Smart water-use feedback:

Options, preferences, impacts, and implications for implementation

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Certificate of original authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

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Abstract

Smart water metering (SW metering) is enabling the water industry to enter into the digital age and to embrace new levels of water usage awareness, data analysis and communication. While implementations have been advancing internationally, less progress has been made in extending the benefits of this data and information to access by householders, including in Australia. This thesis investigates the opportunity for more detailed information and feedback on household water consumption by: (i) conceptualising the different options for the presentation of detailed feedback enabled via SW metering (ii) uncovering householder interests and preferences; (iii) measuring the various impacts of detailed feedback on householders and their consumption of water; and (iv) developing an implementation framework. These issues are investigated in relation to furthering implementations and the contribution of SW metering towards more sustainable urban water management (SUWM).

This empirical research was conducted via two trials in New South Wales, Australia to address the urgent need for improved knowledge and experiences of the issues relating to the provision of detailed water-use feedback via SW metering. The 'Home Water Update' (HWU) study provided detailed household water- and end-use feedback via paper-based reports. The 'My Home Our Water' (MHOW) study provided consumption feedback according to time of use in near real-time via an online portal. A mixed methods approach was used to analyse the trials using smart water meter data, surveys and interviews.

This research shows that providing more detailed water-use feedback through SW metering generates significant householder interest and produces measurable savings (up to 8% in the HWU (paper) study and 4.2% over the longer term in the MHOW (online) study). Moreover, the wide range of options for detailed feedback enabled by SW metering identified in the research—together with the variety found in householder preferences for and responses to detailed feedback—suggests that greater customisation would further elevate the value of feedback to customers and improve engagement.

The implementation framework developed further provides a detailed overview of the key elements for decision-making for detailed water-use feedback programs, categorised as strategic, practical and evaluative considerations. Overall, the research findings cover a broad range of aspects critical to the design of future trials and large-scale roll-outs of SW metering and detailed feedback and the promotion of use that foster more SUWM. For wider industry adoption of detailed water-use feedback programs enabled via SW metering, the importance of the following is underlined (i) conducting quality, robust research and its implications for

project resources; (ii) facilitating knowledge sharing in order to further the water industry's understanding and experience regarding methods and approaches to feedback provision; (iii) building knowledge on how to address heterogeneity among customers is recommended in order to customise approaches to feedback provision (e.g. via a large scale preferences survey and subsequent experimentation with greater levels of customisation, particularly with robust scaled research trials); and (iv) developing the business case for detailed water-use feedback provision by fully documenting methods and making these available for wider evaluation and industry recommendations and improvements. Further developments in this direction, using the implementation framework, will enable the water industry to work towards large-scale implementation of detailed feedback provision which take more full advantage of the customised options made possible via SW metering and the digital age.

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List of publications

This 'hybrid' thesis format is presented as a series of papers (chapters 3, 4, 5 and 6) together with an exegesis comprising introduction and methodology chapters (1 and 2) and implications and conclusions (chapters 7 and 8). The thesis includes the following papers, which are referred to in this thesis by their Roman numerals:

I. **Liu, A.,** Giurco, D., Mukheibir, P. 2015, 'Motivating metrics for household water-use feedback', *Resources, Conservation and Recycling*, vol. 103, pp. 29-46. DOI: 10.1016/j.resconrec.2015.05.008.

II. **Liu, A.,** Giurco, D., Mukheibir, P. 2016, 'Urban water conservation through customised water and end-use information'. *Journal of Cleaner Production,* vol. 112, pp. 3164-3175. DOI: 10.1016/j.jclepro.2015.10.002.

III. **Liu, A.,** Giurco, D., Mukheibir, P., Mohr, S., Watkins, G., White, S. 'Online water-use feedback: household user interest, savings and implications' (Submitted manuscript under review).

IV. **Liu, A.,** Giurco, D., Mukheibir, P., White, S. (in press), 'Detailed water-use feedback: a review and proposed framework for program implementation', *Utilities Policy*. DOI: 10.1016/j.jup.2016.09.002.

Author's contributions to the papers

Ariane Liu led the development of research ideas, methods, data collection and analysis and wrote the manuscripts and revisions in response to the peer reviewers' comments. The concepts in the papers were discussed with Damien Giurco and Pierre Mukheibir, who also reviewed the manuscripts within their supervisory roles, as well as with Graeme Watkins and Stuart White. The statistical analysis in Paper III was provided by Steve Mohr.

Other publications not included in this thesis

The following journal and conference papers were also produced during the course of the author's doctoral research.

V. Boyle, T., Giurco, D., Mukheibir, P., **Liu, A.,** Moy, C., White, S., Stewart, R.A. 2013, 'Intelligent metering for urban water: A review', *Water*, vol. 5, no. 3, pp. 1052-1081.

VI. **<u>Liu, A.,</u>** Giurco, D., Mukheibir, P., Watkins, G. 2013, 'Smart metering and billing: Information to guide household water consumption', *AWA Water*, vol. 40, no. 5, pp. 73-77;
Previously in Proceedings of the 2013 AWA Water Efficiency, Education and Skills Conference, 5-7 March 2013, Sydney, Australia.

VII. **<u>Liu, A.,</u>** Giurco, D., Mukheibir, P. 2014. 'Online household water portal: User interactions and perceptions of water use', In Proceedings of the 2014 SWGIC, Smart Water Grid International Conference, Book of Abstracts, pp. 102–8, 25-27 November, 2014, Incheon, South Korea. *Awarded a 'Certificate of excellent oral presentation of an excellent paper' in the SWGIC best paper awards.*

VIII. **<u>Liu, A.,</u>** Giurco, D., Mukheibir, P. 2015, 'Household water-use feedback: moving forwards towards sustainable urban water'. In Proceedings of the International Conference on Sustainable Water Management 2015, 29 November to 3 December, 2015, Murdoch, WA Australia.

IX. **<u>Liu A.,</u>** Giurco, D., Mukheibir, P. in press, 'Advancing household water-use feedback to inform customer behaviour for sustainable urban water', *Water Science and Technology: Water Supply*. DOI: 10.102166/ws.2016.119.

