Domestic Roofwater Harvesting
Research Programme

VERY-LOW-COST DOMESTIC ROOFWATER HARVESTING IN THE HUMID TROPICS: CONSTRAINTS AND PROBLEMS

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CONTENTS

1 INTRODUCTION

This report forms the second output of the Main Phase of a 27-month research contract (R7833) for the Department for International Development. It is one of two reports due 8 months after the authorisation of commencement of that Phase. Both Reports address 'low-cost' domestic roofwater harvesting. R1 described current practice. This (R2) analyses constraints and problems that any innovations in DRWH need to address. Its geographical scope is the three countries Sri Lanka, Ethiopia and Uganda – countries with either Equatorial or Monsoon climates that make them broadly representative of the 'humid tropics'. It draws on material relating to the three countries from household and community surveys undertaken in 8 low-income locations, from focus group and household interviews with rainwater harvesting users and from a survey of water provision institutions, agencies and policy makers.

The report focuses on the requirements of poor households and so should be taken in the context of limited funds or (in theory, at least) heavy subsidies. Such lack of funds forms one of the most important and most crippling constraints but is mitigated by the other characteristic of the study area; namely heavy and reasonably consistent rainfall. This allows DRWH systems to be built with small and thus low-cost water-storage tanks in contrast to the larger, more expensive stores required for water security in arid zones.

A direct outcome of this report is information that will guide the design activities of this project which is in turn developing new technologies to directly answer some of the problems highlighted herein. The report also identifies what information water professionals and decision makers feel they need in order to sponsor rainwater harvesting projects with confidence.

The Report contains reviews of health and institutional issues, co-ordinated by Lanka Rain Water Harvesting Forum but covering all three target countries. The review of socio-gender issues (already covered in part in Report R1) is based on field surveys. An analysis of the relationship between technology and economics is followed by an appendix that identifies, and briefly discusses, the main technical innovations being explored in the programme.

2 HEALTH

2.1 Introduction

Because rainwater harvesting systems are classified as individual systems there are no public health regulations for constructing them, maintaining them or testing the quality of the collected water. Lack of regulation result in variation in design and lack of incentive for good maintenance or for testing water quality. As a result, the water quality of most systems is not known and varies from system to system.

Recommending domestic roof water collection for drinking has direct health implications due to possible biological and chemical contamination and indirect health implications due to the breeding of disease-causing insect vectors in tanks. Contamination of rain water systems has been linked with a number of human infections (Brodrinbb *et al,* 1995; Murrell and Stewart, 1983) and chemical intoxication (Body, 1986). Many studies have looked at microbiological (Lye, 1987; Fujioka and Chinn, 1987; Fujioka *et al* , 1991; Hable and Waller, 1987; Waller *et a.,* 1984) and chemical (Gumbs and Dierberg, 1984; Olem and Berthouex, 1989; Sharpe and Young, 1982; Young and Sharp, 1984) contamination of roofwater collection.

This section will look at these issues as well as specific health issues posed by very low cost domestic rainwater harvesting systems in the humid tropics.

2.2 Chemical Contamination

There are several sources of chemical contamination of roof water. Atmospheric pollution accumulates on the roof as dry deposits as well as being washed out of the atmosphere in rain as wet deposits. In addition roof materials themselves can be a source of metal contamination.

In rural areas where atmospheric pollution is not generally a problem, several simple steps can be taken to prevent or reduce chemical contamination from the atmosphere.

However in industrialised urban areas, atmospheric contamination can be from heavy metals, organic chemicals, pesticides and herbicides. Heavy metal such as lead in areas of high traffic intensity (Yaziz et al, 1989) and Cr, Cd, Pb, Zn, Cu in the vicinity of heavy industries (Mason *et al* 1999) are reported from samples of roofwater run-off. Other potential source of lead in the rainwater collection system can be from lead-based roof paints (Body, 1986), lead-headed nails, particularly securing galvanised iron roof, lead roof flashings, and lead solder joining copper pipes (Simmons *et al* 2001). Corrugated iron/aluminium sheets are widely used for roofs in low income households in humid tropics. Corrosion of galvanised roofs (of which lead is a impurity) has been suggested as exacerbating lead contamination (Gumbs and Dierberg, 1984). Heavy metal levels in rainwater have also been linked with acid rain (Olem and Berthouex, 1989).

Organic chemicals such as organochlorines and organophophates used in biocides are thought to contaminate rain water (Gould, 1999). Pesticides and herbicides are also reported in rainwater in sample taken from North-eastern United States (Richard *et al,* 1987). However, contamination of rain water from the atmosphere is thought to be low despite severe air pollution in some parts of the world.

Most contamination is thought to occur after contact between rain and the catchment surface (Waller 1989).

Particulate matter from natural weathering or decay of roof materials can also contaminate the roof run-off water. In Africa and Asia, grass-thatched or coconut-thatched roof are commonly used, specially in very low income households. Water run-off from these materials will contain high load of particulate matter which gives colour to the water as well as taste.

Use of asbestos roof for rainwater collection is been much debated for many years. Many health authorities including WHO and US EPA state that there is no consistent evident that ingested asbestos is hazardous to health (WHO 1993, EPA 1991). In many developing countries asbestos is used for roofing materials and there is therefore concern about possible risks. However, many studies of asbestos fibre ingestion in animals and human have shown no conclusive evidence of it causing gastrointestinal or related cancer (Mac Rae, 1988; Millett *et al*, 1983; Polissar *et al*, 1982; Toft *et al* 1981; Conforti *et al,* 1981; Meigs *et a.,*1980; Truhaut *et al,*1989.

In areas of poor urban housing, roof materials are varied and often littered with both organic and inorganic material. There are even reports of faecal wastes being wrapped in polybags and flung over roofs (the ironically named ‘flying latrine’).

2.3 Biological Contamination

Bacteriological

Bacteriological pollution occurs either on the roof surface or during storage. Pipes and gutters that carry the water from the roof to the storage vessel can also be agents of contamination. Organic matter from leaf debris, dust, faecal material of animal or human origin are washed into the storage tank and can carry high-level bacterial contamination. Pollution can also occur through intermediate vectors such as lizards, insects, frogs, snakes and other small animals that get into the tank and often die there. The method of extracting water can also cause bacterial pollution by use of contaminated containers.

A number of disease causing pathogens have been isolated from rainwater system (Gould, 1999). However, only few outbreaks of disease have been linked with rainwater usage, since most supplies are used by single families. Therefore the number of people affected is small and incidents generally go unreported. However, outbreaks of Samonellosis in New Zealand (Simmons and Smith, 1997) and Trinidad (Koplan et al., 1978), Camylobacteriosis in Australia (Brodribb, *et al.,* 1995) and Giardiasis and Crytosporidosis in Australia (Lester, 1992), eight water-borne outbreaks in United States (Craun, 1986) have been linked with rainwater consumption.

Two enteric protozoan *Crytospridium* and Giardia causing water-borne diarrhoea have been found in 50% and 28% respectively of samples taken in the U.S Virgin Islands (Crabtree *et al*, 1996). *Crytosporidium* is capable of infecting rodents, cattle, lizards, iguanas, birds and frogs (Casemore, 1990). Faeces from birds and small animals can carry oocysts that are deposited in the roof and washed into the tank. However, only the species *Crytospridium parvum* from mammals has been shown to cause disease in humans (Crabtree, 1996). Giardia may exist in mammals including birds and rodents. Only *Giardia lamblia* species have been reported to cause disease in humans (Stibbs *et al*, 1998). Chlorination and ultraviolet disinfection has been shown to be ineffective for the inactivation of *Crytospridium* oocysts (Korick *et al* , 1990). Giardia can be inactivated with chlorine at extended contact times but are resistant to U.V. disinfection (Rice and Hoff, 1981). Therefore, a combination of filtration and disinfection would be most appropriate form of treatment (Crabtree, 1996).

Studies have recorded both Total Coliform and Faecal Cliform (*E. coli*) counts from rain water storage (Gould and McPherson, 1987, Fujioka and Chinn, 1987, Aryananda 2000) that exceed WHO standards. It should also be noted using TC and FC counts as indicators of faecal contamination in the tropics has been questioned by some researchers (Hardina and Fujioka, 1991), since both are found in environmental sources such as soil and air. It should also be noted that roof contamination is unlikely to be from humans and large mammals, the source of most pathogens for humans. This also eliminates the risk of many water–borne disease caused by viruses in humans. Fujioka (1987) recorded a higher frequency and concentration of *Faecal streptococci* in rain water tanks than of coliform bacteria, indicating that faecal contamination is due to bird dropping, since these bacteria are found in high numbers in bird faeces (Geldreich, 1976). The presence of indicator bacteria with *Aeromonas spp* has been linked with occurrence of gastrointestinal symptoms in New Zealand (Simmons et al 2001).

The type of roof too can effect the degree of bacterial contamination. Vasudevan et al (2000) recorded that the bacterial count from metal roofs is less than from asbestos, tile or plastic ones. Studies from Kenya had indicated bacterial contamination in water from thatched roof s(Omwenga, 1984).

