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Reducing Rainwater Harvesting System Cost

D. B. Martinson, N. U. K. Ranatunga & A. M. C. H. A Gunaratne

1. Introduction

The cost of existing technology for Domestic Rainwater Harvesting (DRWH) is often considered too high and in Sri Lanka at least, existing options are becoming too expensive for the available subsidies. The generally used storage capacity of 5m^3 is also considered too small for the dry zone of the country. Finally, the government is moving from water provider to facilitator so subsidies may be reduced in the coming years, putting further stress on existing options.

This paper describes several designs produced under a DFID-funded contract: "Roofwater Harvesting for Poorer Households in the Tropics", during an intensive period of product development undertaken in Sri Lanka. Another paper at this conference, "Economically Viable Domestic Roofwater Harvesting" by D. Brett Martinson & Terry Thomas, outlines broader strategies for reducing domestic roofwater harvesting (DRWH) cistern costs.

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2. Methodology

DRWH system cost reduction can be carried out by:

(i) reducing 'unjustified' cistern size and thereby system performance
(ii) streamlining the production process
(iii) reducing 'superfluous' construction quality

These are further explained in Martinson and Thomas. The greatest potential for savings is possible by the third of these approaches, namely by reducing construction quality and this was pursued in our recent work and is the basis of this paper. A parallel project by the Sri Lankan National Engineering Research Development centre (NERD), worked on streamlining production process by producing a segmented tank.

Superfluous quality can be reduced by four basic methods:

(i) Material reduction (using thinner sections, changes in concentration)
(ii) Material substitution (using cheaper materials or "free" materials)
(iii) Functional separation (using more than one cheap material rather than a single expensive material)
(iv) Changing labour content (moving from bought in labour to householder labour– costs quoted disaggregate household labour)

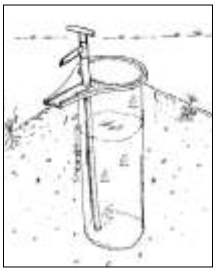
The ultimate expression of this philosophy would be *no*-cost roofwater harvesting where all materials are gatherable and all labour is provided by the household. Rudimentary, covered ponds sometimes used in agriculture can fall into this category, however *domestic* roofwater harvesting requires a slightly higher specification for household use:

- The tank should not have excessive loss through seepage or evaporation
- The tank should not present an excessive danger to its users, either by their falling in or by the tank failing violently
- The water must be of a quality commensurate with its intended use

3. Underground tanks

Below ground tanks have the greatest potential for cost savings, particularly if built in a stable soil which can be relied on to take all or part of the load. Walls can much weaker and materials that have good waterproofing properties but suffer from a low strength (such as polyethylene sheet) can be used

3.1. Tube tank



General arrangement

Overflow

The tube tank is based around a widely available plastic tube of about 500 microns thickness sold by the metre on a roll of 3ft width at a cost of $0.55 to $0.80. When opened, the tube forms a cylinder of Ø54cm resulting in a volume of 0.23m^3 per metre length. The cost of storage, is therefore only $2.45 to $3.40 per m^3 of storage for the tube itself.

The design is underground using the ground for support and uses a precast concrete cover. The cover itself is similar to the drainage arrangements found on some handpumps and so should be familiar to use. It is made using similar casting techniques to pit latrine covers (sanplats). The tube is folded in two, with one end connected to the inlet by a retaining ring and the other to the pump so it can be easily removed for cleaning or replacement. It is proof against groundwater intrusion and so can be used when groundwater height is questionable, however the hole must be prepared with no sharp protrusions which could puncture the polyethylene. Water extraction is by a low-cost pump made from PVC pipe

The finished tank costs less than $25 for an 800 litre tank. Tank size is determined by hole depth, so the deeper a household digs, the larger the store. Extra storage is relatively cheap as the cost of the tank is dominated by the concrete slab.

The tank design is also ideally suited to rapid implementation projects such as refugee camps; if the excavation is done by the householders, an agency can simply transport a number of prefabricated parts and each tank can be assembled within an hour. Costs ranges for the tube tank in Ethiopia, Uganda and Sri Lanka in a range of capacities are below in Table 1

Table 1: Cost of tube tank

Capacity (m^3)	0.6	0.8	1.0
Total	$24–25	$24–25	$25–28
Total (HH labour ignored)	$19–22	$20–24	$24–26

3.2. Direct application of mortar

Directly applying mortar to the walls has proven to be a simple technique to apply in the field. A thin layer of 1cm can be applied with ease and with good quality control. The mortar itself has no need for high strength so can be as lean as 1:8 (cement:sand) in a stable soil. If the soil is less stable, a stronger wall is required so the mix should be enriched to 1:5 or 1:3. Waterproofing is provided by a thin cement slurry applied while the mortar is wet. Several tanks have been built using this method to depths of up to 2.5m and 2m diameter with no visible cracking. This technique is the basis for two interrelated designs of tank, the below-ground cement tank with organic roof and the partially-below-ground tank with ferrocement dome.

