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SUSTAINABLE ENVIRONMENTAL SANITATION AND WATER SERVICES

Economically viable domestic roofwater harvesting

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THE VIRTUES OF domestic roofwater harvesting (DRWH) are well known. However against these virtues, whose value varies greatly with location, must be set a weakness of DRWH, namely that it is usually unsuitable as the *sole* source of domestic water. This is partly because the total resource available to a household (the product of rainfall and the house's roof area) is limited but mainly because storing water in very large cisterns is expensive.

At present the capital cost of a DRWH system that will supply the bulk of a household's water – in the favourable humid tropics – usually lies in the range $20 to $30 per person. In the Monsoon tropics (Summer rains only) these costs may double. A water agency might compare such costs with some investment norm such as $16 to $20 per capita and conclude that DRWH is not cheap and is to be used only where other sources are particularly 'difficult'. Typical forms of such difficulty are unfavourable topography or highly mineralised groundwater. A householder will weigh the cost against the time and money that possessing DRWH would save or might compare the system cost with that of say a bicycle ($50). Household and community surveys recently undertaken in 9 locations in Ethiopia, Sri Lanka and Uganda have indicated that excessive cost is considered the largest impediment to take-up of DRWH among poor households. However willingness to pay appears sufficiently high that if costs were significantly reduced, unsubsidised DRWH would be accepted.

The principal component of cost for all but the smallest DRWH system is the water storage device, which we may call the 'cistern'. So reduction of this component's cost will yield the greatest benefit. Such savings can be applied to make more cisterns, bigger cisterns or simply to speed up the payback. For example a 33% reduction in cistern cost could either increase internal rate of return by 50%, or permit a 100% increase in cistern size. However when modelled using climate data from Western Kenya, representative of the Equatorial zone, the latter volume increase projected into an increase in harvested water value of only ca 13%.

This paper will show that through design innovation tank costs can be reduced by 30% to 50% below current norms. In particular we explore three strategies for making such savings:

(i) reducing 'unjustified' cistern size and thereby system performance

(ii) streamlining the production process

(iii) reducing 'superfluous' construction quality

Current cistern costs

Cistern costs depend upon design, country of construction and size. The sensitivity of cistern cost to size is generally around 0.65, while the sensitivity of whole-system cost to cistern size is even lower. Figure 1 shows data for the Ethiopian costs of a number of cisterns derived from bills of materials reported in the literature or within the authors' experience. On the graph the lines represent constant sensitivity of 0.65. The costs fall into two bands, namely normal-cost cisterns and low-cost cisterns.

Reducing system size

The not-unexpected increase of costs with size (i.e. storage volume) leads one to examine whether size could be reduced. It has previously been shown (Thomas & Rees, 1999) that to optimise economic return from a DRWH investment requires use of very small cisterns – so small that they meet only around half a household's water demands. By contrast to employ DRWH as a 100% reliable sole domestic source requires cisterns 10 to 50 times larger: pursuit of this inappropriate service standard in the past has seriously overpriced DRWH and discouraged its general take-up. Between these extremes, of using typically 400 litre and 10,000 litre cisterns respectively, comes 'medium performance' DRWH. Such systems combined with prudent water management give a reliability similar to that currently attainable from many rural point sources, albeit