Insect Vector Breeding

Very few studies have been done on insect breeding in rainwater catchment systems. However, many studies have been done on various aspects of related mosquito breeding as well as on the spread and control of the related disease. Mosquito-borne diseases like malaria, dengue, yellow fever and filariasis are the primary concern, especially in tropical countries. The *Aedes* group which cause dengue and yellow fever has been most commonly found in rainwater storage tanks and vessels. Chareonsook et al (1985) reported presence of *Aedes* mosquitoes larvae in all 150 households tested in three villages in Khon Kaen province, Thailand. Similar infestations were reported from Queensland, Australia (Tun-Lin *et al*, 1995) and South East Nigeria (Bang *et al*, 1981).

To control mosquitoes various approaches have been used, such as screening, adding chemicals and biological control by fish. The best method is to prevent mosquitoes laying eggs in the tanks. The screen needed to prevent mosquitoes eggs washing into the tank has to be very fine (more than 500 holes/inch^2) (Mittal, *et al*., 2001) A mesh of this small size is not practical. Therefore the best method is to prevent adult mosquitoes getting into or leaving the tank by tightly covering tanks any opening with fine nylon mesh.

Apart from mosquitoes there are other insects such as ants and spiders found in tanks. However, little is know of disease caused by them.

2.4 Special Health Concerns for ‘Low-cost’ DRWH

Low-cost systems are associated with small tanks, poor-quality housing and reluctance to invest in expensive ancillaries such as first-flush diverters.

Small tanks have a low water-residence time. They therefore permit less water clarification by sedimentation and less die-off of pathogens than larger tanks. They also offer less scope for organising beneficial stratified flow operation. This makes it more important to understand natural cleansing processes and to design to take maximum advantage of them. Small tanks may for security reasons have to be located inside houses, especially in urban areas, and this could exacerbate the exposure of household residents to tank-breeding vectors.

Poor households often have poor roofing. Besides the obvious issue of soft (e.g. grass) roofing in rural areas, poor urban housing is particularly associated with the presence of rubbish on roofs and of low-height roofs more readily accessible to both humans and vermin. Specific research into the condition of roofing in low-income urban settlements (and how far it might be improved by residents newly interested in such improvement) will be undertaken later.

Filters, sterilisers and diverters add cost to any DRWH system: many such devices on the international market cost more than what we believe may be a budget ceiling ($50) for an entire DRWH system if it is to be viable in low-income tropical households. For example some first-flush diverters require a buffer storage volume that is comparable with the entire storage volume in a low-cost system. This leads to two lines of research (i) reducing treatment costs and (ii) establishing whether such treatment (omitted from most current systems) is really needed.

A health issue that affects all rainwater harvesting but DRWH in particular is uncertainty how to measure biological contamination reliably and in a way accessible to individual householders. Classic coliform counting is not only believed to be a misleading (‘false positives’) measure of faecal contamination in the context of blown soil but also requires equipment to which householders have little access. For research purposes or public-health monitoring a more reliable technique is needed. For any householder use a much simpler technique (such as H_2S strip detection of organic content) is required.

3 SOCIO-ECONOMIC ISSUES AFFECTING DESIGN OF DRWH SYSTEMS

This part of the report discusses some findings of the socio-economic surveys (combining Community and Household surveys) that relate to the development of new, low-cost, DRWH systems and the ways these systems could be made more acceptable to target groups.

3.1 Potability of Rainwater

The household survey has gathered information on the acceptability of rainwater for domestic purposes to members of households having hard roofs but not yet any permanent DRWHS. Applications have been categorised into those requiring respectively potable and non-potable water. Potable water uses have been deemed drinking and cooking, non-potable uses are therefore dish and clothes washing, bathing and other purposes like gardening, latrine-use and livestock watering.

Table 3.1 Perception of potability of rainwater (expressed in % of responses)

Location Country	Acceptability for potable uses			Acceptability for non-potable uses				
	Drinking	Cooking	Overall potable	Dish washing	Clothes washing	Bathing	Others	Overall non-pot
Mbarara, Uganda*	94	100	98	100	100	100	100	100
Gulu, N Uganda	73	80	77	80	73	70	94	79
Kampala, Uganda	92	92	92	96	96	100	100	98
Arerti, C Ethiopia	35	70	53	100	100	90	100	98
Alaba C Ethiopia	8	38	23	85	92	77	50	76
Nelewa S Lanka*	42	80	61	90	95	90	90	91
Galbokka, S Lnka*	28	56	42	94	100	100	100	98
Colombo, S Lanka	40	40	40	65	75	76	85	75
Average	**52**	**70**	**61**	**89**	**91**	**88**	**90**	**90**

* Locations having some h/hs with permanent DRWH systems

Respondents' perception of potability of rainwater varies significantly between the survey countries, but is more consistent within any of them. Rainwater is most broadly (by ~90% of surveyed h/hs) accepted as potable water in Uganda, followed by Sri Lanka (~47%), and is least regarded as potable in Ethiopia (by only ~38%). Within-country variability is highest in Ethiopia (23% in Alaba *vs* 53% in Arerti). Both these sites have a similar number of wet months, 7 and 6 respectively. This variability might be due to Alaba being considerably more developed than Arerti, with more local stand-pipes and more regular water supply from those sources.

Overall, only 61% of households would accept or already use rainwater for drinking and cooking purposes. Among these two uses, rainwater is more acceptable for cooking than for drinking (70% compared to 52%).

On contrast ~90% of respondents viewed rainwater as suitability for non-potable applications although their grounds for this not being 100% were not established. Variability of this figure between communities was low with the exception of the low figures from Alaba – a community with no experience of formal DRWH.

Based on these findings, it might be concluded that (a) DRWH systems should be primarily designed for non-potable applications, or (b) that evidence of potability should be collected and propagated or (c) design effort should be put into improving potability through use of filters, diverters or disinfection devices.

3.2 Water Consumption Behaviour

Table 3.2 below displays the per-capita water consumption of the respondent h/hs at the different survey locations in respectively the dry season and the wet season. It shows that seasonal variation in water consumption is surprisingly low and in several cases of the opposite sign to that expected. Moreover these figures, from Household surveys appear to contradict descriptions in Community surveys in the same locations indicating greater difficulties in obtaining water in the drier months. The only large seasonal variation (~56% higher wet-season consumption) was found at Alaba, Ethiopia. The two urban sites reported identical wet and dry season figures.

The implications for DRWH system design are debatable. There is apparently not much dry-season water stress (which DRWH would have particular difficulty in addressing) but by the same token there is little preparedness for householders making the sort of adjustments to daily demand that are needed to maximise the performance of small, cheap DRWH systems.

Table 3.2 Water consumption behaviour at different survey locations

Location/Country	Water consumption per capita per day (litres)	
	Dry Season	Wet Season
Mbarara, Uganda	9.5	12
Gulu, Uganda	30	26
Kampala, Uganda	22	
Arerti, Ethiopia	15.5	16
Alaba, Ethiopia	16	25
Nelewa, Sri Lanka	16	15
Galbokka, Sri Lanka	14	12
Colombo, Sri Lanka	12	
Average, all sites	**16.9**	**17.5**

3.3 Constraints on DRWH

The surveyed locations comprised two rural and one urban site in each of the three countries (results for the Addis Ababa site are however not yet available). Major constraints to DRWH were explored, covering such issues as space for water tanks, roofing type, tenancy and security, water theft, malicious damage, fear of poisoning etc.

Space and Tenancy

In the Ugandan and Sri Lankan rural locations, almost 100 percent houses are owner-occupied, but in Ethiopia, about 50% are rented. However, in all the six rural locations, space to build a reasonably sized DRWH tank (e.g. the 0.75 m^2 footprint for a typical 1000-litre tank) is readily available within the homestead area. Of the two urban sites, in Kampala h/hs are well-spaced and could accommodate a DRWH tank whereas the Colombo h/hs are situated in a marginal land along a railway track and thus lack space. Consequently 54% of these h/hs expect space limitation to interfere with their adoption of DRWH. In designing for such h/hs it has yet to be clarified if volume or footprint area is the major constraint.

In terms of tenure, both the Ethiopian sites are dominated by tenant h/hs. Some houses are owned by individual landlords and some by Government agencies or even by banks. A major concern for heads of tenant h/h in introducing a DRWH system is obtaining the permission/authorisation of the landlord. Since such a system is unlikely to cause much damage to the property and as the system would provide a supplemental water supply for household needs, about 70% of Ethiopian tenant h/hs thought they could get the necessary getting authorisation. It remains to be established, however, how far a DRWH system needs to be readily portable by a moving tenant.

Roofing

Hard roofing is the primary prerequisite for a DRWH system, although creation of a separate but still economic rainfall catchment area is under investigation. As can be seen from Table 3.3, all but one location have the majority of the houses with hard roofs.