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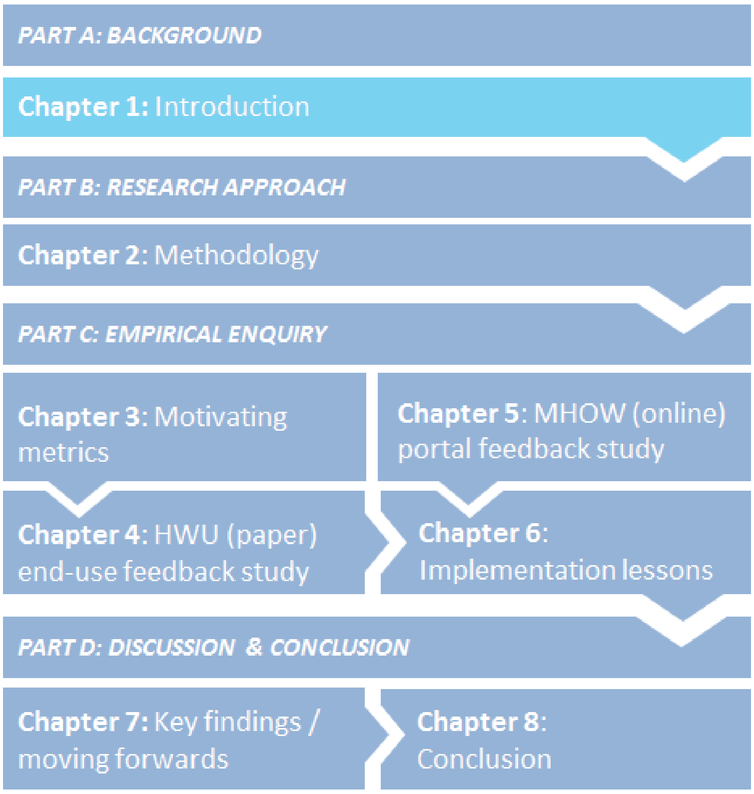
Abbreviations

ARC	Australian Research Council
AUD	Australian Dollar
HWU	Home Water Update (paper-based water and end-use feedback reports)
IHD	In-home display
ISF	Institute for Sustainable Futures
L/hh/d	Litres per household per day
MCW	MidCoast Water
MHOW	My Home Our Water (online water-use feedback portal)
SUWM	Sustainable urban water management
SW (metering)	Smart water (metering)

Glossary

End-use feedback	Feedback disaggregated by water-use fixtures, appliances or other uses (e.g. taps, toilet, shower, washing machine, outdoors, leaks)
Near real-time feedback	Feedback provided within 24 hours of consumption taking place
SW metering	Smart water (SW) metering is advanced metering which involves the collection of water consumption data at highly frequent intervals (e.g. of minutes or seconds)
Time of use	Time of water consumption, for example, 07:03 AM
Water-use feedback	Customised information on water consumption

Chapter 1: Introduction



1.1. Research background

Smart water (SW) metering is enabling the water industry to enter into the digital age (Beal and Flynn, 2015) and embrace new levels of water usage data collection and means for its analysis and communication. Traditionally, management of urban water supplies and use has relied on limited data resources, collected via conventional metering. Under these arrangements, consumers have in particular received little information regarding the nature of their consumption of water, typically in the form of a total meter read on a paper bill three or four times per year (Liu et al., 2013). With the recent advent of SW metering, however, the opportunities for more nuanced data collection and reporting for monitoring and managing water supply and demand extend far beyond what was previously possible, both for water utilities and customers (Boyle et al., 2013).

Implementations of SW metering have been progressing in recent years, both in Australia (Beal and Flynn, 2015) and worldwide (Boyle et al., 2013; Navigant Research, 2013), and noticeably during the course of the 3.5 years in which this doctoral research project has been conducted. For example, according to a recent survey of Australia and New Zealand by Beal and Flynn (2015) there were already 250,000 smart water meters either in operation or planned for in 2014. Global projections have also set expectations for continued growth in excess of 153 million installations worldwide by 2022 (Navigant Research, 2013). While implementations of SW metering have been advancing, comparatively little progress has been made in terms of directly extending access to this potential new wealth of data and information resources to end-customers, especially householders.

The residential sector remains important being the largest contributor to water demand in many urban centres. Therefore, particularly within this sector, a better provision of information on household water use and opportunities to save, which creates more informed consumers, can help realise the potential to promote water consumption savings and contribute towards more sustainable urban water management (SUWM). Greater involvement by householders can particularly be seen in the light of an ongoing need for improved water resources management against mounting pressures from population growth and urbanisation, climate change and future drought, environmental damage and the growing economy; all of which present serious threats to the sustainability of water resources, particularly within the urban sector (Hurlimann et al., 2009; Kayaga et al., 2007).

In order for the water industry to progress more rapidly both with SW metering and the provision of detailed household water-use feedback, various important barriers need to be overcome. The financial business case for large scale SW metering implementations is a primary obstacle for many water utilities that are unable to justify the cost, even when factoring in significant demand response benefits and in some cases reducing supply side capital. Besides this, the current lack of experience with SW metering (Beal and Flynn, 2015) and even more so with detailed water-use feedback provision means there is a considerable lack of 'know-how' within the water industry. Additional targeted research in this field can therefore help by extending practical experience of SW metering and detailed water-use feedback and thereby improve industry knowledge of the opportunities and issues requiring consideration and further lend support to the processes of business case development.

This thesis aims to address the lack of available experience and information surrounding detailed water-use feedback enabled via SW metering. The research particularly investigates the prospects for more detailed information feedback by exploring: the different options for the provision of feedback enabled via SW metering; householder interests and preferences; and the various impacts of detailed feedback on householders and their consumption of water. The issues are further discussed in relation to the goal of more SUWM. The research in this thesis comes at a particularly important time which marks a turning point in the transition towards a digital water industry, in which decision making regarding SW metering will shape the future reality of the potential benefits for water utilities and consumers.

1.1.1. Water utility objectives: financial viability and SUWM

Water utilities are described as operating with "two overarching strategic imperatives", namely financial viability and SUWM (Boyle et al., 2013), which are considered briefly below.

