems in a cost-effective manner. The developing world's need for inexpensive and sustainable water supply technologies is also being addressed (albeit more slowly), however, most research has been within the "institutional" sector which has resulted in most innovation being confined to large-scale/high-reliability systems rather than types poor householders can afford.

This section will outline current practice in rainwater harvesting technology, breaking the system down into components, describing the theoretical requirements of each component and the types of solutions currently employed. Techniques that have application in very low cost (VLC) systems have been given particular emphasis and those that have not as yet been so applied are discussed in terms of their shortcomings or potential for this application. Several case studies are also presented to show how the components work together in systems. Finally, the main areas for future work are discussed.

Component Overview

Rainwater harvesting systems can roughly be broken down into 4 primary processes and 3 treatment processes. These are outlined in Figure 2.1:

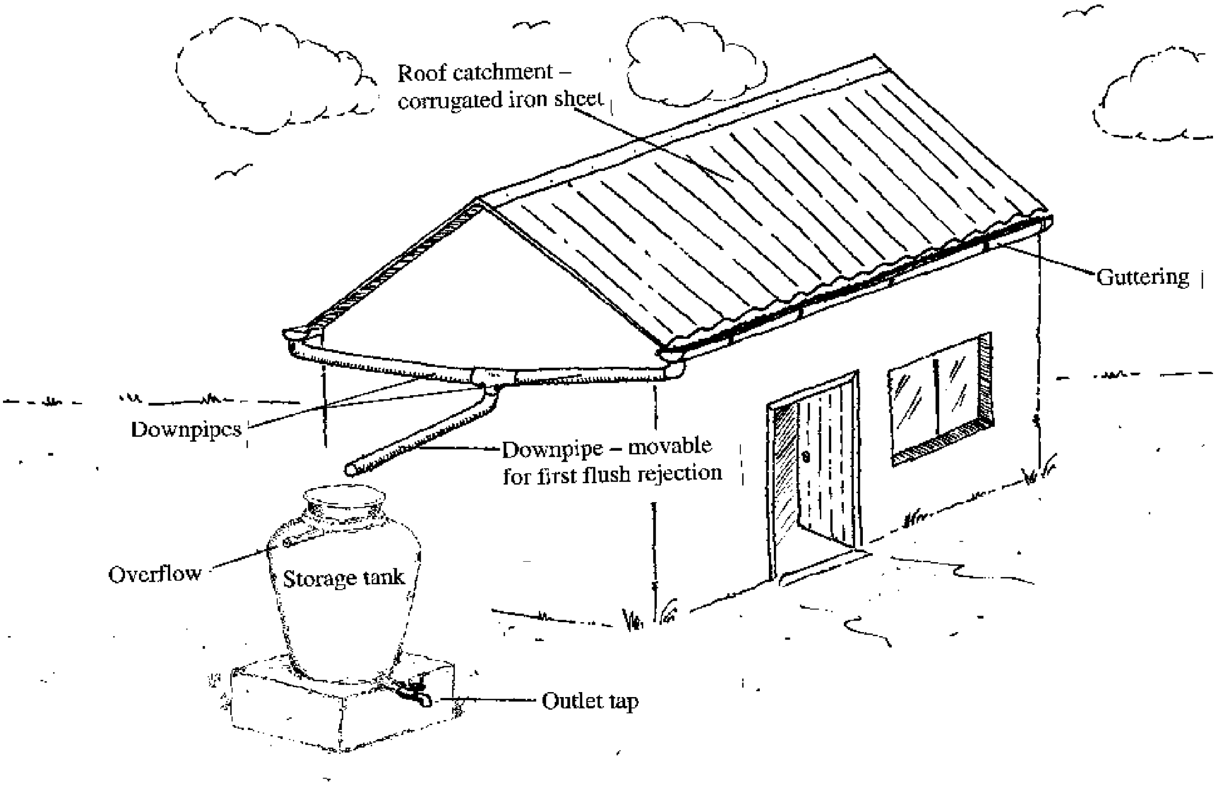
Figure 2.1: Process diagram of domestic rainwater harvesting systems



There is a considerable range in complexity of domestic rainwater harvesting systems, from simple opportunistic practice where the catchment may be a tree, the conveyance a banana leaf and the storage and delivery an earthenware pot, to highly sophisticated systems with automatic treatment at each stage of the process, electronic monitoring and dual reticulation systems.

A typical VLC rainwater harvesting system in developing countries is illustrated in Figure 2.2. The catchment is a roof, usually made of an impervious material such as corrugated galvanised iron sheet, the conveyance is by guttering and downpipe, the storage is a tank, and delivery is by a tap connected to the tank. Installed treatment includes a manual "first flush" system and a before-tank filter. There are also a number of processes that occur within the tank itself such as settlement, floatation and pathogen die-off. Finally, the household may employ some technique of post-storage disinfection such as chlorination, solar disinfection or a candle filter.

Figure 2.2 Typical Very Low Cost Roofwater Harvesting System in a Developing Country



2.2. Catchments

The catchment determines the quantity and to some extent the quality of water that enters the tank. Most losses are through infiltration, although some water will also bounce off the edge of the surface in heavy downpours and usually. The loss is usually represented by a "run-off coefficient" C_R which is a number between zero and one: (1- C_R) expresses the loss fraction averaged over a year. A good impermeable roof such as corrugated iron will deliver to the guttering system almost all of the water that lands on it. Ground catchments tend to have an even lower runoff coefficient as rainwater infiltrates into the ground and flows away as groundwater.

Runoff quality also varies by catchment type. Ground catchments are prone to contamination from many sources including human and animal faecal matter, rotting vegetation and the soil itself. Higher quality water for drinking must be caught from a surface that is less easily contaminated. This usually comes in the form of the roof of the building but can be an separate structure. GI sheet roofs fare best due to their relative smoothness (Fujioka, 1993) and the sterilising effect of the metal roof heating under the sun (Vasudevan, Tandon, Krishnan, & Thomas, 2001).

Types of catchment

Roofs

Roofs are the most popular catchment for water for domestic purposes. An impermeable roof will yield a high runoff of good quality water that can be used fore all household purposes. Roof types are detailed in Table 2.1.

Table 2.1: Characteristics of roof types

Type	Runoff coefficient	Notes
GI 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 can harbour mould • Contamination can exist in tile joins
Asbestos Sheets	0.8 – 0.9	• New sheets give good quality water • No evidence of carcinogenic effects by ingestion (Campbell, 1993) • Slightly porous so reduced runoff coefficient and older roofs harbour moulds and even moss
Organic (Thatch, Cadjan)	0.2	• Poor quality water (>200 FC/100ml) • Little first flush effect • High turbidity due to dissolved organic material which does not settle

The poor performance of organic roofs would seem to preclude them from use for rainwater harvesting systems, however organic roofs have been employed with varying levels of success. The water is usually used for secondary purposes but can is sometimes used as drinking water in particularly desperate circumstances (Pacey & Cullis, 1996). Various treatments for thatch roofs have been tried such as polythene sheeting, however the sheeting tends to degrade in the sunlight quickly and can only be used for a single season. A novel solution has been tried in Ethiopia where a foldaway roof was constructed (Hune: personal correspondence). Problems remain, however as it relies on user intervention to fold and unfold the roof at height and when it is raining. A more practical solution may be the use of auxiliary catchments such as those used in the ALDP project in Botswana (Gould paper). These can also be simple polythene structures (Ariyabandu, 2001). The problem of UV degradation vs. user intervention remains but the latter is now at a more sensible height.

Ground catchments

A ground catchment has a much lower runoff coefficient than a hard roof (in the region of 0.1 – 0.3), however they are usually much larger and so can yield a high overall runoff. Other ground level catchment surfaces yield a higher runoff with paved surfaces having a coefficient on the area of 0.6 – 0.7 and so courtyard runoff is often collected (Li & Liang, 1995) and stabilised threshing floors are also employed (Pacey & Cullis, 1996). The water from these catchments is not usually of high quality, however and so can only be used for secondary purposes, watering livestock or gardening.

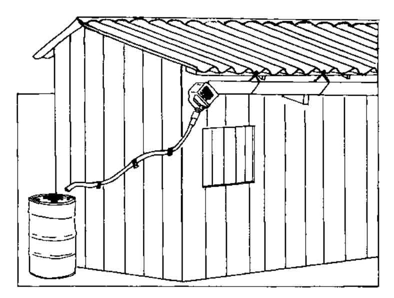
2.3. Gutters

The water from the roof must be conveyed to the store in some way, this is usually by way of a system of guttering. Other systems such as roof slides (Waller, 1982) or ground level drains (Zhang et al., 1995) can be used but are less popular for rainwater harvesting systems as they either spill water or allow ground borne contamination into the conveyance system. Gutters in developing countries are often the weak link in the rainwater harvesting system (Mwami, 1995) and installations can be seen with gutters coming away from their mountings, leaking at joints or even sloping the wrong way. Beyond the mere functional failure, poor guttering can also be a health hazard if it allows water to remain in the gutter and become a breeding ground for mosquitoes. This situation is exacerbated by the common NGO practice of supplying a free water store but insisting that beneficiaries install the guttering. As a general rule, the cost of the gutters is not considered important as the storage tends to dominate the system cost, however with VLC DRWH systems the storage cost becomes less dominant and gutters can even demand over half the total investment.

Case Study:
DRWH in Tegucigalpa – urban poverty finds its own answers

The barrios on the outskirts of Tegucigalpa are composed of low-income settlers who have moved to the city during the rapid urbanisation of Honduras. They are very poorly served by water and other amenities and people there are prone to water related diseases. The DRWH systems found in these areas have grown out of the desperate water situation and are based on local ingenuity. Rainfall is low at 788mm and roofs small at 45m^2 but the systems provide over 50% of water to about 80% of households in the two barrios studied (Brand & Bradford, 1991) usually providing secondary water for washing.

Roofs are mainly GI sheet, but other types are found such as asbestos, tarpaper and various plastic sheets. The gutters are usually fitted to only half the catchment and are composed of bent GI sheet often from reused oil drums or from PVC pipes cut in half. Some prefabricated gutters were appearing on better off houses. Cheaper gutters are held by wires from the roof or by brackets made of reinforcing bar. Most houses have no downpipe with water simply spilling from the edge of the gutter directly into storage but some houses employ downpipes comprising a hose attached by half a bottle. Storage is usually an old drum (of which most contained toxic chemicals and pesticides) but some households have purpose built *pilas* which are an open topped rectangular concrete storage with a built in wash board.



Typical Rainwater harvesting system in Tegucigalpa
(Picture: Brand & Bradford 1991)

Analysis of gutters

The two main criteria for guttering are that it catch the water from the roof and then transport it to the tank. On the surface this seems simple enough, however the relative complexity of achieving this simple aim often confounds, resulting either in poor designs that fail to deliver water to the tank or overly conservative designs with a high cost.

Water conveyance

The flow performance of a gutters varies along its length resulting in a spatially varying flow, however for a long gutter it can be approximated by the manning formula:

$$Q = Av = A\frac{1}{n}R^{\frac{2}{3}}S^{\frac{1}{2}} \qquad (2.1)$$

Where Q = flow in channel (m^3 s^{-1})

A = cross-sectional area (m^2)

V = velocity of flow in channel (m s^{-1})

n = Manning roughness coefficient (usually between 0.01 and 0.15 for gutters)

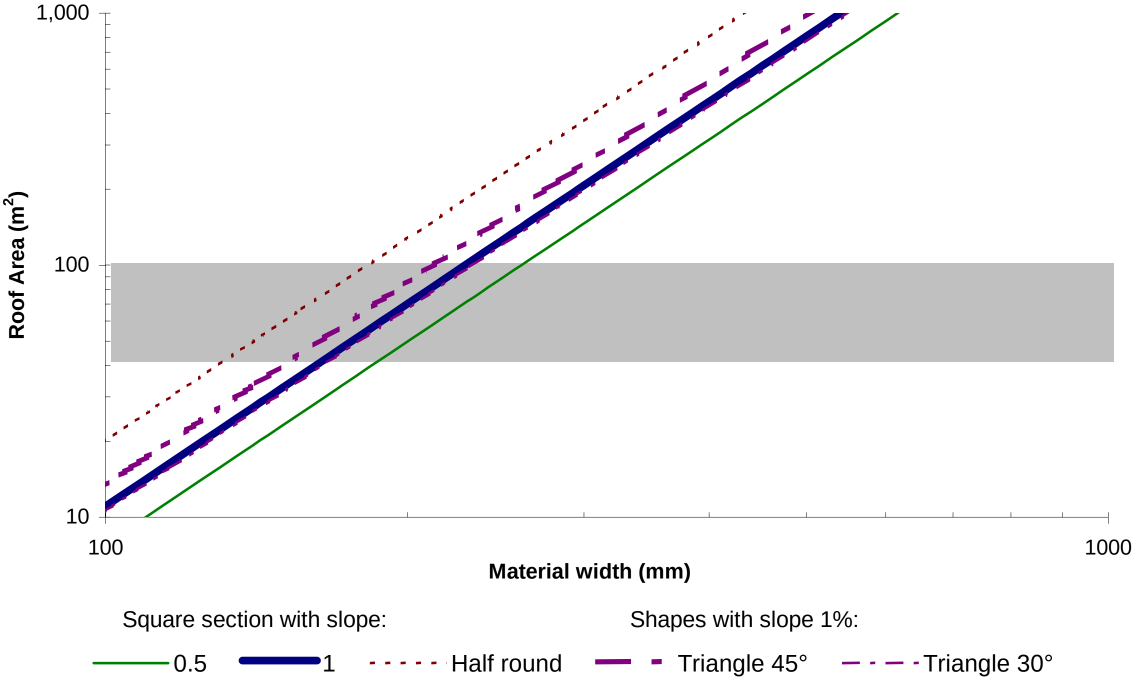
P = Wetted perimeter (m)

R = Hydraulic radius (m) ($R = A/P$)

S = Slope

Using this formula an idea of the actual size of gutter needed can be developed for any gutter profile. Figure 2.3 shows the sizing in terms of material needs for the most popular gutter profiles. The shaded area represents the range of typical domestic roof sizes.

Figure 2.3: Material required for gutters to service various roof areas



For a typical household roof of 60m2 the guttering requirement is shown in Table 2.2. Typical gutter widths for such a roof quoted in the literature are shown in Table 2.3 and generally quote larger gutters (sometime much larger) than are necessary for water conveyance.

Table 2.2: Guttering for a 60m^2 roof

	Square 0.5% slope	Square 1.0% slope	Half round 1.0% slope	45° Triangle 1.0% slope
Material use	214mm	189mm	150mm	175mm
Gutter width (at top)	71mm	63mm	96mm	124mm
Cross sectional area	47cm^2	39cm^2	36cm^2	38cm^2

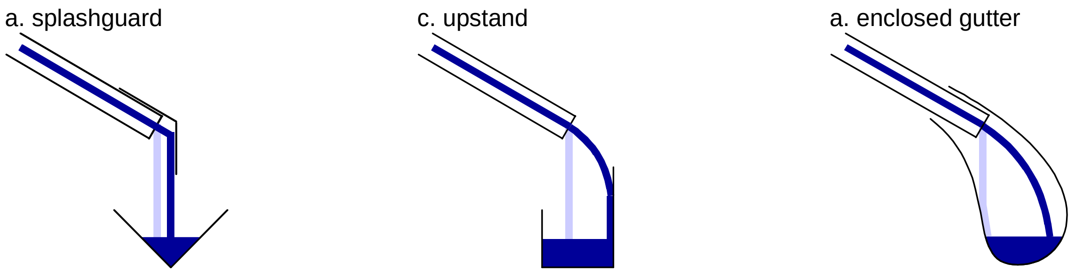
Table 2.3: Gutter sizes quoted in literature

Source	Section	Roof size	Slope	Cross sectional area
(Herrmann & Hasse, 1996)	Square	40 – 100m^2	0.3 – 0.5%	70cm^2
	Half Round	40 – 60 m^2	0.3 – 0.5%	63cm^2
(Nissen-Petersen & Lee, 1990)	45° Triangle	Not specified	1.0%	113cm^2
(Edwards et al., 1984)	Not specified	Not specified	0.8 – 1.0%	70-80cm^2

Interception

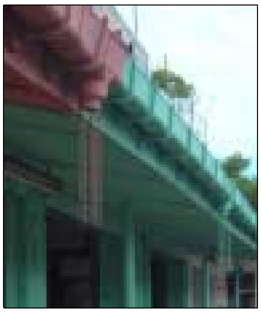
When water falls from the roof, it can curl, around the edge under surface tension, it can drop vertically down or it can follow a roughly parabolic path off the edge depending on the rainfall intensity and the roofing material. Wind also complicates this as storms are often accompanied by high winds that can blow the stream of water from the roof from its natural path. Work at the University of Warwick (WP56 – under preparation) indicates that to intercept the water for rainfall intensities from 0 to 2mm/min requires the mouth of the gutter to be 60 mm wide for a 10cm drop from the roof edge. This distance can be reduced by the use of "splash guards", "upstands" and by enclosing the gutter-roof junction. The splashguard (Figure 2.4a) developed in Kenya and described by Nissen-Petersen and Lee (Nissen-Petersen & Lee, 1990) consists of a piece of downward pointing sheet metal at the lip of the roof. The off-shooting water hits the splashguard and is diverted vertically downwards into the gutter. The upstand (Figure 2.4a) effectively raises the interception height of the gutter allowing it to be mounted lower while still effectively intercepting the runoff. Enclosing the gutter-roof junction (Tapio, 1995) effectively makes interception loss impossible but uses considerably more material and makes the gutter almost impossible to clean as well as making evaporation of any retained water less efficient (Wade, 1999).

Figure 2.4: Methods of augmenting interception



Gutter Types

Rectangular sheet metal gutters with small upstand in Uganda
(Picture: D. Rees)



Extruded plastic gutters in Sri Lanka
Note: Chains used to direct downflow
(Picture: B. Martinson)

Experimental shade cloth gutters in South Africa
(Picture: P. Houston)

Vee shaped gutters with splash guard in Ethiopia
(Picture: S. Akhter)

There is a staggering variety of guttering available throughout the world. From prefabricated plastics to simple gutters made on-site from sheet metal and even bamboo.

Plastic

Gutters made from extruded plastic are popular in developing countries; they are durable and relatively inexpensive. Mounting is usually by way of purpose built brackets and there is an array of hardware for joining, downpipe connection and finishing ends. They are less available in developing countries and tend to be expensive there, however in countries with a good industrial base, such as Mexico, India and Sri Lanka, plastic gutters are readily available for reasonable prices.

Aluminium

Aluminium guttering is extremely popular in countries such as Australia and the USA where it dominates the market. It is rolled on-site from coils of sheet metal in lengths to suit the house, eliminating in-line joints. Aluminium is naturally resistant to corrosion and so the gutters should last indefinitely. In developing countries where it is available, the cost of the sheet is over 1.5 times the cost of steel of the same gauge and the material is less stiff so for a similar strength of gutter a larger gauge of material is required, resulting in gutters up to three times the price. This makes aluminium gutters prohibitively expensive, however aluminium sheet is a growing market in developing countries so the price will almost certainly come down over time.

Steel

In Africa galvanised sheet steel gutters dominate. They are either made in small workshops in lengths and joined together or can even be made on-site by builders. Workshop-made gutters are usually square section and can employ an upstand to aid interception. The cost of these gutters tends to be in the order of 2 – 3 times the cost of similar gutters made on-site but they are readily available in a number of configurations (open lengths, lengths with closed ends and with attached downpipe connectors), standard mounting hardware is available and their quality is usually slightly better.

On-site gutters are usually of a vee shape as described by Nissen-Peterson (Nissen-Petersen & Lee, 1990) and adopted by several agencies such as CARE Zimbabwe (CARE Zimbabwe, 2000). The shape is quite efficient but reportedly has a tendency to block with debris. Mounting the vee shape is also more difficult and they are usually tied directly under the roof or onto a splashguard.

Wood and bamboo

Wooden Planks and bamboo gutters are widely described in the literature (Agarwall & Narain, 1997) (Pacey & Cullis, 1996) (Institute for Rural Water, 1982), They are usually cheap (or even free) and all money tends to stay in the community. They do, however, suffer from problems of longevity as the organic material will eventually rot away and leak. The porous surface also forms an ideal environment for accumulation of bacteri that may be subsequently washed into the storage tank.

Half pipe

Half pipes have been proposed as an inexpensive form of guttering (Hapugoda, 1999) and are used in many areas. The manufacture is relatively simple, and the semi-circular shape is extremely efficient. The cost of these gutters depends on the local cost of PVC pipe, which may be more expensive than an equivalent sheet metal gutter and the opening size at the top is fixed to the standard sizes of pipe available which may not be appropriate. A variant on the half pipe is a full pipe with either a slit is a groove cut into it and mounted over the edge of the roof enclosing the edge. The design is adept at catching the water, however less so at transportation as the gutter can have no slope.

Flexible guttering

The challenge of unusual shaped houses has confounded many gutter designers. The best solution so far appears to be in the area of flexible sheet material. Polythene has been tried, but UV radiation eventually degrades them and they become brittle and fail. Morgan (Morgan, 1998) has experimented with shade cloth (a tarpaulin-like material) in Zimbabwe and developed a bag-like flexible gutter with a nominal slope. The material is connected directly to the roof by wires on top and bottom as with an enclosed gutter.

Mounting

Ad-hoc mounting of vee shaped gutter using wires and roundwood in Ethiopia (Picture: S. Akhter)

Bracket for mounting half round gutter onto eaves in Sri Lanka (Picture: B. Martinson)

Plastic brackets mounting gutter to facia board in Sri Lanka (Picture: B. Martinson)

Mounting gutters to roof in developing countries presents particular problems. The roof edge is very often not straight, facia boards are frequently missing and eaves end at a random distance from the edge of the roof. Any mounting system must account for these deviations and also must allow the gutter slope to be controlled within fairly fine limits.

The usual method of gutter mounting is to use the fascia board usually used to finish the edge of the rafters. Brackets can be mounted to this or nails can simply be put through the top of the gutter with a short length of small pipe as a stand-off. The mounts can be at different heights along the line of the roof to give some adjustment in height, however no adjustment is possible for distance from the roof edge unless packing material is used. The result can be a little hit-and-miss and often requires wider gutter to intercept the water falling from a crooked roof.

The fascia board is often missing so brackets have to be mounted on the top or side of the rafters themselves. The bracket can sometimes be rotated to give height control but the rotation is strongly limited by the rafter width. More often the bracket is mounted parallel to the rafter and projected by varying amounts to adjust both planes simultaneously; so that to achieve a drop the gutter will increasingly project from the building. To combat this the brackets can be bent or individual brackets can be made for each support but this is a time consuming process and can result in the gutters having a varying slope and even points of negative 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 somewhat altering their position.

The roof edge itself is 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. The mounting is also very cheap as only wire is required. The difficulty is in mounting the gutter firmly. Most under-roof systems presently employed use a triangle of wires to tie the gutter under the edge or to a splashguard. This results in a gutter that can be blown from side-to-side which interferes with good water interception (the gutters do however move out of the way of ladders automatically). The gutter is also naturally suspended with its centre below the roof so only half the gutter is available to intercept falling water. The wires themselves are an obstruction when cleaning the gutter, as a brush cannot simply be swept along the length of the gutter. Finally, care must be taken to ensure there are enough tie wires so that the full weight of the water does not damage the roof edge.

2.4. Tanks

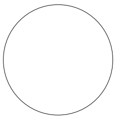
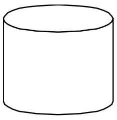
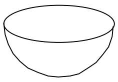
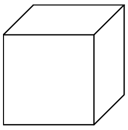
As the rain usually isn't falling when it is needed, some form of storage is required. The size of the storage combined with the water demand and rainfall are responsible for the reliability of the system. The usual form of storage is a tank, which must be relatively watertight (say, leakage of less than 5% of daily abstraction) and hold the required volume. Other requirements include:

- The ability to be able deal with excess input by overflowing in manner which doesn't damage the tank or its foundations
- Exclusion of vermin and mosquitoes
- Exclusion of light (so that algae do not grow and larval growth is inhibited)
- Ventilation to prevent anaerobic decomposition of any washed in matter
- Easy access for cleaning
- Sufficient structural strength to withstand wear and tear, and occasional large natural forces
- No hazards to passers-by or small children
- Not giving the water an unacceptable taste

Geometry

Material economies can be made on water tanks by considering the geometry of surface area to volume. Table 2.4 shows the relationship between various shapes and their respective material economies.

Table 2.4: Idealised tank shapes

Shape	Material Penalty	Notes
Sphere 	**1.0**	• Perfect spheres are only possible underground or partly underground however the shape can be approached using doubly curved structures • Good stress characteristics with little bending stress • All doubly curved structures need great skill or excellent tooling (or both) to manufacture reliably • Only suitable for mouldable materials such as cement and clay or flexible materials such as some textiles and plastic sheeting
Cylinder 	**1.2**	• The most popular shape for water tanks • Hoop Stresses are efficiently accepted, however a fixed joint between the tank wall and base will cause bending and sheer stresses near the joint • Suitable for use with ether mouldable materials or materials which can be bent on one direction (such as metal sheet)
Half Sphere 	**1.3**	• A popular shape for underground tanks as the pit is easy to excavate and it is believed to have good material economies • Requires a large, free standing cover • Underground tanks are simple to make with this shape using mouldable materials
Cube 	**1.4**	• Perfect spheres are only possible underground or partly underground • Bending stresses are high toward the corners • Very simple to construct using familiar house building techniques • Suitable for all materials including bricks and blocks

The aspect ratio can also have an effect on the cost of the tank. As the tank differs from the idealised shape material economies suffer. Figure 2.5 shows this relationship for tanks of constant section such as cylinders and cuboids. As can be seen the material diseconomies are stronger in short, wide tanks than in long thin tanks. This is a distinct advantage, as many users prefer to have tanks with a smaller footprint, as land is often at a premium.

Figure 2.5: Effect of Aspect Ratio on the Material Economies of Tanks of Constant Section

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 some developed countries such as Australia and Germany precast concrete tanks form a large part of the market. The tanks are cast in sizes up to 35m^3 under controlled conditions, delivered to the site by truck and simply installed. 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 reducing 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 developing countries such as Brazil (Szilassy, 1999) and Kenya (Lee & Visscher, 1990) using shuttering with corrugated iron, however the technology has generally proven too expensive to be widely replicated. Precast rings have been used successfully in Bangladesh (Ferdausi & Bolkland, 2000) already being produced in quantity for well lining. This ability to mass produce items gives the technique some promise in the field of tank components such as segmented covers and filter boxes and concrete is often used for ancillary work around tanks such as foundations, drainage and soakaways.

Steel

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

A corrugated steel tank in rural Uganda - note the concrete ring around the bottom repairing leaks
(Picture: D. Rees)

An "Oil" drum 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 ubiquitous steel drum found outside almost every house in East Africa to gigantic 1.5Ml 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. An extremely firm foundation is often not required, as the steel structure will "give" a little to accommodate any settling.

In developing countries problems with corrosion on the bottom of the tank have been observed after about two years service. Building a concrete ring around the base of the tank can repair this, however such failure in the field has limited the steel tank's acceptance and wider application. The problem does not generally appear in tanks built in developed countries as steel tanks are generally either coated with plastic on the inside of the tank (BHP Pty. Ltd., 2000) or lined with a plastic composite bag (Pioneer Tanks Pty. Ltd,).

