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Evaluation of plumbed rainwater tanks in households for sustainable water resource management: a real-time monitoring study

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A B S T R A C T

In recent years, there has been a significant emphasis placed on achieving reductions in urban residential water demand through the application of alternative water resources on various housing development scales based on a "*fit-for-purpose*" concept. One such resource is rainwater that could be used in various non-potable applications at household level in urban areas. Savings in mains water achieved through the inclusion of rainwater as a source for residential use are plausible; however, analyses on quantifying the actual reduction in mains water demand are still at an early stage to incorporate into strategic planning for urban water supply. This paper highlights the real-time monitoring outcomes of 20 detached households with plumbed rainwater tanks in an attempt to assess their volumetric reliabilities, diurnal water demand patterns and water energy nexus. The rainwater usage (or mains water saving) was validated and assessed using 12 months monitoring data and an average yearly rainwater usage of 40 kl/household was found. The volumetric reliability, which is the ratio of the rainwater usage to the total household water demand, was found to be on average 31%. The instantaneous peak water demand was estimated to range between 16 and 93 l/min within the monitored homes, which has a strong implication for the design of household water supply system. Furthermore, the specific energy usage for rainwater supply in the 20 homes was estimated to be 1.52 kWh/kl. This study constitutes important research which provides critical input into strategic urban water planning for sustainable water resource management. The study is focussed on the South East Queensland region of Australia but the methodology developed for the monitoring and assessment of water savings in households with plumbed rainwater tanks will be useful for adoption worldwide by water professionals engaged in alternative water resources planning for urban developments.

1. Introduction

Significant growth in population and changes in lifestyles due to rapid economic growth have had a great impact on urban water management across the world. Increasing demand in urban water resources has created numerous challenges, owing to growing urban communities, their changing water use habits and the variability of local mains water supply, influenced by different factors such as land use and climate change (Pandey et al., 2003). The increasing scarcity of fresh water resource has impelled local governments and water authorities to broaden the range of sustainable water management practices to meet the water demand in urban areas across the world. Growing concerns over the rising urban water demands have motivated researchers to place a major focus on studies involving urban water demand management in various developed countries (Beal et al., 2011; Domenech and Sauri, 2011; Sharma et al., 2009; Villarreal and Dixon, 2005; Zhang et al., 2009, 2010) as well as in newly industrialised countries (NICs) (Ghisi and de Oliveira, 2007; Ghisi, 2010; Mukherjee et al., 2010). Rainfall, being the main source of fresh water in both natural and human-managed ecosystems, has significant untapped potential for being harvested (UNEP, 2009). Rainwater harvesting approaches adopted in different regions of the world are usually universally applicable, due to similar underlying concepts in rainwater capture and use. Consequently, amongst a variety of water planning strategies that have been adopted worldwide, one of the most extensively used and practically viable options is household rainwater tanks. Rainwater tanks

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are mainly used to supply the non-potable portion of the total water demand in urban residential dwellings on a '*fit-for-purpose*' concept implemented under integrated water management approaches. Utilisation of rainwater in households can be effectively targeted towards substituting mains water supply to allocated end-uses that do not require potable water standards (Jones and Hunt, 2010). Hence, plumbed rainwater tank connections to fixtures such as toilets, laundry and garden taps are the most commonly accepted end-use applications.

In SEQ, Australia, various water resource management strategies such as imposed water restrictions, rebate programs for water efficient fittings and appliances (Home and Garden Waterwise Rebate Scheme in 2006) and the Queensland Development Code (QDC) Part MP 4.2 (Department of Infrastructure Planning, 2008), have resulted in a significant reduction in dependency on traditional mains water supply. The QDC MP 4.2 has been one of the most significant steps taken to complement the state government's commitment to utilise alternative water sources to augment the mains water storage in local dams for potable end-uses. Under this code, plumbed rainwater tank systems in SEQ households are required to have a 5 kl tank with roof catchment area of either 100 m^2 or 50% of the total roof area, whichever is lesser of the two (DIP, 2008). The tank(s) must be connected to household appliances such as toilets, washing machine cold water tap(s) and at least one external garden tap. These plumbed-in water fixtures also require back-up mains water supply connections, either through trickle top-up or automatic switching valve systems, to ensure continuous supply of water (DIP, 2008).