Table 3.3 Roofing types and roofing materials at different sites

Location & Country (R = rural, U = urban)	Hard roof (% of h/hs)	Roofing material (% of h/hs)		
		CI sheet	Asbestos	Flat tiles
Mbarara, Uganda (R)	92	100	0	0
Gulu, Uganda (R)	34	100	0	0
Kampala, Uganda (U)	100	100	0	0
Arerti, Ethiopia (R)	96	100	0	0
Alaba/Ethiopia (R)	100	100	0	0
Nelewa, Sri Lanka (R)	85	27	9	64
Galbokka, Sri Lanka (R)	85	5	5	90
Colombo, Sri Lanka (U)	75	100	0	0
All sites average		**79**	**2**	**19**

Concerning roofing material, encouraging is the fact that about four-fifth of the houses are roofed with CI sheet, which is the best rainwater catchment surface yielding the highest quantity and quality of run-off.

In Gulu in Uganda, most of the houses are circular in shape with thatched roofs. Specialised DRWH designs are needed particularly for this type. The first challenge is to put some sort of layer on or near the roof, to make it act as a catchment surface, and the second one is to design some curved guttering system, to catch the runoff off the roof

Funds to Install a Permanent DRWH System

The major factor holding back the adoption of permanent DRWH by interested h/hs appears to be the lack of financial resources to introduce a system. Although many of the surveyed h/hs reported a higher per-capita income than their country's per capita GNP, most consider a system unaffordable. This confirms the project's primary focus on low-cost designs but also raises the priority of identifying ways of helping potential users to evaluate their financial viability.

Table 3.4 A $\$_{US}$50 DRWH system compared with annual household income

Location & Country (R = rural, U = urban)	Reported H/H income ($\$_{US}$ pa)	US$ 50 as a percent of annual H/H income
Mbarara, Uganda (R)	368	13.6
Gulu, Uganda (R)	1008	4.9
Kampala, Uganda (U)	870	5.7
Arerti, Ethiopia (R)	542	9.2
Alaba/Ethiopia (R)	677	7.4
Nelewa, Sri Lanka (R)	631	7.9
Galbokka, Sri Lanka (R)	479	10.4
Colombo, Sri Lanka (U)	614	8.1
All sites average		**8.4**

In order to assess the issue of a DRWHS, we have assumed a reasonable-size system to cost US$ 50. It can be seen from Table 3.4 that such a system would take up from 5% to 14% of a h/h's annual income (although the reported incomes are somewhat unexpected and therefore may need cross-checking). This range of fractions puts DRWH in the category of 'substantial h/h investment', possibly but not always requiring micro-credit. It suggests that there is little point in exploring high-performance DRWH designs that would cost over say $\$_{US}$100.

3.4 Attitudes towards DRWH

It has been attempted in the household surveys to explore the attitude towards DRWH of those h/hs not yet having any form of permanent DRWH systems. Table 3.5 reveals that in general, people have given more thought to installing a permanent DRWHS where there are neighbouring h/hs owning such a system. Even so, only about half of all h/hs have even 'thought about' DRWH. By contrast actual interest in installing a system (~85% once the idea is introduced) is not only higher but is apparently unaffected by the presence of neighbouring examples. Unfortunately surveys are at their least reliable when testing attitudes towards ideas not previously though about.

Table 3.5 Non-permanent DRWH user' attitude towards DRWH (% of H/Hs)

Location & Country (R = rural, U = urban)	H/H practises formal DRWH	H/H practise only informal DRWH	
		H/h has 'thought of' installing a formal DRWHS	H/h would be interested in a formal DRWHS
Mbarara, Uganda (R)	35	94	100
Gulu, Uganda (R)	-	73	96
Kampala, Uganda (U)	-	40	100
Arerti, Ethiopia (R)	-	46	77
Alaba/Ethiopia (R)	-	42	92
Nelewa, Sri Lanka (R)	20	37	89
Galbokka, Sri Lanka (R)	31	50	72
Colombo, Sri Lanka (U)	-	17	56
Average at sites where DRWH already practised		**60**	**87**
Average where not already practised		**43**	**84**

Table 3.6 below explores in detail the attitudes of informal DRWH practitioners to formal systems. The perceived advantages have been grouped under five headings, namely

C	Convenience and water security
E	Economic
H	Health and water quality
Q	Quantity
S	Social

Taking into consideration all three countries and all eight survey locations, the issue of convenience and water security (C) is the most prevalent (carrying a weight of 27 out of 64) among the informal DRWH practitioners. This is the only issue commonly expressed in all three countries. Next in line are the economic concerns (E). Social issues (S) appear to be of least concern. Surprisingly issues of health and water quality (H) did not count highly, and least so in Ethiopia despite the Household surveys there having shown low confidence in the potability of roofwater. It can be derived from this that DRWH systems should be designed primarily so that the people's desire for 'more water in hand at times of need' can be fulfilled. What was not explored was how householders would choose between low cost and high reliability of supply, if that trade-off (a reality of DRWH) were presented to them more explicitly.

Respondents' expectations of how they would utilise the time saved from having a permanent (formal) DRWHS varied widely. It is primarily oriented towards income-generation (e.g. farming, carpentry, handicrafts etc.) in East Africa, but towards subsistence activities (e.g. gardening) in Asia. Attending school regularly and putting more time into studies was a common ambition at all sites. This, in turn, relates to a regular supply of minimal water, which has some bearing on the design of the DRWH systems.

Table 3.6 Informal DRWH users' perception of expected benefits from having a formal DRWH system and what any saved time would be used for

Expected benefits from a DRWHS			Time saved would be used for	
Uganda				
Ready water at all times	(8)	C	More farming	(14)
Additional income through selling water	(8)	E	Attend school	(9)
Cleaner water	(7)	H	More study	(8)
Saves money	(4)	E	More casual labour	(4)
Reduce cost of monthly water payment	(3)	E	Selling goods in local market	(4)
Plenty of water	(1)	C	More h/h work	(3)
More regular washing and bathing	(1)	Q	Graze livestock	(3)
Improved health and sanitation	(1)	H	Kitchen gardening	(3)
Less travel for fetching water	(1)	C	Petty trading	(2)
Reduced scarcity of water	(1)	C	Taking better care of children	(1)
Help neighbours without tank	(1)	S		
Extra water for h/h works	(1)	Q		
Less disturbance at water points	(1)	C		
Use the money elsewhere	(1)	E		
Matter of pride	(1)	S		

Expected benefits from a DRWHS			Time saved would be used for	
Ethiopia				
Water during scarcity	(5)	C	More economic activity	(5)
Nearby water	(4)	C	Farming	(4)
Additional water	(3)	Q	Petty trading	(4)
Saves money	(3)	E	More study	(3)
			More household work	(3)
			Brew local alcoholic drink	(2)
			Livestock rearing	(1)
			Gardening	(1)
Sri Lanka				
Greater water security	(6)	C	Gardening	(5)
High quality water	(3)	H	More study/education	(4)
			Productive activities	(3)
			Income generating activities	(3)
			Extra labour work	(1)
			Extra official work	(1)
			Cleaning	(1)

Note: Figures in square parentheses represent frequency of a given response, in descending order.

4 INSTITUTIONAL INFORMATION NEEDS AND GOVERNMENT POLICY

4.1 Introduction

This report synthesizes reports from the three country written on “information needs and government policy on domestic rainwater harvesting in the tropics”. While the country papers analysed the country-specific situation in the development of DRWH under a number of topics, this paper only deals with the following two key questions:

- What are the information needs with respect to DRWH of government policy makers at various levels that our research should be designed to collect?
- What are the current policies of relevant (levels of) government with respect to DRWH in the three participating countries?

4.2 Country-specific Policies with respect to DRWH

The three countries have their own government policies with respect to provision of water to the rural poor. It is also clear that the three countries would support and encourage any activity which leads to the utilization of water resources for significant socio economic development on a sustainable basis. However, there is an interesting difference among the water policies of Ethiopia and Sri Lanka, where in the former case the policy encompasses “all national efforts to develop water utilization” while in the latter case, the policy covers “all activities leading to provide portable water”. Hence in the latter case, Sri Lankan policy emphasizes the activity rather than the responsibility, whereas the Ethiopian case emphasizes responsibility rather than activity. These subtle differences can sometimes affect development of non-conventional water supply provisions like rainwater harvesting and more specifically DRWH

The policies of all three countries appears to be ‘pro poor’ with respect to water supply provision. In the Ugandan case 95% of the water supply is being subsidised, while the Ethiopian water policy clearly mentions that the government shall bear all costs of water supply development to those who can’t afford to pay for the service. It also emphasizes the concept of meeting “basic needs” in water supply and attempts to introduce a “social Tariff” for operation and maintenance of water supply. This takes place in other countries like Sri Lanka, though it is not specifically stated in the policy. In Sri Lanka, the rural water options are heavily subsidized, sometimes up to 80% of the total cost. Incidentally, the rural domestic water policy of Sri Lanka gives the highest subsidy to domestic rainwater harvesting with the intension of encouraging more people to adopt DRWH. However, the Sri Lankan National Water Resources Policy does not include any cost recovery of capital instillations of water supply options and the small scale (livelihood) water users are protected by the introduction of water entitlements to bulk water users. By contrast, the Ethiopian water policy specifically mentions that all urban water supply provisions shall aim at full cost recovery while poor will be given subsidies for capital costs of water provisions.