Oil drums are one of the most widely dispersed water containment stores in the world. However, they have unique problems due to their previous use.

- Most drums now used for containing water have previously contained chemicals, many of which are toxic.
- They have also usually been opened in such a way that they are uncovered and thus present an ideal environment for mosquito breeding and yield low quality water.
- Water extraction can be a problem.

If these problems can be solved inexpensively, then drums form a readily available supply of inexpensive (if small) storage units.

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 GRP form the fastest growing segment of storage provision. They are already popular in developed countries where they compete directly with older technologies such as steel or concrete on a direct price basis. In developing countries, these tanks are generally more expensive by a factor of 3-5 which has slowed their adoption, however this is changing, In Sri Lanka the price penalty of a plastic tank is down to about 1.5-2 and in South Africa they are generally considered cheaper (Houston, 2001)

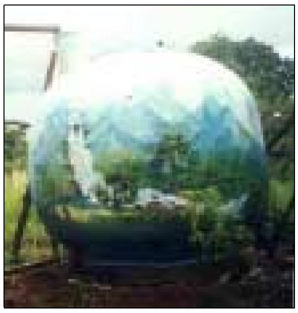
Even in countries where there is a price premium for plastic tanks, they are often employed by water supply organisations, as they are quick to install and are known to work reliably (usually backed by a manufacturers guarantee). Consumers also like the tanks and see them as the most up-to-date method of storing water, however problems of cleaning and the water heating up in the black tanks have been identified.

An application of plastics that is highly cost effective is the use of plastic lining materials with otherwise local techniques. An example of this is the tarpaulin tank originally used by Rwandan refugees in southern Uganda and subsequently improved by ACORD and widely replicated (Rees, 2000). The cost of the tank is roughly ¼ of an equivalent ferrocement tank. The frames of the tanks are, however liable to termite attack and the tarpaulins themselves have failed in service in some areas reportedly also due to termites although this has not been proved out and contrary stories exist.

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 will last indefinitely. The material lends itself to being formed into almost any shape and outside tank construction is used for boat building and even sculpture. It 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.

- 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 0.8-1.5 Mpa before cracking)
- Within reasonable limits, the material behaves like a homogeneous, elastic material

The technique was developed in France in mid 19th century and was initially used for pots and tubs and even boats, (Morgan, 1994) but was transplanted by less labour intensive reinforcement methods. Tank construction with ferrocement has been ongoing since the early 1970s (Watt, 1978) was popularised by its use in Thailand (IDRC, 1986) and has spread to Africa (Nissen-Petersen & Lee, 1990), South America (Gnadlinger, 1999) and Sri Lanka (Hapugoda, 1995) among others. 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 0.4 parts water) onto a steel mesh.

The method of construction involves the plastering of a thin layer of cement mortar (typically 1 part cement to 3 parts sand mixed with about 0.4 parts water) onto a steel mesh. Despite being described as a "low skill" technique, workmanship is strong issue with all ferrocement constructions. The thickness of mortar is often as little as 5mm giving little room for error when covering the mesh. A good former can reduce error and is often the reason behind successful designs. Increasingly though, these formers are being abandoned due to their cost and to gain flexibility in size. The mesh itself is then used as a base to cement on to, but these tanks usually have a consummate increase in wall thickness and thus cost.

The most popular design of ferrocement tank continues to be the straight cylinder. Formers are easy to construct using sheet metal or BRC mesh, and there are usually no foundation problems as the base is wide enough. There can be some problems of cracking at the base if stress concentrations are not accounted for in the design and there have been some reports of cracking at the lid interface. To combat this several designs such as the Sri Lanka "pumpkin" tank (Hapugoda, 1995) have been produced with a rounded shape to break up the sudden junctions.

Even more popular than cylinders, but not technically "ferrocement" is so call "Thai jar", which has been mass-produced in Thailand for about 20 years. There are more than 14 million of these jars throughout Thailand with capacities ranging from 0.5m^3 to 3m^3 (Bradford & Gould, 1992)The jars are manufactured by plastering mortar with no reinforcing onto a mould in the shape of the jar. The moulds are centrally produced to a low cost and the jars are made in reasonable numbers in small workshops(Ariyabadu, 2001).

Another method of employing mass production techniques is to make the tank in sections. This has been applied in India at the Structural Engineering Research Centre (Sharma, 2001) where the tank is made in either full height or half height segments on-site or in a central location. The segments are then shipped out by truck joined together on-site in a single day. The segments themselves 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 (Gnadlinger, 1999) with the segments made on-site. The material cost is similar to same sized ferrocement tanks made on a former but the tanks are quicker to build.

The realm of ferrocement has also seen several attempts to reduce cost by replacing metal reinforcing with other materials such as bamboo and hessian. Although there have been some success stories

Case Study:
Thai jar – consumer level appropriate technology

The 1980s was the Water and Sanitation Decade but by the end of a decade of extended effort and targeted development, most countries were in a similar position to the beginning. Not Thailand, however. By the end of the decade, Thailand could boast almost 100% water-supply coverage. No small part in this was played by the development of rainwater harvesting technologies and particularly the "Thai jar".

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 (Bradford & Gould, 1992) largely through commercial manufacture. The price today is less than US$15 (Ariyabadu, 2001) and the jars are almost universally found in rural homes in northern Thailand and are also to be found in neighbouring countries such as Cambodia where they sell for less than US$10 (Crenn, B., 2001, private correspondence). 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 drop in price is not necessarily "mass manufacture" in the traditional sense as they are often made by part-time farmers in small batch quantities, but in the quality and availability of tooling and in the workshop process. Each jar is made on a mould made of cement bricks, which are coated with mud as a mould release. The moulds themselves are also made locally so a factory may have several. The steel formers for making the moulds, however, are made centrally ensuring tight quality control of the size and shape. The high quality solid mould allows a thin coating of mortar to be applied with excellent quality control resulting in a highly optimised product.

Jar factory with made jars
(Picture: R. Ariyabandu)

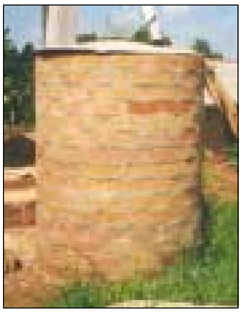
Mould pieces
(Picture: R. Ariyabandu)

Made up mould
(Picture: R. Ariyabandu)

(Sharma & Sen, 2001) there are a number of notable and large-scale failures. In Thailand, over 50,000 bamboo-cement tanks had been built when a study by Vadhanavikkit and Pannachet. (Vadhanavikkit & Pannachet, 1987) revealed that fungi and bacteria were decomposing the bamboo and within a year the strength of the reinforcing had reduced to less than 10% and some 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 1970's 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 (Gould, 1993).

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 building in many developing countries. The materials are found locally and local people prepare the bricks themselves, thus the cost of the bricks is usually low and all monies remain in the local economy. They can be made from a number of different materials such as burned clay, cut stone, soil stabilised with a small amount of cement or even concrete. Unfortunately, while bricks are useful for building work they less well suited to tank construction. As they have a poor strength in tension and so 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 and if the bricks are poorly fitting, such as when making a cylinder of small diameter, they can demand more cement than an equivalent ferrocement tank.

Interlocking bricks, usually using stabilised soil, have been tried in several places including, Thailand (IDRC, 1986) and Uganda (Rees & Thomas, 2000) (New Vision (Kampala), 2001). A machine for making interlocking Mortar blocks is also available (Parry, 2001). Most of these designs interlock vertically relying on sheer between the mortar and block to take the stresses. A more satisfactory solution would be to interlock the block horizontally on top and bottom surfaces, however this does not appear to have been investigated.

Underground or aboveground

The simple gambit of building the tank under the ground is a popular method of cost reduction in tank building. Foundations problems are avoided completely as the tank is immersed in the supporting soil and so very large tanks can be constructed with relative ease. Nissen-Petersen (Nissen-Petersen & Lee, 1990) has developed a $90m^3$ tank in Kenya which has proved popular for schools and public buildings.

Of more interest to the field of VLC, tank building is the property of stable soils to reliably take the force of the water meaning that any cement or render is needed only as a sealant. Thomas and McGeever (Thomas & McGeever, 1997) have made several tanks in West Uganda using a 25mm layer of mortar applied directly to the soil with few reported problems after 5 years service. In Ethiopia, a number of tanks have been made using a similar technique with a soil-cement (Hune, 2001), further reducing the requirement for imported material.

In the northern China, the soil is so stable that people simply dig their houses out of the earth. Here, a bottle shaped store known as a "*shuijao*" has been used for centuries. The ground was simply dug out and mud compacted onto the walls. Recently, the government has been improving these tanks using cement lining for improved water retention (Zhu & Wu, 1995).

Failure of underground tanks can be a problem, leaks are difficult to locate and equally difficult to repair. In a study by Ranasinghe (Ranasinghe, 2001), below ground brick tanks were found to have been holed by tree roots resulting in losses of up to 2.5 litres per day. The other major failure of underground tanks is by the water table raising and empty tanks "floating" out of the ground (Joy, 2001) or simply collapsing under the strain of the outside water (De silva et al., 2001).

Tanks lining the ground with plastics have been tried since the 1970s (Maddocks, 1975), often with little success, however designs such as the Ugandan Tarpaulin tank (Rees,) and the common use of polythene lining for reservoirs and ponds, (Santvoort, 1994) show that the method can be used with careful design. The usual failure modes are tree roots as with other underground tanks, ultraviolet degradation and vermin intrusion. The tanks are, however immune to floatation as they simply flex out of the way. Reports of termites attacking underground plastic sheet tanks are common, however there are equally reports of termites living under the plastic and not damaging it. The matter of UV degradation should be neatly avoided in an underground tank, as given that an appropriate lightproof lid is a requirement for health reasons, the plastic itself should not be exposed to sunlight.

A very inexpensive method of storage is to simply use the groundwater table. In cities such as Delhi, citizens are being encouraged to divert the water from their roofs into the ground to "recharge" the groundwater (Ranade, 2001). As well as generally improving the groundwater level, there is a localised effect whereby the water forms a "mound" under the recharge point creating a nominal private store (although the water will eventually travel outward).

A summary of the advantage and disadvantages of underground and overground storage are shown in Table 2.5.

Table 2.5: Pros and Cons of above ground and underground storage

	Pros	Cons
Above ground	• Allows for easy inspection for cracks or leakage • Water extraction can be by gravity and extraction by tap • Can be raised above ground level to increase water pressure	• Require space • Generally more expensive • More easily damaged • Prone to attack from weather • Failure can be dangerous

	Pros	Cons
Underground	• Surrounding ground gives support allowing lower wall thickness and thus lower costs • More difficult to empty by leaving tap on • Require 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 • If tank is left uncovered animals can fall in contaminating the water • Heavy vehicles driving over a cistern can also cause damage • Cannot be easily drained for cleaning

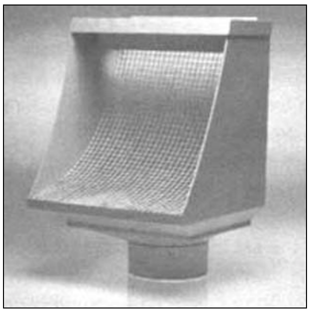
Overall, about 80% of users express a preference for overground tanks despite a cost penalty of 50%.

2.5. Filters and separators

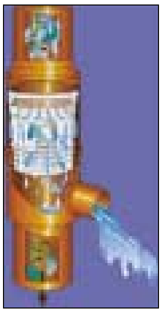
Despite the roof being higher than the ground, dust and other debris can be blown onto it, especially if the roof is near to a roadway. Leaves can also fall onto the roof from nearby trees and flying and climbing animals can defecate upon it. The quality of water can be much improved if this debris is kept out of the system. To accomplish this filters and separators can be added to a rainwater harvesting system at the inlet, outlet or both. Filters simply remove the debris and allow all water to flow; separators remove the debris and wash it away in a portion of the water.

Course leaf filtering

Gutter filter
(Picture: L.B. Plastics, Inc.)



Downpipe top filtering
(Picture: Leafbeater systems Pty. Ltd.)



In-downpipe filter
(Picture: 3P Tecknik GmbH)

Course leaf filter at tank entrance in Sri Lanka
(Picture: B. Martinson)

The first line of defence is a course leaf filter. The filter can be installed anywhere from the gutter to the entrance to the tank. It need not be fine and so no problems should be encountered with flow rate through the filter and the filter itself can be removable for cleaning. The most popular positions are in the gutter, at the beginning of the downpipe, in the downpipe, in the ground before the tank and at the entrance to the tank itself. Of these, the tank entrance is by far the most common in very low cost systems. The pros and cons of each installation are outlined in Table 2.6

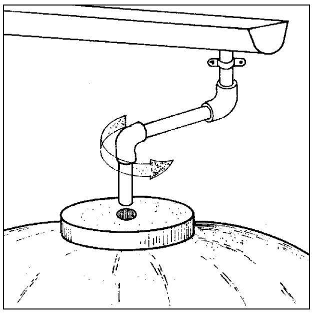
Table 2.6: Pros and cons of leaf filter location

Type	Pros	Cons
In-Gutter	• Prevents leaf build-up in gutter thus; – removes fire hazard – reduces mosquito breeding – avoids cleaning chore	• Can be expensive due to large areas to be covered • Poor installation can; – increase leaf build-up due to leaves catching on filter – make cleaning what isn't filtered more difficult
At downpipe	• Central location minimises filter area • Can be combined with a drop to increase efficiency • Can replace downpipe connection as gutter box • Can be self cleaning (to an extent)	• Difficult to clean due to height • If simply placed into gutter-level downpipe connection can block entire gutter
In Downpipe	• Increase in filter area due to length of downpipe available • Low space use • Wetting requirement means first flush is dumped	• Uses more than 10% of water for self cleaning action • Requires more complex design • Poor design can lead to excessive water loss • Difficult to access for cleaning • Blockages not obvious
In-line (underground)	• Removes mounting problems • Easily accessed for cleaning	• Only useful for underground tanks • Poor design can lead to ingress of stormwater into the tank
At tank entrance	• Simple and inexpensive installation – Can be as simple as a cloth over the tank inlet • Very visible	• Entrance to tank is available to accidental (or deliberate) contamination • Reduces possibility of any further filtration

Whatever location is chosen for the filter, there are several criteria that should be met for good design:

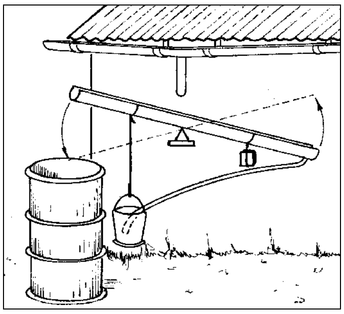
- The filter should be easy to clean or largely self-cleaning
- It should not block easily (if at all) and blockages should be obvious and easy to rectify
- It should not provide an entrance for additional contamination
- The cost should not be out of proportion with the rest of the system – user surveys have shown that people in southern Uganda will only spend about 5% of the cost of the system on filtering, users in Sri Lanka will spend closer to 10%.

First flush diverters



Manual first flush device
(Picture: Lee and Visscher)

Simple downpipe first flush system in Sri Lanka
(Picture:T. Ariyananda)



Seesaw diverter
(Picture: Lee and Visscher)

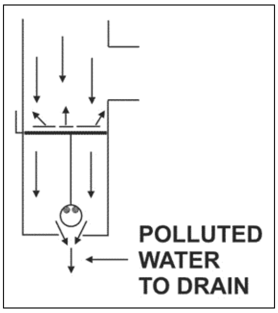


Diagram of "flow-rate" diversion system
(Picture: Saferain Pty. Ltd.)

Contaminants from a roof are usually concentrated in the first run off from the roof. After this runoff has passed and washed the roof the water is considerably safer. The amount to be removed varies and a number of studies have had differing results. Yaziz et al. (1989) found that 0.5mm was sufficient to reduce the faecal coliforms count to zero on two roofs in a Malaysian campus. Coombes et. al (2000) have found that even after 2mm was flushed, there were still significant faecal coliforms in the runoff from a building located close to a bus depot in Australia. Field trials by the DTU in Uganda have shown unacceptable turbidity after 2mm have removed although FC counts were in the WHO "low risk" category. Despite this uncertainty, first flush systems are a popular method of improving the quality of roof runoff prior to storage, particularly in Asian countries.

There are basically four methods of separating the first flush; manual, fixed volume, fixed mass and flow rate. The manual method is the simplest and widely recommended (Lee & Visscher, 1992), (Gould & Nissen-Petersen, 1999), it does, however rely on the user both being home and prepared to go out into the rain to operate the device much reducing its usefulness. The fixed volume method, which relies on the water simply filling a chamber of a set size (usually a length of downpipe) until it overflows is the "automatic" method usually applied in low cost systems. The method can be used either with or without a floating ball seal which helps in reducing mixing between early dirty water and later clean water, however Michaeledes (1987) has found that this mixing is transient. They are also found with either automatic draining over a period of time or require manual draining. Manual draining systems have little to recommend them as if left to drain 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 fixed mass system has also been promoted, mainly in Africa but has met with little success. The devices, usually relying on a mass of water to tip a bucket or seesaw tend to be unreliable and users inevitably disable the system. A newer first flush concept is to use the changes in flow rate over the course of a storm. Stormwater management designers have been using a flow rate model of first-flush for some time to reduce the large land areas required for "volumetric" facilities (Adams, 1998), however recently and Australian company has developed a system whereby flow rate is used for roof runoff. The SafeRain system (Church, 2001) 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).

Fine inlet filtering

Combination sand/gravel filter in Sri Lanka
(Picture: B. Martinson)

Filter media from a large gravel filter in Sri Lanka
(Picture: B. Martinson)

Self cleaning filter from Germany
(Picture: 3P Tecknik)

Finer filtering can remove small sediment which would otherwise either be suspended in the water or settle to the bottom of the tank leaving a sludge. The techniques are well known, employing gravel, sand or fine screens but the needs of rainwater harvesting systems are unique, as in a tropical downpour flow rates can be very high – with short-term peaks of more than 1.5 l s^{-1}. This calls for either very large surface areas or courser screens. A filter consisting of a Ø300mm tube filled with 150mm sand on a bed of 200mm of pebbles has been used in Sri Lanka (Ranatunga, 1999) which copes with all but the very highest peak flows, however the filters were often bypassed or filled with courser material when user saw water overflowing the filter during heavy downpours.

Another problem of fine filters is cleaning. As all water passes through most designs of fine filter, particles become trapped in the filter requiring periodic cleaning. If this is not carried out, the filter will eventually block and simply overflow which has resulted in filters being emptied of media and abandoned. In developed countries self-cleaning filters are available with a fine mesh screen (typically 0.4mm). 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 VLC systems there is usually a significant overflow of water and these types may be viable if suitable filter mesh or cloth is available locally.

In-tank processing

A frequently overlooked feature of rainwater storage is the effect of storage itself. As the water is stored in a quiescent condition, several processes can take place raising the water quality such as sedimentation, floatation and bacterial die-off.

Sedimentation and floatation are the result of differences in density of washed in matter to that of water in the tank. Simply put, sediment tends to be heavier than the water and will settle on the bottom given enough time and can be cleaned out from time-to-time. Vegetable matter is generally lighter and will float to the top and is washed out with overflow water. German systems include special symphonic overflow arrangements to facilitate this (Deltau, 2001)

Typical die-off behavior for microorganisms in water follows the pattern of a short period where numbers remain constant followed by exponential decline in numbers Adverse environmental factors outstrip supportive factors due to removal of organisms from their natural environment. Sometimes there may be a short-term increase in (Droste, 1997). Adverse environmental factors outstrip supportive factors due to removal of organisms from their natural environment. Sometimes there may be a short-term increase in numbers as the microorganisms take up residence. The main factors for the decline are:

- Algae die off from lack of sunlight
- Competition for food increases
- Predation increases reducing the prey micro-organisms and ultimately starving out the predators
- Flocculation and sedimentation remove some bacteria

The level of die off can be calculated using the equation:

$$t = \frac{\ln\left(\frac{C_0}{C}\right)}{k} \qquad (2.2)$$

Where

t is the elapsed time

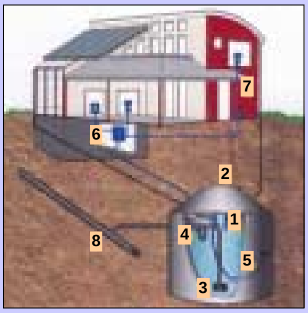
C_0 is the initial bacterial concentration

Case Study:
German DRWH Practice – the "state of the art"

Rainwater harvesting has only been practiced in Germany for about 10 years, however in that time, the state of the art has improved dramatically and systems have undergone a rapid simplification while improving their performance. The principle uses of the water are gardening, clothes washing and toilet flushing but the demands of the consumer and the needs of appliances (e.g. washing machine valves) are such that the quality of water must be high quality, particularly where turbidity is concerned.

The methods used to create high quality water are, however deceptively simple and can easily be adapted to low cost systems. The water is initially washed through a leaf filter and then through a filter with a mesh size of 0.2-1.0mm – smaller filters such as sand filters are not recommended. The filters themselves are often combined into a single removable unit that can be washed in a dishwasher. It is then sent straight on into the tank where it is introduced through a velocity-reducing inlet. The conditions in the tank are kept quiescent allowing the water to shed it's sediment load and for natural die-off to reduce pathogens. Water is removed using a "swimming" intake that removes water from slightly below the top surface where the water is oldest but avoiding floating debris. Floating debris is removed by symphonic overflow outlets and the sediment at the bottom of the tank is cleaned out periodically. The cleaning is done as little as possible as biofilms that develop on the side of the tank and in the sludge greatly enhance the die-off process of pathogens within the tank.

The systems are controlled by a single integrated unit, which does all pumping and maintains a small store of municipal water that is constantly topped up and used when the tank is empty.



Legend
1. Inlet filter
2. Access
3. Calming inlet
4. Syphonic overflow
5. "Swimming" inlet
6. Control centre
7. Dual reticulation system
8. Outlet to sewer

Layout of a typical German RWH system

"Swimming" intake

Calming inlet

C is the concentration at time *t*

k is a constant which depends on local factors such as UV levels, temperature and Ph

In order to take advantage of this effect the water must be kept calm requiring water inflow to be as slow as possible. Water from rainfall is also usually cooler than the ambient water in the tank (Kincaid & Longley, 1989) so water should be introduced from the bottom of the tank while water removal should be from the top, the reverse of the normal practice. Martinson and Lucey carried out a study of various inlet arrangements (Martinson D. B. & Lucey, In Print) and found that radial manifolds were effective in lowering water velocity. Current German practice is to use a downward pointing pipe firing into a large upward pointing inlet (Deltau, 2001).

The residence time in the tank can also be used to introduce more proactive measures to improve water quality. Chlorination is widely recommended as a final sterilisation for rainwater (UNEP, 1998) and methods of introduction as simple as an earthenware pot suspended in the tank have been employed (Pieck, 1985). However generally chlorination is generally not well liked by users ((Fujioka, 1993)) and the chemicals used can be dangerous if misused.

3. SOCIAL AND GENDER FACTORS

Appendix A4 of the DFID Research Contract R7833 Inception Report (posted under 'Incption Report - PDF 400kb' at www.eng.warwick.ac.uk/dtu/rwh/dfid.html) contains a literature review of social and gender issues in RWH.

Rainwater harvesting, despite being an age-old practice in many parts of the world, has been used at the household level only on a limited scale. Many households (h/hs) in the tropics are exposed to abundant (but seasonal) rainfall yet do not have access to an adequate supply of potable water. Historically, critical and widespread water shortages can be attributed to high population growth rates and densities, exacerbated by low disposable h/h incomes (Wehrle, 2001). In this context, suitably harvested rainwater can represent an acceptable new water source and in some areas of extreme water shortage may even serve as the only source of potable water. The extent to which DRWH is able to contribute to overall water needs depends on the disposable income of individual h/hs. Many h/hs are familiar with the basic technology since they practice opportunistic ('informal') RWH during the rainy season, but few progress to permanent RWH with guttering and storage tanks.

One obvious challenge is to develop a RWH technology that is acceptable and affordable by poorer sections of the community. However there appears some wariness of DRWH even where it would appear to offer considerable economic benefits. Research is therefore needed to identify constraints other than just excessive first cost. For example within urban areas high population densities result in there being limited space in dwellings for water storage, there are various possibilities for water contamination, and many tenancies may be too transitory or insecure for householders to invest in any permanent fixtures.

This section focuses on social and gender factors thought likely to influence the adoption and sustained use of DRWH systems at the h/h level. It comprises an extension to the review referred to above and a revision of the key social questions in the light of field experiences in Sri Lanka, Ethiopia and Uganda.

3.1. Update of Inception Phase Literature Review

This review supplements – via additional references – that in Inception Report Appendix A4. It is structured around three core elements of social and gender analysis in terms of DRWH viz. (i) activity analysis; (ii) access to, and control over resources and benefits; and (iii) priorities, constraints and opportunities. In addition to examining the three elements from a gender perspective, where appropriate a poverty perspective has been included.

According to latest estimates, there are today about 1 billion people without an adequate supply of water (JMP, 2000). International development targets are now being reset, possibly more realistically than ever before, to address this water crisis. To that end, DRWH is a promising option among various low-cost, simple-technology alternatives. Of particular relevance to DRWH adoption is the evidence that many tropical households use multiple sources of water to meet their household water needs. Thus we may employ a concept of water security that does not treat single-sourcing as axiomatic. Rainwater plays a vital role in such a multiple water system. Water security has been reported to improve for h/hs with some form of rainwater harvesting systems because

- water availability is increased (with one additional water source available);

- it improves access (both physical and timely) to water, e.g. replaces travelling long distances to a river and still not getting good quality water (Hartung and Mukankusi, 2001).

The gendered nature of providing water for the household is widespread throughout many African and Asian societies (White *et al.*, 1972; Barot, 1995). The fetching and use of water for domestic use is a task predominantly performed by women, perhaps with the assistance of children. However, as with all gender roles, those connected with water vary over time and between communities. Thus patterns may change if the technology alters, or access to the water source improves, or the activity is income generating rather than for domestic use (eg water vending). One cultural barrier inhibiting male participation has been the tradition of transporting water in vessels on the head; a task which only women and girls can do without a loss of dignity in parts of East Africa (Sutton, 2000). Changing the collection container from buckets, bowls and clay jars to jerrycans, has dramatically increased the participation of men and boys in water collection in recent years. Jerrycans can easily be transported by bicycle, wheelbarrow, donkey or ox cart; and men and boys tend to be in charge of mechanised and animal transport.

Women enjoy the use of a wide range of household resources associated with their day-to-day activities such as hoes, water containers, cooking utensils, hand operated mills, and the labour of other household members. However, men dominate access to more substantial and productive assets (such as oxen, ox carts, bicycles and cash crops) as well as external services (sources of information, training and credit). Similarly men exercise most control, determining when and how resources should be used and by whom, and how income should be spent. Expenditure priorities often differ between men and women, with water supplies lying low on an average man's list (Simonds, 1994).

Customs and beliefs about the storage and use of water can act as a barrier to new sources of water and storage methods. In SW Uganda villagers doubted the safety of water being stored in jars which were kept outside since they feared being poisoned; they also disliked the taste of water stored in cement containers (Anguria *et al*., 1994). Bajracharya and Deverill (2001) from their experience in rural Nepal, have emphasised that any people-oriented approach must be practical, not just in terms of technology, the environment and local capacities, but also in terms of being compatible with local culture. Another major constraint to adopting new technologies in rural areas is limited access to cash. When households are able to sell only a proportion of their crops for cash, there are many competing demands on the use of household money, such as food, school fees, medical expenses and clothing.