3.3. Partially below-ground tank with ferrocement dome

Finished tank

Lining the pit

Partially below-ground tanks form a bridge between underground tanks and above-ground tanks. Most of the tank is underground to take advantage of soil support but some of the tank protrudes, avoiding stormwater ingress and providing a structure for overflow arrangements.

In the design developed, the domed above-ground section is made on a removable frame that leaves behind only wire mesh as reinforcement. The mortar can either be applied without any other formwork by using one person outside to apply the mortar and one person inside to provide a backing (the addition of a small amount of sacking fibres to the mortar was found to help this process) or by making a temporary formwork from cardboard. The dome can be built when the tank is first commissioned or added later when more funds are available. Costs for the tank are shown in Table 2.

Table 2: Cost of partially below-ground tank

Capacity (m^3)	3	5	7	10
Total	$54–62	$60–75	$72–91	$79–104
Total (HH labour ignored)	$44–45	$50–62	$58–76	$62–86

3.4. Below-ground cement tank with organic roof

Finished tank with cover in place

Making seals in the plastic liner

As the cost of the below-ground waterproof tank is reduced, the cover of the tank becomes the dominant cost. Organic roofs are used on many buildings in poor households and so the skills to build them are common. The materials themselves also tend to fall into the “gatherable” class. To put an organic roof onto a water tank, however, a number of precautions must be taken.

- The organic material must not fall into the tank and contaminate the water
- Runoff from the organic roof will be of low quality and so must not be allowed to enter the tank
- The roof must provide a good barrier to animal entry, especially as some creatures make their homes in thatch.
- The wooden supports must not be exposed to the humid atmosphere inside the tank which will make them liable to rot
- To prevent algae growth and thus encourage bacteria die-off, the roof must provide a good barrier against sunlight entering the tank

A polyethylene barrier fulfils the need to protect the organic matter from moisture and also to protect the water from falling debris. If the joining is handled well, it can also act as an excellent seal–completed by the use of inner tubes around the rim. Prevention of water entry can be afforded by the use of a sloped ring beam which will divert the water away from the tank and into a drainage channel.

Below-ground tanks also need care with avoiding floodwater ingress and with overflow arrangements. The new design uses a syphonic overflow by employing an upwardly facing elbow connected to an outflow pipe leading either to a nearby slope or to an infiltration pit. Stormwater ingress is handled by digging a channel around the ring beam to a width and depth determined from the runoff.

The overall combination of direct mortar application and low cost roof yields a tank that uses very little material but is quite householder labour intensive. The costs for the tank are shown in Table 3. The below-ground cement tank can also be upgraded to a partially below-ground tank by adding a ferrocement domed cover.

Table 3: Cost of underground mortar tank with organic roof

Capacity (m^3)	2	4	5	8
Total	$41–58	$47–63	$48–67	$54–75
Total (HH labour ignored)	$28–34	$32–42	$34–42	$38–51

4. Above-ground tanks

Above ground designs are generally more popular than below ground solutions, however the cost is often also higher as the tank must now cope with the full force of the water pressure acting on it. The principle of functional separation allows some scope for cost reduction by using an inexpensive material for structure while waterproofing can be done by either mortar or a liner.

4.1. Crate tank

Internal configuration

Finished tank in use

An above-ground tank is almost essential in poor crowded urban areas as the ground can be very contaminated possibly leading to polluted groundwater seeping *into* a damaged underground tank. Ideally, a tank should also be fairly portable as tenure in such communities can often be insecure and many squatter communities live under constant threat of being moved on. The crate tank goes some way to fulfilling these needs by providing a tank with a small footprint, protruding only 45cm from the dwelling. The tank can also be collapsed down for transport.

The design incorporates a polyethylene tube to hold the water while a wooden crate takes the pressure load. The configuration is similar in concept to the tube tank with a retaining ring holding the top of the tube to the top of the tank providing an inlet. The tube than folds around and the other end is attached to the overflow. A tap is attached at the bottom of the “U” and sealed with bitumen. The outlet and overflow can be on any of three sides of the tank to help it fit in with its location. The total cost of the tank is slightly higher than others described here, however the need for a slender profile and portability may make the tank usable in areas where cheaper alternatives will be inappropriate. The manufacture of the tank employs only skilled labour but is very portable (deliverable) so it lends itself to mass production at a central location which should reduce the cost.

