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Communal rainwater tank systems design and economies of scale

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ABSTRACT

Communal rainwater tank systems provide an alternative urban water supply solution for reducing dependence on centralised water supply networks. Rainwater from household roofs is transported through a gravity collection system and stored in a centralised communal tank before being treated and supplied back to homes through a reticulated pumping system. Literature on the design, life cycle costing and economies of scale of communal rainwater tank systems is currently limited. This study intends to develop a methodology for the system design, assess the economies of scale of communal systems and identify the main cost contributors for the total capital and life cycle costs. A methodology developed for this analysis is presented for the benefit of water professionals across the globe to support similar studies in their local regions. Housing layouts were developed, designed and costed for a flat topography and a centralised storage and treatment scenario, ranging from 4 to 576 homes. An economic assessment was then carried out using the net present value method (NPV). The results show that costs of storage and treatment units are more influential for a group of households at lower scale, whilst the diseconomy of scale of pipes is a major cost factor for higher scale of household groups. An optimal scale was observed between 192 and 288 households and sensitivity analysis on the discount rate showed no changes within this range. A basic analysis showed that topography of the land does influence overall NPV. However, the influence factor depends on the nature of the slope, with costs varying for differing scenarios and further work required to have a thorough understanding of its influence in final NPV.

1. Introduction

In 2012, Australia emerged from more than a decade of droughts. The experience highlighted the delicate water security predicament facing a population that is already living on an exceptionally dry continent. At one point, dam storages levels in South East Queensland (SEQ) fell to 17% of capacity (SEQWGM, 2010). With increasing pressure on existing water infrastructure from population growth and climate change, the need for alternative water supply solutions to reduce the reliance on potable water from the water grid has been recognised. One option for addressing this need could be through the implementation of decentralised systems, which involves the collection, treatment and use of rainwater, groundwater or wastewater at different spatial scales (Cook et al., 2009, 2013).

Rainwater tanks are already an established feature of individual households in many parts of the world. Mandatory regulations have been implemented in various countries requiring the installation of rainwater tanks for new buildings with certain garden sizes (Catalonia, Spain) and roof area greater than 100 m^2 (Belgium) (Domènech and Saurí, 2011). In Australia, 26% of households use a rainwater tank as a source of water (ABS, 2010). Prior to 2013, households in SEQ were required to fulfil water saving targets of 70 kL per annum through the installation of a 5 kL tank connected to a 100 m^2 roof area or half of the available roof area, whichever is the lesser of the two, under the Queensland Development Code (QDC) Mandatory Part (MP) 4.2 (DIP, 2008). Studies involving single household rainwater tanks within the SEQ region have shown that water savings of 40–58 kL per household per year (kL/hh/yr) could be achieved (Beal et al., 2012; Chong et al., 2011; Maheepala et al., 2013; Umapathi et al., 2013). However, system failure and maintenance issues may reduce the positive impacts which rainwater tanks have on mains water savings. Indeed, social research conducted in SEQ has highlighted householders' motivation and skills to adequately maintain a single dwelling rainwater system varies, resulting in issues with ongoing maintenance that may lead to

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increased failure rates of system components and poor water quality (Mankad et al., 2012; Walton et al., 2012).

An alternative option to counteract the likely maintenance problems encountered in single household rainwater harvesting systems is to implement communal rainwater tank systems, which collect, store and treat rainwater across multiple households within a residential development. The treated water can then be supplied back to homes for either potable or non-potable purposes. Communal tanks are intended to be plumbed for internal household uses and hence, require a continuous supply to avoid disruptions of such use. As the systems are climate dependant, achieving 100% reliability is improbable and hence requires a supplementary source in the form of top-up from mains supply (if accessible) or on-site bore water supply. These systems could resolve recurring maintenance issues and potential health risks, since a maintenance organisation body would usually be employed to take responsibility of operation and maintenance, as opposed to individual rainwater tanks where the home owner is solely responsible. Thus, communal rainwater harvesting systems are being considered as potential potable options in greenfield developments with the aim to reduce dependence on fresh water supplies.