Water and sanitation projects have great potential for addressing strategic as well as practical needs of women (Smout and Parry-Jones, 1999). As the key player responsible for collecting and using water, it is appropriate that women are trained in the maintenance of facilities and their appropriate use (Dewa, 1999; Omua and Wanyonyi, 1999). Thus, not only do improved water supplies release women's time from fetching water (which may then be used for other activities) but also present opportunities for women to utilise existing knowledge and develop new skills in operating, maintaining and managing water supply systems. As the primary water carriers, managers, end-users and family health educators, it is crucial that women's perspective is heard for developing and implementing any water augmenting initiative (Ball 2001). The benefits to their lives along with the drawbacks that have been observed must be considered within the planning and implementation of a project which affects such a major portion of their life.

Efforts can be made to facilitate the participation of women. In the Mahapani Project in Maharashtra State of India, for example, women were favoured in management roles and opportunities for employment or skills enhancement in order to increase their contribution to decision making, and to improve their public status (Baldwin *et al.*, 1999). SEWA (Self Employed Women's Association) is a trade union of poor women working in the informal sector of Indian economy. SEWA has developed an integrated approach of women, water and work, which it has taken up as its millennium water campaign (Misra, 2001). Their campaign statements interestingly include 'we want to collect and save rainwater'. SEWA members believe that women, water and work cannot be separated because the majority of water users are women, and they also make up a large proportion of workforce in India. Therefore, SEWA has targeted the integration of women, water and work to enhance women's capacity and effectiveness to fight exclusion and poverty. As part of their water campaign, they have established various forms of RWH systems.

Benefits for participatory women's groups evolved around DRWH are manifold in terms of decreasing women and children labour, saving time and energy, increasing agricultural production and improved household hygiene and sanitation (Rwabambari, 2001). Lessons learnt from a pilot project in SW Uganda indicate that there is need to re-examine the current approaches in order to reach poor people. Addressing people's needs requires involving them in the process of project preparation, decision-making, technology choice, implementation, monitoring and evaluation. This is a pre-requisite to sustainability, replicability and proper management of a project. In addition, subsidies to these RWH groups have a positive role to play. In turn, by recognising and utilising women's potential as agents of change and uplifting their social status though their involvement with water and sanitation improvements, such initiatives can become entry points for other development activities. Experience in a rainwater harvesting project in Zimbabwe demonstrated that not only did women grow in self confidence and self esteem through running village water committees but also that men's attitude to their capabilities changed (Dewa, 1999). As a result, women's contribution to decision making and community affairs increased. Moreover, through the new opportunities for women to meet regularly, they interacted in an informative manner, exchanging ideas and learning from each other. The success of RWH programmes depend on the interest, enthusiasm and active support of the users (Ferdausi and Bolkland 2000). The programme can only be implemented when people have the willingness to use the system. Failure to involve the community in the planning, design, siting and construction of the system is commonly a cause of failure.

Mbugua (1999) has described 10 years of RWH activities in Kenya, which were used as a catalyst for development to alleviate poverty and to promote economic and social well-being of rural people. Pinfold (1995) has reported on WaterAid's experience of applying different participatory tools [e.g. community mapping, seasonal calendar, gender analysis etc.] for designing, implementing and monitoring water supply and sanitation projects in Asia and Africa. He admitted that there is a lot more to making water supply and sanitation activities sustainable than just applying these participatory techniques. However, these techniques are a distinct improvement over traditional, top-down methods previously employed. Furthermore, they give a practical focus for training which makes it much easier to train people to be more participatory in their approach to communities.

3.2. Key socio-gender questions needing answers

A list of 'Key Questions' was included as Appendix B of the R7833 Inception Report. The socio-gender questions in that list have been refined by discussion and field observation into the following list.

- How are any benefits from DRWH distributed between different household members?

- Does the nature of DRWH exclude particular sections of a community from participating in its benefits, and are they disadvantaged by others adopting DRWH?
- What are the most significant socio-economic characteristics that influence the adoption of DRWH at household level?
- What effect does h/h income have on the adoption of a DRWHS?
- What bearing does landholding/tenancy have on the adoption of DRWH?
- Is it socially practical to employ the roofs of communal buildings like schools/churches to supply water to neighbouring households?
- What major changes in family relations and gender roles are likely to arise from the adoption of DRWH for the bulk of a household's water supply?
- How might people be motivated towards using rainwater for drinking and cooking?
- What could be done to utilise locally available building materials with a view to enhancing people's confidence and ease in installing DRWH?
- How could the experience of those h/hs having DRWH systems best be communicated to those not having any such system?
- Does the introduction of DRWH increase or decrease income-generating opportunities for the poor?

4. SOCIAL AND GENDER ANALYSIS: FINDINGS FROM THE INITIAL SURVEY

An Initial Survey of small sample size was undertaken in all three partner countries in January and February 2001. Its purpose was twofold:

- to identify social and gender issues that would be worthy of more in-depth analysis, and
- to establish the suitability of various Rapid Appraisal techniques for gathering information about water collection and use from social and gender perspectives.

Two rural locations were studied in Uganda, three urban locations in Ethiopia and one urban community in Sri Lanka. Individual interviews were conducted in 22 households.

The findings from the social and gender analysis are relevant to the DRWH project in three principal areas: to the engineering component, in terms of the design and construction of DRWH systems; to aspects of project management in terms of disseminating DRWH systems, likely rates of uptake and their sustained use; and as development practitioners for addressing issues of poverty and gender disparities.

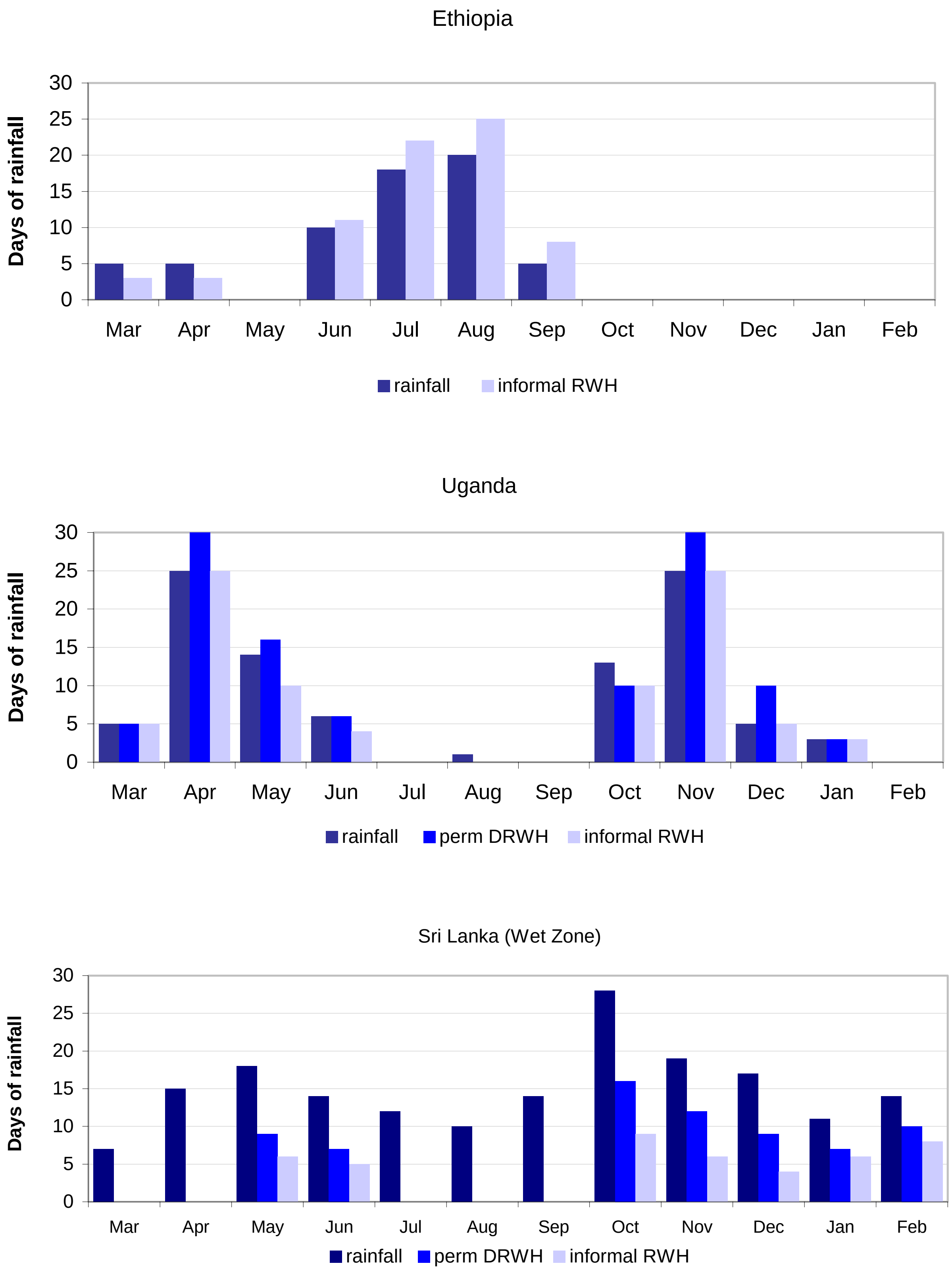
The findings are presented in six sections, covering rainfall patterns, water collection and water uses, communities' experiences and interest in rainwater harvesting to date, gender analysis and poverty analysis of water collection and rainwater harvesting. The final section discusses the implications of the gender and poverty analysis for the focus of the research to be conducted during the main study, as well as the manner in which this research will be conducted.

4.1. Rainfall and Patterns of Water Collection

In Ethiopia, the rainfall is unimodal. The survey sites in Sri Lanka and Uganda experience bimodal rainfall but the distribution and intensity of rain (in terms of the number of days on which it rains each month) varies (Figure 1). The main rains in Ethiopia fall from June to September, followed by five dry months. Uganda experiences two rainy seasons of similar duration and intensity: March to June and October to January, with two or three dry months in between. In the Wet Zone in Sri Lanka rain falls throughout the year, with peaks in October to December, and April to May.

The rainfall pattern has a direct bearing on the use of rainwater by season. The use of rainwater would appear to be most widespread in Uganda, where both permanent and informal systems are used throughout the rainy seasons. Among the survey communities in Ethiopia, where there is no use of permanent DRWH, informal RWH is most significant during the heavy rains. In Sri Lanka, although rain falls throughout the year in the Wet Zone, rainwater harvesting is also most popular during the months in which the rainfall is heaviest.

Figure 4.1: Rainfall Distribution in Survey Communities



4.2. Water Sources and Uses

Water sources in rural communities

During the wet season in Uganda (Orukinga Valley, S Mbarara District), rock tanks are the main water sources; they are located within 1 km of the houses that use them and the return journey time is completed within 1 hour 45 minutes. During the dry season, people have to travel much further to a spring or lake, 4 km and 11 km respectively, with a return journey time of between 5 to 7 hours over fairly steep/steep terrain covered in loose stones. There are many hazards associated with collecting water from the springs and lake, including attacks by wild animals, sharing the water source with livestock, falls, and personal assaults. All water sources are owned in common and no charges are levied.

Water sources in urban communities

All three communities surveyed in Ethiopia (Addis Ababa) have access to three water sources: standpipes (from boreholes) are used throughout the year, the river is used during the light rains (February to May) and rainwater is used during the heavy rains (July to September). The standpipes are very close to the homes (200 – 300m) and travelling time is no more than 15 minutes. The rivers are 2 to 6 km away from the homes, the terrain is steep and muddy in the wet season, and journeys take up to 1 hour 45 minutes one way. Falls and road accidents are the principal hazards faced en route to the river.

Queuing times at the standpipes in Ethiopia varies considerable between seasons and communities. In one community, queuing takes four days during the dry season; to minimise conflicts a numbering system has been introduced to mark the position of pots and jerrycans in the queue. None of the sources have experienced pollution. All standpipes are under the administration of the town council and a charge of between US $ 0.05 to 0.1 per jerrycan is levied.

In Sri Lanka, the surveyed community has access to three tube wells throughout the year and two dug wells which are used in all but the driest month (August). Travelling time to the water sources varies from 10 to 15 minutes over flat land and short distances (350m), up to 25 minutes when the gradients are steeper and the distance slightly further (500 m). Falls and road accidents are hazards associated with two of the sources.

Queuing times in Sri Lanka vary from 30 minutes during the wet season at any of the sources, to between one and two hours during the dry season at the tube wells. Whilst the tube wells are more reliable throughout the whole year, the dug wells are more reliable during the times of the year when they are in use. None of the sources have experienced pollution. All are under common ownership and no charges are levied.

Preferences for Water Sources

Communities use a range of criteria to determine their preferences for water sources (see Table 4.1); proximity, accessibility, and quality of the water are the most important. The Ugandan community is also concerned about the risk of accidents (such as attacks by wild animals or assault or abuse) and the physical appearance of the water (turbidity) whilst the Sri Lankan community is interested in the quantity of water available. Water charges are only cited by the Ethiopian communities, where they are levied at standpipes.

Table 4.1: Criteria Used to Determine Preferences for Water Sources

Country	Preferences		
	First	Second	Third
Ethiopia - urban	**Bore hole:** safest water quality (good for drinking and cooking), reasonably close and accessible to community but user cost levied	**Rainwater:** closest to the home and very accessible, no cost, soft water (minimises use of soap)	**River:** least attractive on all counts (quality, distance and accessibility) but useful when the public system fails
Uganda - rural	**Rock tank (wet season):** closest to community along a good path with least risk of accidents, best taste (not hard, not mineralised) but poor physical appearance (turbidity) **Spring (dry season):** closer to community than lake but poorest quality water (taste), very steep gradient with loose stones	**Lake (dry season):** least popular because furthest from community and highest risk of accidents en route, fairly steep terrain with loose stones; but best physical appearance of water	**Rainwater:** Only recently has RWH reached the plateau village surveyed
Sri Lanka – urban	**Dug well:** short distance, good quantity, good quality, reasonable access	**Tube well:** average distance, quantity and quality but least accessible	**Rain water:** closest to home, easiest access but poorest quality and small quantity

The attractions of rainwater are its proximity to the home and accessibility. Moreover, for the Ethiopians who have to pay for collecting water from other sources, they value the fact that rainwater is available at no charge. Whilst the Ethiopians also appreciate the soft quality of rainwater, the Sri Lankans rank rainwater as the lowest quality and is available only in small quantities.

Water Vendors

Vendors are most widely used in Uganda and Ethiopia. The majority of Ugandan households use water vendors during the dry season (June to September) when it is tiring to walk long distances to fetch water, or when water is needed urgently. Purchases may take place daily during severe dry periods. Prices may double during this time, from 250/- to 500/- per 20 litre jerrycan (from US¢ 0.14 to ¢ 0.28 per litre). Vendors source their water either from their own water storage tanks, or collect it from the lake or spring by bicycle.

Most of the Ethiopian households (90%) rely upon water vendors throughout the year for a variety of reasons, such as scarcity of supplies at public fountains or other water points, failure of water supply systems, avoiding queues and saving time. Only two Ugandan and one Ethiopian households did not purchase water from vendors on the grounds that it is expensive.

In contrast, water vendors are not widely used in Sri Lankan households unless there are many people staying in the house and it is difficult to collect sufficient water.

Storage of Rainwater

Storage capacity varies according to the nature of the rainwater harvesting system. In households with permanent DRWH, storage capacities are substantial and the duration of rainwater use extensive: 6000 litre ferrocement tank: 245 days (Uganda); 40 m^3 stone masonry tank: 190 days (Uganda; this person also sells water to others in the village); and 1200 litre tank: rainy season plus one month (Sri Lanka).

Non-permanent systems are characterised by much smaller storage capacities, with an average of 150 litres per household.

Storage of other water

The majority of households surveyed (73% total) do not store water outside the rainy season. The main reasons given include:

- the volume of water collected in one day is only sufficient to meet the immediate needs for that day (this response is independent of household size) (Uganda)
- non rainwater is highly mineralised and not worth storing (Uganda)
- insufficient storage containers
- the water source is close to the house (Sri Lanka) or the house has a piped supply (Ethiopia)
- daily water quota from the borehole (50 litres) is too small to permit storage (Ethiopia).

A few households store water overnight throughout the year to cover activities which take place in the early morning and require water (Uganda), or for holidays and special occasions (Ethiopia). In Sri Lanka two households store water regularly for two to three days, using 200 litre barrels.

Storage facilities

Most urban households would prefer to store one large quantity of water (1000 litres) outside the house and above the ground. The exceptions come from Sri Lanka: one household would prefer to store small quantities and another prefers a one metre diameter pit. Only one tenant from Ethiopia indicated that it would not be possible to construct a store because of their tenure status; the other two tenant households did not raise this point.

Water Collection

The volume of water collected per household varies with:

- season
- family size
- health of the people involved in water collection
- other demands on water collectors' time (e.g. working in the garden)
- distance to the water source
- amount of water available at the source
- availability of water collection containers
- size of storage containers in the home
- money available to purchase water (Ethiopia)
- activities taking place in the home (cooking, cleaning etc)
- holidays

Nearly all households have to fetch at least some water every day, even during the wet season, including all those with no or limited storage capacity. However, even in households with significant storage capacities, daily water collection is necessary if rainwater is used selectively. In Sri Lanka, for example, the households surveyed only use rainwater for sanitary purposes whereas rainwater is used much more extensively in Uganda and Ethiopia (see section 2.6 below). In Ethiopia, households substitute rainwater for water from the standpipes and collect less during the wet season (Table 4.2). In Sri Lanka water consumption also rises during the wet season but this is achieved by collecting more water from the wells.

Table 4.2: Volumes of Water Fetched and Used Each Day

Per household	Ethiopia		Sri Lanka	
	Wet season	Dry season	Wet season	Dry season
Total volume of water fetched/day	80 litres	100 litres	135 litres	90 litres
Total volume of water used/day	125 litres	100 litres	135 litres	90 litres

During the rainy season some households are in a position that they do not need to collect water every day. These range from one household with a piped water supply (Ethiopia), one with permanent DRWH and a 6000 litre tank (Uganda), two with a storage capacity of 160–180 litres, to one household with only 50 litres storage. The last, an Ethiopian household headed by an elderly woman, is also constrained in purchasing water by monetary considerations.

Water Use

The amount of water used in the home varies by season, with up to 50% more water being used during the wet season (from a household average of 90 to 100 litres per day in the dry season, to 125 to 135 litres in the wet season) (see Table 2). Factors, other than season, influencing the amount of water used include:

- the number of people in the house on the day (for drinking, eating and sanitation)
- the presence of sick or elderly people
- the number of infants (more clothes to be washed)
- cooking specific foods or drinks (for example, baking *injera* and preparing *tela* in Ethiopia)
- religious observance (e.g. during Muslim prayers in Ethiopia).

All households consider drinking and cooking to be the most important use of water. These activities also consume considerable volumes of water. Washing dishes is also important but fairly light on water use. Other activities which are water intensive often take place intermittently and are performed at the water source, such as bathing, washing clothes and watering livestock.

The use of rainwater differs considerably between the countries (Table 4.3). The most popular uses of rainwater in Uganda are for cooking, drinking and washing clothes, whilst in Ethiopia rainwater is used most frequently for washing clothes and dishes. Amongst the sample interviewed in Sri Lanka the only use noted for rainwater is for sanitation purposes. However, in other parts of the country rainwater is also used for other purposes.

Table 4.3: Uses of Rainwater (% of respondents using rainwater)

Activity	Ethiopia	Uganda	Sri Lanka
Cooking	44%	100%	-
Drinking	22%	100%	-
Washing dishes	56%	60%	-
Washing clothes	78%	100%	-
Sanitation	-	-	100%
Bathing	11%	40%	-
Cleaning house	22%	-	-
Total	100% = 9 h/h	100% = 5 h/h	100% = 3 h/h

Coping with Water Shortages

All households experience water shortages during the dry season when traditional sources become depleted. In addition, shortages are experienced in Ethiopia when the public water supply system fails or the slow sand filtration unit is changed.

Households respond by changing their water collection habits. They switch to alternative (usually more distant) sources, collecting water from rivers and small pits adjacent to streams (Ethiopia), purchasing water from vendors (Ethiopia and Uganda), begging from neighbours with tanks (Uganda) or storing water. More household members (such as husbands and the elderly) assist with water collection (Uganda).

Households also respond by using water more economically, prioritising their uses for drinking and cooking purposes. Some activities may be omitted during the dry season (such as cleaning the house, washing clothes and bathing) and any stored water is strictly rationed (Uganda).

4.3. Experiences of Domestic Rainwater Harvesting

About 14% of all the sampled households had already installed a permanent DRWHS (2 in Uganda and 1 in Sri Lanka, but none in Ethiopia). Among the remaining 86%, 27% of the households have neither considered, nor would be interested in having a DRWHS. This reluctance has been traced largely in Ethiopian households, while none of the Ugandan households have expressed this attitude. Another 27% have not yet considered but would be interested in having a DRWHS. Encouraging enough is the fact that the highest proportion (32%) of households have actually thought of and would be interested in a permanent DRWHS. About 70% of them are Ugandan and the remaining are Ethiopian. The following sub-sections discuss these issues in greater detail.

Households with Permanent DRWHS

All the households having a permanent DRWHS are MHHs. They have expressed their clear contentment in having the system, both as an occasional main or only source of water for household uses, and also as a complementary source at other times. The largest tank was found in Uganda (40 m^3), established back in 1993. The other Ugandan tank was also of some considerable size (6 m^3), established recently in 2000. The Sri Lankan tank encountered in the inception phase survey was relatively much smaller in size (1.2 m^3). Water holes and rock tanks were the alternative water sources for the Ugandan households, while the Sri Lankan DRWH household relied upon dug well or tubewell besides the tank.

Other Households

The opinions of householders not having permanent DRWHS were also explored. In Uganda, there was no household who has neither thought of, nor was interested in a permanent DRWHS. One household expressed interest in adopting permanent DRWHS, though he has not thought of it earlier. It was a MHH, the head being of middle age (34 years), having a family of 6, and doing farming for livelihood. He did not thought of a DRWHS because his house has got an unsuitable (soft) roof, and he did not have the money either to improve the house, or to install a DRWHS. The other Ugandan households (50% of the Ugandan sample) not having any permanent DRWHS, have actually thought of DRWHS and would be interested in adopting a system. Most of them are MHHs, middle aged farmers. Their family size varied from small (4 members) to very large (14 members). There was one young (24 years) FHH with a family of 5. The major reason for their not having a system is lack of money.

Half of the Ethiopian sampled households have neither thought of, nor are interested in a DRWHS. The FHHs are headed by elderly housewives. One MHH is headed by an elderly daily labourer. All of them have expressed the lack of financial resources as their cause of aloofness from DRWH. The other MHH was headed by a middle-aged merchant, having private water connection and thus feeling no need or interest of DRWH. 30% the sampled Ethiopian households had no permanent DRWHS, but would be interested to have one. Two were FHH and the other was a MHH. One female was a young cashier and the other was an elderly housewife. The male's occupation could not be identified. One Sri Lankan household has neither considered, nor is concerned in a DRWHS. It was an elderly FHH of two. Other two Sri Lankan households have not thought of a DRWHS but would like to adopt the system. Both are MHH. One is a vendor supporting a family of four and the other one is a mechanic having a family of six

The issues that were in the non-DRWH households' mind were the cost of the materials and labour, source of financial and technical support and possibility of joining a credit scheme. The factors that they thought as important before introducing DRWHS include: type and size of one's house, roof catchment size, material and labour requirement, household water demand and thence tank size and location of tank (Uganda); preparing a place for construction of tank; changing the catchment area, i.e., the roof; arranging materials for construction of the system and saving money for construction of DRWHS (Ethiopia). The Sri Lankan households have not expressed any concerns in this regard.

These households have expressed their expected benefits out of a DRWHS as:

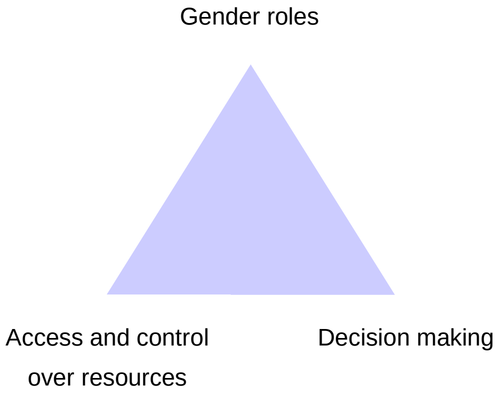
- saving the burden of walking long distance for carrying water;
- improved quality and quantity of water at doorstep;
- reduced risk of accidents, assaults and abuse for the family;
- money used for buying water can be diverted to other uses;
- reduced expense on medical grounds;
- solution to the problem of water shortage;
- get additional water for household use;
- save time in fetching water;
- improve the overall quality of life.

They would utilize the time saved by using DRWHS in diverse productive activities including, attending village and other meetings; getting involved in leisure activities like sports; devoting more time to study.

4.4. Gender Analysis

This section reviews issues associated with water collection from a gender perspective. It is structured around three core features of gender analysis (Figure 4.2). The section concludes with an overview of likes and dislikes associated with collecting water.

Figure 4.2: Framework for Gender Analysis



Gender Roles

The nature of the task of collecting water is time consuming, occurs on a daily basis, and fragments the use of people's time (several journeys are made each day). It is physically demanding, particularly on the return journey, and becomes more burdensome during the dry season.

Women and girls usually perform the task of fetching water. However, their relative contribution, and that of men and boys, varies between cultures, water sources and season. In an urban community in Ethiopia, the task is evenly divided between women and girls (each accounting for 40 - 50% of collection activities), with men and boys participating to a small extent (10%) (Table 4.4). Between one and half to two hours are spent each day in fetching water, with half of that time spent queuing at the standpipe (Table 4.5). All journeys are on foot.

Table 4.4: Fetching Water (% of people collecting water from each source)

Performance of task	Ethiopia	Uganda		Sri Lanka
		Wet season	Dry season	
Women	40%	80%	37%	80%
Girls	45%	15%	4%	10%
Men	5%	1%	25%	5%
Boys	5%	1%	4%	5%
Water vendors	5%	3%	30%	-

Table 4.5: Daily Activities Associated with Fetching Water

Per household	Ethiopia		Sri Lanka	
	Wet season	Dry season	Wet season	Dry season
Number of journeys/day	2	2	3	3
Total travel time/day	1 hour	1 hour	1.5 hours	1.5 hours
Total queuing time/day	0.5 hours	1 hour	1.5 hours	3.5 hours
Total time spent fetching water/day	1.5 hours	2 hours	3 hours	5 hours

In the urban community in Sri Lanka, women bear the burden of water collection (responsible for up to 80% of total collection), with some support from girls (10%) and the balance from men and boys. The time burden of water collection is significant, with up to five hours spent collecting water in the dry season; much of that time is consumed by queuing at tube wells. Women and girls may travel on foot or by bus; men and boys may also use bicycles or motorcycles.

