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Revealing the determinants of shower water end use consumption: enabling better targeted urban water conservation strategies

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ABSTRACT

The purpose of this study was to explore the predominant determinants of shower end use consumption and to find an overarching research design for building a residential water end use demand forecasting model using aligned socio-demographic and natural science data sets collected from 200 households fitted with smart water meters in South-east Queensland, Australia. ANOVA as well as multiple regression analysis statistical techniques were utilised to reveal the determinants (e.g. household makeup, shower fixture efficiency, income, education, etc.) of household shower consumption. Results of a series of one-way independent ANOVA extended into linear multiple regression models revealed that females, children in general and teenagers in particular, and the showerhead efficiency level were statistically significant determinants of shower end use consumption. Eight-way independent factorial ANOVA extended into a three-tier hierarchical linear multiple regression model, was used to create a shower end use forecasting model, and indicated that household size and makeup, as well as the showerhead efficiency rating, are the most significant predictors of shower usage. The generated multiple regression model was deemed reliable, explaining 90.2% of the variation in household shower end use consumption. The paper concludes with a discussion on the significant shower end use determinants and how this statistical approach will be followed to predict other residential end uses, and overall household consumption. Moreover, the implications of the research to urban water conservation strategies and policy design, is discussed, along with future research directions.

1. Introduction

1.1. Urban water security

Water is one of the most vital resources on earth. Due to climate change consequences such as the increasing frequency and severity of droughts and the unpredictable changing rainfall patterns, water availability is becoming more variable. Drought, together with growing populations which results in an escalating urban water demand are making water a scarce resource in many regional and urban centres (Dvarioniene and Stasiskiene, 2007; Giurco et al., 2010; Hubacek et al., 2009; Willis et al., 2009a, 2010b). Scarcity of water is forcing many governments and public utilities to invest significantly in the development and the implementation of a range of water strategies (Correljé et al., 2007; Stewart et al., 2010), including dual supply schemes (Willis et al., 2011b), shower visual display monitors (Willis et al., 2010a) and the installation of rainwater tanks (Tam et al., 2010). These strategies aim at improving urban water security through a more sensible and sustainable water consumption to meet future demand (Mahgoub et al., 2010; Palme and Tillman, 2008). This scenario is common in Australia and to some extent the world (Commonwealth of Australia, 2011a; Giurco et al., 2010; Inman and Jeffrey, 2006).

South-East Queensland (SEQ), Australia has been suffering a long drought period, varying rainfall patterns, and a rapid increasing population. These factors together have lead to the enforcement of water demand management (WDM) strategies. Such strategies include water restrictions, rebate programmes for efficient fixtures, water efficiency labelling, and conservation awareness programs (Inman and Jeffrey, 2006; Mayer et al., 2004; Nieswaidomy, 1992). In spite of reductions in water consumption resulting from the implementation of such WDM strategies, government usually follows reactionary-based approaches rather

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than proactive-based approaches (Beal et al., 2010). Additionally, their effectiveness is dependent on differences in location, community attitudes and behaviours (Corral-Verdugo et al., 2003; Turner et al., 2005; Stewart et al., 2011). Further, estimations of water savings yielded from the implementation of such strategies and programs are often calculated based on limited evidence and with many assumptions due to the lack of appropriate data at the end use level, thereby deriving understated or grossly inaccurate values for water savings associated with them (Willis et al., 2009d). Therefore, the development of effective urban water conservation strategies, policies and forecasting models is essential to better manage our urban water resources.

1.2. Smart metering

The development of effective strategies and policies requires more detailed information on how and where residential water is consumed (e.g. shower, washing machine, dish washing, tap, bathtub, etc.) (Mayer and DeOreo, 1999; Willis et al., 2009a). This detailed knowledge of water consumption can provide a greater understanding on the key determinants of each and every water end use, and in return, will allow for the development of improved long-term forecasting models (Blokker et al., 2010; Stewart et al., 2010). The formulation of such models is paramount, especially when there is a distinct lack of micro-component level models that have been created from empirical water end use event data registries into forecasts for total urban residential connection demand as presented in the herein study.