Financial viability concerns the generation of sufficient revenues to meet operating expenditures and capital financing costs (Productivity Commission, 2011). For water utilities this has been and often still remains of primacy. At the same time, however, various external drivers (e.g. climate change, drought, population growth and urban consolidation (Hurlimann et al., 2009; Kayaga et al., 2007)), have been steering water utilities to adopt more sustainable approaches to urban water management. In recognition of this growing need, water utility management has thus gradually shifted from a focus on the supply-side towards additionally embracing a variety of demand-side management (DSM) options to meet projected demands for water (Dawadi and Ahmad, 2013; Turner et al., 2008; White et al., 2006). DSM measures represent efforts to reduce water consumption (i.e. promote water conservation) and have generally been equated with improved water-use efficiency and are therefore widely considered as contributing towards more SUWM.

The exact objective of SUWM is not as easily defined (Larsen and Gujer, 1997). However, SUWM has been described as both a philosophical and technical approach (Brown and Farrelly, 2009) which suggests not only a vision to aspire to, but something to also practically work towards. In this case, since reduced water demands directly reduce the pressures on water utilities to provide additional water supplies and alleviate from the associated costs of production, it seems reasonable to accept that conservation efforts by customers can help with the availability and quality of water resources—both across time and space (Larsen and Gujer, 1997)—which are widely accepted concepts in the wider field of sustainability (see WCED, 1987). In addition, reduced water demands can defer capital expenditures on costly supply infrastructure augmentations.

In practice, DSM measures can involve managerial, behavioural or technical strategies; each of which "critically requires accurate, adequate and reliable data that can be meaningfully and cost-effectively interpreted" (Boyle et al., 2013). By presenting the opportunity to meet these data needs, SW metering can thus support water utilities in DSM strategies and contribute to both the achievement of financial viability and SUWM (Boyle et al., 2013).

1.1.2. The SW metering opportunity: definitions and benefits

Various attempts have been made to define SW metering and calls have been made for the standardisation of definitions due to the disagreement over what exactly this constitutes (Boyle et al., 2013; Darby, 2010; Hauber-Davidson, 2009; Idris, 2006; Oracle, 2009). It seems the most important and basic distinguishing feature of SW metering essentially involves *advanced data capture technologies*, which provide a more comprehensive record of water consumption than conventional meters. However, other definitions have also used the term SW metering to refer to advanced data capture and (automatic) data transmission at set intervals (one-way from the customer to the utility) or even two-way communication and therefore a customer display or interface (Darby, 2010). Other features referred to in SW metering definitions have included: additional data collection and processing software (e.g. a meter data management application) at the water utility; on demand readings and recent usage checks by the water utility; and remote commanding by the water utility (e.g. to disconnect or restrict water flow) (Oracle, 2009).

While a variety of definitions of SW metering have been proposed in the literature, the definition of SW metering adopted for use in this thesis focuses on the primary function of advanced customer water consumption data collection, particularly with measurements of flow/volumes at high frequency intervals (e.g. of seconds or minutes) and recorded according to time of use. Certainly, the transmission of this high resolution data is important; and so is the customer interface, which is a central tenet of this thesis, but this should not detract from the underlying function of collecting detailed data records from which all the other value and benefits derive.

The opportunities for improved monitoring and management are essentially the overarching benefits of the detailed data collected via SW metering. Most of these benefits relate to various specific uses of this detailed water consumption data, although a number of benefits relate to the additional remote functions associated with automatic data transmission and control. A wide range of possible applications have been identified for the data enabled via SW metering (Giurco et al., 2010; Idris, 2006; Marchment Hill, 2010), which are organised in Table 1 as relating to improved water planning, network efficiency or customer management, and contributing to SUWM.

Table 1 Applications for data enabled via SW metering

	Planning	Improved Network efficiency	Improved customer management	SUWM
Water planning / modelling parameters	X			X
Evaluation of demand management programs	X			X
Leak detection		X		X
Usage feedback to consumers			X	X
Improved billing accuracy		X	X	
Reduced non-registration		X	X	
Customer relationship management (query handling)		X	X	

Much focus has been placed on the benefits of SW metering in terms of network efficiencies including via remote meter reads, non-revenue water and leak detection (Boyle et al., 2013). However, in Idris (2006) it was proposed that most value will ultimately be derived from the *detailed information* that smart metering produces; suggesting further that this will require the 'translation of data to information to knowledge to wisdom' (Idris 2006). This view suggests that the analysis of smart water meter data and its use will remain essential to harnessing the deeper value of SW metering. This applies both to the use of information for the purpose of guiding internal planning and decision making within the water utility business, and externally for the provision of information and consumption feedback to customers, further to contribute to more SUWM.

1.1.3. Current water utility context

Water utilities are at different stages of maturity with SW metering. Many are currently taking no action; others have begun with exploratory trials; and some have achieved full scale roll-outs. According to their respective status, each is contemplating different challenges. Despite reservations being expressed about the business case, significant interest in SW metering is widely apparent. Where water utilities are leading progress, the availability of funding or the pursuit of innovation has been a driving factor. Questions as to what are the benefits and costs and how they are quantified have therefore been addressed in different ways.

While smart water meters have been described as "orders of magnitude more expensive than normal meters", such as "AUD 50 for a traditional meter, and AUD 150 for a smart meter, excluding network infrastructure costs (see Cowan, 2014, for interviews with Water Corporation CEO, Susan Murphy; and COO, Peter Moore), the methods of calculating the return on investment and the definition of objectives for SW metering play a more important role. Rather than a reliance on tangible benefits alone (e.g. capital infrastructure deferral, reducing meter reading costs and non-revenue water), additional benefits on the customer-side (e.g. meeting customer needs), which are widely considered intangible, also need to be quantified in the cost-benefit analysis and investment decision (Collins, 2015). However, customer information and feedback services are generally considered as optional add-ons, particularly since water utilities currently operate as regional monopolies, so there is less focus on customers than in other sectors, such as banking. As a result, the decision to invest in SW metering is generally considered a precursor to feedback, but somewhat independently of the feedback opportunity. Feedback is thus more generally considered as more of a 'nice to have' rather than a 'basic requirement' (see Kano et al., 1984) of SW metering implementations.

Opinions regarding the overall business case seem to differ widely. SW metering technology vendors claim the cost of the technology will pay off through water savings; and possibly through non-revenue water management alone (Hill and Symmonds, 2013). Others claim the price of water is too low, for example, "One of the problems is that the water you save will never pay off the extra cost of the meter in the life of the meter. Water is a very low-price commodity" (see Cowan, 2014, for interview with Water Corporation CEO, Susan Murphy). At Thames Water in the UK, it was suggested that the SW metering rollout "is not cost beneficial, but it is the least-cost option for tackling a water resource issue" (see Ockenden, 2014) for interview with Steve Plumb, Head of Metering). In this view, SW metering is the solution which from among the alternative options costs the least to meet impending water supply needs.

