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A novel mixed method smart metering approach to reconciling differences between perceived and actual residential end use water consumption

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ABSTRACT

Studies have shown that householders' perceptions of their water use are often not well matched with their actual water use. There has been less research however, investigating whether this bias is related to specific categories of end use and/or specific types of socio-demographic and socio-psychological household profiles. A high resolution smart metering study producing a detailed end use event registry as well as psycho-social and socio-demographic surveys, stock inventory audits and self-reported water diaries was completed for 252 households located in South-east Queensland, Australia. The study examined the contributions of end uses to total water use for each group that self-identified as "low", "medium" or "high" water users. A series of univariate tests (i.e. analysis of variance) were conducted to examine a range of variables that characterise each self-identified water usage group including age, income, percentage of water efficient stock (e.g. low-flow taps), family size and composition and water conservation intentions and attitudes. The level of information consumers receive on their water bill as well as the diurnal end use patterns were also examined. The paper concludes with a discussion of the general characteristics (i.e. income, age, gender and family composition) of groups that tended to overestimate or underestimate their water use and how this knowledge can be used to inform demand management policy such as targeted community education programmes and community-based social marketing. Further, the potential for positive economic and sustainable development outcomes from this research is also discussed.

1. Introduction

1.1. End use studies to inform water demand managers

Water security remains one of Australia's greatest issues of concern as many urban and rural regions are facing a severe drought after years of continued lower than average rainfall. In 2009, South-east Queensland (SEQ) emerged from one of its most harsh and protracted droughts on record. The variability of rainfall in the region, combined with high population growth and strong economic development, means that effective supply and demand side water management is critical. In an attempt to improve water security, many government authorities in Australia have imposed water restrictions and water saving measures to manage demand and ensure the conscious use of water across the residential, commercial and industrial sectors. Both in Australia and internationally, recent research suggests that attitudes and behaviour towards potable water supplies have changed due to greater social awareness and increasingly widespread exposure to drought conditions; people are beginning to genuinely value water as a precious resource (Jones et al., 2010; Jorgensen et al., 2009; Fielding et al., 2009). For example, the combination of state and local government rebate programmes for water efficient fixtures and rainwater tanks, and enforced water restrictions have resulted in a large reduction in household water use in SEQ (Beal et al., 2011; Willis et al., 2010a; Queensland Water Commission [QWC], 2010). Internationally, the success of demand management strategies such as pricing, restrictions and water conservation education has been shown to have variable effects on changing the public perception on water consumption (Arbues et al., 2010; Olmstead and Stavins, 2009; Nieswiadomy, 1992).

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The shift in public perception of water requires renewed understanding of the relationships between the end use *and* the end users of residential water. Furthermore, despite successful demand management outcomes, approaches by many regulating authorities to reduce water consumption are often reactionary rather than proactive (Farrelly and Brown, 2011; Kennedy, 2010; Renwick and Archibald, 1998). Although there are many examples of proactive water demand management approaches emerging (e.g. Domènech and Saurí, 2011; Farrelly and Brown, 2011; Inman and Jeffrey, 2006), the often reactionary policies to reduce water demand in a time of potential supply crisis highlight the need for more detailed information at the "coalface". For example, information on how the water is proportioned in households and how this may change both spatially and temporally across any given region would provide good insight for demand managers about which local regions to target. To this end, Chang et al. (2010) examined spatial variations of residential water consumption in Oregon and conclude that such a dataset would greatly enhance the development of urban water policies in regions of limited water resources. Blokker et al. (2010) suggest that measuring end use data across seasons and regions is the foundation for water consumption predictions and the development of demand forecasting/water distribution network models. Similarly, Arbues et al. (2003) and White and Fane (2002) emphasise the need for such basic building blocks in the creation of effective demand side management policy. Empirical end use data is essential for validating water use forecasting models such as presented by Blokker et al. (2010), Chu et al. (2009) and Druckman et al. (2008). Thus, the disaggregation of residential water end use is a critical first step in the development of relevant and successful water policy. A number of end use studies have been conducted both in Australia (e.g. Water Corporation, 2011; Beal et al., 2011; Willis et al., 2010a, 2011b; Roberts, 2005; Loh and Coghlan, 2003) and internationally (e.g. Heinrich, 2008; DeOreo et al., 1996).