The advent of advanced technology such as water smart metering, which encompasses high resolution data capturing, logging and wireless communication technologies has facilitated the collection, wireless transfer, storing and analysing of abundant detailed and useful water end use information (i.e. time and quantity of each and every end use) (Willis et al., 2009d). The alignment of such detailed and accurate water end use data with a range of socio-demographic, stock inventory, residential attitude and behavioural factors, will aid the development of models that are capable of revealing the determinants of each and every end use; thereby providing the foundations for more robust urban water demand forecasting models.

1.3. Water end use studies

Many residential water demand forecasting models have been developed based on historical billing data, existing statistical reports, or technical information from stock appliance manufacturers (Beal et al., 2010). Such models are not able to provide an accurate disaggregation of consumption into water end use categories. Therefore, long-term actual measurement and disaggregation of water end use data (i.e. micro-component analysis) using smart metering technology and computer software is considered the most robust and accurate foundation for the development of urban water demand forecasting models.

In general, there are few residential water end use studies that have been conducted using high resolution smart metering technologies. Internationally, a number of end use studies have been conducted in the United States of America (Mayer and DeOreo, 1999; Mayer et al., 2004) and more recently in New Zealand (Heinrich, 2007) and Sri-Lanka (Sivakumaran and Aramaki, 2010). Additionally, in South Africa, a conceptual end use model was developed by Jacobs (2004). Moreover, a number of water end use studies (also called water micro-component studies) have been conducted in the United Kingdom (Barthelemy, 2006; Creasey et al., 2007; Sim et al., 2007). In Australia, three major studies have been completed to date in Perth (Loh and Coghlan, 2003), Melbourne (Roberts, 2005) and most recently in Gold Coast City, Queensland (Willis et al., 2009a,b,c,d, 2010a,b, 2011a,b). Table 1 summarises established averages of total and indoor daily per capita water consumption volumes, as well as the indoor water end use breakdown percentages of previous studies conducted in Australia.

In 2010, a South-east Queensland Residential End Use Study (SEQREUS) was commissioned with the objective to gain a greater understanding on water end use consumption in this large urbanised region. This study was funded by the Urban Water Security Research Alliance (UWSRA), which is a partnership between the Queensland Government, CSIRO's Water for Healthy Country Flagship, Griffith University, and University of Queensland. The main aim of this alliance was to address SEQ's emerging urban water issues to inform the implementation of enhanced water strategy (Beal et al., 2010). The primary objective of the greater study was to quantify and characterise mains water end uses of single detached dwellings across four main regions (i.e. Sunshine Coast Regional Council, Brisbane City Council, Ipswich City Council, and Gold Coast City Council) in SEQ, Australia, as shown in Fig. 1 (Beal et al., 2011).

This herein described study utilises information collected in the SEQREUS July 2010 baseline data, where a Permanent Water Conservation Measures (PWCM) daily target of 200 L per person per day (L/p/d) was set by the State Government (Beal et al., 2011). Both the reported SEQREUS and Queensland Water Commission (QWC) water use averages of 145.3 L/p/d and 154 L/p/d, respectively, fell well below the government set target as shown in Fig. 2 (Beal et al., 2010; QWC, 2010). PWCM are not considered restrictions but mainly guidelines for the efficient use of potable water for irrigation purposes (e.g. irrigating lawns after 4 pm when less heat, etc.). Moreover, PCWM guidelines only provide very broad guidance on efficient indoor consumption. Thus in summary, there was not any restriction regime in place at the time of data collection related to this study that could have directly influenced householders' indoor consumption.

This paper describes a component of this greater SEQREUS study. The herein described research study seeks to formulate a bottom-up residential end use demand forecasting model, which includes a comprehensive listing of predictor variables.

1.4. Residential water demand influencing factors and forecasting models

There are several factors influencing water consumption that have been reported previously. Such factors are socio-demographic

Table 1
Previous residential water end use studies conducted in Australia (Beal et al., 2010).

Authors	Loh and Coghlan (2003)	Roberts (2005)	Willis et al. (2009a)
Study title	Domestic Water Use Study	REUMS	Gold Coast Watersaver End Use Study
Region	Perth	Melbourne	Gold Coast
Reporting year	1998–2001	2004	2009
Sample size (No. homes)	120	100	151
Average indoor consumption (L/p/d)	155	169	139
Average total consumption (L/p/d)	335	226	157
Bath/shower (%)	33	31	42
Washing machine (%)	28	26	22
Toilet (%)	22	18	15
Tap (%)	15	17	20
Leaks (%)	2	8	1