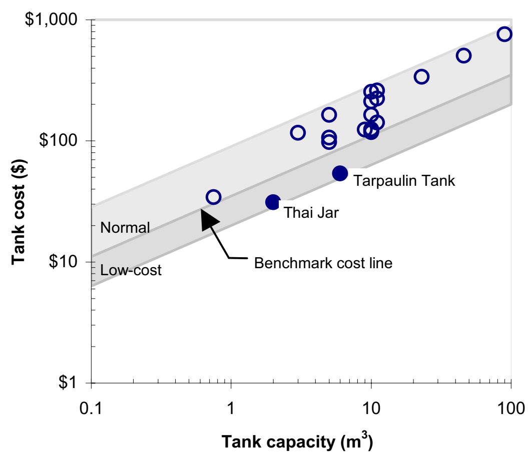

Figure 1. Tank costs versus size

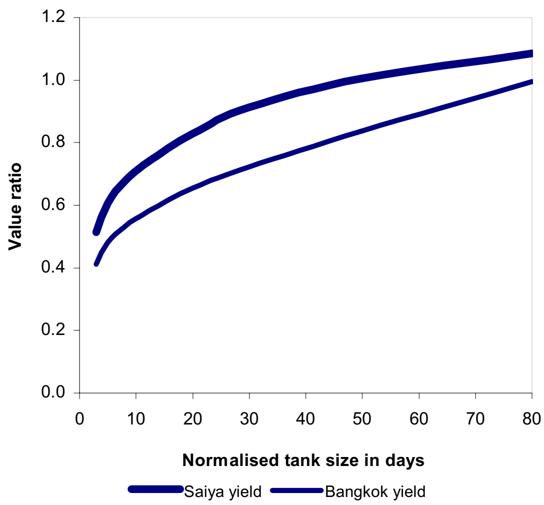

Figure 2. Diminishing returns with increase in tank size

with much higher convenience. 'Prudent water management' generally consists of adjusting daily demand to reflect both the diminishing unit value of water with increasing daily consumption (i.e. a strongly falling demand curve) and the higher cost of back-up water during the dry season.

Undoubtedly householders aspire to having large – e.g. 10,000 litre – cisterns, but this aspiration is rarely accompanied by ability to pay and it is in open contrast to the very small size of stores used by the many households that already practice opportunistic or 'informal' DRWH.

Figure 2 shows how the performance of a RWH system increases with cistern size in two locations, Saiya & Bangkok, representing Equatorial and Monsoon climates respectively. The actual cases plotted correspond to a high fixed daily demand: the loci would be higher if that demand were less. (The variable plotted is the ratio of the annual 'value' of the water drawn from the cistern to that of the roof runoff. The combined importance of water volume and supply reliability have been crudely reflected here by giving each litre of dry season water twice the value of a wet season litre.) The graph shows clearly the diminishing returns from increasing tank size beyond about 20 days consumption. Similar curves are obtained using demand that adapts to tank contents.

Streamlining the production process

Figure 1 shows two tanks whose costs fall substantially below that of normal practice. The first is the Thai jar which has been the subject of much description in the literature (Gould & Nissen-Petersen, 1999; Pacey & Cullis, 1986). The jars are made in small batch quantities in a workshop, often by part-time farmers, but the true secret is in the quality of tooling. Each jar is made on a mould of cement bricks, which are coated with mud as a release agent. The moulds themselves are also made locally so a workshop may have several. The steel formers for making the moulds are, however, made centrally ensuring tight quality control of the size and shape. The high quality solid mould allows an especially thin coating of mortar to be applied with excellent quality control resulting in a high quality, optimised product. Solid moulds, however become expensive when tanks become larger and workshop production is impossible when tanks are too large for available transport. These factors conspire to limit the size of such tanks to 1 – 3m^3 and it is interesting to note that larger Thai tanks tend to fall into the "normal" range of costs. (In some developed countries where labour costs dominate equipment costs, even large tanks are factory-built because they can be delivered by truck and crane.)

An approach to maintaining workshop-oriented practice for larger tanks is to manufacture them in segments. This approach has been used in India since the late '70s and recently the National Engineering Research & Development Centre of Sri Lanka has been working on an octagonal segmented ferrocement tank. Segmented concrete tanks have also been developed in Brazil (Gnadlinger, 1999). Costs tend to be lower than similar ferrocement tanks made on open moulds but similar to cylindrical tanks made on solid sheet-metal moulds and thus they tend to fall at the bottom of the "normal" range. This is a promising area for further developmental work.

Lowering construction and material quality

Construction and material quality includes such features as longevity, ease of use, appearance and potential to generate pride of ownership and to satisfy its builder's desire to do a "proper job" (Construction quality does *not* necessarily equate to water quality). A good example of successfully lowering construction quality is the Tarpaulin tank, designed by ACORD for refugees in southern Uganda (Rees, 2000). The tank uses a plastic tarpaulin in a pit to hold the water while the above-ground structure is wattle and daub. Large savings are made by exchanging expensive high

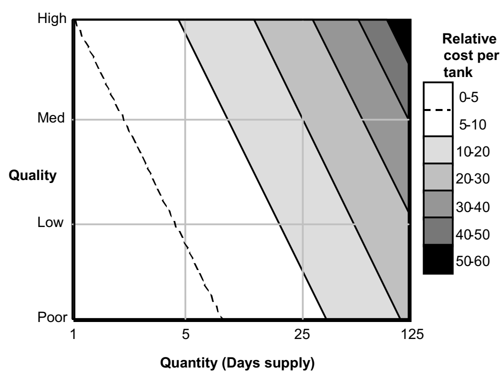

Figure 3. Schematic graph of cistern cost versus size and construction quality

Figure 4. Typical wattle-and-daub building in Ethiopia with large ferrocement tank

Figure 5. Some of the tanks developed

quality materials such as ferrocement for lower quality materials which can simply be gathered.