This range of views reflects the distinct objectives of individual water utilities and therefore perceptions towards a cost-benefit analysis of SW metering. Therefore, each water utility needs to be clear about their objectives with SW metering, the associated costs and benefits, and questions of who pays[1], and to whom benefits will accrue—and these all need to be made explicit and transparent.

Extending SW metering to include the provision of detailed household water-use feedback programs incurs additional costs, so the ways in which the benefits are foreseen and the customer value proposition can be decisive. Underlying the need for business cases for SW metering and detailed water-use feedback provision is the need for greater industry knowledge and experience which can be obtained through additional research in the sector. While it is beyond the scope of this thesis to investigate the business case in detail, the research aims to increase knowledge of the issues for consideration in detailed water-use feedback provision and thus makes an important contribution in terms of laying a foundation for this.

Besides the business case for SW metering, a lack of knowledge and experience emerged as a key challenge to planning and implementing SW metering according to the recent survey of Australasian water utilities (Beal and Flynn, 2015). In addition, a review of the water sector shows information on existing SW metering projects is not readily accessible, despite their roll-out in regions such as Mackay, Isaac and GWMWater. The limited available experience also leaves water utilities having to grapple with many design and implementation issues and the challenge of evaluating alternative approaches. These challenges apply further to detailed water-use feedback, for which there is still less available experience. A comprehensive overview of available knowledge is thus required.

Roll-outs of smart metering are more advanced in the energy sector. One explanation for the delay in the water industry was proposed in a recent consulting report which described water utilities as "traditionally conservative, budget constrained, and risk averse – particularly

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[1] Regarding who pays, the options include water utilities themselves, governments or customers. A distinction can also be made between financing capital and ongoing operational costs of SW metering and of detailed water-use feedback provision. Currently, the business case involving self-financing is challenging. Also, passing the costs on to customers would needs careful consideration and communications. This may particularly be important in areas where water customers have recently had to pay for other significant infrastructure costs. For example, in Sydney customers have been paying for an idle desalination plant unneeded for another four of five years (ABC, 2010). Clearly, more research is required that focuses specially on business case development, examining and quantifying alternative options, however, this is beyond the scope of this research.

hesitant to adopt something new" and moreover, that "until forced to make a change, water utilities will generally seek to focus on delivering water supply to their customers via the existing infrastructure (Weeks and Tilson, 2015). Although possibly referring to the US water industry, the description is also applicable to many water utilities elsewhere, including in Australia. Naturally, however, this alleged conservatism also has to be viewed in the light of the financial business case and the available knowledge and experience with SW metering.

The concerns regarding the business case for SW metering, the lack of information and experience, and the potentially conservative attitude of water utilities are interrelated. The research in this thesis targets extending available experience and improving knowledge of detailed water-use feedback enabled via SW metering. It is hoped this will contribute somewhat towards better informing water utilities of the opportunities; help support the business case; and shift water utility attitudes towards a greater willingness to embrace SW metering and detailed water-use feedback, particularly as the costs of implementation are expected to come down over time.

Other key roadblocks on the journey towards more widespread adoption of SW metering and implementations of detailed water-use feedback programs include a variety of technical issues (e.g. data collection, transmission, storage, analysis, communication (Boyle et al., 2013; Turner et al., 2012)); and social issues (e.g. equity of access to detailed water-use feedback, how far should conservation be promoted, and other risk such as health, privacy and control) which need to be addressed (Boyle et al., 2013; McHenry, 2013). While these challenges are not the focus of the research in this thesis, they are raised here for completeness and touched upon where relevant.

1.1.4. Industry outlook

A lack of conviction of the benefits of SW metering means that water utilities may either delay or choose not to invest in SW metering and/or in the provision of detailed water-use feedback to their customers. However, delays will postpone the potential benefits of the new opportunities they create and their contribution towards a more sustainable consumption of water resources; ill-informed approaches and inaction will also result in a lost opportunity for greater involvement by householders in a more sustainable consumption of water resources.

At the same time, for water utilities which do proceed with SW metering in the absence of detailed plans for customer water-use feedback, initial decisions in terms of the technology and infrastructure may risk technology lock-in, carrying implications for the scope of future possibilities for introducing detailed water-use feedback. For example, the selection of particular SW metering technologies will shape, and potentially limit, the opportunities to provide different types of water consumption feedback in future, as raised in Liu et al. (2015b), and therefore the potential contribution towards more sustainable outcomes.

Some forward-thinking water utilities, notably Mackay Regional Council have recently managed to embrace the opportunities afforded by a SW metering roll-out to provide detailed household consumption feedback. In such cases and in those where detailed water-use feedback is under consideration, a variety of intents and purposes have been articulated, but especially to promote water conservation.

Water utilities around the world have largely been working independently on their individual SW metering projects with the result that industry knowledge is fragmented and distributed. In addition, the paucity of published studies means that a potential wealth of knowledge and experience remains largely concealed. In Australia, the Water Services Association of Australia (WSAA) has attempted to bring water industry practitioners together in order to share experiences via the 'Towards the Digital Water Utility Conference' in Melbourne and organisation of monthly webinars used to communicate experiences by water professionals as guest speakers (see www.towardsthedigitalwaterutility.org). However, opportunities exist for greater cross-utility knowledge sharing and collaboration in order to more fully understand the outcomes of different approaches, to learn from each other's lessons and work together to further knowledge. Especially with the collaboration with research institutions, the opportunities for improved knowledge sharing can be extended through rigorous research design and evaluation.

1.2. Overview of the literature

This review is purposely succinct since more comprehensive reviews of the literature are provided in the Introduction and Discussion sections of the individual journal paper chapters.

1.2.1. Progress with detailed water-use feedback

The global water industry has witnessed recent growth in the introduction of more detailed water-use feedback through deployments of SW metering by water utilities. However, these implementations of detailed household water-use feedback programs still lag behind the adoption of smart water meters for more primary, utility rather than customer focused functions.