Water consumption patterns and behaviours are highly varied amongst households due to the influencing factors of climate, socio-demographics, house size, family composition, water appliances, cultural and personal practises (Russell and Fielding, 2010; Juárez-Nájera et al., 2010; Arbues et al., 2003; Loh and Coghlan, 2003). As the end use of water is influenced by a number of subjective or manual water use practises within a household (e.g. length of shower, height of bath and frequency of tap use), surveys or questionnaires are key components of any end use study. End use data in combination with such socio-demographic information can facilitate the identification of correlations between water behaviours and key demographical subsets within a population (e.g. income, age, gender and family composition).

1.2. Social perspectives of water consumption and conservation behaviours

Effective and relevant implementation of demand management and water conservation strategies is strongly underpinned by an understanding and knowledge of how consumers perceive and use their water (Jones et al., 2010; Jorgensen et al., 2009). There have been many studies that have identified the drivers of water consumption and conservation. Jorgensen et al. (2009) and Russell and Fielding (2010) both present detailed overviews of the literature in this field. Direct drivers include climate, household characteristics (e.g. size, composition, income), regulatory environment (e.g. rebates, incentives, restrictions), personal characteristics (e.g. intention and knowledge on water conservation) and property characteristics (e.g. garden size, pool, house age) (Jorgensen et al., 2009; Corral-Verdugo and Frias-Armenta, 2006; Gregory and Di Leo, 2003). Indirect drivers relate more to the personal characteristics (subjective norm, attitude), environmental and water conservation values, socio-economic status, and a sense of trust and fairness to institutions and other consumers (Russell and Fielding, 2010; Jorgensen et al., 2009; Corral-Verdugo et al., 2002; Syme et al., 1990–1991).

In Australia, there is growing evidence to suggest that residentia; consumers' attitudes to water conservation have become more positive and this change in attitudes is parallelled by behavioural shifts in water use (Beal et al., 2011; Millock and Nauges, 2010; Willis et al., 2010a, 2011). Despite the growing awareness of the need for water conservation amongst the public, studies have shown that householders' perceptions of their water use are often not well matched with their actual water use (Millock and Nauges, 2010; Corral-Verdugo and Frías-Armenta, 2006; Hamilton, 1985). The mismatch between water use perceptions and outcomes is one that echoes the low correspondence that is often found between attitudes and behaviour (Kraus, 1995, see also Dolnicar and Hurlimann, 2010). Kantola et al. (1984), for example, showed that peoples' self-reported attitudes towards energy conservation and their actual energy consumption differed and observed that people reduce the dissonance between attitudes and behaviour by bolstering or reaffirming their initial attitude (Kantola et al., 1984). Others describe the differences between beliefs and actual behaviour as more of a conflict between good intentions and difficulties in actually acting on them (Anker-Nilssen, 2003).

In the context of household water use, there are a small number of studies reporting on perceived and actual water consumption. Hamilton (1985) observed that self-reported water consumption was not an accurate method of determining residential water use. The disparity between believed and actual water use was influenced by socio-economic status and conservation behaviours, where people from higher income categories and people who were 'conservation aware' tended to more accurately estimate their water use (Hamilton, 1985). Syme et al. (1990–1991) explored the relationship between householder attitudes and actual water consumption in Perth, Australia. They found, during drought-free conditions, that external water use and associated attitudes to the investment and recreational assets of gardens were important consumption predictors. A key conclusion from this work was the need for water policy to consider consumer attitudes to garden water use and upkeep (Syme et al., 1990–1991). Aitken et al. (1994) found that attitudes, habits and values were poor predictors of water use and hence did not support the relationship of water use attitudes to actual behaviour (i.e. water consumption). Building on this, Aitken et al. (1994) identified a number of homes in a dissonant situation, and conducted a second study to explore whether this dissonance between perceptions and actual water use would be reduced with interventions such as feedback of the household's actual water consumption. As a result of this feedback, there was a significant convergence between perceived water conservation and actual water consumption. Using a combination of water billing records and survey responses, De Oliver (1999) examined water consumption following voluntary and mandatory water restrictions and investigated whether consumption reductions, if any, were influenced by socio-demographic variables such as family composition and income. The results demonstrated a substantial disconnect between survey responses and manifested actions, of which the latter were influenced in differing degrees by income, political persuasion, ethnicity, home ownership and education. Gregory and Di Leo (2003) matched averaged household annual billing records with a household survey designed to elicit information on the habits, attitudes, awareness and contextual factors to explore relationships between water conservation and consumption and psychological drivers. They found that lower water users (using a benchmark of a council free allowance water usage rate) tended to be older, less educated and of lower income than the higher water users (Gregory and Di Leo, 2003). The authors