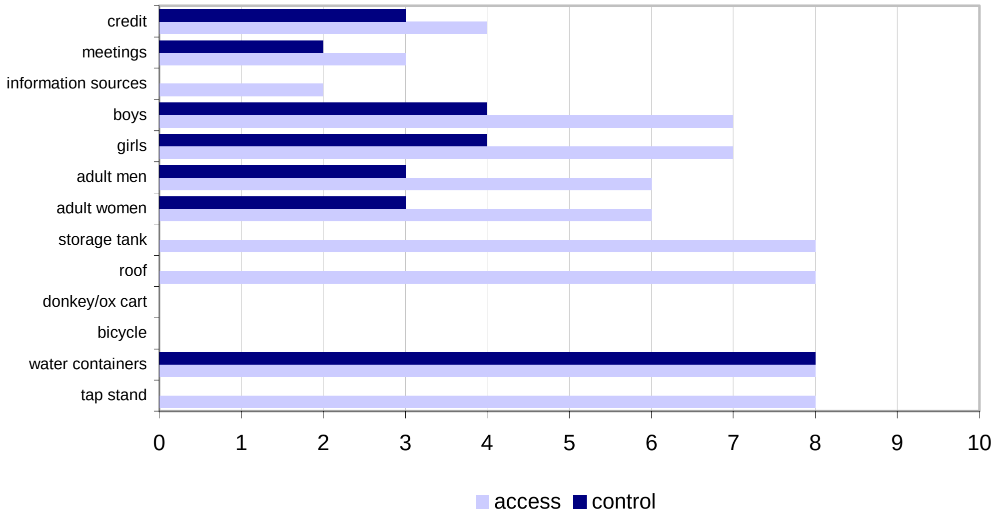
Men are most active in collecting water in the rural community in Uganda: they assist with fetching water from distant water sources used during the dry season (lake or spring) (accounting for 25% of water collection activities). Nevertheless, women still account for over one third of water collection activities from these sources. These sources are also important for water vendors. Children are not very involved with collecting water from distant sources. During the wet season when water is collected from rock tanks close to the community, women are the principal carriers (80%), along with girls (15%); there is almost no contribution from men and boys. Women and girls usually travel on foot. Men, including vendors, use bicycles when the terrain permits; boys either walk or cycle.

Access and Control over Resources

The resource base of women and men differ significantly, in terms of the resources they are able to use (access) and those which they control (that is, with full authority to make decisions about the use of a resource). These points are illustrated in Diagrams 3 and 4, demonstrating differences between women's and men's access and control over resources associated with water collection from a community in Ethiopia.

Women typically enjoy high levels of use of resources associated with water collection, such as tap stands, water containers, roofs and storage tanks (Figure 4.3). They also have good access to labour to assist with water collection, particularly girls and boys. However, they have no access to any means of transport, such as bicycles or animal drawn carts. Similarly they have very limited access to sources of information, meetings and credit. In contrast with their high levels of access over essential resources, women have almost no control over these assets, with the exception of water containers.

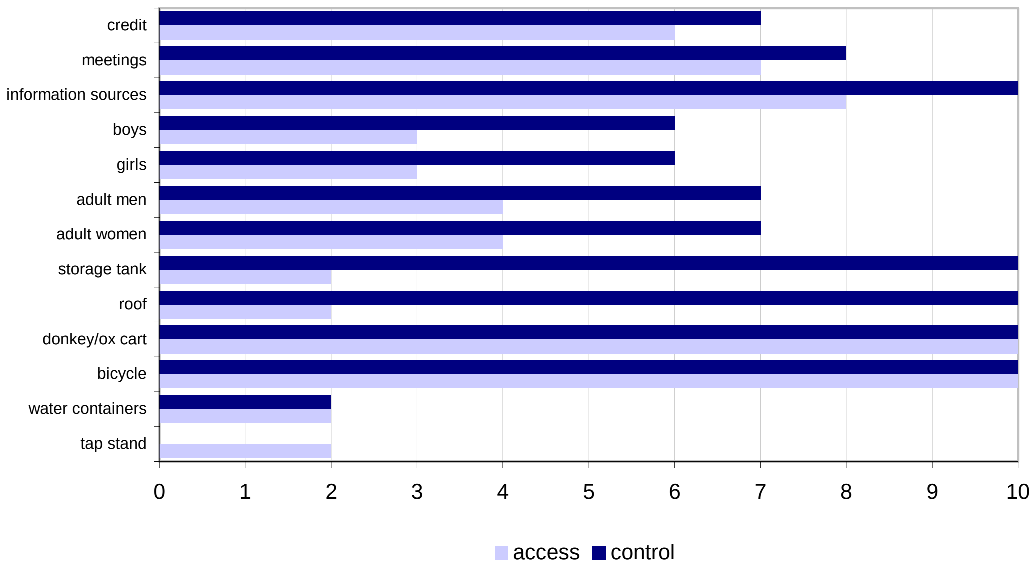
Figure 4.3: Women's Access and Control over Resources, Ethiopia



NB A maximum of 10 points was allocated between women and men to represent their relative access to, and control over, each resource listed. A score of 10 for access indicates that that person has sole access to a particular resource, whereas a score of 5:5 would indicate women and men enjoy equal access. A similar procedure is adopted with regards to control.

Men are resource-rich, dominating the control of nearly all resources available at the household level (Figure 4.4).

Diagram 4.4: Men's Access and Control over Resources, Ethiopia



Decision Making

Women are usually responsible for deciding which source of water to use, how much water to collect, and how to cope during periods of water shortage. A few households in Uganda indicated that the male head of the household makes these decisions and another indicated the selection of the water source is a joint decision between husband and wife.

Even though women play the principal role in the day to day decisions regarding water, men usually control the decision to introduce permanent DRWH systems into their household. However, once installed, wives usually have responsibility for the system. The exception is female headed households where women take all these decisions.

Likes and Dislikes of Fetching Water

All respondents noted at least one dislike associated with fetching water, in particular the time consumed in this activity which could be put to other uses (Table 4.6). All Ugandan households dislike the long distance to the water source which is tiring, particularly when carrying water; many are also concerned about the risk of accidents (such as children drowning in the well, children developing bad habits from others, women and girls being raped, and attacks by snakes and other wild animals). In Ethiopia concern focuses around the long queues at the standpipes which sometimes result in conflicts and queue jumping. In Sri Lanka, people dislike the time they spend fetching water and carrying heavy loads.

Three quarters of the respondents were unable to note any reasons why they liked collecting water. However, a few enjoyed socialising with their friends at the water source, as well as the opportunity to exchange experiences and share ideas. It is relevant to note that this response may be influenced by the sex of the respondent; female headed households were more likely to record some positive aspects of water collection than male respondents. Hence this question should be addressed to those people responsible for collecting water, not necessarily the head of the household (who is usually male and may not have direct experience of water collection).

Table 4.6: Likes and Dislikes of Fetching Water

Likes	Dislikes
• socialising with others, sharing experiences • unlimited access to water from natural sources (no rationing)	• tiring due to distance, terrain and weight of water • waste of time due to long distance and queuing (particularly in dry season) • less time for other productive activities • waiting a long time when the standpipe tap attendant is late • risk of assault, rape, abuse, accidents • fear of wild animals (snakes rampant in dry season) • risk of children drowning • children develop bad habits from mixing with others • theft of containers • limited number of containers and carriers (bicycles) • conflicts if the water is scarce

4.5. Poverty Analysis

There are marked associations between socio economic characteristics of the household and the practice of DRWH. An example from a rural Ugandan community is presented in Table 4.7. Households in the community are typically involved in commercial banana farming, owning several cattle and a range of household assets. Only 6% of the have permanent DRWH systems. Whilst they do not participate a lot in community activities, they regularly attend meetings and training courses, belong to groups and enjoy good access to credit. Both husband and wife have completed upper primary school.

At the other extreme, households with non-permanent roofs usually farm on a very small scale, growing bananas and beans for subsistence purposes. Their sole income source is subsistence agriculture, although some of these households do receive remittances from family members living elsewhere. They have very few assets and do not own any water storage containers. Whilst these households have a high degree of participation in community activities, they are under-represented amongst groups and on committees, have no access to information sources and extremely limited access to credit. Adults in the household have attained minimal standards of education.

There is little association between female-headed households (FHH) and use of non-permanent RWH systems; however, there are no FHH amongst those households with permanent DRWH systems.

The most marked association would appear to be between those households with impervious roofs and those without, rather than those with permanent DRWH and those practising opportunistic rainwater harvesting.

Table 4.7: Socio Economic Characteristics of Households and the Practising of DRWH, Uganda

Characteristics	Households with permanent DRWH	Households with hard roofs but no permanent RWH system	Households with soft roofs
Number of people living in house	10	6	10
Number of children	8	4	6
Main economic activities (farm/off farm)	Fairly large commercial farm (bananas)	Subsistence farm (bananas, vegetables)	Very small subsistence farm (bananas, beans)
Number of livestock	5 cattle	A few	None
Income sources – men	Cultivation, livestock, local brew	Cultivation, livestock, local brew	Cultivation
Income sources - women	Cultivation, local brew	Cultivation, saloon, local brew	Cultivation
Remittances	No	No	Yes
Type of house (materials of floor, walls, roof)	Mud or cement floor, brick walls, iron sheets	Mud or cement floor, mud and poles walls/ bricks, iron sheets	Mud floor, mud and poles walls, thatch roof (grass or banana)
House ownership	Yes	Yes	Yes
Assets in household (radio, bicycle, etc)	Common	Rare	Very rare
Water containers	Permanent cement tank	Clay pots; barrels - rare	None
Education of adult male	Upper primary	Upper primary	Mid primary
Education of adult female	Upper primary	Upper primary or lower secondary	Lower primary
Participation in community activities	Average	Very high	Very high
Attendance at meetings and training	High	High	Average
Membership of groups and committees	High	High	Minimal
Contact with information sources	Average	Average	Nil
Use of credit	Good access	Limited access	Little access
Number of houses in community in each category (277 = 100%)	17 (6%)	230 (83%)	30 (11%)
Number of FHH in community in each category (25 = 100%)	0	22 (88%)	3 (12%)

Similar patterns are observed in Ethiopia and Sri Lanka. In Ethiopia, those households with permeable roofs (usually old iron sheets) have less diverse sources of income (mainly brewing local alcohol or engage in petty trading) than households with permanent roofs (farming, rental income from the house, working in town, trading in pepper, making and selling local food and drinks, or running a pharmacy). In Sri Lanka, the household with permanent DRWH receives remittances from one family member working in the Middle East.

4.6. Implications of Social and Gender Analysis

The main findings from the social and gender analysis of activities associated with water collection and use are summarised in Table 4.8. The existing position of women and men with regards to their active participation in water collection, their access and control over resources, and participation in decision making is recorded in the left-hand column. The socio-economic characteristics of households with and without permanent DRWH systems are also noted. The implications of these findings for the design, development and promotion of DRWH systems are recorded in the right hand column.

From the fieldwork findings, four principal socio-economic and gender issues were identified as needing address during subsequent study:

- How does DRWH fit in with existing patterns and preferences of water collection and use in the community?
- What socio-economic and gender factors influence the adoption and sustained use of permanent DRWH at the household level?
- What role does DRWH have in addressing the issues of poverty?
- How might DRWH be best disseminated?

In addition, the gendered nature of water collection has significant implications for many aspects of conducting the main study:

- ***Conducting meetings in the community and the household***: Who will attend? Who will speak? Who will make decisions? Who will be affected by those decisions? How can efforts be made to ensure all voices are heard, including those of women and the poor?
- ***Developing new technologies***: Whose needs are being met? How will they use the new resource? What implications will it have for the use of other household resources, including the use of time?
- ***Constructing new technologies***: Who will develop the necessary skills? Will the training be an opportunity to empower certain members of the community?
- ***Testing the new designs***: in whose households will the new tanks be sited? Will all members of the community have access to these sites?
- ***Assessing the impacts***: Whose views are being recorded? Who will benefit from the introduction of DRWH? How will they benefit? What will they do with any time saved? How will any cash savings be used? Who will make those decisions? Has any member of the community been disadvantaged?

The findings stress the importance of adopting a gender approach, rather than focusing solely on women. Although women are principally involved in fetching water, many decisions about investing in new household resources, and redeploying household labour, involve men. The challenge is to develop a DRWH system that men will want to buy and women will want to use. Hence it important that both are involved in any decisions regarding new RWH designs and have opportunities for skills development.

Table 4.8: Summary of Social and Gender Issues Associated with Water Collection

What is Happening?	What are the Implications?
Gender roles • women (with varying assistance form girls – depending on the season, location of water source and culture) are responsible for the task of fetching water • collecting water is time consuming, occurs on a daily basis, and fragments the use of people's time (several journeys are made each day, occupying a total of between 1.5 to 5 hours per day) • women ands girls usually travel to water sources on foot • the task of collecting water is physically demanding, particularly on the return journey, and becomes more burdensome during the dry season • men help occasionally (travelling to more distant water sources in dry season) • men may travel to water sources by bicycle if the terrain permits • men become active in water collection as an income generating activity (for example, water vendors (in Uganda)	• collecting water consumes a lot of time • women loose the opportunity to undertake other productive activities • water collection can interfere with children's studies (attending school, completing homework) • collecting water exposes family members to various risk (attacks, abuse and assaults) • although women derive enjoyment from socialising whilst collecting water, their main concern is with the time this activity consumes
Access and control • women have access to, but little control over, practical resources which help with water collection • women don't have access to means of transport • men exercise control over a wide range of household assets associated with water collection and use, even though they don't use many of them • men benefit more from external services (information, meetings, credit) than women	• both women and men need to be involved in discussions regarding water source options: women do the work, have access to the assets, and make many of the decisions; however, men control most of the assets, attend meetings, are in contact with information sources, use credit • whilst priorities for HH expenditure include improving home and installing permanent DRWH, the reality is that current expenditure is dominated by food, school fees and medical expenses • households without impervious roofs tend to be resource poor; hence they may find it difficult to invest even in very low cost systems
Decision making • women play a central role in deciding which source of water to use, how much to collect, and how to cope during periods of water shortage • decision to introduce DRWH undertaken by men but women have overall responsibility for system once installed	
Socioeconomic characteristics • households with impervious roofs have more diverse sources of livelihoods, are more involved in monetary economy, better educated • households with soft roofs tend to have fewer assets, less contact with external sources, remittances often more important, lower levels of education	

5. MAIN SURVEY FINDINGS

5.1. Justification for Undertaking the Socio-Economic Surveys

A socio-economic and gender survey has been undertaken during August/September 2001 in 8 selected communities within the three partner countries (Sri Lanka, Ethiopia and Uganda). The survey was designed to serve two purposes. Firstly, it analyses the existing situation of those communities and households within them, paying particular attention to characteristics that may have some bearing on the interest in, and the response to, opportunities to participate in DRWH. Secondly, through increasing the understanding of social and gender issues associated with rainwater harvesting, it will contribute to a successful outcome for the whole research programme.

From initial fieldwork conducted during January/February 2001, four principal socioeconomic and gender questions emerged which need to be addressed during this (2001-2003) research programme. They were:

a. How does DRWH fit in with existing patterns and preferences of water collection and use in the community? (Year 1)

b. What socioeconomic and gender factors influence the adoption and sustained use of permanent DRWH at the household level? (Year 1)

c. What role does DRWH have in addressing the issues of poverty? (Year 2)

d. How might DRWH technologies be best disseminated? (Year 2)

5.2. Criteria for Selection of Survey Sites

A range of criteria were identified to guide the selection of survey sites, including climate, water-source alternatives, degree of water stress, presence of RWH systems, and representativeness of wider communities. Each site was deemed sufficiently accessible to the partner NGO to permit regular visiting to monitor variables like water quality. Survey at one intended urban site has not yet been started as it took 5 months to obtain government permission to operate there. The sites are to be used, during 2002, for trials of new DRWH technology, whose design has included a response to issues and constraints identified during this survey. Some of the data is therefore needed for ‘before and after’ comparisons. Three sites were selected in each country.

An urban-rural mix was achieved in Sri Lanka and Uganda by focusing on two rural locations and one urban/peri-urban location. In Ethiopian two rural surveys have been completed; a survey in a poor district of Addis Ababa will take place in early 2002. In Sri Lanka, one of the rural sites was located in the dry zone (Nelewa, Kurunegala District) and the other in the wet zone (Aranayaka, Kegalle District). Although both communities participated in opportunistic (‘informal’) collection of rainwater, it was only in the wet zone village that some households had permanent RWH systems. Similarly in Uganda, one community had substantial exposure to DRWH (Kibengo, Mbarara Distric, S Uganda) whilst the other had no permanent systems (Oguru, Gulu District, N Uganda). In Ethiopia, where DRWH is as yet little known, neither site had any prior experience of it (Arerti and Alaba villages).

5.3. Design of H/H and Community Surveys

The survey was conducted at two levels: first at community level and then at individual household level. The community surveys involved gathering a large and representative fraction of villagers, discussing and extracting relevant information from them, a process that took most of a day. It was assumed that the urban people might not be willing to spare so much time, and the community surveys were conducted only at the rural survey sites.

Table 5.1 Principal Research Questions in Rural Community Survey and Data Collection Methods

Research Questions	Data Collection Methods	Informants
Seasonal variations in rainfall, fetching of water, collection and use of DRWH, use of water vendors, use of water, water-related illnesses	seasonal calendar	key informants
Spatial location of water sources, for each source identifying: months of use, reliability, age and sex of water-collectors, queuing, secondary usage, hazards, ownership and charges; Water-source access matrix identifies, for each water source: distance, terrain, mode of travel, journey time	village map, water source matrix, water-source access matrix	people involved with water collection
Organisations involved with water supplies: activities, operational status, links with other organisations, composition of membership and leadership (women/men, socio-economic groups), importance	Venn diagrams, organisational profiles	key informants
Socio-economic characteristics of households with permanent DRWH/informal DRWH/soft roofs	socio-economic classification	key informants
Classification of houses by wealth and roofing materials	wealth ranking	key informants
Criteria used to appraise different water sources	pair-wise ranking, preference matrix	people involved with water collection
Daily activities of women, men, girls and boys including the fetching and use of water at the busiest and quietest periods of the year	daily activity profiles in wet & dry seasons	people involved with water collection
Access to, and control over, household resources associated with collection and use of water by gender	access and control matrix	separate groups of women and men

An overview of physical and organisational aspects of water collection and water use was obtained at this community level. Table 5.1 above presents an outline of the principal research questions and survey methods used during the community surveys in rural areas. Information was gathered using a variety of Rapid Appraisal methods from key informants, such as village leaders and local elders, as well as the general public, and from separate groups of women and men assembled during the community survey.

Within each community, 26 household interviews were also conducted, the selection of actual households being guided by the results of the community survey. Households were selected to reflect the different roofing systems: houses with hard roofs and permanent RWH systems; houses with hard roofs and no permanent system; and houses with soft roofs (Table 5.2). Within each household category, efforts were made to ensure there was a representation of female-headed, as well as male-headed households, and tenants as well as owner-occupiers.

Table 5.2: Households Selected for Interview – Distribution by Roof Type

Household characteristics	Ethiopia		Uganda		Sri Lanka	
	Alaba	Arerti Minjar	Oguru Gulu	Kibengo Mbarara	Nelewa Kurunegala	Aranayak Kegalle
HH with hard roofs and permanent DRWH systems	0 [0]	0 [0]	0 [0]	35 [10]	30	30 [13]
HH with hard roofs and no permanent system	100 [95]	96 [95]	35 [10]	57 [55]	54	55 [85]
HH with soft roofs	0 [5]	4 [5]	65 [90]	8 [35]	16	15 [2]

Notes:

(1) Numbers in square parentheses are percentages of h/hs having each roof type according to Community Surveys.

(2) Total interviewed households was 25 for urban sites and 26 for rural sites

5.4. Findings of Community Survey at 6 Rural Sites

This section highlights some of the new findings emerging from the community survey conducted during the first year of the Main Phase.

The incidence of hard roofs and permanent RWH systems varies between the survey communities (Table 5.3). Aranayaka village in Sri Lanka had the highest proportion of households with permanent RWH systems, although these were traditional rectangular brick tanks of about 900 litres capacity. Kibengo village in Uganda had 10% h/hs with modern DRWH systems built during a recent RWH promotion programme. Neither of the villages in Ethiopia had any such system. However the introduction of RWH systems there would appear to be timely due to the shift towards hard roofs that has occurred in recent years. On average, 83% of h/hs in the surveyed communities had hard roofs [except for Oguru village in Uganda, where 90% of h/hs have permeable/soft roofs]. Moreover, opportunistic rainwater harvesting is widespread, with all but the Oguru community collecting rainwater during the rainy season.

Of major importance to the relationship between poverty and water equity, in the context of roofwater harvesting, is the distribution of the ‘hard’ roofing that low-cost RWH requires. Table 5.3 below shows relevant findings for the four E African villages surveyed. Whilst the few ‘rich’ households do, as might be expected, have the highest fraction of hard roofs, the poorest households are generally not far below the average.

When asked to compare hard-roofed and soft-roofed households, villagers thought the former more prosperous in terms of attendance of children at school, and the range of household assets in the home. Other socio-economic characteristics, such as family size and the significance of farming as their main economic activity, vary less between the former and the latter.

Table 5.3: Roof type and wealth category (as judged by group)

	% of all households				% in category having hard roof				
Wealth category	R	M	P	VP	R	M	P	VP	ALL
Alaba, Ethiopia	3	14	29	54	100	84	88	90	**89**
Arerti, Ethiopia	1	7	75	17	100	100	100	88	**98**
Kibengo, S Uganda	9	27	24	40	73	76	70	64	**69**
Oguru, N Uganda	15	24	44	17	75	31	25	33	**35**

Notes: (R = Rich; M=Medium; P=Poor; VP=Very poor)

Water collection remains a burdensome task, consuming a considerable amount of time per day, both for journey time and queuing time (Table 5.4). It is most onerous during the dry season when people often have to travel to sources far from the community. Most of the responsibility falls on women, often assisted by girls, usually travelling on foot. Men and boys may participate when travel distances are farther. Bicycles (Uganda), donkeys (Ethiopia) and three wheeler vehicles (Sri Lanka) may be used to carry water containers.

The amount of water fetched varies significantly between seasons, from 15-20 litre *per household* per day in Alaba village in Ethiopia during the dry season to up to 120 litre in Oguru village in Uganda (Table 4). Dry season consumption is typically two thirds to half of the wet season consumption. Priority activities are cooking and drinking, indicating the need for potable water.

Table 5.4 Travel and Queuing Time, and Volume Collected per Day by Season

Activity	Ethiopia				Uganda				Sri Lanka			
	Alaba		Arerti Minjar		Oguru Gulu		Kibengo Mbarara		Nelewa Kuruneg ala		Aranaya ka Kegalle	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
One-way journey time (minutes)	10	10	5-10	5-10	30	30	30	90	15	15	15	15
Queuing time (minutes)	120	'2 days'	60	'7 days'	x	60	x	x	15	30	30	60
Daily vol. collected (litres)	65	15 - 20	60	40	120	60	100	60	60-80	48	80	40

Note: Queuing times of 'days' indicate times containers are left in a queue. Queuing times in minutes are human waiting times.

Although women shoulder most of the responsibility for water collection, their control over water assets (such as roofs, water containers and modes of transport) varies between communities. Similarly, their participation in training, meetings and access to credit differs. Hence, it is important to undertake site-specific studies in order to understand these variations prior to promoting specific technologies.

5.5. Findings of Household Surveys at 6 Rural and 2 Urban sites

Table 5.5a below summarises the characteristics of the two hundred households surveyed. They have yet to be fully calibrated against national statistics for their respective countries, a process necessary before measurements of water behaviour in these villages can be projected nationally. However we may usefully note some expected and unexpected characteristics. Thus the household size of 5 is fairly typical of developing counties, and the much higher fraction of children in Uganda as compared with

Sri Lanka reflects their known different demography. The country-averaged figures for schooling are however surprisingly similar despite the expectation that Sri Lankan schooling would be longer.

We might look to household or *per capita* income to place these villages both within their national economies and to make international comparisons. In fact the income per capita is unexpectedly similar. Unfortunately the currency exchange rates are such that these dollar comparisons may mislead. Prices are generally considerably lower in S Asia than in E Africa.

Table 5.5a Household Characteristics

No	Location	Nation	Urb Rur	H/H size	F:M ratio	Child <16yr	Female headed	School of head	Own house	H/H income	per cap incm
				Pers	Pop	% pop	% H/H	years	% H/H	$ pa	$ pa
1	Colombo	S L	U	4	1.0	27	24	5	92	614	154
2	Galboka	S L	R	5	1.2	27	27	6	100	479	96
3	Nalawa	S L	R	4	1.1	23	15	6	100	631	158
4	Kampala	Ug	U	6	1.4	49	28	6	88	870	145
5	Mbarara	Ug	R	5	0.9	47	19	4	100	368	74
6	Gulu	Ug	R	7	1.1	43	27	7	95	1008	144
7	Arerti	Et	R	4	1.2	42	42	4	54	542	136
8	Alaba	Et	R	5	1.1	35	38	7	50	677	135
9	Addis A	Et	U	survey not yet completed							

Table 5.5b Comparison of wealth: surveyed households to national average

	Sri Lanka average of 3 sites	Uganda average of 3 sites	Ethiopia average of 2 sites
(A) Income per capita in surveyed H/Hs	$136	$121	$135
(B) GNP/capita 2000	$810	$310	$100
Ratio A/B	0.17	0.39	1.35

Table 5.5b compares income per capita in the surveyed households with national GNP per capita (World Bank 2000) and reveals wide differences between the three countries. Despite the intention of selecting representative poor communities, it seems that by their respective *national* standards the Ethiopian sites are relatively prosperous and the Sri Lankan ones very poor.

Data on gender indicates an average of 1.1 females per male, higher than the national averages, and a significant fraction of female-headed households (averaging 40% in rural Ethiopia). These figures taken together might indicate an absence of adult males, however it is noteworthy that the highest female:male ratio occurs in a city (1.4 in Kampala) rather than in a village.

Of relevance to the installation of DRWH is household tenure. In both Uganda and Sri Lanka the ownership rate is high – around 95%. In Ethiopia by contrast nearly 50% of H/Hs are in rented property, which is expected to reduce interest in DRWH investment.

Table 5.6 presents water use and water source variability over the eight sites, showing much variability between them. Many different source types are in use. A table of survey findings specifically concerned with RWH has been omitted from this report, as its main import is for DRWH system innovation, which is the subject of parallel report R2.

We look first at water quantity. The average over all sites is about 18 lcd. The E African average of 20 lcd is high by regional standards, whereas the 14 lcd average in the Sri Lankan households is much below expectations in that well-watered country. In S L and Uganda the survey was undertaken during wet months, in Ethiopia during a dry one, so that any seasonal corrections would accentuate rather than diminish the inter-continental contrast. It is also notable that the presence of standpipes in three locations has not raised their relative consumption – though whether this is due to intermittency of pressure, queuing or water charges is not yet clear.

Overall some 38% of surveyed households use but one water-source. The rest use two or more, confirming previous research that showed multiple-sourcing to be common amongst poor tropical H/Hs. Uganda contrasts with the other two counties in having a much higher rate of sole-sourcing.

Rainwater harvesting is practised informally in 50% of households, but is only considered a main source in 15% (a figure dominated by one site where formal DRWH has been strongly promoted in the last decade). Informal practice rarely extends beyond 90 days per year, during only some of which is rainfall heavy enough to satisfy all household water needs.