Table 4: Cost of crate tank

Capacity (m^3)	0.8
Total	$33–41

4.2. Wattle and daub tank

Bamboo frame

Finished tank

A simple way of producing an above-ground tank with the economy of a below ground tank is to bring the ground up. Several earth technologies have been used in building for millennia and such techniques are often the mainstay of housing for the poor. Wattle and daub is a widespread practice for building from earth, particularly when householders build their own homes. The technique uses unmodified mud to fill a frame structure made from roundwood such as bamboo. The materials necessary for this type of constructions are all in the “gatherable” class so cash costs are extremely low, being limited to the liner and plumbing.

Walls have to be made quite thick–typically 15 to 20cm to take the stress and the design is unsuitable for tanks of capacities greater than about 5m^3. Initial tests used cement as a liner, however the mud structure expands slightly under load cracking the lining which resulted in leakage and damage to the mud walls. The use of a plastic liner has proved much more satisfactory.

Table 5: Cost of wattle and daub tank

Capacity (m^3)	1.25	2	3.5	5
Total	$37–54	$40–59	$45–66	$50–70
Total (HH labour ignored)	$23–26	$25–29	$29–34	$32–38

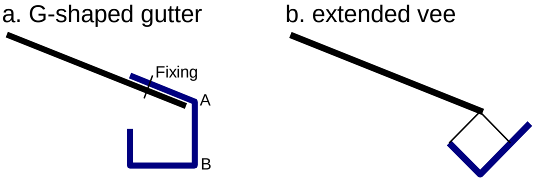
5. Gutters

Guttering can account for a substantial part of the cost of a very-low-cost roofwater harvesting system so its design optimisation is important. Gutters in developing countries tend to be relatively expensive, with a typical 10m length costing from $15 to $35. Some work has been done in East Africa with vee shaped gutters which have a typical cost of $12 for a similar length. Research at Warwick on optimising gutter size based on carrying capacity suggests that on a domestic sized roof, a vee shaped gutter of only 7.5 cm width and a 1% slope is sufficient to carry water from all but the most severe downpours and will deliver more than 90% of the water it catches (Thomas and Still, 2002). Such a small gutter should cost less than $4.50 for a 10m run.

Water interception is a slightly more difficult issue. Water often has to fall some distance from the roof to the gutter and is thrown from the roof different distances depending on the intensity of the downpour. It can also be blown by wind in unexpected directions. Two solutions for this have were tried in our recent work.

Figure 1: Gutters configurations

a. G-shaped gutter b. extended vee



The first (Figure 1a) is a complete solution that captures the water at the end of the roof and directs it into the gutter below. The gutters are also very quick to install as the slope is determined by a variable length of vertical support (between A and B) set during manufacture so no adjustment is necessary on installation. Cleaning is also simple as the inside edge is open for a brush all the way along its length. Problems with the gutter appear when the length to be guttered is longer than 5m or when thick roofs need to be accommodated. Under these circumstances the vertical support becomes very long and can flex causing the gutter to spill. This can be alleviated by using support wires with the some loss of cleaning ease, however as the vertical support can use a substantial amount of material, the gutter starts to become expensive at over $13 for 10m.

The second uses the concept of an "upstand", where one side of the gutter stands proud of the other, effectively raising the catchment height of the gutter. In the design the usual square gutter has been simplified to a vee and the upstand is merely an extension of one arm of the vee. This extends the catchment of the gutter upwards and moves the centre of the catchment out from the roof edge better matching the profile of water flowing from a roof. The gutter is extremely cheap (about $5 for a 10m run) and can be applied to any sized roof without the need for a facia board. Like all suspended gutters, the design does need adjustment to maintain the slope and suffers from guy wires obstructing cleaning and from swinging in high winds when empty.

6. Conclusions

These designs comprise much of the final output from the design phase of our project. At the time of writing, 180 tanks of these designs are being field tested in Ethiopia, Sri Lanka and Uganda and most will have been used over a wet season and into a dry season by the time the paper is presented so a good idea of their field service will be gained.

A series of technical releases describing the designs in detail, including working drawings and instructions for manufacture can be obtained at www.eng.warwick.ac.uk/dtu/pubs/rwh.html. or from the authors.

7. References

Still G. & Thomas T. H., 2001, *Guttering for roofwater harvesting in the tropics*, DTU Working Paper 56, Warwick University, UK

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