Literature on the design, economies of scale and life cycle costing of communal rainwater harvesting systems is currently limited, as it is a relatively new and emerging approach in the Australian context. A financial assessment of a communal rainwater harvesting (RWH) system in the UK resulted in average annual savings of 756 GBP with a payback period of 23 years (Ward et al., 2010) although this did not delve in the economies of scale of such a system. A comparison of two separate studies in Florianópolis, Brazil, demonstrated the economies of scale of using a rainwater system in multi-dwellings, with reduced payback periods of less than 5 years for 3 blocks of four-storey apartments (Ghisi and Ferreira, 2007) obtained, against more than 20 years for single dwelling households (Ghisi and de Oliveira, 2007). Domenech and Sauri (2011) showed similar results for a study in Sant Cugat del Vallès, Spain, with payback periods significantly lower for a multi-family dwelling (14 flats) against a single family house for a range of rainwater tank supplied end uses.

Booker (1999) investigated into the economies of scale for greywater collection, treatment and reuse systems, and demonstrated a diseconomy of scale in pipe networks affecting system size of above 12,000 connections whilst treatment units were the dominating costs for connections at the lower scale (<1200). A separate study conducted by Clark (1997) used a simple communal sewer model and historic pipe cost data from South Australia Water to demonstrate the diseconomies of scale prevalent in pipe collection systems. An analysis by Fane et al. (2002) into Clark's (1997) study was in agreement with Booker's (1999) observations and showed an economy of scale existed below 500 connections with treatment costs dominating, whilst a slight diseconomy of scale was present beyond 10,000 connections. Sensitivity testing on the discount rate carried out by Clark (1997) showed slight changes in the life cycle costs, although there was no significant difference at where the optimal household was located. Furthermore, Clark (1997) concluded that local factors will influence costs varying from the averages, although the findings are believed to reflect the average situation.

This paper presents the results of a study investigating the economies of scale of a communal rainwater harvesting system through a desk study that quantifies the whole life cycle costs of the system using the net present value (NPV) method of life cycle costing. A methodology used for this study is also presented for the benefit of water professionals to conduct similar studies in other parts of the world.

2. Methodology

A methodology was developed for designing and understanding the optimal scale of communal rainwater tank systems. Such systems harvest rainwater from the roofs of multiple dwellings which then flow through a gravity collection system to communal rainwater tanks, where it can be stored and treated, then pumped back to homes for fit for purpose applications. The rainwater collection potential, estimated communal rainwater tank capacity, distribution system, treatment units and water capacities were designed and costed based on the housing layout, density of housing and its topography. The process was repeated for various scales of housing layouts and the communal harvesting system cost per household of various layouts was then compared. As each housing layout will be designed under similar specifications, the housing layout that has the minimum cost per household was considered to be the optimal scale for a communal rainwater tank system. Variations in design approaches and cost data for different states and countries will exist, which must be considered when utilising the outlined methodology. The overall methodology is described in the following steps and depicted in Fig. 3:

1. Select a typical housing layout being adopted in new greenfield developments based on information from local state housing development agencies and local developers. Collect information of variables which may influence the system design such as average size of housing land, average roof area, housing density, street width, historical rainfall data and public open spaces.
2. Develop a typical housing layout to be used in the housing developments of various scales with varying number of houses in each planned development.
3. Develop layouts of various housing scale developments (4, 8, 16, 24, 48, etc) as shown in Fig. 1a and b for 4 and 24 homes respectively.
4. Select the location of a communal rainwater tank for each housing layout considering the overall topography of the area. For a development on a flat terrain, the communal rainwater tank should be situated in the centre of the development (Fig 2a) to minimise the depths of pipes which increases the cost of rainwater collection and supply networks as a result of pipe depth factors (Table 2). Alternatively, in the case of a sloping topography, the communal rainwater tank can be located on the lower side of the housing development to maximise the benefits of the land gradient (Fig. 2).
5. Plan the layout of the rainwater collection and distribution systems for the various housing scale layouts similar to that shown in Fig. 2a and b.
6. Collect information on the rate of water supply for various end uses and decide on whether the application of rainwater will be for potable and/or non-potable uses.
7. Collect information on the local water supply system design guidelines and approaches. Estimate peak flows in the rainwater collection and distribution systems for each housing layout using local guidelines (See Sections 3.2.2 and 3.2.3).
8. For each layout, conceptually design the communal rainwater tank system using the following approach:
    - Estimate the size of the rainwater tank with optimal volumetric reliability based on water balance approaches considering roof area connectivity, rainwater patterns and end uses (i.e. water demand/consumption estimates). Also explore the availability of an alternative water source to top-up the rainwater tanks as a supplementary source in case the water level in rainwater tank is low.