The overall recent growth in activities relating to the provision of detailed water-use feedback enabled via SW metering — both in research and practice — is not well covered. The field still lacks an overview of the state of detailed water-use feedback programs enabled via SW metering, the lessons learned to date, and a research agenda. Without comprehensive knowledge of the current state of affairs it remains challenging, for water practitioners on the one hand, to know where to start when considering whether to introduce more detailed feedback provision to customers; and for researchers on the other hand, to know where further research efforts are required. An overview of the current state of knowledge concerning detailed feedback in conjunction with consumption data resources collected through SW metering remains therefore essential.

Specifically, in Australia, there are still few wider scale implementations of more detailed household water-use feedback which take advantage of SW metering technologies introduced in water utility networks. At the same time, detailed reports on these activities and their impacts are not readily available. The Water Corporation introduced feedback letters and a 'self-service' online water portal to various towns in Western Australia (e.g. Kalgoorlie and Pilbarra); and in 2015, Mackay Regional Council released their own self-service portal 'MiWater', accessible to some 30,000 smart metered residential and commercial properties (Mackay Regional Council, 2015). The remainder of reported detailed water-use feedback programs in Australia have been implemented on trial-sized scales. However, for the larger roll-outs, both in Australia and internationally, it is noted that most progress with detailed water-use feedback together with SW metering still lacks publicly available documentation. Moreover, this work lacks accompanying academic research which critically would require a rigorous approach to the evaluation of methods and results.

A comprehensive literature search and review of *detailed water-use feedback* studies conducted internationally had not previously been undertaken prior to this work, but was particularly required in order to provide a clear overview of precise approaches to water-use information feedback provision.

Reviewing international studies and practices revealed a growing number of studies in the water sector which have begun to specifically investigate the new opportunities enabled via SW metering through the implementation and analysis of detailed feedback trials. This review further showed that most work in the field of advanced water consumption feedback provision has been conducted in Australia and the US, with some recent activity in Europe. Regarding implementation, the SW metering studies reported vary in terms of the types of feedback medium used; their information content; the timing, frequency and duration of trials; the SW metering technology and approach to water consumption data collection (i.e. granularity and upload frequency) and sample size. The studies further differ with regards to their discussion of theoretical explanations for their chosen approaches to feedback and its impacts; and the evaluation method and impacts reported. These issues are discussed further below.

1.2.2. Theoretical contributions from the literature review

Distinct theoretical contributions about consumption feedback from the existing literature include: how feedback works; the distinction between short- and long-term effects of feedback; and a limited discussion on the role of user preferences between alternative approaches to presenting consumption feedback.

Theoretical insights as to 'how feedback works' in the literature have focused mostly on the 'information-deficit' model of rational behaviour (Burgess et al., 1998). This suggests that when imperfectly informed householders are provided with new information they will systematically evaluate alternative course of action and respond in a way to pursue their own self-interest. Water-use information or feedback can therefore lead householders to revise their consumption behaviours or upgrade water-using appliances to pursue financial or other gains. This explanation is not without its critics who have pointed to consumers' cognitive limitations to evaluate information and alternatives, and to act accordingly; as well responses with automaticity, and emotionally (Jackson, 2005). The concepts of individual choice, action and change have even been questioned by social practice theorists and researchers who would rather view people as carriers of practice; directing attention to the effect that 'socially, institutionally and infrastructurally configured' practices have on consumption patterns (e.g. what is socially or culturally 'normal' for laundering and the associated water consumption) (Shove, 2010). It is, however, noted that such criticisms have not been specifically levelled at particular types or levels of detail of information feedback, which could conceivably give rise to different impacts and provide a closer link to specific practices. Also, the mechanisms for more detailed forms of feedback, especially detailed end-use information, have yet to be investigated.

Consumption feedback literature points to a distinction between short- and long-term effects of feedback. The so called 'rebound-effect' suggests initial consumption savings may gradually return to pre-intervention levels; e.g. due to a loss of interest over time (Faruqui et al., 2010). However, more research has been called for in the energy sector due to a prevalence of studies lasting less than four months (Van Dam et al. 2010), and this applies still more to the water sector where some studies have measured impacts after just one or two months (Anda et al., 2013; Erickson et al., 2012).

Research from the energy sector has identified the topic of householder interests and preferences to be of relevance to feedback design (e.g. Karjalainen, 2011) but this has scarcely been researched for the water sector. Householder interest should not be taken for granted and considerations as to what householders might prefer also need to be applied to the design of water-use feedback, since well-designed feedback can help householders to better understand, monitor and ultimately reduce their consumption.. At the same time, while there are certainly lessons to be learnt from the energy sector, such as regarding expected levels of engagement with feedback and preferences, this cannot be merely assumed for the water sector on the basis of experience in other sectors alone.

Regarding options, detailed water-use feedback literature offers some limited theoretical insights on the possibilities as well as their distinct impacts, including their motivating properties. Different feedback mediums have been experimented with, each with some variation in content but studies are, however, lacking in an explicit rationale for their design. Regarding mediums, in-home displays (IHDs) and online portals have been used on the premise that (near) real-time feedback will promote immediate action. Regarding content, comparative feedback has been provided with the understanding that householders will be motivated to conform to water-use benchmarks such as of average household use (e.g. increasingly on water bills); or 'descriptive norms' with messaging of the form "what people, like you, who are low water users do to save" (Fielding et al., 2013); or 'social identity framing which links a water conservation behaviour with the identity of the local area, with the behaviour being a normative part of "who we are" (Seyranian et al., 2015). The issue of frequency has also been discussed in energy literature, with the idea that feedback needs to be frequent and long-term (Abrahamse et al., 2005). Finally, the literature indicates various drivers of water conservation in general and positive responses to detailed consumption feedback which may include financial, environmental and social motivations.

1.2.3. Analysis of interventions and results

To understand the role for and benefits of detailed water-use feedback, an analysis of its impacts is required. Most of the literature focuses on the impacts of access to detailed water-use feedback in terms of a quantitative assessment for water-savings. However, some studies have included additional analyses of more qualitative impacts beyond the calculations of water-savings, such as through interviewee reports of specific changes in behaviours or to infrastructure (Doolan, 2010).