Though the three countries have very comprehensive water resources policies, none is specific about DRWH or for that matter rainwater harvesting as a whole. However, a district policy in Uganda specifies community rainwater harvesting for schools.

In Sri Lanka, the Draft National Water Resources Authority Act mentions development of rainwater harvesting and other non-conventional water sources for agriculture, industrial and domestic use. National Water Resources Policy there makes an implicit reference to rainwater harvesting for domestic use under the category of "livelihood water use", where users are entitled to enjoy the benefits of using water without holding an entitlement or making any direct payment for capital cost. However, the National Policy for Rural Water Supply and Sanitation Sector of the National Water Supply and Drainage Board (NSWDB) specifically mentions "protected rainwater catchment systems" which directly includes DRWH as a water supply provision. The only difference in this case is this is only a sectoral policy.

In Ethiopia, rural water supply is promoted through affordable and appropriate technologies but there is no direct reference to DRWH, mainly due to the high percentage of thatched roofs in rural areas, which automatically limits the rainwater harvesting technology to schools, clinics and other institutions with more permanent roofs. Therefore, rainwater harvesting in Ethiopia is as yet only limited to trials.

However, DRWH is actively promoted by NGOs working in the water sector. NGO activities on DRWH in Sri Lanka and Uganda have been successful in influencing national water policy to consider rainwater harvesting as an option for domestic water supply provision. In Uganda, the government is making partnerships with NGOs who have experience in rainwater harvesting to learn lessons to be incorporated in the water policy. In Sri Lanka, it is the results of NGO work and other special projects that have sensitised the water supply sector policy to incorporate rainwater harvesting as a domestic water supply option. However, it is important to note that the Sri Lankan water supply sector policy considers "basic water needs" rather than "household water security" in the rural water supply sector. Although Water Aid has been very active in promoting DRWH in Ethiopia it appears to have had no significant impact yet on the rural water supply policy of the country. One reason for this situation could be the poor housing conditions of more than 85% of the population whose livelihood depends on farming and livestock.

4.3 Limitations to Development of DRWH

Development of rainwater harvesting in the three countries is constrained by number of issues. These issues will be discussed under the following topics:- policy environment and institutions, cost and financing, awareness, technology, water quality and health concerns, research and politics.

Policy Environment and Institutions

One aspect that has been highlighted from all three countries is the lack of a clear policy for the development of rainwater harvesting or DRWH. The present work on rainwater harvesting in Ethiopia and Uganda is primarily been handled by NGOs while in Sri Lanka, special projects funded by multilateral and bilateral donors supported by NGOs have been responsible for the development and promotion of RWH. However, there is a concerted effort in all three countries to influence the respective governments to adopt RWH into their development mandate. In response to some of the work done by NGOs and special projects, RWH has been included in the Rural water supply and sanitation policy of the NWSDB in Sri Lanka, but its importance is masked by other options which are conventionally categorized as higher service level options. Therefore, a need for a clear policy for the development of RWH is advocated. It may not be possible to have a National policy for rainwater harvesting used on its own, given the limited service level it can offer. However, a separate policy for a district / province / sensitive area / otherwise-unreachable area can be possible if the policy makers are adequately convinced on the importance of RWH or DRWH.

Lack of a clear policy has resulted in not having a stable institutional arrangement to support RWH/DRWH. Of the three countries, the newly created Rural water supply and sanitation division in Sri Lanka will be a stable institutional arrangement to all rural water supply options; this invariably will cover RWH/DRWH as well. In Uganda, the Uganda Rainwater Harvesting Association along with other NGOs is attempting to influence government policy through advocacy and practice. In Ethiopia there is no evidence to an establishment of a state institutional arrangement to support and foster RWH/DRWH. Presently, NGOs are active in promoting RWH.

Cost and Financing

One of the major constraints highlighted in Ethiopia and Uganda is the high cost of DRWH structures and hence, lack of adequate financial support mechanisms. It is being clearly stated that lack of cost benefit analysis of DRWH as against other options have been one of the limitations to promoting DRWH amongst the policy makers. Lack of information on low cost technologies, their relative merits and demerits, cost breakdowns and feasibility of DRWH are the constraints highlighted from Uganda. In Ethiopia too, high cost of storage and ancillary components with no financial support has been a major limitation in developing RWH/DRWH. Unlike the other two countries Ethiopian people understand the cost of water and it is always considered as an economic good. Therefore, the users are willing to pay for the service rendered. However, in a situation where people are unable to pay due to their relative poverty, micro financing has been proposed by NGOs and other donor governments to develop water supply options to rural areas.

In Sri Lanka, cost has not been raised as a limitation, mainly due to the government policy on social infrastructure development and high subsidy associated with development of RWH/DRWH. The subsidies in Sri Lanka varies from 50% to 80% of capital cost per household. Hence, the need for more low cost technologies have not been reported. Community contribution for DRWH in Sri Lanka has mainly come in the form of voluntary labour which is not recorded in costing RWH/DRWH at household level. In Uganda one of the key factors for high financial commitment for DRWH is the inability to select deserving households among communities in water stressed areas under limited financial situations.

Awareness

Although considerable amount of work has been done during the past decade on RWH/DRWH in the three countries under study, awareness regarding the merits demerits and potentials for the development rainwater harvesting is lacking among the policy makers. In Sri Lanka, with all the efforts from NGOs and special projects to construct over 8000 DRWH tanks, still policy makers in responsible positions are unaware of the proper establishment and utilisation of the “concept”. While much research has been conducted during the past five years most of the out puts have been available for limited circulation. Inadequate use of the media has been cited as one of the problems for lack of awareness. In a country like Sri Lanka, where the media is very well developed with availability of media access to more than 70% of the population, more wider use of the media would have given a higher awareness to the policy makers as well as to the general public. In Uganda and Ethiopia too, inadequate awareness on the technology among the beneficiary community has been one of the primary reasons for poor adoption of RWH/.DRWH by rural people. In the above two countries there is also a greater need for more research on RWH/DRWH, generation of reliable information and dissemination of data among policy makers. The policy makers on the other hand are in need of reliable information on cost benefit aspects DRWH. In the Ugandan context, lack of a platform to conduct advocacy has been cited as a constraint to disseminate information on technological innovations.

Technology

Ferro-cement technology for DRWH storage tanks is popular in all the countries under study. Capacities of storage tanks vary depending on the standard designs used in different countries. The size of the storage tanks vary in size from less than 1 m^3 to about 40 m^3 as found in some community schemes in Ethiopia. However, the common problem found in the three countries is the compromise necessary between the size (i.e. performance) and cost of DRWH storage tanks. It appears that country requirement is for larger size tanks, 10m^3 tanks have been the request from policy makers in Uganda and even in Sri Lanka there is a request for larger size (more than 5m^3**)** storage tanks particularly from the dry zone areas. This essentially means that small capacity storage tanks in countries with long dry spells are not favored, and it will be difficult to promote such tanks with water policy makers. The size of the tank has a direct relationship to household water security and improvement in livelihood of the poor as pointed out in the Ethiopian case, where large storage could be used to replace labour shortages in the farming sector.

With the high cost associated with larger tanks, it will be outside the reach of the poor to purchase large tanks. This essentially means that DRWH has to be subsidized, either by the state or NGOs who are working in the water sector.

There are number of other constraints associated with DWRH infrastructure, like maintaining the quality of water, availability of space and treatment of storage water. However, users in the African countries were satisfied with fetching or drawing water from storage tanks usually located outside one's home. In the Sri Lankan context, even the policy makers were of the opinion that the technology should be developed to deliver water within the household. This issue is stressed in the Sri Lankan context because one of the social indicatorsin the rural sector is access to pipe-borne water. Another problem which was indicated by policy makers in Sri Lanka was the promotion of water-seal toilets alongside the development of DRWH, which is essentially a water conservation strategy.

Development of accessories to improve the quality of water was another issue raised by policy makers in all the three countries. Improving quality of rain water was rated very high in Sri Lankan . This has apparently being one of the major concerns for the acceptance of rainwater as a water supply option. In the two African countries improving quality of rainwater through filters and first flush systems have been recognized while accepting that rainwater is comparatively better than other available water sources.

Health Concerns

This is one area that has not been properly addressed mainly due to lack of awareness on health related aspects of DRWH. One of the main issues on health is the problem of vector breeding in insecurely covered storage tanks. However, this problem is mainly limited to humid tropical countries like Sri Lanka where environmental conditions are suited for mosquito breeding. Though this problem has not been raised in Uganda, vector breeding in high humidity areas is a possibility. Discoloration of stored water with time is a common problem associated with high vegetative cover in the wet zone of Sri Lanka. Implementation of DRWH programmes without any concurrent health programmes has been another problem in all the three countries, though it has not been specifically mentioned in any of the countries.