Finally we have a little information on water commerce. In four of the five African sites, water purchase is very common, the price and quantity taken varying with season. At the time of survey, the payment per litre varied from 0.24 to 0.7 $¢_{US}$, (average 0.41 $¢_{US}$) being sometimes just for water and sometimes including carriage. If all consumption were to be costed at these rates, the high figure of $\$_{US}30$ per capita per year would apply. In Sri Lanka by contrast, charging for water is almost politically taboo.

Table 5.6 Water sources

Site	Nat	Urb Rur	Water Use	Purchased water		Only 1 source	Primary source (% H/H using)						
			lcd	% H/H	cost ¢/litre	% H/H	Stand -pipe	Sprin g	Vend er	Shall Well	Rain water	Bore- hole	Other
1	S L	U	12	0	n/a	28	80	na	na	4	na	na	16
2	S L	R	13	0	n/a	52	15	na	na	62	13	na	10
3	S L	R	15	0	n/a	12	20	na	na	80	na	na	na
4	Ug	U	22	64	0.4	60	na	60	20	10	10	na	na
5	Ug	R	12	90	0.7	42	na	na	na	na	80	na	20
6	Ug	R	26	27	0.4	62	na	5	na	25	na	70	na
7	Et	R	16	84	0.3	20	86	na	6	na	4	na	4
8	Et	R	25	92	0.24	24	30	na	20	na	20	na	30
9	Et	U	survey not yet completed										

6. INFORMAL AND VLC DRWH PRACTICE

6.1. Brief history of informal and low-cost DRWH

We have defined 'Informal' DRWH as involving no permanent equipment. 'Very low cost' DRWH we have variously treated as costing less than some threshold (e.g. $50), having a small storage capacity (e.g. <1000 litres) or meeting much but not all (e.g. 60% to 80%) of a household's water needs. Each definition entails the unavoidable if arbitrary choice of a ceiling value. For the purposes of the discussion here, we wish to largely exclude 'Sole-source' DRWH, such as is still widely practised in Australasia and is being introduced on a large scale in N China and NE Brazil.

Prior to the development of commercial water-distillation, historically some locations have employed Sole-source RWH, whether domestic or communal in scale, for lack of any alternative water sources. Bermuda and Gibraltar were classic examples. Generally however the arrival of roofing and storage techniques compatible with DRWH by poor households has been quite recent. Therefore collection of domestic water from nearby natural features such as trees and rock surfaces was the only feasible DRWH option.

Collection from trees barely survives in a few spots in Africa, India and perhaps elsewhere. Containers are linked to tree trunks via some sort of spout, such as a banana leaf or bamboo. The water quality is usually low. The process of retrieving and replacing containers *during* a storm is unpleasant. Harvesting from trees or rocks meets the water needs of but the tiniest fraction of the world's population. It even gets little mention in the recent encyclopaedic survey of traditional RWH systems in India (Agarwal 1997).

The steady replacement of vegetative roofing by harder materials, especially by corrugated sheeting in the Tropics, during the last 20 years has opened a new RWH possibility, that of informal *roof*water harvesting. Some estimates of likely yields have been made in Section 7 of this report. For present purposes however we may simply characterise Informal RWH as meeting around 10% of a household's annual water needs at the cost of some inconvenience. Such harvesting requires possession of wide-mouthed vessels, and the rapid growth in numbers of cheap plastic bowls since 1980 has been very convenient. Informal RWH also requires considerable vigilance on a household's part – for example to respond to night-time rainfall. It is highly unpredictable. It interferes with the normal uses of the collecting vessels. It doesn't yield high quality water unless collecting vessels can be lifted onto a bench or frame well clear of the ground. And of course it isn't an option for those still living in grass or fibre-roofed houses. So the history of Informal roofwater harvesting is rather short and the technique has generally been disregarded by water experts and RWH promoters alike.

The application of guttering – even just a single 1.5 m length – and of some bespoke storage converts Informal to 'VLC' RWH. The combination of a short gutter and an oil drum (capacity 200 litres) be widely observed today on houses in most poor countries. It yields water only during the rainy season, and may fully meet water needs for only perhaps 50 days per year. However its practice is locally sometimes so widespread that one hears of inconvenient point sources like valley wells being unused for days on end. Its practice also extends to communal buildings like schools, but here the low reliability often leads to abandonment after initial enthusiasm has worn off. Defects in its design are quite evident. Extraction of water from the store is often difficult. Growth of mosquito larvae and algae in the store are common. The guttering may be ill-aligned.

In countries with a longer experience of hard roofs, such as Sri Lanka, this minimalist form of RWH has developed into a normal household practice of building some permanent storage capacity such as a small brick tank. However it is still uncommon to find more than rudimentary guttering systems.

Since about 1980 there has been a visible RWH 'movement' that has promoted roofwater harvesting as a special-purpose supply technique for both agricultural and domestic water. The 'special purpose' in potable water supply was initially the relief of water-stress in semi-arid areas and much emphasis was (and still is) placed upon dry season water security. This focus excludes VLC designs. Moreover the movement's base in NGOs made it favour conservative and supposedly high reliability designs that were too expensive for unsubsidised use by the target group. Meanwhile an expectation 'Central Government should supply free water' developed in most tropical countries from 1960, leading to the general abandonment of local efforts to maintain or extend water provision. The failure to deliver that political promise has led in different directions in different settings. In many cities and a few countries there has been an attempt to attract foreign capital into water supply via the sale of water supply monopolies. Throughout the developing world NGOs and foreign aid play some role in water supply. In India there is a vigorous campaign to return management of water to District or even village government. (Agarwal *et al*, 2001). And there has been vigorous growth in householder-managed water supply using RWH, domestic tube-wells, shallow garden wells and the purchase of bottled water.

VLC DRWH has sat uncomfortably in this overall setting. It was for long scorned by RWH promoters, NGOs and government officials as having insufficient reliability – typically 70% - because none of these agencies imagined multiple-sourcing of a household's water. Research by the Rainwater Harvesting Research Group (Ariyabandu & Ariyananda, 1999-2001) and others since 1998 has shown that multiple-sourcing is quite common amongst the urban and rural poor and that the *prima facie* economics of VLC DRWH often look promising.

The great flurry of activity in NE Thailand in the mid-80s (analysed below) involved a mix of 'VLC' and more expensive 'Sole-source' DRWH. Its carry-over into neighbouring Asian countries and to other parts of Thailand itself was slow, although it still progresses, most notably in Cambodia. In Africa, particularly after the active support of SIDA in E Africa, domestic RWH installations grew, mainly using technologies from the colonial past, from Asia or from more local Institutional RWH. Rainwater-jar production (in sizes like 1500 litres that lies between VLC and Sole-source DRWH) was commenced in Kenya, Tanzania and Uganda in the early 90s and there are now about 10 national RWH associations in E and S Africa. Many delegates from W Africa attended the latest IRCSA Conference which promises to expand DRWH beyond its main regional base in Nigeria. In Latin America other than Brazil, the developments have been mainly in agricultural applications of run-off management, with Mexico by far the most active practitioner. There may well be rural Informal and VLC DRWH being practised in the Amazon Basin, but they are not well documented. By contrast urban VLC DRWH was early reported from Honduras.

As for a decade or more, the expansion of VLC forms of DRWH has been constrained by failure to understand that very low cost and high reliability are not compatible, by uncertainties about water quality and by an absence of efficiently-produced and accessible hardware.

6.2. The Thai experience 1980-2001

A large-scale programme to promote roofwater harvesting in Thailand in the late 1980s has left a legacy of millions of tanks and jars still in regular use. In one area in particular, the relatively dry NE of Thailand around the city of Khon Kaen, rainwater harvesting remains the main form of rural water supply, despite major growth in the Thai economy in the intervening years. The area was visited in June 2001 by Rajindra Ariyananda from Sri Lanka on behalf of this (DFID-funded) programme. Currency conversions have used $1.00 = ThB 44.

The need to introduce RWH in Thailand

Rainwater harvesting for domestic use is probably more widespread in Thailand than any other country in the world. Within Thailand such harvesting is most popular in the North East where ground water is often saline and where there was already some tradition of using rainwater for domestic purposes including drinking.

With more than 70% of the people living in rural areas, there was in the late 1980s a great need to improve rural access to drinking water. An average annual rainfall of 1000-2000 mm made harvesting rainwater for domestic use an economical option provided the right technologies were adopted. Traditionally, people of NE Thailand used 400-600 litre ceramic (earthen) jars for such collection. However, due to the limited size of the containers and poor management of collected water, there was often household water scarcity.

Government, NGO and private sector participation in the implementing RWH in the 1980s

In 1979, the Royal Thai government announced a new policy for water resources management in rural areas. Three technologies were considered. For irrigation the construction of small weirs was proposed, while shallow dug wells and rainwater-collection jars and tanks were promoted as drinking water sources. The implementation of these technologies was decentralised with co-ordination and planning responsibilities given to the local Districts and management shared by local authorities and the user community.

A construction boom for rainwater jars followed the announcement of the nation-wide rainwater jar construction programme by the Ministry of Interior in 1985. The government, working jointly with locally active NGOs, supported the first several million jars and tanks (Raindrop 1992). The Population and Community Development Association (PDA) was one such NGO; it has some 16 centres all over Thailand and it has constructed over 16000, 11 m^3 rainwater tanks. Though the pace of construction is now less than during the initial phase of the programme, PDA still construct rainwater tanks on request. Presently it cost Baht 40,000 for a set of three 11m^3 tanks. PDA construct these tanks for a 3-year (zero interest) payback period. As the implementation of the programme was decentralized, each district had its own system of obtaining operational funds. However, a major source of funding came from the well-established Rural Job Creation Project.

Initially, the jar construction programme was to be financed by a revolving fund, using start-up funds from the government. However, the rapid growth of the programme made it difficult to administer the revolving fund. Although it was envisioned that householders would construct their own jars, the small-scale private sector became very active in rain jar construction. In some villages groups of people were paid to construct rain jars and deliver to households. At the peak of the programme, small village-based manufacturing companies were turning out around 30 jars per day and including delivery on orders in excess of six jars.

Current situation

Jar at a household in Thailand
(Picture: Ariyabandu 2001)

Jars at a household in Thailand
(Picture: Ariyabandu 2001)

Currently the momentum of jar manufacturing is much less. However, same small-scale jar manufacturers produce between 4-6 jars per day with three to four workers and follow the same criteria for delivery. While jar manufacturing appears to have been a full-time occupation during the Programme, it is now a part-time occupation to be fitted round farming and other activities.

Travelling through NE Thailand today one observes that every household has more than one jar and even those with rainwater tanks still have at least two jars. Hence, there could be a kind of saturation with respect to the market for jars. This could explain why the sale of jars is no longer so evident in NE Thailand, though one can observe numbers of jars standing in front of manufacturers' premises. According to some manufacturers, demand for jars increases with the onset of the dry season in rural areas, while in the urban areas people buy jars to store delivered water.

While a number of methods for jar construction were tested during the programme, the most common design that can be seen today employs a mould of interlocking cement blocks. Jars made by this method do not require any reinforcement and can be cured within one day. While jars produced earlier had no provision for water abstraction and cleaning, the present jars incorporate water taps and drainage outlets. However, to simplify transport these facilities are fitted at the household rather than at the factory.

After almost 15 years of implementation, there are no visible problems with respect to the structural design of jars. However, there was an isolated case where two jars have burst due to transporting approximately 100 meters and immediately filling with water. The only problem that was evident was lack of jar covers. Presently a galvanized cover costs Baht 70-100, but few appear to have purchased their own covers. This incidentally is due to inadequate awareness on the health and sanitation aspects of rainwater harvesting for domestic use.

The cost-effectiveness of rainwater jars

In a situation where no other option is available to provide water to households, rainwater jars become a cost-effective technology. With the rapid development of the Programme and the emergence of micro-enterprises to construct jars, the cost per jar was just $\$_{US}$22 in 1988 and $\$_{US}$40 in 1992 (Raindrop 1992). This low price was possible due to the large-scale production and ensuing economics of scale. Now in 2001 the cost of a 1200–2000 litre jar has fallen to only Baht 600 ($\$_{US}$13), even though the demand for jars is much lower. This price reflects the low cost of cement and the use of rock dust as a reinforcing agent. According to one manufacturer in NE Thailand, the present cost of production of one jar is Baht 250-300. In 1985, with the boom in the Thai economy, purchasing 1 to 2 jars per households was not seen as a problem. Following the country's recovery from the economic slump in the late 1990s, again rural Thai people find it within their reach to purchase jars at full market cost. Thai jar manufacturing is now totally a commercial venture.

Given that the annual yield from a pair of 2000 litre jars is likely to be around 40,000 litres and using a crude payback time of 3 years gives an approximate water cost of Baht 10 per m^3. This is similar to the cost of urban piped water of inferior taste. However piped water is often more convenient to use, and for that reason may be preferred to rainwater for applications that can be satisfied with highly mineralised water.

Rural water supply coverage

The overall goal of the Thai jar programme was to provide 5 lpcd of clean drinking water and 45 lpcd of other domestic water by 1990. In 1981 the *clean* water supply coverage with 2 lpcd (*sic*) was only 26 %, but by 1986 it had increased to 70% and by 1998 to 76% (Raindrop 1992). Though recent statistics are not available, the clean water supply coverage in NE Thailand is thought to be now much higher than 76%. Presently there are two formal sources of domestic water to NE Thailand, namely the Provincial Water Authority (PWA) which supplies pipe water to some of the rural areas and bottled-water companies mainly providing water within the city limits of Khon Kaen. The cost of PWA water is low at Baht 9 per m^3; if connected an average rural household pays Baht 20-50 per month for it. By contrast bottled water is extremely costly at Baht 15 per 10 litres (Baht 1500 per m^3). Besides these sources there are areas where water is also provided from shallow wells. Hence, the water supply coverage is much better than what it was two decades ago.

Health and sanitation

One of the problems identified in large-scale rainwater water harvesting is the non-inclusion of health and sanitary aspects in the development programme. This was one of the main drawbacks in the Thai jar programme as well. Research conducted by the Khon Kaen University in mid 1980s had clearly identified that the Thai jar programme was primarily a construction programme with set quantitative targets and put little emphasis on development aspects. As a result most of the jars constructed did not have pipe outlets to extract water and there were no jar lids to prevent contamination of collected water. However, this situation was later corrected under the Ministry of Health programme, where pipe outlets, lids and drain outlets were incorporated into the tank design. What is apparent at present in NE Thailand is a mixture of these jar types, some having galvanized jar lids while others are just covered with pieces of wood or asbestos.

Due to poor management of stored water, concerns were raised at the early stages, about mosquito breeding and possible spread of dengue and other vector-born diseases. This situation appears to prevail even at present as large public banners are displayed in connection with the dangers and eradication of dengue fever. However, people do not directly attribute rainwater jars to the spread of dengue. This incidentally was confirmed in an earlier study, under the Thai-Australia project where mosquito larvae were found only in 0.2% of jars. It was found that the small water containers were more prone to breed mosquitoes than large water bodies like rainwater jars. Incidentally, this was the response given by an old Thai couple when the same question was posed on them in a recent visit to Khon Kaen in 2001. Public health advice to cover jars with mosquito netting seems to have yielded limited response. While some jars have been covered with netting, most of the traditional ceramic jars are not and offer good breeding grounds for mosquitoes. This situation is most common in rainwater jars found in schools. Most of these jars appear to be neglected leading to large-scale water contamination and vector breeding. Hence, it is time that some concerted efforts are made to maintain the rainwater jars, specially the ones that are in common property like schools and temples.

Management and acceptance of rainwater

Lids left off tanks
(Picture: Ariyabandu 2001)

Poorly designed first flush system which cannot be operated by the user
(Picture: Ariyabandu 2001)

Management of stored grainwater is an area of concern. Most of the jars found in NE Thailand do not have filters or first-flush systems. Even the $11m^3$ tanks do not have filters, though most are fitted with first flush systems. However, most of these systems appear to be ineffective as they are not properly operated. This could be due to inadequate knowledge and lack of any follow-up on operation and maintenance of rainwater tanks and jars. One of the defects identified in first-flush systems was that their end caps were always kept closed (thereby thwarting their proper operation). In several instances the location of the first flush was beyond the reach of users. However, what is interesting is none of these problems appears to be of any concern to the people who use DRWH, despite their probably affecting negatively the quality of stored rainwater.

Rainwater Quality and Use

Studies conducted by Khon Kaen university in late 1980s found that only 40% of the tanks and jars met the WHO recommended standards for bacterial counts of drinking water, 66% meeting the total coliform standard and 57% the faecal coliform standard (Raindrop 1992). However these percentages are high in comparison with much rural water practice in the tropics. It was found then that secondary handling of water was the most common cause of contamination. Hence, it had been decided that improving secondary water handling through education and awareness would be more beneficial than trying to achieve WHO standards of water quality at source. It is unfortunate that there has been no continuation of research into water quality. However, householders appear to be little concerned about the quality of collected rainwater. They use it for both drinking and cooking. Due to lack of epidemiological data there is no assessment of health implications using rainwater for domestic use.

In the absence of any reliable data on water use it can only be said that there is wide spread use of rainwater for all domestic purposes. However, research conducted by Khon Kaen University in the early 1990s has revealed that more than 70% of the households use rainwater for drinking purposes (Wanpen et al 1993). As in the past, most rainwater use for drinking purposes is through secondary containers. However, there are times when water is directly consumed from rainwater tanks found in schools.

Probable reasons for success of Thai DRWH programme

The driving forces behind the success of the rain jar programme in NE Thailand are believed to be:

- A tradition of using rainwater for domestic purposes.
- The availability of skilled artisans trained in building traditional earthen jars
- The unpalatability of ground water due to very high salinity.
- The affordability of rainwater jars and their ready transportability.
- Good quality control due to factory-based production and appropriate tank designs, both leading to excellent durability.
- The dedication and commitment of all government and non-governmental organisations involved in the implementation of the programme and the early commitment to decentralised management.

The Thai rainwater harvesting programme provides an excellent example of collaboration between a state bureaucracy and NGOs, universities and other stakeholders in implementing a rural development programme. The important lesson in this process is how such a programme can be successfully operated when it is decentralised. The delegation of authority to district officers as programme managers and provincial governors as programme directors enabled the programme objectives to be fulfilled (Raindrop 1992). The most important aspect of this approach was the training of village artisan in jar construction and subsequently encouraging manufacturing micro-enterprises to develop. Presently what is left are those micro enterprises, operating in a fully commercialised mode depending on demand. The transition from a state-owned programme to a commercial venture took many years, however, it appears that the foundation is strong and prospects for future sustainability is good.

Cambodian comparison

It would be unwise to expect the same achievement under different conditions, for example ones where good quality water is already available from multiple sources. However it may be noted that similar rainwater containers are now appearing in neighbouring (but poorer) Cambodia, whose rainfall pattern is very similar to that of central Thailand. In Table 6.1 below the two Cambodian villages show an interesting contrast. That in Prey Veng Province neighbouring Vietnam uses traditional small ceramic jars, almost every household having one. The village in more westerly and prosperous Kampong Speu Province has a mix of new (larger) Thai-style cement containers and the traditional jars. The new containers have a 4-times lower unit cost and their owners have installed 10 times the storage capacity of their jar-using neighbours. As happened in Thailand in the 80s, we see today in Cambodia the pattern of traditional roofwater harvesting being revived with the arrival of a new and cheaper water-storage technology.

It would be interesting to survey the use of rainwater in NE Thailand (specially around Khon Kaen) in five years time, since the consumption of bottled mineralised water is increasing steadily. According to knowledgeable sources there were only two water-bottling companies 20 years back. Today there are 80 such companies delivering bottled water to most Khon Kaen city residents. With the improvement of the Thai economy more and more rural people will also be able to afford bottle water in future.

Table 6.1 Survey of rainwater jars in 2 S Cambodia villages, November 2001

Measure	Unit	Poor village in Prey Veng		Richer village in Kampong Speu	
		Old jars	New tanks	Old jars	New tanks
% of houses[1]		99	0	50	18
Mean storage cap	litre	292	-	166	1675
Mean cost/house[3]	$\$_{US}$	6.5	-	3.2	9.2
Mean unit cost	¢$_{US}$/litre	2.22	-	1.94	0.55[2]

Notes : 1 100 houses surveyed in each village, survey undertaken by G & B Crenn

2 A few houses have mixed new and old containers: new ones come in multiples of 600 litres and cost ¢$_{US}$ 0.51/litre

3 Household income in Cambodian villages is around $\$_{US}$1 per day.

6.3. Informal & VLC DRWH as revealed by 8-site Main Household Survey

The main site averages for the Household Surveys undertaken at 6 rural and 2 urban sites were tabulated in Section 5 above.

The practice of VLC DRWH at these sites is low. Where there *is* formal DRWH (3 out of 5 sites, at which it averages 29% of households) it was generally installed on a Sole-source basis at a cost higher than ‘VLC’. However 2 of the sites are Sri Lankan, where high water expectations mean that even systems with 2500 or 5000 litres storage may not be used as a sole water source, and indeed none of these users regarded their systems as sole sources. In the Ugandan site, where a RHW promotion agency has been working for some years, most users relied solely on their systems. It will be after the introduction of new *VLC* systems now underway that reactions to them will be sought.

We may also note from those having some exposure to formal RWH is that perceptions of water quality vary strongly with country – 30% think RW potable at the 2 Sri Lankan sites, 95% do at the 1 Ugandan site.

As expected, in none of the rural sites is ‘space’ considered a constraint on RWH adoption. In peri-urban Kampala it was also not an issue, but in the railway-side slum in Colombo over half of respondents doubted enough space was available.

Moving to the numerous practitioners of Informal DRWH (about 50% of the whole sample of 208) we find an overwhelming connection with roofing. In the two sites with 100% hard roofing, almost all households put out containers to collect rain; at the good-rainfall N Ugandan site where only 1 roof in 3 is hard, no-one puts them out. The roof areas recorded, averaging over 10 m^2 per household member, are all more than adequate for Informal DRWH and sufficient, given the good mean rainfall at all sites, for VLC DRWH to deliver 20 lcd for much of each year. The average current consumption of all respondent households is only 18 lcd, despite 5 sites having stand-pipe supplies.

Finally we note that at only 1 of the sites is RWH of any form regarded as the primary source of water. This is significant because RWH functions better as a primary source than as a secondary one.

7. ECONOMICS

7.1. DRWH Economics - Overview

The economic viability and the 'affordability' of DRWH systems are important issues yet difficult to assess.

Literature and the recent field and policy-maker surveys under this contract agree that DRWH's supposed high cost is a major impediment to its wider adoption. It is a major objective of this research programme to reduce system costs by technological innovation. However in some of its forms and in some quite common situations, DRWH is already cheaper than other forms of water supply. Economic assessment and cost comparison therefore need to be undertaken in clearly defined contexts.

In any case, it is the form as well as the size of DRWH costs that causes difficulty. Not only are costs predominantly construction ones (running costs are usually negligible) but they are also incurred by individual households rather than concentrated on point sources shared by those households. Moreover roofwater often differs in both quality and in security from water from other sources, both factors that may affect its value.

One can conveniently define 5 categories of house from a DRWH point of view:-

i) houses unsuitable for conventional DRWH for lack of suitable roofing

ii) houses with suitable ('hard') roofs but so far unused for any form of DRWH, where all water needs are met from point sources such as wells, stand-pipes or ponds

iii) houses with hard roofs but no *permanent* RWH infrastructure where opportunist (or 'Informal') DRWH is practised using domestic vessels like basins to supply a small fraction of annual household water demand

iv) houses with hard roofs used to supply, via very low cost ('VLC') DRWH, a significant fraction of their water demand

v) houses with hard roofs used to meet, via large 'Sole-source' RWH systems, almost all their water demand.

Moreover we might further classify environments by rainfall pattern, by existing water provision, by topology, by settlement type and so on. All of these factors will affect the cost, the investment return or even the absolute feasibility of introducing DRWH in one of forms (iii) to (iv) above.

In section 5.2 below two main situations are discussed, firstly the one where DRWH is used by an individual to replace and perhaps supplement water from other existing sources and secondly where DRWH is being contemplated as an alternative to (further) developing other water sources for a community.

However before we can address either situation, we need to be confident that the form and scale of DRWH we assess is designed and operated in a near-optimum way subject to the constraints of climate and roof size.

Valuing and costing quality

Water of different qualities is used for different domestic purposes and has therefore different unit values. Unlike residents in Northern cities, those of poor tropical communities do not generally experience 'one water quality serves all uses'. A water's quality may be categorised according to its cleanliness (absence of biological pathogens), its level of chemical solutes and its turbidity. However for economic modelling purposes it is probably more useful to define the following grades according to application:

Grade 1: Usable for direct drinking (waste is grade 5).

Grade 2: Usable for cooking, boiling and brewing (some grade 4 wastes; but improvement to grade 1 is possible)

Grade 3: Usable for washing, laundry and livestock (degrades to grades 4 or 5)

Grade 4: Usable for cleaning, horticulture and building purposes (little wastewater)

Grade 5: Unusable – urine, water vapour, waste

Although the ratio between the prices charged for grade 1 (e.g. bottled) and for grade 4 (e.g. irrigation) water can be extremely high, the market for premium water is growing rapidly even in poor countries. Taking as a starting point 100 and 0 as the unit values of respectively grade 1 and grade 5 water, it would aid analysis if we could assign unit values to the other grades. No study of such values has been located. A crude estimate might be that shown in the table below. The table contrasts a severely constrained household in a dry season with a lightly constrained one (but no yard tap) in a wet season.

Table 7.1: Grades of domestic water

Water grade	Typ % of a 10 lcd usage	Typ % of a 30 lcd usage	Unit value (est'd) dry/wet	Typ % of dry season value	Typ % of wet season value	Typical source
1 (potable)	20	8	100	43	28	Bottled, filtered RW, treated cont. piped, protected spring/well,
2 (e.g. cooking)	25	12	50	27	22	Unprotected well, crude/informal RWH, interrupted piped
3 (e.g. washing)	50	50	25	27	45	Stream, dip hole, unprotected spring
4 (e.g. garden)	5	30	15 / 5	3	5	Lake, pond
5 unusable		--	0			Urban drains, soda lakes

Daily access to the ca 2.5 lcd of potable water is of course essential for human life. Grade 1 water therefore can assume a relative value even higher than assumed in the table. *In extremis*, and the total absence of a supply, its value is measurable by the cost of migrating to a less water-stressed location. Occasionally there have been reports during famines of food aid being traded for drinking water or for cooking water. Under more normal conditions, we may assume some 'consumer surplus' whereby water of various grades costs household members less than its mean value to them.

On the basis of the crude estimates above, it would seem that drinking and cooking water account for 50-70% of the total value of household water. It also looks as if water recycled within the household (grade 4) would not contribute significantly to reducing the value of new water brought into the household. From this or similar data one might construct a demand v cost consumer curve wherein the first 2 lcd are very valuable, whereas quantities beyond the first say 50 lcd have no value.

Although most poor households in the tropics use more than one water source, few have continuous access to four different grades of water. In practice therefore, either an unnecessarily high grade of water is used for lower grade activities or an insufficient grade is used, causing other costs such as illness. However high water prices inhibit some activities more than others, for example consumption for washing may be reduced before consumption for livestock even though the former normally employs a higher water grade than the latter.