A variety of statistical techniques have been adopted to analyse the impacts of detailed water-use feedback interventions and provision. Regarding water consumption savings, some early feedback studies have shown quantitative results ranging from 5-10% (e.g. Doolan, 2010; Erickson et al., 2012; Fielding et al., 2013). However, these water-savings results differ in terms of how they were arrived at, so are not directly comparable. In the analysis of interventions in all fields, robust analyses are recognised as particularly essential. Data handling issues and especially, data cleaning is also of relevance to the analysis in addition to the methods of quantitative data analysis.

How data collected via SW metering is *cleaned*, and how study outliers and drop outs are identified and subsequently treated prior to data analysis is often overlooked. However, these processes will carry implications for the final study sample upon which savings calculations are ultimately based. Depending on the relevance of any study drop-outs, this could have implications for the significance of savings results. Most authors have given minimal indication on the number of study dropouts. Fielding et al. (2013) have provided a detailed description of their data handling approach in supplementary materials to their article, but this does not bring this important consideration to the fore.

The *statistical techniques* adopted to analyse smart water meter data depend in part on the research designs, including the sample size(s); whether or not there is a control group or other subgroups; whether or not a baseline period is measured; the periods or duration of data collections; the number and timing of interventions; and the resolution of the meter data. However, the choice of statistical techniques of analysis does not always have to result directly from certain research design characteristics, for example, the choice as to when to measure for impacts and for how long to run trials is not necessarily decided *a priori*. In relation to this point, the measurement of impacts in both the short and long term is advised, since the literature has shown effects may dissipate over time (Fielding et al., 2013).

One or more forms of *additional data collection and analyses* may be used to assess the impacts of detailed feedback provision beyond data collected via SW metering. This has been practiced more so for feedback trials than roll-outs. For example, to improve understanding of the impacts of feedback via in-home displays (IHDs), Doolan (2010) used householder surveys and interviews; and (Britton et al., 2013) also used a post-intervention householder survey to evaluate the provision of leak information letters. To evaluate an online water-use portal, (Erickson et al., 2012) used computer logs in addition to householder interviews and a survey. Other studies, however, (e.g. Joo et al., 2014) have mostly relied on analyses of smart water meter data alone to assess the impacts of detailed water-use feedback. Regarding qualitative evaluations, there appears to be little in the way of measuring changes in consumption awareness, due in part to the limited conduct of both a baseline and an evaluation survey to capture this.

The variety of detailed studies conducted has provided important insights into the impacts of detailed water-use feedback provision enabled via SW metering. However, due to scope limitations of the trials and subsequent evaluative work, various important research gaps remain.

In particular, little is known about householder *preferences* and their *responses* to different types of information, since even the more qualitative approaches to evaluating detailed feedback trials have only considered these issues very briefly and not investigated what other types of information might be preferred, or indeed would motivate behaviour changes. However, in order to guide the design of feedback programs and maximise the potential of SW metering, these remain topics in much need of research in the water sector.

1.2.4. Conclusions of the literature review

This section has presented an overview of the literature relevant to the research, covering both theory and practice. The review of previous information feedback interventions yielded the following overall methodological and analytical findings:

1) A variety of approaches to the *design and implementation* of detailed water-use feedback programs have been experimented with. These vary in terms of various defining and methodological aspects of feedback, which particularly signal a variety of *options* for its presentation (e.g. in terms of *content*, *frequency* and *medium*).
2) Very little work has been directed to investigating householder *preferences* for the provision of detailed water-use feedback.
3) Recent trials of more detailed household water-use feedback enabled via SW metering have in a variety of instances signalled positive impacts in terms of *consumption savings*.

4) A variety of approaches have been adopted in the *quantitative evaluation* of water-use feedback programs, ranging from simple descriptive statistics to more statistically robust analytical techniques (e.g. ANOVA, Regression and Growth Curve Modelling).
5) Studies vary in terms of when the interventions were analysed, with a tendency towards the measurement of short-term impacts only (such as from as little as five weeks). However, longer term research has shown that savings impacts may diminish over time, particularly if feedback ceases.
6) Some studies have further explored *qualitative impacts* of detailed feedback (e.g. via the use of a survey or interviews) in addition to a calculation of water consumption savings.
7) Studies vary in terms of the *theoretical explanations* given for the approaches to feedback-information design/choice and the results of feedback-information interventions; and further the magnitude of importance that theory plays in the studies (i.e. from theory provided as background information to theory testing).

1.3. Problem definition and research gaps

The new opportunity presented by SW metering and more detailed household water consumption feedback creates many important research gaps, which will be addressed in this research as follows:

a. Characterisation of and knowledge about the possibilities (*options*) for the presentation of more detailed household water-use feedback in conjunction with SW metering.
b. Exploring householders' perspectives on more detailed water-use information in terms of their *preferences* and what types of information motivate water conservation.
c. An exploration with the fuller range of *detailed water-use metrics* made possible via SW metering, including more detailed metrics of end-uses of water.
d. Knowledge on the *impacts* of access to more detailed water-use information using a mixed methods approach to analysis.
e. More statistically robust approaches to the *analysis of impacts* of feedback interventions.
f. More research on the *long-term impacts* of access to more detailed water consumption information made possible via SW metering.
g. Comparisons between *different mediums* for the presentation of detailed water-use feedback e.g. paper versus online approaches.

h. Discussion of the relationship between different approaches to detailed water-use feedback enabled via SW metering and its potential contribution towards more *SUWM*.

1.4. Research objectives

1.4.1. Research aims

The research reported in this thesis was conducted to address the aforementioned research gaps, with the principal overall aim of investigating the role for more detailed household water consumption information feedback. To this aim, the main research topics aimed at exploring:

1. The different options for feedback enabled via SW metering [OPTIONS];
2. Householder interests and preferences for more detailed water-use information [PREFERENCES]; and
3. The various impacts of detailed feedback on householders and their consumption of water [IMPACTS].
4. Finally, to advance progress, these key issues are further discussed particularly in relation to the implications for water utilities and the higher goal of SUWM [IMPLICATIONS].

To achieve these aims, the research implemented and evaluated two household water-use feedback trials. Key elements in decision making for detailed water-use feedback provision were additionally identified and developed into an implementation framework, which was used to review previous work and provide recommendations for research and practice to advance implementations of detailed water-use feedback and promote more sustainable water resource consumption.

1.4.2. Research questions

The work presented in this thesis is summarised by the following four main research questions:

RQ1: **What are the possible and practical <u>options</u> for presenting detailed household water-use feedback in a digital future?**

RQ2: **What are householders' <u>preferences</u> in terms of detailed feedback enabled by SW metering?** (Are householders interested and motivated? And what metrics can motivate water savings?).