Research

Reliable data and information on DRWH is scarce in all three countries. While Sri Lanka may have advanced with respect to research on DRWH, the data available is mostly location specific and can not be used for general interpretations. Ethiopia has clearly highlighted the need for supportive information on opportunity cost and cost benefit of DRWH for policy makers. Defining realistic household water consumption rates and means of identifying individual households as beneficiaries have been raised as issues for further research.

Research on system capacity verses roof size, cost effective storage, water quality improvements and water consumption rates within both multiple-source and single-source situations are some of the areas specifically deficient in the two African countries. Hence, it is imperative that research should be given high priority in both Ethiopia and Uganda, while encouraging further research in Sri Lanka. Therefore, convincing and development of DRWH in the two African countries will largely depend on accurate data and information provided to policy makers.

Politics and Conceptual Misunderstanding

Another aspect which indirectly affects the development of DRWH in developing countries is the conflict between “basic water needs” and “ household water security”. When DRWH is given as an option to satisfy basic water needs it invariably limits the opportunity for household water security through water supply options with higher service levels. This is particularly important where funds are limited and development takes place according to a master plan. This situation has led communities not to accept DRWH fearing that they would then no longer qualify for other (better) water supply options.

While political interference has not been mentioned in the African context, it very much prevalent in Sri Lanka. There has not been very strong support for the development of DRWH by politicians due to ignorance of the technology, additionally some have been indifferent to the development of DRWH mainly due to the inadequate political mileage DRWH can bring to politicians in person.

4.4 Conclusions

The three countries either already have comprehensive water resources policies or are in the process of preparing them at present. However, none of the countries specifically mentioned DRWH in main policy documents. Efforts are under way, mainly by NGOs to influence their respective governments to accommodate DRWH/RWH in the their national policies. Absence of a clear policy has been highlighted as a major concern for limited development of DRWH. Nevertheless sectoral policies encouraging DRWH/RWH do exist within some countries. However, these policies are either project driven or NGO initiated hence, the possibility of influencing the government may be limited.

In the absence of a clear policy there is no indication of any state-owned institutional arrangement to support and foster DRWH. However, new institutional arrangements emerging to cater for the rural water supply sector may include DRWH/RWH in future. Lack of information on cost benefits of DRWH and affordable storage tanks for rural poor has increased the dependency on subsidies by the state or NGOs. There is a greater need for research and development in DRWH, mainly in the two African countries. Non availability of reliable data and information, to policy makers have been raised as a major issue to convince the policy makers on DRWH.

While much research work has been done in the world on DRWH, there is lot more to be researched in the humid tropics, specially with respect to health concern associated with DRWH, storage capacity verses cost and implementing DRWH in the sphere of integrated water resources management.

5 TECHNOLOGY

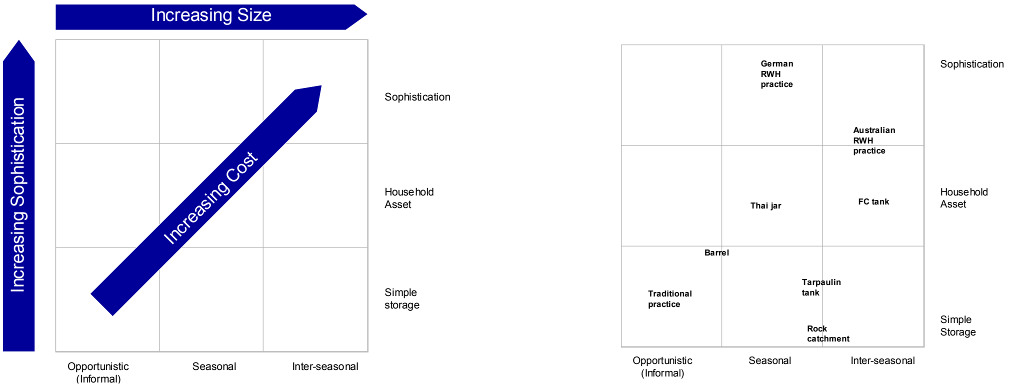
5.1 Cost vs. Quantity

In focus group sessions in Sri Lanka, Uganda and Ethiopia, the number one problem highlighted by respondents was cost – RWH systems are too expensive for poor people to afford. The second biggest problem was quantity – The sub 1m^3 systems people are being offered (or are using) are too small to meet their requirements. As the cost of a rainwater harvesting system is a function of its capacity, these two problems are heavily interrelated.

In the areas selected for fieldwork, a typical household is only able to spend between £10 and £25 on a rainwater harvesting system based on current cash flow. Meeting this requirement is difficult but not impossible. Just as meeting the demand for cheap transport has revealed a multiplicity of solutions from bicycles to three wheeled taxis to buses, a product-oriented approach to rainwater harvesting provision should have multiple answers. The bus equivalent is now quite commonplace in East Africa and parts of South Asia in the form of the school tank or the tank on a community centre. The bicycle equivalent is less common and less simple to define.

For some years there has been in existence a “sanitation ladder”, a catalogue of designs from which a project manager, a community or individual can select an appropriate well designed sanitation system to suit local conditions and the available funds. Such “ranges” are the norm in consumer products and usually form the basis for consumer choice. Rainwater harvesting systems are very amenable to this product range approach, as uncertainties about the location of the water resource don’t exist; it simply falls from the sky. They are however, slightly more complex than sanitation systems as their service provision is in two main areas; quantity of water that can be obtained from the system and quality of the system (which includes such things as longevity, ease of extraction, pride of ownership and the engineers need to do a “proper job” – It does *not* necessarily equate to water quality). It is in fact this quality aspect that is predominant in the sanitation ladder whereas rainwater harvesting systems are dominated by the question of quantity with a certain quality taken as read, particularly in designs created or promoted by water agencies and NGOs who form the mainstay of RWH design. Figure 5.1 shows how rainwater-harvesting systems can be mapped onto quality and quantity axes each with its own demand on resources available to build the system. Generally, rainwater harvesting projects in developing countries are at the household asset level using materials and techniques taken from the housing sector. The exception is rock catchments, which are a low level community supply. Developed countries usually operate with a higher level of sophistication typified by dual reticulation, electronic monitoring and high tech industrial inputs such as injection moulded parts and specialised filter meshes.

Figure 5.1: Service framework for rainwater harvesting systems



a. Framework

b. How current systems map onto the framework

It is also interesting to note that the quality of system usually found in poor households (oil drums and traditional practices) is generally lower than current offerings, implying a mismatch between the quality that can be afforded by poor households and the solutions currently available. Similar differences can also be found between housing quality and current systems. This points the way to achieving the goal of reducing the cost of systems and thereby increasing the quantity of water available from a similarly priced system.

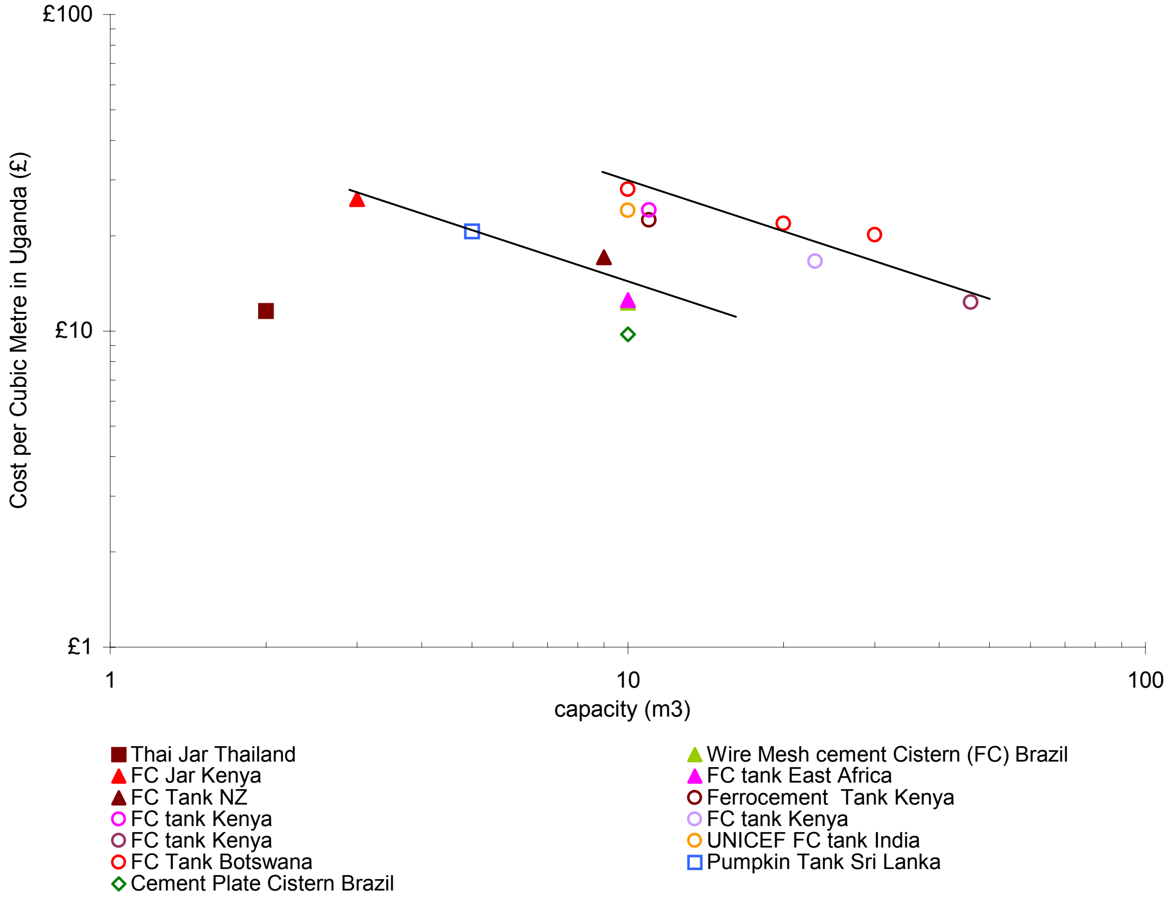
In reducing the quality, however, there are a number of critical functional constraints that should be regarded as a minimum specification:

- Gutters should deliver a good fraction of the water falling on the roof – dependent on the local rainfall, roof size storage size and demand pattern
- The tank should not have excessive loss through seepage or evaporation – as compared to the water demand
- The tank should not present an excessive danger to its users, either by falling in or by the tank failing explosively
- The water must be of a quality consummate with its intended use – water that is used for drinking requires a certain care in transport and storage:
  - The catchment area should be smooth and free from accumulated debris
  - The water should be filtered to remove gross impurities or the first flush removed
  - The tank should be covered to prevent entry of light, and sealed against intrusion by mosquitoes and small creatures
  - The tank should be ventilated to prevent anaerobic decomposition of any washed in matter

5.2 Reducing Cost

Using Less Material

Figure 5.2: Comparisons of costs of ferrocement tanks



Improved formwork

Figure 5.2 shows a comparison of 15 ferrocement tanks based on their bills of materials. A comparison of tanks with formwork (filled triangles) with those made on open frames (open circles) reveals the ability of good formwork to significantly reduce the cost of a tank. The lowest material use by far is the Thai jar (filled square) which is built on a cement-block formwork which itself is formed on a factory made template. The formwork provides an excellent working surface and allows tight quality control of wall thickness. Formwork does suffer from a lack of flexibility as each size of tank must have it's own form making it difficult to justify the investment unless a large number of similar size of tanks is being contemplated.

Shape optimisation

Material economies can be made on water tanks by considering the geometry of surface area to volume. The Sri Lankan pumpkin tank (whose cost is shown in Figure 5.2 as an open square) is a good example. Highly optimised shapes should, however be balanced against the additional skill required to form them. If skilled labour is inexpensive, they can save money, however when labour is expensive, it may be better to use a simpler shape that is quicker to manufacture. Doubly curved sections also tend to need specialised moulds that should be factored into any cost calculation.

Function separation

Waterproof materials are generally more expensive than non-waterproof materials so cost can be significantly reduced if the quantities of such expensive waterproof materials are reduced. Underground tanks, where the ground itself provides the structural strength of the tank are a good example of this. The technique can also be used in conjunction with above-ground structures using earth material such as stabilised soil blocks, rammed earth and even wattle and daub. The waterproof lining itself can be a plastic sheet, cement/water slurry or in some cases a painted dope.

Greater use of “free” materials

The costs constraints identified by users are strictly in the realm of cash costs, other resources such as time and effort are much more available. An emphasis on “free” gatherable local materials will reduce the need for cash inputs and maximise the available resources; a standard “appropriate technology” argument but little seen in rainwater harvesting outside of the occasional use of bamboo guttering. Gatherable materials are almost never used for storage as they tend to be based on earth technologies, which are not watertight and often have a lower longevity than modern engineering materials, however the housing of the poor almost always make use of these “traditional” materials. Separation of function should go some way to removing this problem with the traditional materials doing what they have done for centuries and a small input of a specific engineering material performing the waterproofing function. An excellent example of this is the Tarpaulin tank developed in Southern Uganda which uses an imported tarpaulin to hold the water, while the structure itself is partly underground and partly wattle and daub.

Mass production

Significant material and labour savings can be made if products are manufactured in quantity. Buying power of the manufacturer increases and proper workshop practices such as batching and subassemblies can be incorporated reducing labour cost. Mass production can be used for sections of the system such as filters or tank covers as well as complete tanks. Tanks can also be made from factory-produced sections and assembled on-site allowing simple and rapid implementation. The cement plate cistern from Brazil (Figure 5.2; open diamond) is an example of this method. The sections or components should be of a manageable size and can benefit from high performance manufacturing practices such as vibrating tables and underwater curing.

Use of existing containers

Many households already hold significant storage in the form of jerrycans, water jars and “oil” drums. These containers can be used in an organised manner to form a small but often significant storage volume. 5 jerrycans contain about 100l which itself should provide about 40% of total water needs (assumed 20lpcd) or 75% of primary water (drinking an cooking – assumed to total 5lpcd). Drums, found in many homes provide a higher level of service and can even be built into a reasonable VLC storage (3 drums can provide 70% of water needs). Using existing containers in an organised manner, however requires them to be plumbed together in such a way as to eliminate indoor flooding either by accident or during removal of a container. The use of drums also has health concerns as the drums may have contained toxic chemicals and not been cleaned properly. They also need suitable covers and decent water extraction.

5.3 Urban Areas

Despite many problems, the very real shortage of water in rapidly growing cities has forced many people to consider rainwater harvesting as an option in both developed and developing countries. Urban environments have many constraints of their own. They are much more crowded than rural areas and space (land) is expensive, tenure is often uncertain with many people living as tenants and many others squatting and living with the daily possibility of being "cleared away". Urban areas are particularly hostile places to install a rainwater harvesting system as roof sizes can be quite small (as low as $9m^2$), the materials they are made from are often scavenged and less than ideal. Water use is often high as the rainwater is expected to perform many functions such as personal hygiene that would take place at a central water source in a rural area. Finally, pollution levels can be high in urban areas from automotive exhaust and industrial activity as well as the possibility of blown human faecal matter from unhygienic toilet practices. This will probably mean in urban areas rainwater will mostly be used for secondary water uses, quite the opposite of rural rainwater use. Designing for urban constraints, particularly for the poor may result in quite unusual solutions

Aspect Ratio

As land is at a premium, the usual economies of aspect ratio are heavily modified by the value of the land itself and squat designs become very unattractive. A more appropriate aspect ratio for an urban area is a tall, thin design with a maximum footprint of about 70cm, allowing it to be placed under the eaves of a dwelling without encroaching on the pathway. Many urban households already have stores such as "oil" drums, which have a similar sized footprint. The tall thin design is also ideal to encourage plug flow within the storage maximising in-tank effects such as die off and sedimentation of heavy metals.

There are two main problems with tall thin tanks, stability and capacity. Having a small footprint and a slender profile makes any tall structure naturally unstable and quite likely to topple, especially if pushed over either accidentally by a passer by or deliberately by a vandal. A water tank is particularly bad in this respect as the liquid can move within the tank, aiding the collapse. Water is also very dense and the collapse could cause quite some damage. Possible solutions include the use of strategically placed guy wires and attaching the tank to the dwelling itself. The capacity issue is basically a direct function of aspect ratio losses, A Ø70cm tank 2m high has a capacity of only 3/4 m^3, so for a larger capacity more than one will be necessary. The size is, however optimal for houses with smaller roofs.

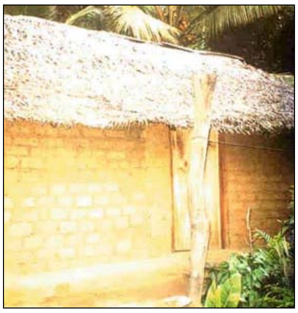
Portability

The uncertainty of tenure of many of the urban poor means that any DRWH equipment must be able to move along with the owner. Systems must be light and not too unwieldy, designs that collapse into a movable package are also possible.

Distributed storage

Smaller objects are both easier to store and to move, they can also be placed inside the dwelling and will therefore be secure. Many houses also already own a number of jerrycans or water jars, all that must be done is to connect them together in a manner that will not spill water inside the house either in use, by accident or by overflowing. The container size is, however, limited (5 jerrycans contain only 100l), but could form a useful and convenient supplemental water source.