The use of household water for income-generating activities such as animal husbandry, building, brewing and taken-in laundry has been widely noted (de Mendiguren & Mabelane 2001). Some of these activities, like watering cattle and commercial laundry, are somewhat mobile in that they may sometimes be moved to a distant water source. Some can be postponed until a wetter season, although their performance in the dry season may well match the availability of labour or of raw materials. Conversely some are very time-critical: small livestock die after a couple of days without water, salad vegetables after five days. VLC DRWH systems are highly seasonal in their performance, fairly cheaply meeting increased demand in the wet season, but only expensively doing so in the dry season They are therefore poorly matched to water-demanding income-generating activities that are concentrated in the latter.

In the context of DRWH, we are interested in deciding what level of design sophistication (e.g. chlorination) is justified and by what other source we might value RW. The figures above suggest that if using a treatment to raise harvested RW from grade 2 to grade 1 would increase system costs by less than 25%, it would be worth installing. Both valuation and system design should allow for the high quality of harvested RW. For example where grade 3 or 4 water is cheaply available from other sources, it would be prudent to design RWH output only to meet grade 1 and grade 2 needs. Thus the use of RWH to counter the Bengali arsenic menace – in a context of plentiful but low-grade groundwater and pond water – might be sensibly be limited to meeting just drinking and cooking needs.

We would also like to know if the re-use of water within a household significantly affects its water economy. Using the crude estimates from Table 7.1 we see that grade 4 water – the only grade readily obtained by domestic recycling – contributes little to total value: so whether it was obtained from outside or inside sources becomes unimportant. This finding is robust in that its validity is not undermined by even a substantial shift in the unit values assumed above.

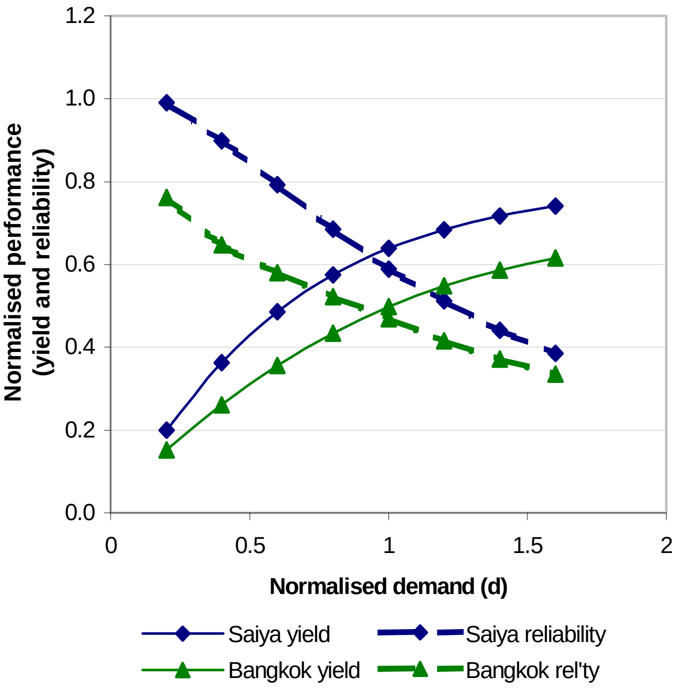
7.2. Economic Optimisation of a DRWH System

Optimum System Design

As design precedes construction and use, design optimisation has to be based upon estimates of future performance. There is large literature on how to predict the future performance of a RWH systems of specified size and climatic location. Many computer models have been developed and their refinement (e.g. to aid access by www or to reduce their requirement for costly data) continues – see Appendix C. By contrast there is little experimental data available about the performance of such systems. This may be due to difficulties of usage measurements or to the inherent variability in such usage that requires large samples to be used before significant findings can be made. Neither researchers nor RWH programme managers have felt it worthwhile solving the problems of documenting domestic RW usage. Within this Programme, usage data for informal DRWH has yet to be gathered and data for new VLC DRWH systems has only recently begun.

Performance is not a single measure. At the least it comprises ‘quantity’ and ‘reliability’ in addition to ‘quality’ discussed above. ‘Quantity’ harvested can be expressed by the ratio of the annual volume of water used to the annual volume that runs off the roof. ‘Reliability’ can be measured by the annual fraction of days that at least some RWH supply is available. Both measures are dimensionless and conveniently in the range 0 to 1. Generally both measures improve with increase in roof area or storage tank size. Roof area is usually taken as a 'given' in DRWH system design, whereas the tank size is a key design variable. However the two performance measures are not necessarily correlated: increasing factors such as nominal daily demand can increase the former while reducing the latter as shown in Figure 7.1

Figure 7.1: Effect of varying daily demand upon annual yield and annual reliability



Solid lines show yield, dashed lines show reliability, both normalised such that their maximum possible value is 1

Normalised yield (*alias* 'tank efficiency') = fraction of the water annually reaching the tank entry that is used by the household.

Reliability is the fraction of days when the household was able to withdraw what it planned (*D*).

d is the fixed daily demand normalised to mean daily tank inflow, i.e. $d = D \times 365/Q_a$

The data corresponds to a system in which tank size *V* equals Q_a / 52 (a '1 week' tank).

Upper (bold) lines represent Saiya in W Kenya which has a bimodal rainfall, lower lines are for Bangkok which has unimodal (Monsoon type) rainfall. Both places get about 1500 mm/year

Annual averages fail to reveal a critical dimension of performance. A dry-season litre is generally more valuable (or more costly from other sources) than a wet-season one. Indeed one could view the storage component of a RWH system as a value-enhancing device, receiving low-value water and delivering back higher-value water. The low value of the input is because the delivery of rainwater from the sky (typically during 50 to 100 hours per year) in no way matches a household's ability to use it, so that in the absence of storage, almost all would be wasted. For economic analysis we seek a way of valuing the water a DRWH system delivers that is more realistic than simply multiplying its volume by a fixed unit value. Any unit value should at the least vary seasonally (with prices) and at the best reflect the mix of qualities of the water required.

The issue of 'reliability' is particularly problematic. Our interviews with policy makers and a good part of the relevant literature indicate that DRWH is widely expected to perform a role for which it is fundamentally ill-suited, namely to offer high reliability as a sole water source. Putting a realistic value on reliability and then explaining that valuation will be critical to the future acceptability of DRWH. DRWH systems designed for very high reliability are rarely economically viable.

In modelling we have the option of simply separating the quantity and reliability measures and relying upon whoever is specifying the system to weight each appropriately. However it would be much more attractive to be able to combine them into a single measure of delivered value, which could then be used to define optimum sizes for system components. As indicated above one might use a weighted sum of annual quantity and reliability measures, but this is both crude and arbitrary.

If, reflecting reality, we can assume that another source is always available at some cost, then that places a ceiling on the penalty for a DRWH tank running dry. So one approach to dealing with reliability is to just value all the water that a DRWH system actually does supply and compare this with the cost that would be incurred if the system were absent. However, in recognition of the well-being generated by a householder knowing she has water in store and of the extra transactional costs of obtaining water from a source not normally used by that household, we might additionally incorporate a 'failure day' penalty in any DRWH economic performance model.

A less crude modelling approach would be to link value per litre to the season – a dry-season to wet-season ratio as high as 5 has been suggested by some field workers, although venders' rates rarely vary that much. Alternatively successive litres on the same day may be valued differently in a way (unit value declining with quantity) that reflects some combination of the user's value curve with the seasonal cost of water from alternative sources. One such source incidentally is bowsered water delivered to the convenient DRWH tank. Whatever method is used, it should be compatible with the household's water management strategy as discussed below.

Having chosen some formula for the 'value' of the water delivered and evaluated it (by simulation) for a range of system designs, we need to place that value alongside the cost of the system. Such cost can be broken down into a roofing component, a tank component, a guttering component, a component for ancillaries (e.g. pumps and filters) and a system construction overhead. The last item, which may be larger than the others in the case of such modes of installation as initiation by an NGO, we will neglect in the subsequent discussion. The first item (roof) is both in theory and practice normally taken as 'existing' and not chargeable to RWH. As however in this project there is a particular bias to the poor, whose houses may not have suitable 'hard' roofing, a study will be made later of whether the benefit of RWH is sometimes high enough to justify also paying for a suitable catchment surface to be installed. For purposes of present discussion we will focus on two cost components, that for the tank with its core ancillaries and that for the arrangement of gutters and downpipes.

The storage tank is usually the most expensive part of a DRWH system, typically accounting for over 60% of the total cost of a VLC system and over 80% of a large system. Until the technical size limit of a particular tank type has been reached, the sensitivity of tank cost to size ($ to litres capacity) is typically only 0.6. The RWH system benefit – expressed as mean annual value of water delivered – has a sensitivity to tank size of typically under 0.5 for small tanks and under 0.3 for large ones. Figure 7.2 shows the way volumetric yield varies with tank size for two types of tropical climate. If we combining these effects into a Benefit:Cost ratio, we find that the ratio normally falls with increase in tank size as is illustrated in Figure 5.3. In that Figure, for which yield/cost has been arbitrarily normalised to its maximum value, the maximum return occurs when the tank is equal in size to only about 3 days mean run-off. Even allowing for guttering costs, the system with the highest return (i.e. minimum Payback) has a very small tank. If we use some more complex economic B/C measure than Payback Time, we still find that the optimum tank size is small. Such a small system gives a low reliability, so penalising unreliability very heavily (within our formula for calculating value) would shift the optimum tank size upwards a little. Even so, the calculations confirm that by the criterion of return on investment, RWH is best used as a partial supply of only modest reliability. It is on this basis that Informal DRWH finds favour with its practitioners and that VLC designs are so worth exploring.

If instead of maximising 'return' we change to maximising the profit (e.g. NPV) from installing a system, we can expect the optimum size to increase. Unfortunately we need to first select a discount rate in order to perform such a calculation and there is great uncertainty concerning what rate to choose.

Fig 7.2: Annual water value v Tank size

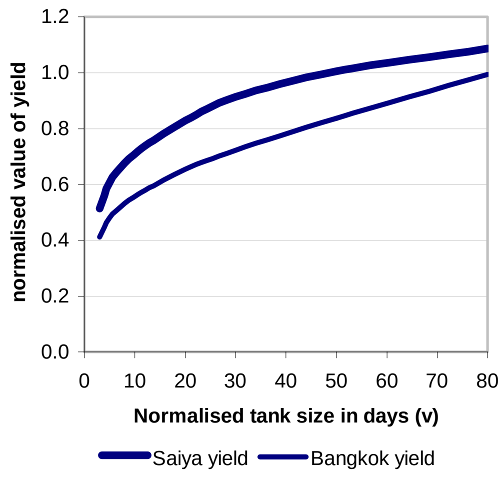
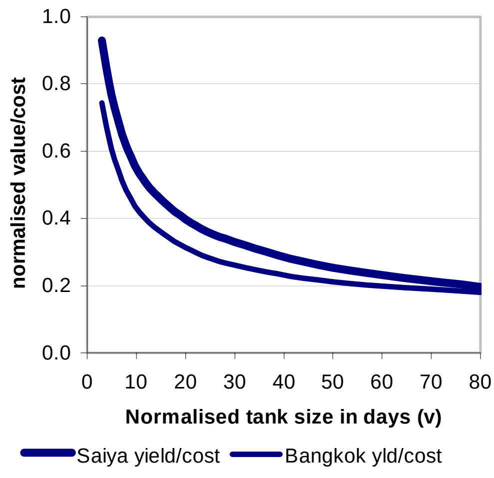


Fig 7.3: Value/Cost v Tank size



Notes: Upper (bold) curve represents Saiya Kenya (bimodal rainfall); lower curve represents Bangkok, Thailand (unimodal/Monsoon)

Normalised daily demand d = 1.0; Dry-season value weighting K_d = 2; System cost proportional to $V^{0.7}$

The optimum sizing of gutters is less important, and mathematically more complex, than the sizing of tanks. Making a gutter larger will increase its width, its capacity to convey water to a downpipe and of course its cost. A greater width may reduce the fraction of roof run-off that is lost by overshooting the gutter during a downpour or a gale. The greater capacity will normally reduce the annual fraction lost through gutter overflow. Unfortunately it is misleading to simply multiply an interception fraction (to measure the first) and a conveyance fraction (to measure the second). The two types of failure, overshoot and spillage, are highly correlated and so the measures cannot be treated as statistically independent. Generally the sensitivity of gutter performance (fraction of water successfully both intercepted and conveyed) to gutter cost is greater than unity for very small gutters but falls rapidly as one approaches a realistic gutter size. A typical economically optimum gutter size occurs around that which would overflow at rainfall intensity i_{90}, i.e. the intensity that only 10% of rainfall exceeds. This size will give an annual overflow fraction of about 2%, and a similar annual overshoot fraction. The issue is discussed at length in (Still, 2001).

A final issue of interest to both householders and DRWH promoters is whether 'staged' building of a domestic system is economic. The answer is unfortunately generally 'No', as demonstrated by calculations for a Kenyan location (Thomas, 2001) where the Payback Time for the second of two 600 l water jars to be separately installed is 7 times longer than for the first jar. This is partly because building a particular storage capacity in stages is more expensive than installing it all in one go, and partly because each addition to storage brings diminishing increase in returns. Although the B/C ratio for, and hence the return on, additional storage will usually be low, it may give an increase in NPV.

Optimum System Use

From the field there are many examples of variation in water management strategy. Thus at one extreme tank-water may remain unused in the wet season in order to maximise that available in the dry season. At the opposite extreme, water is drawn lavishly in the wet season in order to minimise tank overflow. Users often adjust withdrawals in response to the amount remaining in the tank. Withdrawals are normally some multiple of a nominal or peak withdrawal rate whose selection strongly influences the quantity-to-reliability trade off. Oddly the effect of different management strategies on the size of annual benefit seems not to have interested the many designers of performance-forecasting models. Instead each has assumed a single management strategy, usually one consistent with such a simplified objective as 'just achieve 100% reliability over 10 years' or 'maximise dry-season yield'.

Using 10 years data from Western Kenya (where the bimodal rainfall pattern is favourable to VLV DRWH) the impact of different tank management strategies on reliability, yield and value was simulated. The results are shown in Table 7.2, from which it is clear that a fixed demand strategy is far from optimum. The actual four demand patterns modelled were

A. Demand is fixed at $D = D_n$ where in this case D_n was set equal to the mean daily roof runoff.

B. Demand is varied with the amount left in the tank. $D = 1.5D_n$ when the tank is more than 2/3 full; $D = D_n$ when it is 1/3 to 2/3 full; $D = 0.5D_n$ when it is less than 1/3 full.

C. Demand is varied with the season, being $D_w = 1.2D_n$ in the wet season and only. $D_d = 0.8D_n$ in the dry.

D. Demand is varied with both season and tank content. In the wet season $D_w = 1.2D_n$ when the tank is at least 2/3 full, otherwise $D_w = 0$. In the dry season a low fixed demand $D = 0.8D_n$ is applied.

These are of course but a selection from the infinite variations possible: they are fairly mild versions of demand management.

Table 7.2: Effect of different demand-management strategies

Water withdrawal strategy	Reliability (%)	Seasonally adjusted output value (as % of maximum)	
		$K_d = 1$	$K_d = 5$
A – fixed	59	64	71
B – varies with tank content	70	69	74
C – varies with season	54	68	72
D – varies with season & content	81	55	81

K_d is the ratio of dry-season to wet-season unit water value, where 'dry season' is defined by total rainfall in last 14 days being under 50% of the fortnightly mean. When $K_d = 1$, the normalised output *value* measure is the same as the normalised volumetric yield.

Tank size equals 7 days mean roof run-off. Nominal demand equals mean daily roof run-off.

In these calculations the valuation of water has incorporated only a dry-season premium (via the weighting factor K_d). The differences between the strategies would be more marked if water had been valued on a sliding scale that applied an enhanced unit value to the first say 5 litres/capita withdrawn each day.

In general it *is* worth regulating the withdrawal rate on a particular day according to how much remains in the tank on that day. Indeed this is widely done by householders after owning a tank for two or more seasons. It also has some implication for tank design, as it makes it desirable that the user can quickly if roughly estimate tank contents. Means of doing this vary from opening a cover and looking in, using a dip-stick, feeling the tank surface for temperature changes and employing electronic measurement. What seem not to work in the tropics are sight tubes, as these are invariable obscured by algal growth after some months' use.

In Maharashtra India, NE Brazil and elsewhere, DRWH has been introduced first in locations where water problems had already led to the periodic use of water bowsers. Such distribution is made cheaper by the ability of each household to store say 3 weeks dry-season consumption. Thus the introduction of small RW tanks may not mean that all dry-season needs can be met, but it will reduce the volume and even more the frequency of transporting back-up supplies from afar. In Africa one can observe the dry-season topping up of RW tanks from distant point sources at times like weekends when schoolchild labour and bicycles are readily available. More generally, roofwater is 'mixed' with water from other sources in proportions that reflect the latter's cost and perceived quality. To economically model such behaviour is however very complex, and appears not to have been yet attempted.

7.3. Economic viability

Benefits

In the discussion during the previous section, the benefits of DRWH have been normally considered to be measurable via reduction in previously incurred water costs, whether time savings or direct cash savings. Classic examples of such savings following a specific and intensive RWH dissemination programme are Northern China (Lusheng *et al*, 2001) and Up-country Sri Lanka (Aheeyar, 2001). In the former the saving in water-fetching time was 75%, in the latter 53%, so that both programmes represent partial RWH.

However there are also health benefits. In the China case, health-care expenses were claimed to have dropped by 52%. In Sri Lanka a significant concomitant improvement in hygiene and household sanitation was noted.

It would be nice, for a RWH protagonist to add in such health benefits into any economic model. In practice it is wiser to keep the economic analysis to only the most obvious costs and benefits and to treat indirect benefits under the heading of DRWH acceptability by users.

'Informal' Roofwater Harvesting

As we *define* Informal DRWH as opportunistic collection of run-off using only already available utensils, we effectively exclude the use of gutters. With some roof plans, there is a concentration of run-off in the gulleys where perpendicular roof sections meet. More commonly however the roof plan of low-income housing is rectangular, so that the run-off per unit length of roof edge cannot exceed the product of the roof length perpendicular to its edge and the rainfall intensity. In a typical setting (e.g. with corrugated iron roofing sheets of length 3 m) each 1 mm of rainfall will yield about 2.6 litres of runoff per m length of roof, of which some 2.3 litres might be intercepted by a ground-level vessel. (Collecting vessels are likely to be placed 1 to 2 meters below the roof edge, so there is considerable scope for splash-spillage.)

The vessels most commonly used for informal DRWH are plastic washing bowls or metal cooking pots (e.g. sufurias). Vessel diameter is more relevant than capacity as it determines how much can be intercepted; inadequate capacity can be compensated by regularly transferring collected water into a jerrycan or other narrow-necked container.

Analysis of rainfall records from three different tropical climatic zones (bimodal, unimodal and semi-arid, see Appendix C) showed that the rainfall amplitude distribution on *wet* days is fairly similar. However the number of wet days varies with location, very roughly in proportion to annual rainfall (approx 1 wet day per 9 to 12 mm rain). In particular the thresholds corresponding to the first, second and third quartile of cumulative rainfall were quite close, averaging 12, 25 and 48 mm/day respectively. This data is re-expressed in terms of fractions of wet days and combined with the 'standard' roof length discussed above to give Table 7.3.

Table 7.3 Collection yields from common utensils

Collecting vessel	Capacity	Diameter	Maximum litres intercepted at specified daily rainfall			
	litres	cm	4 mm rain	9 mm rain	20 mm rain	29 mm rain
Exceeded for (fraction *wet* days)			60%	40%	20%	10%
Washing bowl	22	48	4.4	10	22	32
Large saucepan	14	35	3.2	7.2	16	23.3
Measuring cup	1	12	1.1	2.5	5.4	8

In the case of the larger vessels the amount collectible will be limited by the vessel's volume, whereas in the case of the cup we may assume transfer to another store. For the Equatorial (humid) tropics and the Monsoon belt, the fraction is typically 0.37 – see Appendix C. If we assume, reasonably, that a normal household's total storage capacity equals 1 day's consumption, we can come to a crude estimate of the degree to which informal DRWH can meet the household's water needs.

Of the 3 containers analysed, the measuring cup offers the poorest service – it must be used in considerable numbers, it needs frequent transfer to another vessel and its small diameter will lead to much water being missed during wind gusts or lost by splashing. A generous provision of the other containers would be 1 bowl + 1 saucepan per *two* poor-household members, although enthusiasts in African villages have been seen to put out as many as 6 bowls. 18 lcd may be taken to represent a comfortable level of water supply. On this basis and using averaged, wet-day, rainfall amplitude distributions:

- all water needs could be met from informal DRWH for about 20% of wet days; during such days the limitation is storage, since run-off into the vessels exceeds demand,
- at least half of water needs could be met for a further 20% of wet days,
- averaged over all wet days, 44% of water needs could be met.

Noting the fraction of days that are wet, we might thus expect conscientiously practised Informal DRWH to meet some 13-20% of annual water needs in the tropics. The collected water is only of medium quality, since there is some danger of mud splashing into the containers. The process of collection requires some care and interferes with the regular uses of the utensils employed: its cost is thus low but not zero. In urban areas it is unlikely to be safe to leave those utensils outside at night. That Informal DRWH is considered worthwhile is reflected by the large fraction of households in many communities that practice it, however it will rarely contribute a very significant fraction of annual household water needs. We may continue to associate Informal DRWH with up to 20% satisfaction of water needs, VLC DRWH with 60% to 80% satisfaction and 'Stand-alone' DRWH with >95% satisfaction. The intervening bands (20-60% and 80-95%) represent forms of DRWH with little economic appeal.

Viability of DRWH for an Unsubsidised Individual Household

For an individual household, DRWH may represent the only option for improving its water supply above the level adopted by the surrounding community. The improvement may be one of water quality but is most commonly one of water convenience. The primary benefit from installing a DRWH system is a reduction in the running cost (time or money) previously expended in obtaining water from point sources. There is little or no capital saving to a household from reducing usage of such sources, so the primary economic test is simply whether the savings in running costs justify the capital cost of the DRWH system. Other benefits may be improved water quality (argued above to be only of value for that fraction of water demand required to be of superior quality) and increased water quantity. As already argued, this situation lends itself to the use of Payback Time as the primary economic measure.

A household that already receives adequate quantities of quality water reliably and at a low unit cost – whether due to convenient geography or subsidy – would be unwise to install DRWH. Conversely where the nearest point source is distant or difficult to access or where full tariffs are imposed, adopting DRWH will generally be profitable. Again, where available water is too mineralised for Grade 1 or Grade 2 applications, DRWH to provide the bulk of dinking/cooking water should be viable.

A crude calculation sequence that may be just within a householder's capacity is as follows:

for the largest DRWH tank affordable under local conditions of credit or savings, obtain its cost and also an estimate of its dry season and wet season yield for the available roof (this will need design curves for the locality prepared by a RWH promotional agency);

- value the water for each season at their respective water-carrier or water-kiosk tariffs;
- divide capital cost by 1 years projected value and re-express as a Payback Time in months;
- assess the acceptability of this Payback Time.

However water-vendor rates seem generally to be higher than the opportunity costs of householders' own water-drawing labour, despite vendors often employing transport aids such as bikes, carts or donkeys. This is especially so where the distance to a point source is short. Payback Times calculated on a vendor pricing basis should probably be less than 12 months for acceptability by poor households.

System costs vary with tank size, country and extent to which RWH is established. For a say 1000 litre system, representative of VLC DRWH, the lowest tank cost in various countries vary widely. Table 7.4 was calculated using a cost to size sensitivity of 0.6, whenever cost data was for a size other than 1000 litres. In some cases (India, Brazil) the extrapolation is large and may overestimate costs. Moreover some sources quote production costs, others sale prices.

Table 7.4: Tank costs

Country	Cost of 1000 litre tank ($)	Source of information
Cambodia	5	Crenn, Kompong Speu, Private communication, Nov 2001
Thailand	10	Ariyabandu, Tour of Khon Kaen, May 2001
India	43	Renu Gera, ferrocement, UNICEF Maharashtra, 2000
Ethiopia	34	WA, jar construction in Arerti, Oct 2001
Brazil	43	Gnadlinger, IRPAA, Juazeiro, 1999 (10,000 litre tanks)
Bangladesh	19	ring tank/jars, (Ferdausi 2000)

The low figures from SE Asia are striking. The corresponding overall system cost ranges from $10 to $50, and we will use the higher figure in the ensuing calculations as they give the least optimistic economic returns.

The cost of water purchased from vendors in E Africa cited in the surveys reported in section 5 of this report ranged from 0.4 $¢_{US}$/litre to 0.9 ¢/litre. Tariffs for standpipe water are much lower, e.g. 0.06 ¢/litre, but do not cover any time expended in queuing or carriage. Combined with a typical VLC DRWH costing $50 and yielding 22,000 litres per year, the vendor rate gives a Payback range of 3-7 months.

Payback Times for the most and least promising households in a small sample in Kyenjojo, Uganda (Rees 2000) ranged from 4-9 months, in a situation where water yields were inferred from reduction in use of carried water and valuation was at vendor rates.

Using an opportunity labour value of 20 ¢/hour, the mean water-fetching time of 2.2 hours/day reported from 240 houses (12 hilly locations in 3 E African countries) and an assumed 66% reduction in fetching gives a Payback Time of 5.5 months.

There seems little doubt that in hilly country or where point sources are widely spaced, 6-month Payback Times are obtainable. As DRWH system should last several years and operating costs are negligible, a 6-month Payback looks very attractive.

However, as noted in the socio-gender section, the beneficiaries of VLC DRWH investments are mainly women and children, yet control of investment in such systems is predominantly by male family members. The conflict of interests is unfavourable to investment taking place.

The capital sums involved for VLC DRWH are a little less than those needed for buying a bicycle, an ox or 40 m^2 of hard roof. These are all items beyond the savings of very poor families and hence for which some form of credit would commonly be required. The availability of micro-credit and the admissibility of its use for DRWH purchase are therefore key determinants of its uptake.

Payback Times for large ‘Sole-source’ DRWH systems are likely to be 2 to 3 times longer than for the VLC DRWH systems just discussed. Middle-class families are more likely to value the convenience of a single source, to have access to the necessary investment, to be already paying cash for their water and to tolerate a Payback Time of up to 2 years.

Viability of DRWH as a Water Supply Option for a Settlement

In the case of a growing settlement - where installing DRWH might bring both operating savings, such as reduced walking and queuing, and the avoidance of some capital expenditure on new point sources – the return on DRWH investment should be even better. At a cost of under $10 per capita, VLC DRWH might be justified on capital savings alone, with operational savings an extra bonus. However the financing of DRWH from communal, governmental, NGO or commercial budgets raises many difficulties. These include

a. VLC systems require some backup from point sources at the most difficult time of year (dry season), so some point sources must be maintained.

b. Not all households are suited to DRWH systems so that their installation may exacerbate wealth differences or be seen as discriminatory.

c. Satisfactory supervision of installation at so many locations poses logistical problems for most agencies; VLC systems in particular cannot easily carry the cost of inspection by a remotely-based officer.

Difficulty (b) above especially affects agencies focussing upon poverty alleviation. Where the lack of suitable (hard) roofing excludes the poorest households from participating in DRWH, it may be necessary to economically model a new roof as well as the guttering and storage components of a system. It is likely however that adding roofing costs will double VLC DRWH Payback Times.