RQ3: **What are the <u>impacts</u> of the provision of detailed water-use feedback enabled by SW metering to householders in terms of water savings, behavioural and infrastructure changes[2] and awareness?**

RQ4: **What are the <u>implications</u> of the research for the future of SW metering for utilities and customers and for SUWM?**

1.4.3. Key thesis topics

This thesis explores the role for more detailed water-use feedback via SW metering in contributing towards more SUWM. A visual representation of the key topics discussed in the thesis is provided in Figure 1. 'Detailed feedback' is located at the core, and represents the opportunity under investigation in this research. 'Options' represents the different approaches that may be taken to provide detailed feedback to householders. 'Preferences' represents the interests of householders towards more detailed water-use information. 'Impacts' refers to the results of the provision of detailed water-use feedback to householders. The key topics of options, preferences and impacts are shown to overlap one another since they are proposed in this thesis as interrelated. Finally, 'Implications for SUWM' is set as the background and thus represents the underlying focus and ultimate goal under consideration.

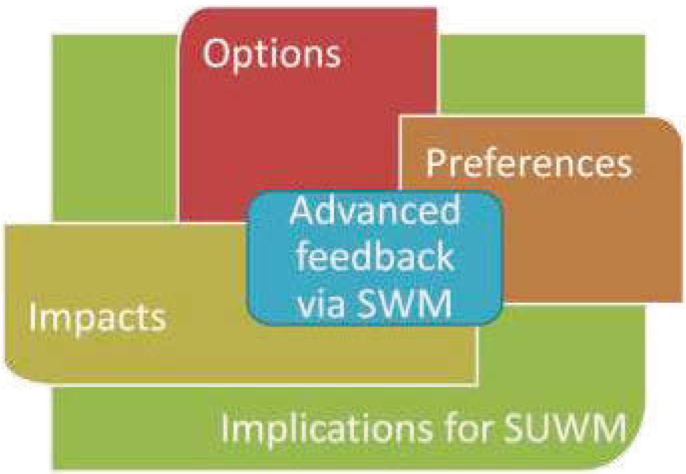


Figure 1 Representation of the main thesis topics

[2] Here, infrastructure changes refers to changes to the household water-using infrastructure including both the appliance stock (e.g. clothes and dish washing machines) and fixtures (i.e. water pipes, showers and taps).

1.5. Research approach

The research was conducted within an Australian Research Council (ARC) Linkage Project (LP110200767) as an industrial related project. Two research studies were conducted within the present research in order to investigate the impacts of detailed household water-use feedback enabled via SW metering. The first study involved paper-based reports, termed 'Home Water Updates' (HWUs), which provided detailed household water- and end-use feedback. The second study involved an online portal, termed 'My Home Our Water' (MHOW), which provided consumption feedback according to time of use in near real-time. The implementation of these two trials allowed an exploration of the levels of interest and engagement of householders with different forms of customised water-use information and the resulting impacts of access. Detailed descriptions of the research study methods are provided in Chapter 2. Following mixed methods analyses of the two trials, the research develops with a discussion of the research findings in the context of the current state of the Australian water industry and approaches to detailed water-use feedback and what this means for the future of SW metering. Finally, an implementation framework for detailed water-use feedback is developed together with a research agenda to signal the possible directions for household water-use feedback enabled via SW metering and guide future research and practice.

This work was conducted within a wider body of work for the ARC project shown in Figure 2.

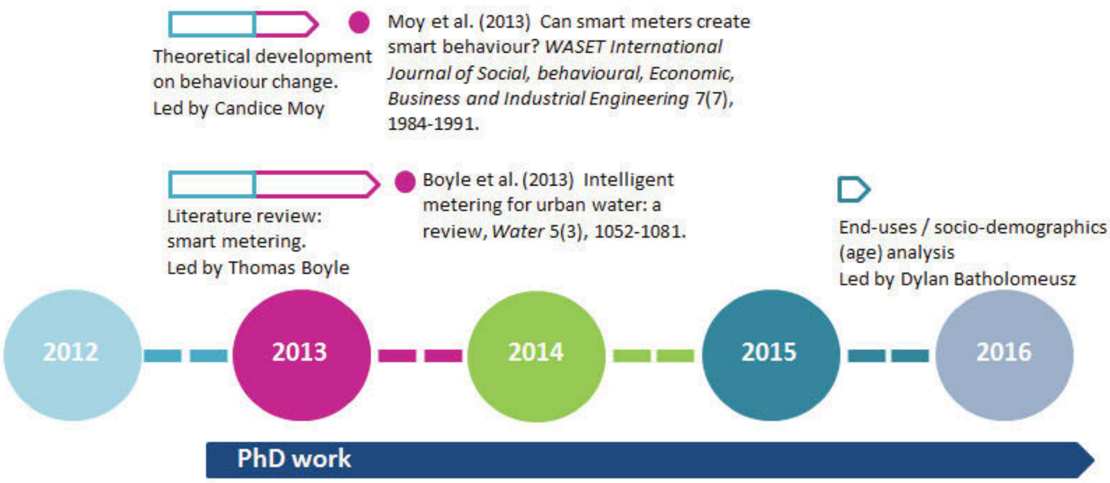


Figure 2 The Author's PhD work in the context of the wider body of work undertaken

1.5.1. Research scope

The scope of the research was limited to investigating:

- The context of two urban areas in New South Wales, Australia.
- Urban water consumption (i.e. not the rural sector, which comprises of different demands and challenges as compared to more populated areas).
- Residential water consumption (i.e. not commercial or industrial consumption, which entails different patterns and types of water usage).