5.4 Organic Roofs



Cadjan **(palm leaf) roof In Sri Lanka**
(Picture T. Ariyananda)

Thatched Roof in Uganda
(Picture D. Rees)

Round thatched roof in Kenya
Note the bent guttering
(Picture Lee and Visscher)

The continued prevalence of organic roofs such as thatch and palm leaves is a particular challenge to rainwater harvesting provision. The roofs are more prevalent in poor rural households than elsewhere, but it is not necessarily only cost that leads people to choose a thatched roof. Other reasons include insulation from the heat and the ability to have a stove in the house without a chimney.

The quality of runoff from an organic roof is in the order of 200 – 300 FC/100ml, which is well outside all drinking water guidelines and even outside many guidelines for bathing water! The water is also very turbid, mostly with dissolved matter that will never settle out and will provide food for bacteria. Therefore, water caught directly from an organic roof cannot be used for drinking without further treatment, fortunately the water also “tastes of grass” and so is will only be used for drinking in the most extreme of circumstances. There have been some reports of rice husk ash being useful as a filter for thatch roofs in South-East Asia (Edwards, Keller, & Yohalem, 1984), but no measures of FC count improvement etc. Similarly burned bamboo or activated charcoal have been used as filter media.

Organic roofs also make poor catchments from a water quantity point of view. The runoff coefficient can be as low as 0.2 due to leakage and seepage into the organic material so a very large area is needed to make a substantial contribution to household water needs. Unfortunately, this is not the case as most organic roofed houses observed are between 7 and 20m^2, often forming part of a multi-building complex where each building serves as a “room”.

The catchment of runoff from an organic roof is particularly problematic as the roof usually has a very poorly defined edge and water tends to drip slowly from any point over a range that can be as high as 30cm from the nominal edge, this is particularly true of the thick thatch found in east and southern Africa. The other problem is that many thatched houses in Africa are round so guttering must also be curved to follow the profile. Such curved guttering is not available on the ready market and is difficult to form from sheet material as the half-toroidal shape necessary is not developable. Attempts have been made to bend straight gutters to fit round roofs but the results are, at best partially successful as the open gutter, when bent tends to open and twist resulting in a shape that will spill water and can also retain some water making an ideal breeding ground for mosquitoes. Flexible gutters made from cloth have been tried with mixed success, the problems are mainly in establishing a constant gradient on a round path and in preventing ponding in the bottom of the gutter caused by the flexible material stretching in unpredictable ways and by the use of closed shapes preventing evaporation.

All of these factors tend to conspire to make organic roofs a poor candidate for a rainwater harvesting catchment. The roof surface can be improved however by placing a cover upon it to improve its runoff quantity and quality. The cover must be resistant to UV radiation or be able to be easily removed or stored during dry spells, as UV damage has been the cause of a number of failures in previous attempts to employ roof covers. It should also be tough enough to resist damage from wind borne particles. A roof cover must also not effect the roof itself, encouraging rotting or blocking the exit of smoke from the household. Polythene is a particularly poor candidate for this task despite its popularity. Better materials are fabric's such as canvas or jute gunnysacks, tarpaulin and tar sheeting. Primary problems with these materials will be in their pervious nature, which may allow dirt and bacteria to obtain purchase. Early results from experiments with tar sheet and gunnysacks suggest this is the case but they both exhibit good first flush effects and so the water becomes more readily treatable.

The round shape of most thatched dwellings in Africa presents even more of a challenge. The solution lies in the nature of a rural compound, which is usually composed of a number of buildings within a plot of land. The land itself can usually contain some other structure and so could conceivably support a purpose built catchment made from similar materials as with the roof cover. If funds permit, the catchment could even be made from roofing sheets as was done in Botswana with the ALDP project. Table 5.1 shows the material costs in Sri Lanka of a 20m^2 catchment made from a number of possible materials.

Table 5.1: Catchment material costs for 20m^2

CI sheet	Asbestos sheet	Plastic Sheet	Tarpaulin	Gunnysacks
£37.04	£34.97	£4.10	£9.46	£1.91

5.5 Quality Enhancement

An important constraint cited mainly by water professionals is heath and particularly water quality. The "is rainwater safe to drink?" question continues to predominate. The usual answer to this is that a well designed, built and maintained system will provide water of high quality whereas a poor system will almost certainly provide poor quality water. Generally the features of a well designed system are:

- Smooth non-toxic and clean catchment surface
- Guttering with a continual, even slope
- Filtration of matter from the incoming stream either by filters or first flush diversion
- The tank should be sealed from vermin entry and light
- Outlets should avoid drawing off settled particles

If these guidelines are followed, the water should reach WHO "low risk" criteria there and should be little need for other treatment.

Even the current "state of the art" German practice is quite simple in operation and lends itself to adaptation for use in developing countries. The system currently employed uses a two-step filter to remove large debris such as leaves and then smaller particles. The course filter is a simple grid and the finer filter, typically has a 0.2–1mm aperture which can be achieved with gauze or cloth. The main penalty for a larger aperture size is more frequent tank cleaning. Final polishing of the water quality takes place in the tank where particulate matter settles either to the top or to the bottom of the tank. Bacteria also die off with isolated, darkened storage of more than a few days so if water is added and subtracted from the tank appropriately, very low bacterial counts will result. The usual method is to add the water to the bottom of the tank through a large aperture or suitable manifold and draw the water from the top by way of a floating outlet. This arrangement is unusual in developing countries but can be simply achieved at very low cost and will result in the highest quality water.

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APPENDIX

The Design/Prototyping Phase

THE DESIGN/PROTOTYPING PHASE

The constraints and problems outlined in this document form the basis of the second phase of the technical programme – design and prototyping. Analysis of existing practices and brainstorming both during the inaugural meeting and over the course of the surrounding few weeks has generated a number of design ideas. Some have been taken on by Water Action and ACORD and some will be handled by the DTU in collaboration with members of the Lanka Rainwater Harvesting Forum. The end result of this process should be several products that can be widely disseminated through manuals, training and building programmes. The list has became quite large and so several ideas have been postponed until year two and several ditched altogether.

There are several technical research and development issues related to existing designs to be solved. Once again some of these will be investigated by ACORD and Water Action and some by Warwick and Lanka Rainwater Harvesting Forum.

Design ideas

Tanks

Bag in hole (tube tank modification)

Based on Warwick's previous work with tubular polythene bags and influenced by user surveys carried out in Uganda, the design will seek to further reduce the cost and increase capacity by reducing the protrusion above ground and introducing a mass-producible cast concrete lid. The bag should also be removable to aid cleaning and possible replacement in case of tearing or vermin action. There is also a possible variation whereby the bag is partly laid horizontally, resulting in a higher capacity.

Potential problems are dealing with possible puncture of the tubes and quality control of the tubes themselves for pinholes in manufacture, and preventing possible ingress of stormwater without adding to the cost. The horizontal variant will also have problems of covering the horizontal section cheaply and with enough strength to resist any loads that may be placed upon it (such as a vehicle)

Caged bag

Similar to the bag in a hole, this design is based on the tube tank but is an above ground variant. The bag itself will be placed inside a hessian or basketwork tube, which in turn will be held up by a frame structure resulting in a very low cost above ground tank that is also portable.

Possible problems with the design include, how to deal with the lateral stresses vertical stresses will be very small as the bag will sit on the ground), how to remove the water, how to seal the top "elegantly"

Several connected jerry cans

Based on the notion that urban households may prefer to have many smaller storage containers than one large one in order to fit the storage into their households and reinforced by the fact that many households already own quite a few jerry cans, the idea is to connect them together to form an overall larger store which would also vary in quality, the furthest from the inlet being the best.

Possible problems with the design are creating a good seal on the manifold connecting the cans together but allowing cans to be removed *without spilling any water* the potential disaster if a can is left off the piping when it rains spilling water into the house.

Tank built into the wall of a building

The tank is built between two walls of a building, in a corner, as the basement of a building resulting in cost savings due to the double use of material for walling and for water retention.

Difficulties include the inefficient shape of an in-wall structure may reduce or even reverse any material saving, leaks may result in water in the house and the tank may be difficult to clean. There is also the problem of just how to research such a design as it requires a new dwelling to be built.

Small high quality tank and large low quality tank

A constant worry with rainwater harvesting users is that the tank will be too small for their needs, which must be balanced with the cost of building good quality storage. One possible solution is to build a small high quality store based on, say drinking and cooking needs and a larger low quality store (such as a covered pond) for other water use. Any first flush water can also be diverted to this store reducing the fear of “losing water” through FF systems.

The solution is, however only suitable for rural areas where there is space for such a pond and where ground conditions are appropriate.

Use of drums

One of the most common storage solutions at present is the use of drums. They are used singly and even in some cases welded together to form a larger store. The advantages are that they are readily available for a reasonable sum of money and many households already have at least one

The problems with this approach are mainly from the health point of view. The drums usually come from an unknown origin and have often contained very toxic substances. They are also (usually) uncovered and thus allow entry to vermin, mosquitoes, dirt and provide a good environment for algal growth.