Figure 3 schematically shows the relationship between cistern size, construction quality and cost. Generally, rainwater harvesting projects in developing countries operate at a medium quality level using materials and techniques taken from the formal housing sector. Many houses especially those of the poor use different, much cheaper (often free) materials to the cement and brick favoured by such projects. As a result rainwater cisterns are often of a inappropriately higher quality and higher cost than the houses they serve, as can clearly be seen in Figure 4.

It is also interesting to note that the quality of informal RWH systems commonly found in poor households (using oil drums and kitchen utensils) is generally lower than the DRWH systems installed by water providers.

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

There are a number of critical functional constraints that should be regarded as a minimum specification for any domestic rainwater harvesting system.

- The tank should not have excessive loss through seepage or evaporation
- The tank should not 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. Drinking water in particular requires that:
  - the water be filtered to remove gross impurities or the first flush removed
  - the tank be covered to prevent entry of light, and sealed against intrusion by vermin including mosquitoes
  - the tank be ventilated to prevent anaerobic decomposi tion of any washed-in matter

The current technology development project coordinated by the DTU has developed a number of designs based on reducing superfluous quality and these designs achieve up to 50% lower cost than the benchmark cost line in Figure 1. They include:

- A partially-below-ground tank incorporating a thin low-cement-content lining and a ferrocement dome roof
- A below-ground tank based on the same lining technique but with an organic roof
- An 800 litre tank based on a polythene tube and a precast slab that can be installed in a single day
- A light and fairly portable wooden tank lined with a polythene tube with a 0.5m^2 footprint but an 800 litre capacity
- A wattle and daub tank with a polyethylene liner
- A 600 litre combination of treated oil drums including a slow-sand filter

Most of these tanks are detailed in Gunaratne, Martinson &. Ranatunga, 'Reducing Rainwater Harvesting System Cost' and details may also be found at www.eng.warwick.ac.uk/dtu. The costs for the tanks are shown in Figure 6.

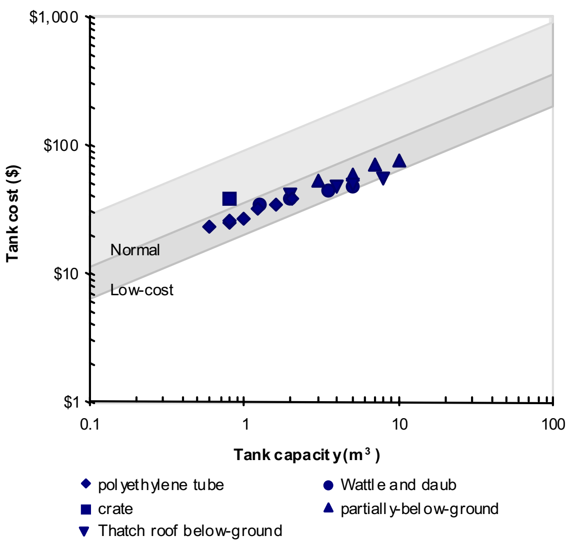

Figure 6. Costs of newly developed cisterns

Conclusions

Domestic Rainwater Harvesting is often seen as expensive by water providers and is simply unaffordable to many householders. Inappropriate size and system quality contribute to these views by placing unrealistic expectations both upon the technology itself and upon the types of construction that can be replicated by poor people.

An alternative approach is to introduce a hierarchy of technologies. Hierarchies have been used for some time in the sanitation sector where the sanitation ladder is a frequently used tool for assisting informed choice of technologies. It is the quality aspect that is predominant in the sanitation ladder whereas choice of rainwater harvesting system has been dominated by the question of quantity, with only a single (high) quality considered. With the quality dimension reinstated as a variable, and system service replacing raw quantity as a criterion for selection, a community can be offered choices of service provision within a given budget – Larger (or more) low quality structures can compete with smaller (or fewer) high quality structures.

Accepting low initial quality can make staged investment in RWH attractive, whereas there are few advantages in staging investment in very durable tanks.

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