In practice, community-wide DRWH funded/subsidised by public or charitable sources have so far found favour only under rather specialised circumstances. These include gross problems with groundwater (e.g. Bengal, W Germany, plains India), the partial exhaustion of traditional sources (e.g. N China) and the application of a public service ethos in locations particularly unsuited to rival water technologies (e.g. Sri Lanka, NE Brazil). As both groundwater problems and reaching limits to further expanding surface sources are becoming common, it seems timely that the comparative economics of DRWH and point sources be better understood. Unfortunately VLC DRWH is not well-suited to use in those 15 or so semi-arid countries most vulnerable to growing water scarcity. As, unlike with most other water supply technologies, the production of a DRWH system has no large inherent collective or communal dimension, its immediate progress may lie mainly outside either the public or the water company sphere.

However the main long-term role of DRWH may prove to be filling the growing deficit in surface water in countries where groundwater management is failing. In this respect it becomes urgent to evaluate RWH by such classical criteria as production cost per kilolitre delivered, a process that requires agreement about the discount rate to be used in converting capital costs to unit product costs. Assuming a discount rate of 25% pa, VLC DRWH may be able to reduce its production cost to $0.5 per kilolitre, which would be comparable with the cost of extra supplies from surface or underground sources in some tropical areas today.

Aid agencies have been involved in RWH mainly in connection with water supply to communal buildings like schools. However the relief of female drudgery, opportunities for women’s empowerment and some scope for livelihood generation have interested some agencies in domestic systems. Because water vending is most often practised by young men, this group would lose most by any replacement of vending by DRWH.

The evidence from Thailand and elsewhere is that DRWH system production is moving from the mason to the factory. Whether that will remove production from the local to the national economy is less clear, because key DRWH components are bulky and therefore costly to transport. At present tanks manufactured on a small scale within a few kilometres of where they will be installed are still cheaper than tanks mass-produced in cities. Moreover there is as yet little international trade in DRWH components. Current low oil prices have favoured mass production of lightweight plastic tanks in India and Australia, but it seems unlikely that plastics can maintain any cost advantage in future, at least in low-income countries. For guttering, pumps and filters however, the advantages of mass production and of using materials like plastics are rather greater than for tanks.

7.4. Economics conclusions

- VLC DRWH systems, providing 60-80% of a household’s water, exhibit Payback Times of 6 months or less in hilly or otherwise ‘difficult’ areas of East Africa, despite the unusually high (e.g. 4 ¢US/litre capacity) cost of tanks there. In S Asia now and E Africa in the future, the Payback should be shorter, however it seems unlikely that DRWH can provide water for under $1 per m3 unless Payback Times exceeding 2 years are acceptable.
- Informal DRWH, in which households have storage in the form of wide-mouthed bowls or pans equal to 1 day’s demand, can yield on average up to 44% of demand on wet days. However the

fraction of wet days on which all demand is met rarely exceeds 20%. In tropical regions the fraction of days that are wet is about one third.

- 'Sole-source DRWH' exhibits Payback Times that are 2 or 3 times higher than those of VLC systems and is unlikely to appeal to poor households. Such higher Times will also apply to those VLC systems in which the cost of the roof has to be charged against DRWH.
- As about half the value (but not necessarily half the cost) of domestic water is associated with its higher quality fraction, VLC DRWH is viable for providing drinking/cooking water alone in situations where cheap but poor-quality sources are available for other uses.
- The impact of VLC DRWH on local employment is hard to evaluate. Its widespread adoption will release much householder time for productive purposes and generate some jobs in construction. It will however reduce employment in water vending, currently usually carried out by young males.
- VLC DRWH is particularly beneficial in areas currently dependent on groundwater sources whose quantity or quality is declining. It is less valuable where surface water is the main current source, because of its weakness in providing water in the driest months (when surface sources are also most stressed).
- Elaborate valuation formulae allow the optimisation of computer models of DRWH systems, but are too complex for use by householders or installers. However they confirm what is already perceived by many users, that there are significant advantages in replacing a constant-demand regime by an adaptive one. Modifying the rate of water withdrawal partially in proportion to the amount still remaining in store is a simple and efficient tank management strategy.

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APPENDICES

A: Example Of Rural Community Survey - Arerti Village, Ethiopia

B: Examples Of Urban Household Surveys – Colombo And Kampala

C: Tank Sizing In The Context Of Climate Variation

D: Tank Stress Analysis

APPENDIX A

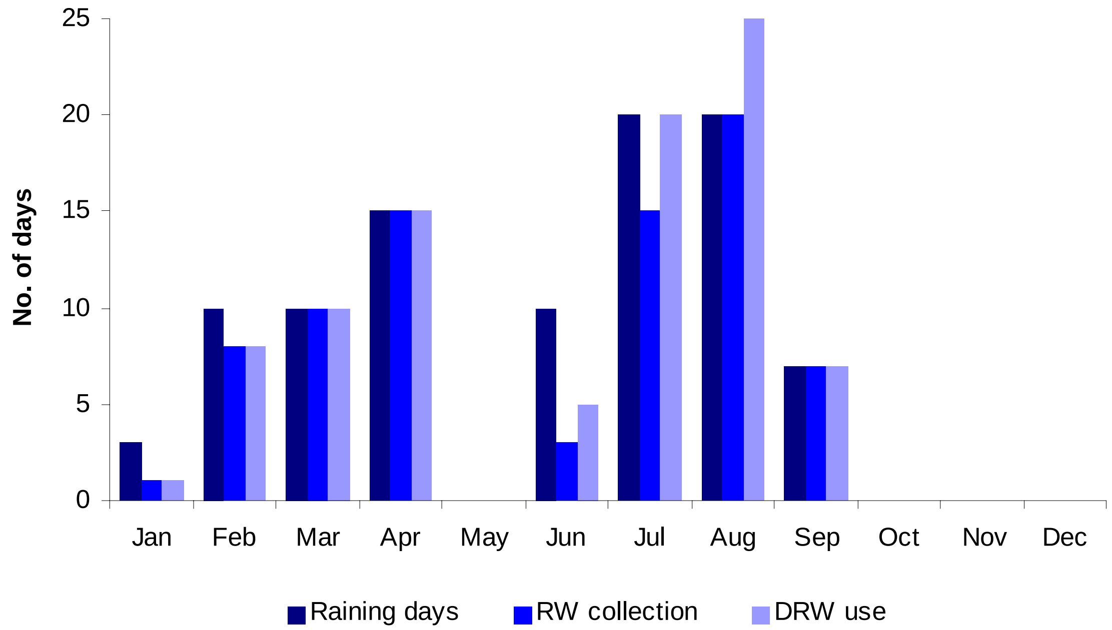
EXAMPLE OF RURAL COMMUNITY SURVEY - ARERTI VILLAGE, ETHIOPIA

Seasonal calendar

Formal roofwater [RW] harvesting requires the installation of purpose-built equipment such as gutters, down-pipes and different forms of tanks for the collection of RW. Informal harvesting employs household articles like bowls, open-top cans, barrels etc.

The number of rainy days, of informal rainwater collection and use of rainwater for each month over the year in Arerti village, Ethiopia have been depicted in Figure 1.

Figure A1. Monthly number of rainy days, informal rainwater collection and domestic use of rainwater in Arerti, Ethiopia.

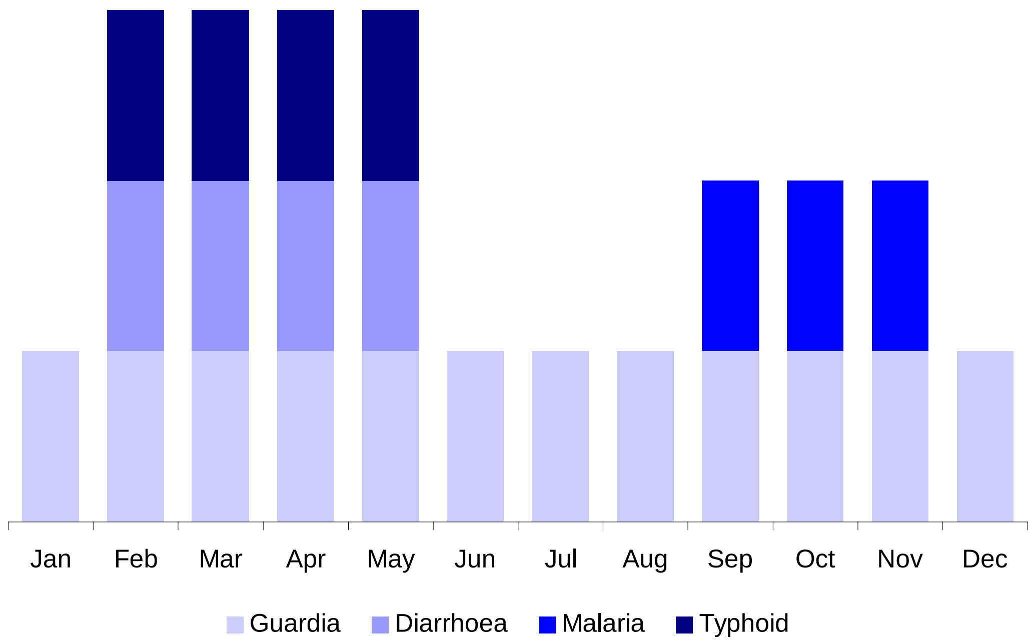


It can be seen from the figure that October-December is the main [long] dry season, with a shorter dry spell during May. July and August are the wettest months, each experiencing about 20 days of rainfall. February, March and June are months with moderate [10-15 days] rainfall. In four out of the seven raining months [March-April, August-September], rainwater is collected on all the days that it rains. In other wet months, rainwater is collected for fewer days than it actually rains.

Arerti h/hs use rainwater in all the seven months when it rains, even if only a single day as in January. October-December is the period when there is no use of rainwater, because there is no rain at all over that period. Rainwater is used almost all through the month in August and for about 20 days in July. It is evident that use of rainwater from informal DRWH varies in line with rainfall and rainwater collection.

The occurrence of diseases [Figure 2] was found to have little correlation with rainfall [Figure 1]. Guardia is endemic throughout the year. Other water-related diseases are seasonal. February-May is the period of greatest misery, being simultaneously affected by guardia, diarrhoea and typhoid, despite May being a rainless month. Surprisingly, the two months with highest rainfall in the region [July-August] are minimally affected by water related diseases.

Figure 2. Water related disease occurrence over the year in Arerti



Water sources and access to them

The tap-stands are about 30m at best from the farthest homestead, but the river is about 7 km from the village. Access to the tap-stands is over flat terrain, while access to the river is over steep terrain. Paths in the wet season are muddy to the river and loose stony to the tap-stands. In the dry season, footing on the way to the tap-stands is dusty, while that for the river is stony and dusty. Women and girls usually walk to the tap-stands and also to the river, but they take donkeys to the river to fetch water. There is no hazard on the way to the tap-stands but the way to the river is hazardous due to wild animals and risk of abduction and fall. The tracks to the tap-stands are suitable not only for four wheeled vehicles, but also for bicycles and for walking. The river is accessible only by foot. It takes only about 5-10 minutes to walk to the tap-stands and the same for coming back from there, but the journey to the river takes about 1½ hour, while it takes about 2½ hours to get back from the river with the load of water.

Table 1 Water sources at Arerti, Ethiopia

Measure	Water Source	
	A	B
Type (tube well, protected spring, unprotected spring, etc)	Tap-stand	River (Burka)
In which months is this source used?	All year	When tapstands fail and in dry season
Which region of the community uses this source (refer to map)?	All region	All region
Which income groups use this source?	All groups	All groups
Who usually collects water from this source? (% total fetchers):		
Women	50	30
Men	5	5
Girls	30	30
Boys	10	20
Water venders	5	15
What other uses of the water take place at the source?		
bathing	No	Yes
washing clothes	No	Yes
watering livestock	No	Yes
Time to Queue (dry season)	1 week	No queue
Time to Queue (wet season)	1 hour	No queue
What hazards are there at the water source?		
Animals	No	Yes
Risk of Assault	Yes	No
Falls	No	Yes
Insects and disease	No	Yes
Road accident	No	Yes
Other		Abduction
Long term reliability (% of year source is available)	65%	100%
Short term reliability (% of days per week source is available)	100% [unless fails]	100%
Has the source ever become polluted? How?	No	Yes. By animal faeces
Who owns the source?	Government	God
Is any payment made? How much?	10c*/Jerrycan, 40c*/Barrel	No

c are Ethiopian cents

Organisation/Group profiles

Three types of organization/groups were found operating in Arerti village at the time of this survey. The most important category is called the *edir*, which is primarily a social group involved in weddings, meetings and mourning activities. These groups have both male and female members from all socioeconomic groups within the village, while leadership lies on the men. Second in the ladder of relative importance lie *ekub* groups. These are basically financial institutions dealing with rotational savings and extend support to people in times of distress. They have separate men's group and women's group and also for different socioeconomic group within the society. The leadership follows the membership pattern. The least significant groups are called *mahiber*, which are religious groups and takes care of communal feasts.

It can be visualized from Plate 1 that *edir* and *mahiber* groups are in close interaction with each other, but the *ekub* groups function on their own without having any interaction with either of the other two groups. However, none of these groups receive any external assistance of any kind. So, they are working on a self-sustaining basis.

Socio-economic characteristics of households [h/h]

In Arerti village, there was no h/h with both hard roofs and permanent DRWHS. About 95% of h/hs had hard roof but no permanent DRWHS. The remaining h/hs [5%] were with soft [thatched] roofs.

H/hs with hard roofs and with soft roofs are similar in many of the socioeconomic characteristics. They have a mean family size of 6, with 3 children under the age of 16. Both these h/h types have farming as their main economic activities. They also grow similar kinds of crops like *Teff*, sorghum, wheat, along with occasional farming of barley and chick-pea. Livestock include one cow and one sheep. Houses are generally made of pole/mud walls and earth floors. They use standpipes as the main water source during the wet season. Jerricans are commonly used for fetching water, while smaller pots are used for storing water. They follow similar pattern of group/committee membership and have similar sort of contact with information sources.

H/hs with hard roofs and with soft roofs are dissimilar in some of the socioeconomic characteristics. 80% of children from h/hs with hard roofs attend school, while 50% of those from soft roofed h/hs attend school. Hard roofed h/hs pursue retail trading as their other main economic activity. The soft roofed h/hs generally have two ox used as draught animals. Household assets include radios and bicycles for hard roofed ones but soft roofed ones have just a radio. The former h/hs use informal DRWH as the secondary water source in the wet season, while the latter h/hs use the river during the same period. Hard roofed h/hs are frequent users of available credit. Among them, there are about 60% female headed h/hs while in the latter category [soft roofed h/hs], there are about 40% female headed h/hs. There are about 75% tenant h/hs in the hard-roof category, but all soft-roofed h/hs are house owners.

It was also revealed in they community survey that about 5% of h/hs with soft roof are aspiring to make hard roofs, while none of the hard roofed h/hs are declining in socio-economic status by converting from hard roof to soft roof.

Wealth ranking and roofing material

The community members were asked to identify the main wealth groups commonly recognized by the locals. They came up with four groups as the rich, the middle-income, the poor and the very poor [Table 2].

Table 2. Wealth groups and roofing category, Arerti, Ethiopia

	Rich h/h	Mid-income h/h	Poor h/h	Very poor h/h	All h/h
Percentages of all h/h	9	27	24	40	100
Having a hard roof (%)	73	76	70	64	86
Having a soft roof (%)	27	24	30	36	14

Table 2 reveals that the highest proportion of h/hs in Arerti are in the 'very poor' category of wealth ranking as done by the people present at the community survey. There are very few h/hs in the 'rich' category. Both the 'mid income' and 'poor' h/hs are represented by about a quarter each of the local population. 'Very poor' h/hs are the ones in need of greatest assistance in terms of meeting household water needs.

After completing the wealth ranking, the community members were requested to allocate the h/hs into two broad roofing categories, viz. Hard roof [e.g., tiled roof, or CI sheeted roof] and soft roof [i.e., thatched roof]. All the three wealth groups were thought to have a more or less similar fraction of hard-roofed houses, namely about two thirds. However the overall estimate was that 86% of all h/hs have hard roofs.

Fetching and use of water

In the wet season, the standpipe is the main water source for the residents of Arerti village. They usually start fetching water from 8AM and finish about 4PM. Women and girls usually fetch water from this source. Normal daily collection from this source in the wet season is about 3 jerrycans [i.e., 60 ltrs] per h/h. This figure, which corresponds to only about 10 litre per capita per day, is supplemented on wet days by informal DRWH. The travel to and from the standpipe takes about 30 minutes, while another hour is spent for queuing. Besides water from the tapstand, rainwater is collected whenever it rains, in all sorts of containers.

It can be seen from Table 3 below that preparing lunch and washing clothes are the largest consumers of h/h water, while drinking takes up the lowest proportion. Further analyses of the available information reveals that about 80% of daily water is used for high priority activities like, cooking, drinking and washing, while the remaining water is used for low priority works like cleaning house. Such analyses also depict that 60% of the water should be of potable quality, while the remaining water can be of poor quality like that needed to clean house. About half of the water-related works are transferable, meaning, if needed, they can be carried out outside the house, but the other half are non-transferable, that is, they need to be done within the homestead.

Table 3. Quantity and use of water per household in the wet season

Time of day	Quantity of water		Purpose
	Units *	Percent	
7 AM	5	4	Washing up face and body parts
8 AM	8	6	Preparing breakfast
9 AM	10	8	Washing dishes
10 AM	20	15	Preparing lunch
11 AM	10	8	Cleaning house
12 noon	3	2	Drinking
1 PM	10	8	Brewing local drink
2 PM	10	8	Washing dishes
3 PM	6	5	Cleaning house
4 PM	20	15	Washing clothes
5 PM	10	8	Preparing dinner
7 PM	3	2	Drinking
8 PM	10	8	Washing hands
9 PM	5	4	Making coffee/tea
Total	130	100	

Note: [*] arbitrary unit.

In the dry season, the standpipe is the primary water source, supplemented by water from the river. They usually start for the river from 4AM. Boys, girls, men, women – all go to fetch water from this source by rotation. Normal daily collection from this source in the dry season is about 2 jerrycans, i.e., 40 ltrs per h/h. This gives only about 7 litre per capita per day, but is slightly supplemented by river water and the possibility of performing laundry and bathing at the river. The travel to and back from the river takes about 3 hours time but there is no need for queuing.

Table 4. Quantity and use of water per household in the dry season

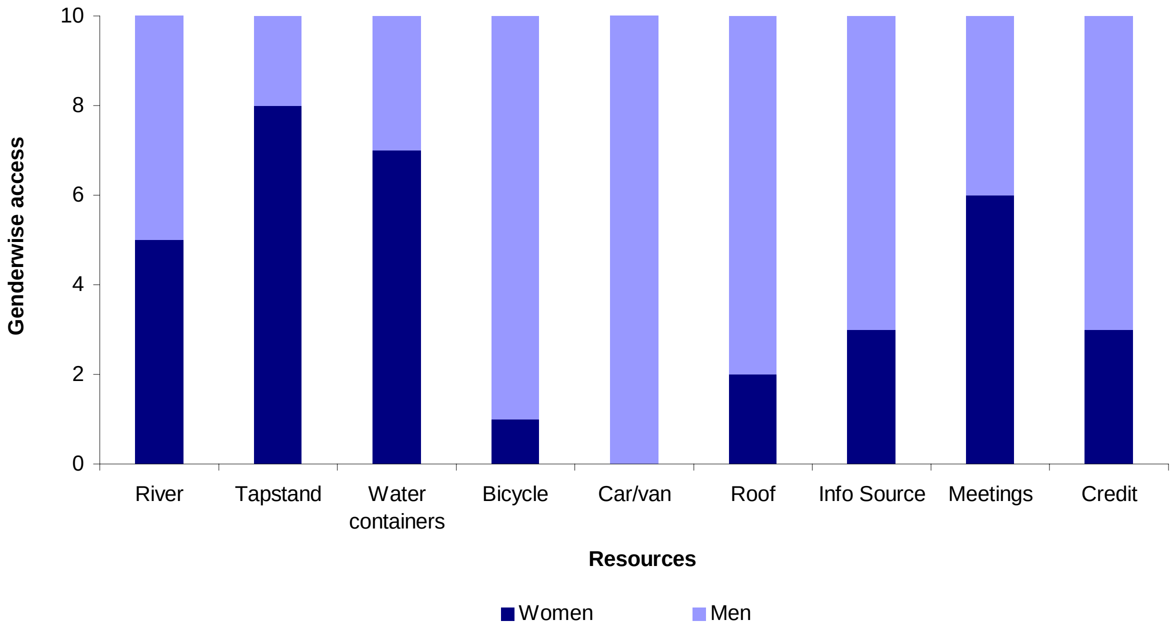
Time of day	Quantity of water		Purpose
	Units*	Percent	
7 AM	5	7	Washing up face and body parts
8 AM	6	9	Prepare breakfast +
9 AM	8	11	Wash dishes
10 AM	10	14	Prepare lunch
11 AM	5	7	Cleaning house
12 noon	3	4	Drinking
1 PM	7	10	Wash dishes
2 PM	2	3	Cleaning house
3 PM	5	7	Washing clothes
5 PM	7	10	Prepare dinner
7 PM	3	4	Drinking
8 PM	6	9	Washing body
9 PM	3	4	Tea/coffee
Total	70	100	

Table 4 shows that preparing lunch is a major consumer of h/h water in the dry as in the wet season, use of water for washing clothes get down half of that used in the wet season. But, the overall priority, water quality and transferability remain more or less same in both the seasons. Although the main water related h/h activities are the same during both the seasons, but the figures in Table 3 and Table 4 reveal that water usage in the dry season comes down to nearly half of that in the wet season.

Access and control over resources

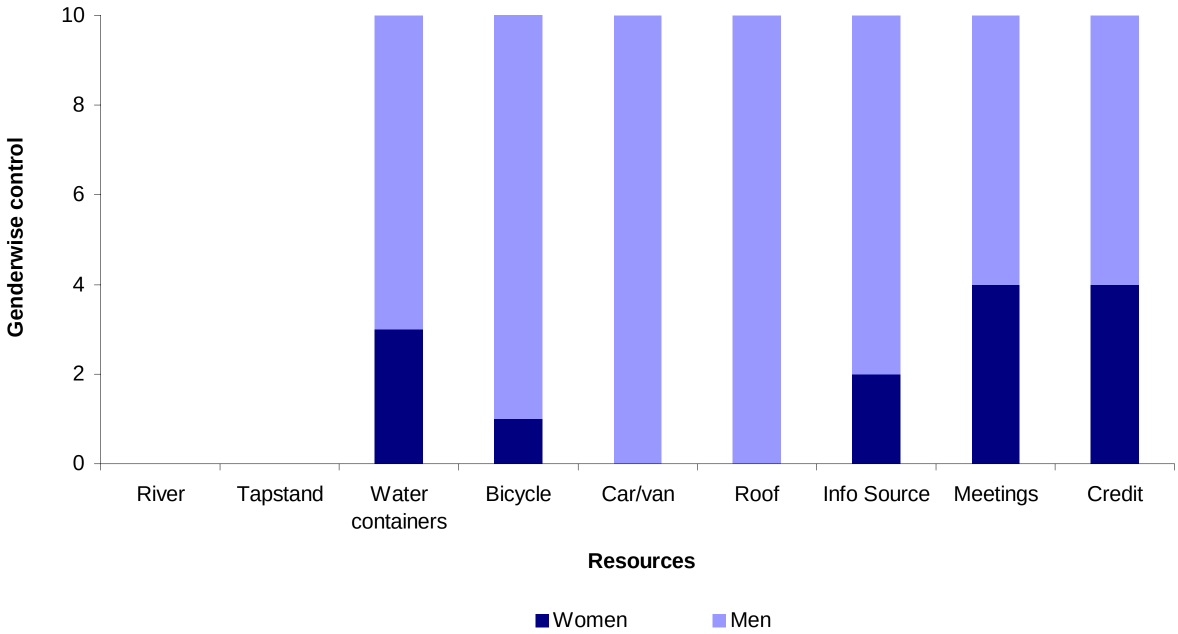
This section discusses the relative access and control over household resources associated with collection and use of water. Figure 3 depicts access or use of resources.

Figure 3. Access to resources related to collection and use of water



It can be visualised from this figure that the women have access to all of these household resources, except to car/vans [of which there are very few in Arerti]. Among the two water sources, the river is less accessible to women primarily owing to its distance. Women have greatest access to the tapstands and to water containers. Bicycles, roofing and credit are the other resources to which women have little access. Both men and women have sort of equal access to village meetings/training. Overall, women have about 40% access to resources, while men have 60% access. Figure 4 portrays control over household resources related to collection/use of water.

Figure 4. Control over resources related to collection and use of water



The river is a god-gifted natural resource, whereas the tapstands are controlled and maintained by Government water personnel. So, the villagers have no control over these two resources. It can be perceived from Figure 4 that women have very little control over bicycles, water containers and information sources as resources related with collection or use of rainwater. They have sort of moderate control over meetings and credits. All the other associated resources are wholly controlled by the men folk. Overall, women have just a little control of 20% over the resources, while men dominate with 80% control. Thus, the gender issue as encountered in Arerti must be dealt with due concern.

APPENDIX B

EXAMPLES OF URBAN HOUSEHOLD SURVEYS – COLOMBO AND KAMPALA

B1 Sri Lankan Urban Household Survey – Colombo

25 H/Hs surveyed by Mr. Epakanda on 15, 22 and 23 September 2001 at Station Road, Nugegoda, Colombo (6° 56′ N, 79° 50′ E). Approx local pop = 400

Introduction

The survey location is situated in the SE periphery of Colombo. The homesteads run along both sides of a railway line. There was no h/h with permanent DRWHS. About 90% of the h/hs had hard roof of some kind [mostly rusted CI sheets], while the rest had tar-sheet roofs.

Household Information

Family-related Information [expressed in percent except where otherwise stated]			
Average family size			4
Male: Female ratio			1.0
Female headed h/h (%)			24
Mean years of schooling (h/h heads)			5
Child fraction [<16 yrs old] (%)			27
		Male	**Female**
Age distribution (%)	0 – 15 yrs	26	29
	15 – 30 yrs	38	29
	30 – 45 yrs	12	19
	> 45 yrs	24	23
Education of h/h heads (%)	No schooling	4	8
	Yr 01 – 05	36	32
	Yr 06 – 10	60	60
	Yr 11 – 12	0	0
	> Yr 12	0	0
Occupation of H/H head (%)	Unemployed/not working	20	68
	Farming & Agricultural labour	0	0
	Non-agricultural labour	44	16
	Small trading	4	8
	Govt.job	8	4
	Private sector job	24	4

Water Fetching

Water is fetched daily in this railway-side, shanty-like locality. On the one hand, there is not enough water storage in the houses for less frequent collection, and on the other hand, water is available throughout the year from local stand-pipes. About 70% of the daily water fetching is done by women, with 40% of that done by women alone (the rest being done in cooperation with other family members). 20% of daily water fetching is done by men, while the rest is done by children alone.