Thus the problem is to find ways of either effectively cleaning these drums or introduce a cheap liner (cement has been tried with some success). Some method of covering the drums should also be found as well as useful methods of removing the water and connecting the (covered) container to the guttering. There is also the possibility of having a “dirty” storage which overflows into another drum after it has the water has been allowed to lose its sediment load and perhaps aged for some time allowing die off of micro-organisms. The water in the second container will then be of a higher quality.

Rammed Earth

Rammed earth is a common building technology in many parts of the world. The technique requires that earth is rammed down between two shutters. The earth can either be as nature intended or can be stabilised with cement for a stronger structure. Warwick has built two round tanks using this technique with some success, however the walls had to be made overly thick and the process was seen as labour intensive and problematic as the mould tended to move and twist off the structure due ton its off centre, centre of gravity.

The proposed approach, therefore, is to build a rammed earth tank but in a square shape removing the problem of producing the circular shape. The problem then is how to deal with stress concentrations in the corners. . .

Removable tank covers (based on previous DTU work)

The DTU removable cover eliminates the need for large amounts of false work when making the cover of a tank, which can often be a large part of the cost however the current design is inflexible in sizing and has resulted in some cracks around the join with the tank. A newer design should be more flexible in size and stiffer around the edge

Very low cost roof

As the cost of the tank itself is reduced, the lid becomes a larger part of the overall cost. For particularly low cost storage (such as lined pits and covered ponds) a lower cost lid should be developed. This could be a thatch construction but with an underlining of polythene. The thatch should protect the polythene from wind and UV while the polythene will prevent the thatch from falling into the tank and could provide a good seal to prevent entry of mosquitoes etc.

Cascade of water jars

Pottery water jars are inexpensive and readily available in many parts of the world. Conceivably they could be stacked and arranged so that as one pot overflows it flows into the next pot and so on. The result is an (attractive) storage which lends itself to quality differentiation and is made up of small containers suitable for direct use in the household

Problems include the lack of lids (or screens) on the pots and the need for a stable stand (or set of stands). It also may not work – water may just splash everywhere.

Nilled hole

If the soil is suitable nil could be applied in several coats with a brush to seal the hole without any further preparation. Alternatively the hole could be prepared with local clay to provide a smooth surface upon which to “paint” the nil coating

A small complication (assuming it works at all) is that a base will have to be provided as a platform upon which to stand when cleaning the tank and for a ladder to stand on.

Factory produced bag

Similar to the caged bag but mass-produced to purpose with all fittings in place. Development of this idea will depend on interest from industry

Prefabricated segmented tank

There have been a number of segmented tanks produced in Brazil and India. One new idea is to use a geodesic dome structure to provide material economies. Advantages include possible good quality control and excellent curing of the panels and standardisation of a small shape to build a larger tank

Problems will be in joining the pieces together to cope with the bending loads they will be under, foundations for the small base and dealing with misalignment of the pieces.

Gutters

Very low cost steel gutters

As tank costs reduce, gutter cost also become more predominant. Developing on the vee (or square) shaped gutters, stripping them back to the bare bones. How small can they be? Are splashguards necessary? Are end plates necessary? How to mount them reliably and cheaply? How to deal with downpipes (if at all)

Suspended gutters

Suspended gutters from cloth, sacking or tarpaulin. Do they need doping? How is their runoff quality and quantity? How do their costs compare?

Roof treatments

Roll up roof

A roof-on-a-roof that can be rolled away when it isn't raining. This could also include gutters as a part of the structure.

Problems include whether anyone *will* roll it away and if they don't what effect will this have on the thatch roof itself (rotting etc.). Also the flexible material could decompose in UV (polythene) or become quite dirty itself (sacking/tarpaulin)

Auxiliary roof

In households with reasonably large compounds, an auxiliary roof might be a better option. A simple pole structure can be erected and covered with a tarpaulin. Appropriate shape may also do away with the need for guttering

Problems include wind loads both on the attachments from the tarp and on the structure itself and the quality of runoff from a porous material (polythene has proved to be unreliable due to UV – but could be possible if it is rolled up after the rain)

Filtration

First flush pit

A first flush system can be built using the ground seepage to bleed the water from a pipe or cement lined hole. The aperture could be matched to the local seepage to give any desired emptying time. Costs would also be low. A basket of stones could be kept in the bottom to catch dirt and be rinsed out regularly.

This system is only suitable for underground tanks and needs to be made proof against stormwater ingress and be well covered.

First flush pot

Another material with a natural seepage rate is pottery. The FF system could be a pottery container that would empty in an appropriate time. The main possible problem is that leaf debris has oil in it that may block the pores in the pottery container.

Vorticity filter

A filter that uses centrifugal force to accelerate settling. Can the force be enough?, is the geometry loose enough to allow small scale manufacture?

Selection

This is clearly too many designs for one small project. After some consultation the following priority list has been developed.

Tanks

Type	Action
Rectangular rammed earth tank	ACORD
Using storage drums	Water Action
Bag in hole (tube tank modification)	DTU/LRWHF (1)
A caged bag	DTU/LRWHF (2)
Prefabricated segmented tank	DTU/LRWHF (3)
Removable tank covers (based on previous DTU work)	DTU/LRWHF (4)
Nilled hole	DTU/LRWHF (5)
Very low cost roof	DTU/LRWHF (6)
Several connected jerry cans	DTU/LRWHF (7)
Cascade of water jars	DTU/LRWHF (8)
Factory produced bag	DTU/LRWHF (?) Based on interest from industry
Small high quality tank and large low quality tank	Modelling only
Tank built into the wall of a building	Literature research only

Roofs

Type	Action
Auxiliary roof on an existing structure	?
Auxiliary roof on an new structure	?

Gutters

Type	Responsibility
VLC metal gutters	DTU/L RWHF (1)
“hanging gutters”	DTU/LRWHF (2)

Filters

Type	Responsibility
Vorticity filter	Year 2
FF pit	Year 2
FF pot	Year 2

Research and development

Joining tarpaulins with leak-proof seams

A The tarpaulin tank is a successful low cost design being widely replicated in southern Uganda. However it’s capacity is limited to one tarpaulins worth, if a greater capacity is required, then more than one must be built providing no economy of scale. If a way of joining these tarpaulins reliably and without leakage can be developed, then the tanks can be made any size or shape.

Creation of reusable moulds that will work for more than one size of tank

Several people have expressed a desire to have a set of moulds that can be used to produce more than one size of tank. At present there are three main types, skeletal moulds as used for the Sri Lankan pumpkin tank, block moulds and “star fruit” segmented moulds as used for Thai jars (inflatable moulds have also been tried but have been less than successful). The latter two tend to be the cheapest to use whereas the skeletal mould is the most flexible. Can a mould be designed combining the best of these types and capable of use over a range of ,say, 500l, 700l, 1000l and 1500l?

The use of shaped bricks to take tensile load

Bricks are a common building material for tanks, however their use is often seen as labour intensive and the cement for the mortar can exceed that needed for a similar ferrocement tank! A major opportunity when making bricks, burned, cement, or stabilised soil is that the geometry can be altered from the standard “block”. Some work has been done on curving the bricks (for aesthetic reasons) and making keyways to increase sheer. It is also possible to produce bricks that interlock with either pegs or mounds to produce a structure where the cement performs the role of sealer only. This could mean thinner walled brick tanks, easily built and with a much reduce cement content to the tank.

Gutter interception

Warwick has been working on the mechanics of gutters for some time. In order to reduce the cost of gutters (see above), gutters recommended in most manuals seem large when the *flow* of water down them is considered, however we have yet to gather sufficient data of the *interception* of rain from the roof. How does rain project from the roof? How does wind effect it?

Most of this work has already been done and just needs tidying up.

Runoff characteristics of roof materials

There is some data available on the "runoff coefficient" of several conventional materials but what of unconventional roof materials such as sacking, tarpaulin and polythene? Also what are the relative dirtiness of these materials' runoff.

How much to flush in a ff system

Much has been written about first flush but there seems no consensus on how much to flush off. Obviously it is best to flush as little as possible but if the amount becomes too large are ff systems simply not economical (in a water sense)?

Appropriate safety factors for cementicious materials from unknown sources in tension

Given the uncertainty of cement quality and age as well as the working practices in the field. What are appropriate safety factors to include in structures containing water built under such uncertain conditions? Hitherto field manuals have suggested figures such as 3x and even 5x. Is this too conservative?

Selection

Some of these ideas ally themselves to lab work as well as collection of field data and some form design problems themselves. The following table gives a breakdown of how they will be tackled.

Type	Responsibility
Joining tarpaulins with leak-proof seams	ACORD
Creation of reusable moulds that will work for more than one size of tank	WA
Gutter interception	DTU/LRWHF (mostly already done)
Runoff characteristics of roof materials	DTU/LRWHF (initial – crude field data)
How much to flush in a ff system	DTU/LRWHF – field data Year 2 lab work; extension of field data collection to Africa
The use of shaped bricks to take tensile load	Year 2
Appropriate safety factors for cementicious materials from unknown sources in tension	Year 2