Previous studies have been conducted to understand the end use water consumption in South East Queensland households through mixed method research design approaches; real-time monitoring methods using smart metering approaches to assess water savings in households employing water efficient fixtures and devices have been widely studied, taking into account the socio-demographic factors influencing end use consumptions (Makki et al., 2011; Willis et al., 2011a, 2011b). Although a number of studies (Beal et al., 2012; Chong et al., 2011) have attempted to estimate the magnitude of mains water savings achieved from the installation of household rainwater tanks, real time monitoring approaches to assess rainwater usage have been limited. Hence, the focus of this research is on actual quantification of water consumption associated with installed plumbed rainwater tanks in households located in regions across South East Queensland (SEQ), which have been previously targeted by several research groups (i.e. Beal et al., 2012; Chong et al., 2011) owing to high population density and rapid growth in new greenfield urban residential developments. Beal et al. (2012) conducted a pair-wise statistical analysis where households with plumbed rainwater tanks were randomly paired with households without rainwater tanks of similar biophysical characteristics, to estimate mains water savings. In another study to estimate mains water savings from rainwater tanks, Chong et al. (2011) performed a benchmark analysis of households with plumbed rainwater tanks using their actual mains water billing records and household occupancy data, and compared them with regional average residential water demand for the same period (years 2009 and 2010). The findings from these studies showed that the average household mains water savings from plumbed rainwater tanks ranged from 50 to 58 kl per household per year (kl/hhy) across the studied regions. Several analytical methods and modelling tools have been used to predict rainwater harvesting potential from rainwater tank systems for intended end-uses, connected roof catchment and tank size (Coombes and Kuczera, 2003; Fewkes, 2000; Ghisi, 2010; Imteaz et al., 2011). However, results obtained from desktop and modelling analyses were generally not validated to support claims on mains water savings being achieved from installation of plumbed rainwater tanks. Thus, monitoring and validation are required to determine the effectiveness of household plumbed rainwater tanks implemented under strategic water planning to reduce the demand loads on fresh water resources and to incorporate sustainable changes in existing water demand management and practices.

The present study aimed to validate and analyse the actual magnitude of mains water savings achieved from rainwater harvesting and usage, and to estimate corresponding energy demands in the rain tank pumping systems. The town supply mains water and rainwater consumption of a set of houses was monitored in real time for actual usage and the volumetric reliability of rainwater tank systems was estimated. Although the findings from this study are based on a case study conducted in SEQ, Australia, the methodology adopted in estimating actual mains water savings by implementing plumbed rainwater tank in households, their volumetric reliability and impact on households water usage and diurnal water demand patterns can be applied globally where similar strategic water planning approaches are adopted.

2. Methodology

A real-time monitoring strategy was developed for households with plumbed rainwater tanks in the SEQ region to estimate: mains water savings, rainwater tanks volumetric reliability, water use diurnal patterns and rainwater tank pumping system energy consumption attributable to plumbed rainwater tanks. The methodology is described below and depicted in Fig. 1:

- Select a set of households willing to participate in the study in various local council areas of the region. The selection of household numbers for the study would depend upon the size of the local council area, variations in climatic conditions, occupancy rates and also on the available funding. Such information can either be obtained from local councils' databases (if available) or from a targeted survey of a significantly large number of households. All selected households must have rainwater tanks plumbed to specified end uses.
- Conduct an on-site audit of the selected households, prior to monitoring, of the mains water supply and rainwater system. Collect information on parameters including: size and dimensions of rainwater tanks for overall and active volumes, rainwater pumping capacity and specifications, types of devices attached to the rainwater tank systems such as backup devices, details on end-use connections, and actual roof catchment areas connected to the rainwater tank(s).
- Meter selected households to record water flow and energy consumption, using smart water meters of fine pulse resolution, at a number of relevant water flow points in the mains water and rainwater supply lines. Obtain subsequent water balance, demand profiling, end-use analysis and energy consumption in supplying rainwater. Install data loggers to record the metered data at different time steps.

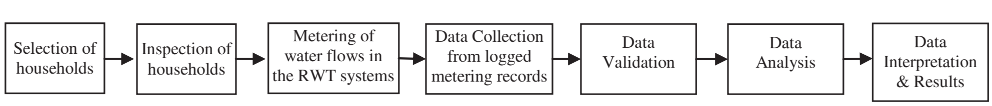

Fig. 1. Schematic of the methodology.