Housing characteristics

Housing characteristics [expressed in % H/H except where otherwise stated]		
Ownership pattern	Own house	92
	Rented house	8
Walling pattern	Plywood/cardboard wall	92
	Pole and mud	8
Flooring pattern	Cemented floor	72
	Earth floor	28
Roofing material	CI sheeted roof	76
	Tar sheeted roof	16
	Asbestos roof	8
Roof condition	Good roof	20
	Fair roof	64
	Very poor roof	16
Roof slope	Sloping roof	100
	Flat roof	0
Guttering in roof	Complete guttering	0
	Partial guttering	0
	No guttering	100
Roof area	Gross – per household [m^2]	35
	Effective – per household [m^2]	33
	Effective – per capita [m^2]	9

Household income and expenditure

Average household income and expenditure pattern in Sri Lankan Rs/month (SLR1 = USD 0.011)		
Expenditure sectors	Food	2,970
	Water	0
	Other regular expenses [a]	495
	Other occasional expenses [b]	380
	Loan	15
Total monthly expenditure		3,860
Savings		170
Household income		4,650
Per capita income		1,270
Balance of income and expenditure	Surplus (% of households)	72
	Deficit (% of households)	28
	Average amount of surplus	790

[a] includes school fee, travel, fuel etc.

[b] includes clothing, house repair/renovation, health, travel etc.

Collection and Use of Water

Household water collection and use of water [expressed in percent of households except where otherwise stated]		
DRWH type	Permanent DRWHS	0
	Hard roof but no DRWHS	90
	Soft roof so no DRWH	10
Primary water source	Stand-pipe	80
	Neighbour's well	12
	Shallow well	4
	Well in house	4
Secondary water source [a]	Shallow well	67
	Well in house	28
	Rainwater	5
Average container size [litres]		10
Average number of containers of water used per day [number]		4
Average distance traveled per trip [metre]		32
Average time taken per trip [minute]		12

Household water collection and use of water (continued) [expressed in percent of households except where otherwise stated]		
Water fetched by	Women alone	44
	Women with children	48
	Men	8
Primary-source water used for drinking/cooking		100
Primary-source water used for other purposes [b]		48
Reason for using the primary source	No cost	12
	Easy access	12
	Nearby	16
	Good quality	28
	Only source	12
	Best alternative	20
Decision regarding water source made by	Women	60
	Men	16
	Both	24
Decision regarding water quantity	Women	76
	Men	8
	Both	16
Experience seasonal water shortage		20
Months of shortage	July-August	8
	August only	12
Decision regarding coping with water shortage made by	Women	80
	Men	20
Priority during water shortage	Drinking	40
	Drinking and cooking	60
Water is shared with neighbours		24
Total water consumption per household [litres/day]		44
Total water per capita [lcd]		11

[a] used by 72% of sampled households.

[b] the remaining [52%] h/hs use the secondary water source for other h/h activities.

DRWH [Domestic Rain Water Harvesting] : Expectations of households with currently no permanent DRWHS

Use of rain water and concern about DRWH [expressed in % households]		
Suitability of rainwater for	Drinking	40
	Cooking	40
	Dish washing	70
	Clothes washing	80
	Bathing	80
	Others	90
Has thought of DRWHS		20
Is interested in DRWHS		60
Preferred tank type	Individual	100
	Communal	0
Availability of space in house for DRWH installation		50
Decision making regarding introducing a DRWHS	Women	50
	Men	25
	Both	25
Saving time by having a DRWHS		100
Time saved [if any] of	Women's	60
	Men's	10
	Children's	20
	Everybody's	10
Purchased water		0

B2 Ugandan Urban Household Survey – Kampala

25 households surveyed by Dunstan/Shakil *et al* on 17-18 September 2001 at Nabweru locality, Wakiso district, Kampala (0° 22′ N, 32° 32′ E). Approx local population = 800.

Introduction

The survey location is situated in the NW periphery of Kampala city. The homesteads are scattered on a slightly hilly terrain. There was one h/h [4% of the sample] with permanent DRWHS. All remaining h/hs had hard (mainly CI) roofs but no permanent DRWHS.

Household Information

Family-related Information [expressed in % of H/H except where otherwise stated]			
Average family size (No.)		6	
Male: Female ratio		0.68	
Female headed h/h (%)		28	
Mean years of schooling (h/h heads)		6	
Child fraction [<16 yrs old] (%)		49	
		Male	**Female**
Age distribution (%)	0 – 15 yrs	54	45
	15 – 30 yrs	24	35
	30 – 45 yrs	10	13
	> 45 yrs	12	7
Education of h/h head (%)	No schooling	28	12
	Yr 01 – 05	8	24
	Yr 06 – 10	40	44
	Yr 11 – 12	16	20
	> Yr 12	8	0
Occupation of H/H head (%)	Unemployed/not working	28	32
	Farming & Agricultural labour	8	8
	Non-agricultural labour	0	4
	Small trading	16	24
	Govt.job	12	4
	Private sector job	36	28

Water Fetching

Water is mostly fetched on a daily basis in this peri-urban location. This is perhaps because of year round water availability from the local waterholes. So, the local residents hardly bother for weekly or monthly water fetching [just about 15% of sampled h/hs, and that also by children]. Children alone are the major drawers of water [45%], while women fetch the rest accompanied by children. Men play a very negligible role in fetching water.

Housing characteristics

Housing characteristics [expressed in % H/H except where otherwise stated]		
Ownership pattern	Own house	88
	Rented house	12
Walling pattern	Burnt bricks	80
	Sun dried bricks	12
	Pole and mud	8
Flooring pattern	Cemented floor	80
	Earth floor	20
Roofing material	CI sheeted roof	100
Roof condition	New roof	24
	Good roof	40
	Fair roof	28
	Poor roof	8
Roof slope	Sloping roof	100
	Flat roof	0
Guttering in roof	Complete guttering	4
	Partial guttering	40
	No guttering	56
Roof area	Gross – per household [m^2]	72
	Effective – per household [m^2]	68
	Effective – per capita [m^2]	12

Household income and expenditure

Average household income and expenditure pattern in Ugandan Shillings/month (UGS1000=$0.585)		
Expenditure sectors	Food	83,800
	Water	8,100
	Other regular expenses [a]	39,300
	Other occasional expenses [b]	14,930
	Loan	1,600
Total monthly expenditure		147,730
Savings		59,500
Household income		267,800
Per capita income		50,900
Balance of income and expenditure	Surplus (% of households)	80
	Deficit (% of households)	20
	Average amount of surplus	120,000

[a] includes school fee, travel, fuel etc.

[b] includes clothing, house repair/renovation, health, travel etc.

Collection and Use of Water

Household water collection and use of water [expressed in % H/H except where otherwise stated]		
DRWH type	Permanent DRWHS	4
	Hard roof, no DRWHS	72
	Soft roof	24
Primary water source	Waterhole	64
	Vendors	20
	Shallow well	8
	Rainwater	8
Secondary water source [a]	Vendors	30
	Rainwater	70
Average container size [litres]		20
Average number of containers of water used per day [number]		6
Average distance traveled per trip [metre]		500
Average time taken per trip [minute]		40

Household water collection and use of water (Continued) [expressed in % H/H except where otherwise stated]		
Water fetched by	Women alone	21
	Women with children	26
	Children alone	53
Primary-source water used for drinking/cooking		100
Primary-source water used for other purposes		100
Reason for using the primary source	No cost	12
	Easy access	16
	Nearby	28
	Good quality	36
	Only source	4
	Best alternative	4
Decision regarding water source	Women	80
	Men	20
	Both	0
Decision regarding water quantity	Women	88
	Men	12
	Both	0
Experience seasonal water shortage		24
Months of shortage	June-July	58
	Jan-February	42
Decision regarding coping with water shortage	Women	60
	Men	40
Priority during water shortage	Cooking	60
	Drinking and cooking	40
Water sharing with neighbours		44
Total water per household per day [litres]		116
Total water per capita per day [litres]		22

[a] used by 40% of sampled households.

DRWH [Domestic Rain Water Harvesting]

Expectations of households with currently no permanent DRWHS

Opinions concerning DRWH (expressed in % H/H)		
Suitability of rainwater for	Drinking	90
	Cooking	90
	Dish washing	95
	Clothes washing	95
	Bathing	100
	Others	100
Has thought of installing DRWHS		40
Is interested in installing DRWHS		95
Preferred tank type	Individual	100
	Communal	0
Space is availability for installation of DRWHS		100
Decisions regarding introducing a DRWHS made by	Women	35
	Men	45
	Both	20
Saving time expected by having a DRWHS		90
Estimated time saving (minutes/day)	Women's time	20
	Men's time	5
	Children's time	70
	Total time	5
Purchased water		65
Regular purchaser		55
Purchased quantity [per h/h per week – litres]		600
Purchased cost [per 20 litres]		150

APPENDIX C

TANK SIZING IN THE CONTEXT OF CLIMATE VARIATION

C1 Data for Practical DRWH Tank Sizing

For research purposes one can seek out appropriate data with which to examine tank-sizing strategies. If tanks are ‘small’, say less than ‘14 days’ volume, the RWH system performance is strongly affected by the daily detail of rainfall, since tropical rainfall is highly variable over the short term. Its coefficient of variation (CoV = standard deviation / average) over one month, one week and one day is many times the CoV of annual rainfall. On average these respective CoVs are 2.5, 5.3 and 15 times higher than annual CoV for the representative tropical locations of Saiya (Kenya), Bangkok and Panama.

Given only actual monthly rain data, one could use 1 month instead of 1 day as the time-step in modelling. Or one could retain 1 day as the step but assume constant daily precipitation throughout a month. However even modest accuracy requires the modelling time-step to be under say ¼ of the normalised tank size, so monthly steps will give very misleadingly optimistic performance estimates (Heggen 1993) for small (say ‘7-day’) tanks. Assuming even daily rainfall over a month will also give inaccurate results.

However even ‘actual monthly rainfall’ data is not very easy to acquire for most tropical locations and daily records are yet more scarce and costly. Since the development of the world-wide web, some detailed meteorological data can be downloaded for free [NCDC web]; however its form and the large size (e.g. 30MB) of the relevant files exclude its acquisition by non-specialists. In practice the only data really widely available is *mean annual* rainfall. It is portrayed in national and international atlases and yearbooks. Sometimes *mean monthly* rainfall alone is displayed and sometimes the *mean number of wet days* per month (Pearce 1998) is also provided.

For the NGO or Water Ministry wishing to recommend RWH tank sizes for a particular district, there are several options. One is to combine actual daily data with a mass-flow (spreadsheet) model to computer-generate performance curves. A second is to accept the very inaccurate performance estimates attainable using simple rules of the type “with a 7-day jar, demand is met for 80% of days in wet months and for 20% of days in dry months”. A third is to adjust mean monthly data into ‘pseudo’ daily data for use in such a model.

Because of the high cost of the first option and the inaccuracy of the second, we have a considerable interest in the third. Generating the requisite *pseudo daily* rainfall data from published *mean monthly* data, the full modelling process would involve 6 steps:-

i Randomise *mean monthly data* into (say 10 years of) *pseudo monthly* data – see the distribution in Figure C2.

ii For each month obtain a likely *number of wet days* using such a relationship as is shown in Figure C1.

iii Randomly allocate these days within the month.

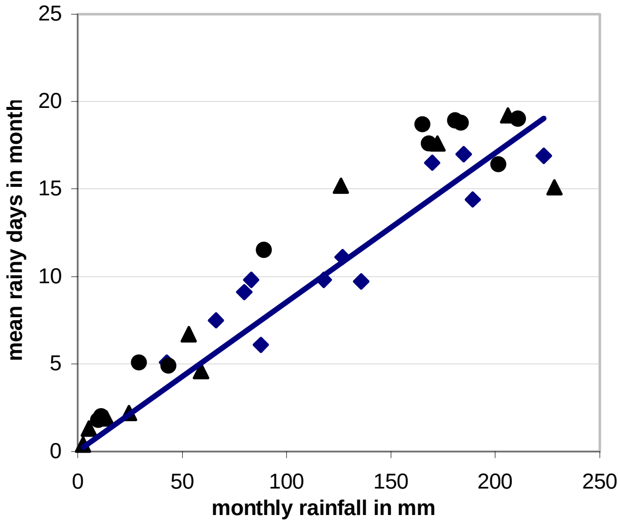
iv Using the *pseudo monthly* rainfall as a guide as well as meteorological experience of how daily rainfall varies about its mean, randomly generate *rainfall amounts for each wet day* and hence *pseudo daily* rainfall data.

v Use the resultant *pseudo daily* data over 10 years in a mass-flow type of simulation to forecast the performance of systems of various sizes.

vi Recommend a particular size taking into account its cost and its forecast performance.

This process is too long and complex for practical applications, and entails three stages of randomisation. A much cruder version would be to replace step *iii* by a look-up table that spaced the given number of rainy days uniformly through the month and to replace step *iv* by some simpler algorithm. For example we might assign 50% of a month's rain to the first wet day and share the remaining 50% evenly between the remaining days. A single look-up table, randomly-generated to match

Figure C1 Relation between mean monthly rainy days and mean monthly rainfall



Combined data for Kenyan, Thai & Panamanian weather stations taking 10 year means for each calendar month. All 3 stations have a similar annual mean rainfall (~1500 mm).

The relationship between number of wet days and rainfall is fairly linear. The line slope would differ slightly if annual mean rainfall were different – as illustrated by Table C1.

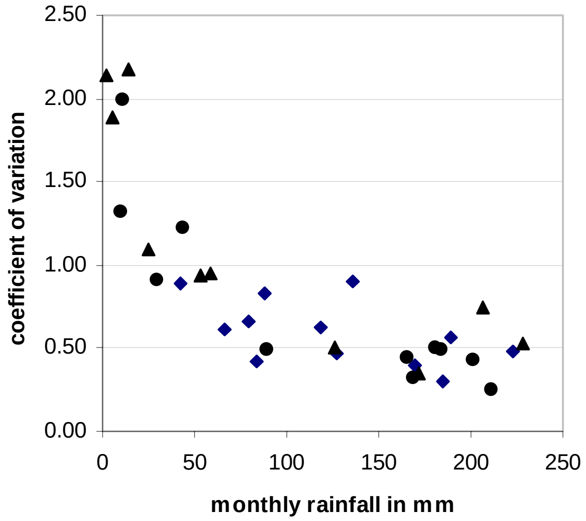
Initial experiments with such a crude model indicate reasonably close agreement with the results from simulations using *true* daily data. After further refinement, this approach will be used to generate a web service via which NGOs can convert mean monthly data into locally valid design curves.

For the individual builder or householder the situation is less satisfactory. There is access neither to accurate data nor to computers. Guidance therefore has to come from past experience, from the crudest of 'rules of thumb' or from suitably simple design guides developed by a specialist for that particular district. As system performance depends upon so many variables (demand, climate, architecture) considerable skill is required to generate readable guides – especially for users having no familiarity with formats like graphs, formulae or tables. It is worth remembering that components like tanks often come in only a few sizes whose volumes increase by about 50% per size step. The system specifier therefore does not need to know a precise optimum size, only the relative merits of the few sizes available.

C2 Climatic variability

Modelling will give us overall or 'mean' estimates on which to base an economic assessment. Of course in practice there are large fluctuations on both the demand and supply sides. Households do not have constant water needs, as is interestingly illustrated in several countries by the growth of water committees out of older burial societies. A funeral is a clear example of an unpredictable social event requiring a sudden large jump in water demand.

Figure C2 Relation between variability (CoV) and mean of monthly rainfalls

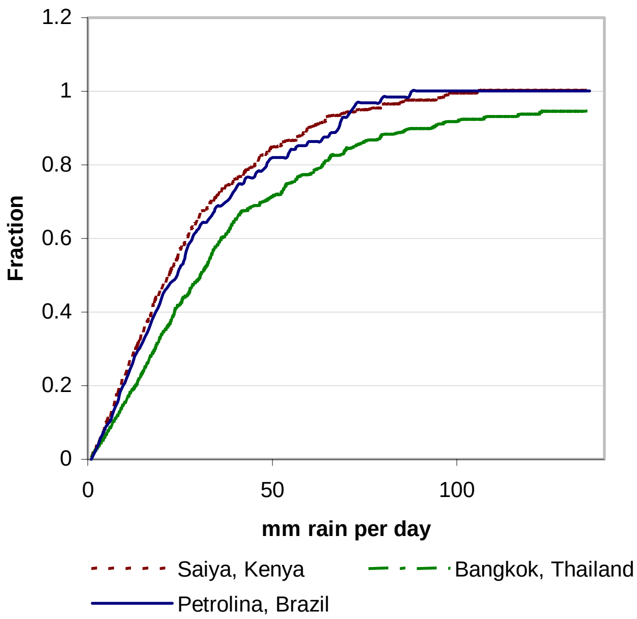


Combined data for Kenyan, Thai & Panamanian weather stations taking 10 year records for each calendar month, estimating population standard deviation (for each of the 36 [*n*=10] data sets), dividing by the mean of each set and plotting against that mean.

On the supply side there are climatic variations both short and long term. In particular monthly rainfall is variable in both a predictable ('seasonal') and unpredictable manner. The drier the month, the more unpredictable its rainfall, as Fig C2 illustrates.

RWH systems however offer some compensation for rainfall variations, since their efficiency (capture fraction) rises as rainfall falls. In consequence the variability (CoV) of annual water harvested from an existing system is only about half that of rainfall variability from year to year. Unfortunately a dry year reduces reliability more proportionally than total yield. It is because of unpredictability rather than seasonality that a withdrawal strategy based on recent reality performs better than one based on seasonal expectations.

Figure C3: Exceedence curve for daily rainfall at representative tropical locations



Saiya has an Equatorial climate (bimodal rainfall).

Bangkok has a Monsoon climate (unimodal rainfall).

Petrolina is semi-arid with particularly erratic rainfall.

For RWH systems to be installed in the humid tropics, design modelling can practically be based on rainfall records for 1 'typical' year or better for 10 years. If reliability is of unusual importance, one might use records for just the driest year in the last decade. In semi-arid regions reliability may be of such over-riding interest that building very large and expensive tanks is justified. To size these it may be worth acquiring monthly rainfall records as long as 25 years and applying corrections to account for long-term climatic trends. Predicting rare events, for example assessing the probability of extreme droughts, requires specialist skills.

Table C1: Rainfall per wet day

Location	Climate type	Annual rainfall mm	Wet day fraction of year (%)	Mean rainfall per wet day (mm)
Saiya, Kenya*	humid tropics	1505	35	11.3
Manaus, Brazil	humid tropics	1831	46	11.0
Jakarta, Indonesia	humid tropics	1799	34	14.3
Bangkok, Thailand*	unimodal	1573	29	12.8
Panama City	unimodal	1770	40	12.0
Addis Ababa, Ethiopia	unimodal	1236	38	9.6
Petrolina, Brazil*	semi-arid	514	13	9.0
Niamey, Niger	semi-arid	554	11	13.8
Peshawar, Pakistan	semi-arid	344	8	11.9
Average		*1,236*	*28*	*12.0*

Sources * daily records otherwise Pearce & Smith, 1998

APPENDIX D

TANK STRESS ANALYSIS

Pressure forces in tanks

Water exerts a pressure proportional to its depth equivalent to 10 kPa/m. The pressure always applies a force perpendicular to the inside surface of the tank, so at the bottom it acts downwards, over most of the walls it acts outwards and near the top of a doubly curved tank it can even act upwards (see Figure D1)

Figure D1: Action of pressure in a water tank

a. Straight sided

b. Doubly curved

Generally this pressure puts the tank walls into tension (stretch). This is unfortunate because many materials traditionally used for building and transferred to tank construction are only 10% or 20% as strong in tension as they are in compression.

Stresses in cylindrical tanks

In the case of a simple cylinder, the tensile stress acts around the cylinder and is called "hoop stress". This stress can be found using the equation:

$$\sigma_h = \frac{p\,r}{t} \qquad (2)$$

Where:

σ_h is the hoop stress (MPa)

p is the water pressure (MPa)

r is the tank radius (m)

t is the wall thickness (m)

This simple result however is only true when the walls of the tank are free to move as shown in Figure D2a. The movement is only very small and can be achieved by using a flexible material between floor and wall such as bitumen or by allowing the wall to slide along the floor. Where the walls are fixed, such as at the base of a tank, they will tend to bow out as shown in Figure D2b

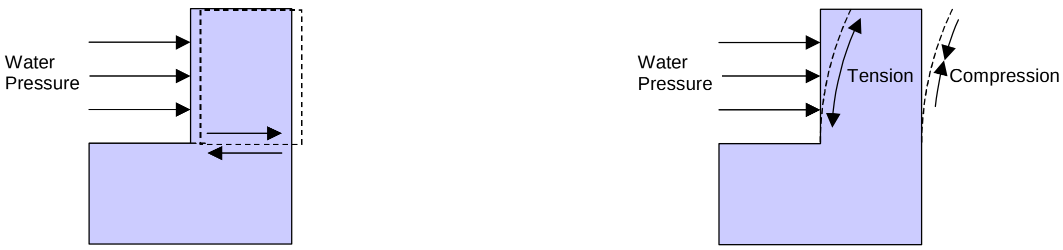
Figure D2: Movement of tank walls due to pressure

a. Unconstrained a. Constrained

This will change the hoop stress and also cause two other stresses acting in different directions as are shown in Figure D3.

Figure D3: Stresses caused by constrained walls

a. Shear Stress b. Bending stress



The wall will be stressed in shear at its edge where the water pressure forces it outwards but the base opposes this: the shear stress acts through the wall in a horizontal plane (Figure D3a). Another stress is due to bending of the tank walls as they bow outwards. This is especially high near the joint and will cause vertical compression of its outside face and tension on the inside face of a tank (Figure D3b) both acting vertically up the wall which, unless dealt with appropriately, can cause cracking of the inside face leading to failure.

Quantifying this situation is rather more complex and uses the technique of shell theory where the tank walls are idealised as being very thin (like egg shells). The tank is also considered to be made of a material whose properties are constant throughout and which will deform in direct proportion to the forces acting on it (Hooke's law). The relevant equations (Flugge, 1967)are:

$$N_\theta = \gamma r\left(h - x - he^{\frac{-\lambda x}{r}}\cos\frac{\lambda x}{r} + \left(\frac{r}{\lambda} - h\right)e^{\frac{-\lambda x}{r}}\sin\frac{\lambda x}{r}\right) \quad (3)$$

$$M_x = -\frac{\gamma r t}{\sqrt{12\left(1 - v^2\right)}}\left(\left(\frac{r}{\lambda} - h\right)e^{\frac{-\lambda x}{r}}\cos\frac{\lambda x}{r} + he^{\frac{-\lambda x}{r}}\sin\frac{\lambda x}{r}\right) \quad (4)$$

$$Q_x = \frac{\gamma t\lambda}{\sqrt{12\left(1 - v^2\right)}}\left(\left(\frac{r}{\lambda} - 2h\right)e^{\frac{-\lambda x}{r}}\cos\frac{\lambda x}{r} + \frac{r}{\lambda}e^{\frac{-\lambda x}{r}}\sin\frac{\lambda x}{r}\right) \quad (5)$$

where:

N_θ is the radial hoop force (N)

M_x is the bending moment (Nm)

Q_x is the shear force (N)

γ is the specific weight of water (density times gravity)

r is the radius (m)

h is the height water height (m)

x is the height of the stress to be calculated (m)

t is the wall thickness (m)

v is Poisson's ratio (the ratio of a materials change in shape in the direction of a stress to the change in shape perpendicular to the stress – as a rubber band is stretched it gets thinner)

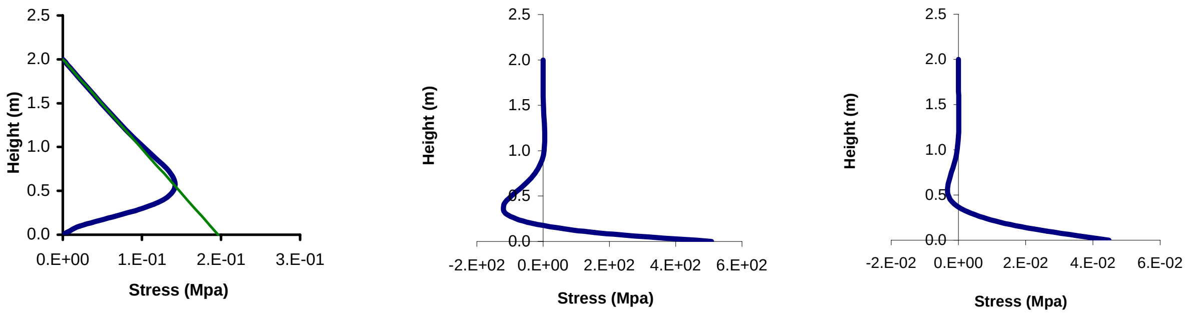
λ is given by

$$\sqrt[4]{3\left(1-v^2\right)\left(\frac{r}{t}\right)^2} \qquad (6)$$

These fairly daunting equations can be easily coded into a spreadsheet and used to provide useful curves for designing tanks. Typical output is shown in Figure D4

Figure D4: Stress curves for cylindrical tank with fixed base

a. Hoop stress b. Bending stress c. Shear stress

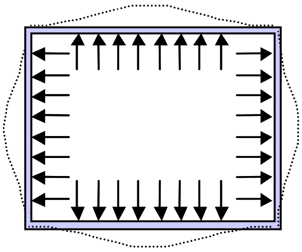


Stresses in rectangular tanks

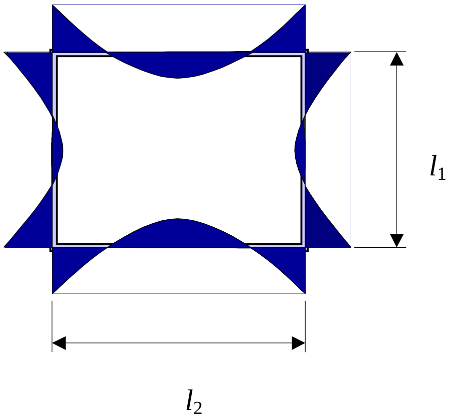
In addition to these stresses, rectangular tanks have additional stresses at localised at the corners because the pressure will slightly bow out the flat walls as shown in Figure D5a. The corners restrain this movement in a similar way to a constrained base, resulting in bending stresses.

Figure D5: Stresses in rectangular tanks

a. Movement of tank walls



b. Bending stress in a rectangular tank



In a tall thin tank these stresses can be quantified by considering each wall as a constrained beam. The relevant equation for the maximum moment which will occur at the corners (Manning, 1967) is:

$$M = \frac{1}{12} p\left(l_1^2 - l_2 l_2 + l_2^2\right) \quad (7)$$

Where:

M is the moment (Nm)

p is the pressure force (MPa)

l_1 and l_2 are the wall lengths as shown in Figure D5b (m)

The additional stress means that, generally rectangular tanks must be thicker than cylindrical tanks and should usually have some reinforcing on the inside face of the corners.

Stresses in doubly curved tanks

The tensile stresses in doubly curved structures such a spheres or jar shapes act in both horizontal and vertical directions just as the pressure in a balloon stresses the rubber, stretching it in both directions. The weight of the water on the curved sides will also put a bending stress on the structure, however bending stresses tend to be lower in doubly curved tanks as there is no sudden change in shape such as at the base of a cylinder or the corners of a rectangle.

Quantifying these stresses requires the balancing of tensile stresses in two planes and bending stresses in two planes, usually requiring a numerical solution. Turner (Turner, 1999) has developed a computer programme to deal with the tensile stresses, however bending is much more complex. Readers are referred to specialised texts on the subject such as those by Flugge (Flugge, 1967) or Kelkar & Sewell (Kelkar & Sewell, 1987)