1.5.2. Contributions to knowledge

The contributions to knowledge from this thesis are as follows:

a. **Conceptualising the options (i.e. possibilities) for the presentation of detailed household water-use feedback via SW metering (CHAPTER 3).** While some characteristics of feedback have been listed and described within literature relating to household energy use feedback (Fischer, 2008; Karjalainen, 2011), it is a topic that has hardly been addressed for household water. However, understanding feedback possibilities is fundamental to decision-making concerning the design and implementation of household water-use feedback studies and programs. For the first time, this paper summarises in detail feedback options specifically enabled via SW metering.

b. **Exploration of householders' perspectives on detailed water-use feedback information (CHAPTERS 3, 4 & 5).** This paper explores whether householders are interested in more detailed information about their water use; what types of feedback are preferred; and what information motivates water savings. This is an important contribution as no research involving SW metering and/or end-use analysis and feedback has focused specifically on the householder side of the SW metering equation. The research provides evidence of considerable interest among householders and reveals their preferences and responses among the different options.

c. **Analysis of impacts of detailed water-use feedback information using a mixed methods approach (CHAPTERS 3, 4 & 5).** Smart meter data is analysed for quantitative impacts (aggregate and end-use water consumption savings). Survey data and interview data are used to assess more qualitative impacts of feedback (e.g. on awareness, motivation to save, actual behaviours and infrastructure changes) and thus provide a more extensive evaluation than previously provided.

d. **A detailed overview of the state of current approaches to detailed water-use feedback (CHAPTER 6).** This contribution provides water industry researchers and practitioners with a first comprehensive overview of work to date. This review demonstrates the wide variety among current approaches to detailed water-use feedback, yet opportunities to more fully embrace the greater range of possible options (e.g. by combining distinct approaches) enabled by SW metering and furthermore on a larger scale.

e. **Development of an implementation framework and research agenda for detailed feedback via SW metering to foster a greater contribution towards SUWM (CHAPTER 6).** This contribution adds significantly to the 'knowledge bank' on how to approach household water-use feedback via SW metering. This involves a review of the research process and challenges (i.e. questioning assumptions; reflecting on decision making and technical and research challenges; and considering alternative approaches including against current practice). Through the introduction of an implementation framework for detailed feedback via SW metering, this contribution serves as a practical guide to industry regarding important considerations for detailed feedback via SW metering and for research in signalling directions for future investigation to direct SW metering towards greater sustainability outcomes. This contribution thus summarises what experiences from the research project and the current status of SW metering and detailed water-use feedback mean for its future in the digital age and thus guides both research and practice.

1.5.3. Connection between the research questions and the thesis chapters

Table 2 shows the connection between the research questions and the thesis chapters and papers or sections.

Table 2 Research questions and corresponding chapters

Research Question	Chapter (Paper/Section)
1. Options	3 (Paper I)
2. Interests & Preferences	3 (Paper I), 5 (Sections 5.6)
3. Impacts	3 (Paper I), 4 (Paper II), 5 (Paper III), 5 (Section 5.6)
4. Implications for SUWM	6 (Paper IV), 7 Discussion

1.6. Thesis layout

This thesis is presented as a 'hybrid thesis' which includes exegesis chapters that are organised around research papers inserted as chapters. Importantly, the production of peer-reviewed journal papers targeted dissemination of the research findings to meet public funding expectations and strengthen the overall thesis.

The 'hybrid thesis' layout employed differs from a traditional thesis by incorporating published or submitted papers in the place of traditional data analysis and results chapters. However, traditional Introduction and Methodology chapters are used in the exegesis to introduce the overall research aims, provide an overview of the relevant literature and detail the research methods. Then, following presentation of the research paper chapters, a discussion and conclusion of the overarching results of the research is provided in the final chapters of the thesis document. The 'hybrid' approach therefore targets completeness and congruence.

Each of the individual publications contains an independent Abstract, Introduction, Materials and methods, Results, Discussion/Conclusion section, according to the specific research topic and objectives addressed in the paper. As these papers were created as stand-alone publications, there is some unavoidable overlap between the papers and traditional chapters, particularly in terms of the descriptions of the research methods and literature reviews. Attempts have been made to keep overlap to a minimum, while ensuring necessary details are provided to present the research in a coherent manner.

The Results (publications) chapters are followed by an overarching Discussion chapter, which provides a synthesis of the key findings that were raised in the individually reported research studies; summarises conclusions, contributions and research limitations; and highlights key areas for future research. The final chapter concludes by summarising the research and addressing the research questions. All References, including from the individual publications, have been collated at the end of the thesis document.

The thesis consists of eight chapters in all which are organised in four parts, providing the Background, Research Approach, Results, and Discussion and Conclusion, respectively. This first chapter introduced the research. This introduction included the research background; a succinct overview of the literature of relevance to the present research and the research gaps to be addressed; and the research aims and scope. The research background included an overview of water utility objectives, SW metering, the water utility context, and the water industry outlook. The main topics covered included in the overview of the literature included detailed water-use feedback provision, analysis and theoretical contributions. This review was purposely succinct since additional targeted reviews of the literature are included in the papers which form Chapters 3 to 5. This structure of the remainder of the thesis is further detailed below:

Chapter 2 provides details of the overarching research methodology and design adopted for this investigation. The chapter explains and justifies the mixed methods research approach, the situational context, the research samples, methods of data collection and the analytical approaches adopted. More detailed discussions on the methods of data collection and analysis are provided in the individual papers which comprise Chapters 3 to 6. This aim of this chapter is to rather focus on presentation of the wider, overarching research methodology and design.

Chapter 3 presents the first of the journal papers (Paper I), which explored the role of householder *preferences* for and *responses* to different approaches to detailed water-use feedback. The paper first presents a conceptual framework, which built on existing literature to characterise the different *options* for the presentation of detailed water-use feedback might take. Second, the paper presents a detailed evaluation of the types of feedback information that were specifically provided to householders during the 'Home Water Update' (HWU) study, which explored the role for the provision of detailed water and end-use feedback via paper-based reports. Third, the results of a survey of householder *preferences* are presented, showing how householders evaluated and responded to different forms of feedback. The results highlight the need for a greater understanding of the different ways to provide information to household water consumers, and how this will influence engagement, responses and ultimately, the contribution of SW metering towards water conservation and more SUWM.

Chapter 4 presents Paper II, which details the results of the HWU study. The chapter presents the study design, which involved the design, production and distribution of customised water-use reports, as well as the quantitative and qualitative analysis of their impacts on householders and their consumption of water. The widespread appeal of the HWUs and reports of changed household behaviours and to water-using infrastructure demonstrated a positive role for more detailed water-use feedback.

Chapter 5 presents Paper III, which turned to investigate the impacts of detailed water-use feedback information via an online portal, 'My Home Our Water' presented in near real-time, including according to time of use. Paper III provides details of the study design, an analysis of portal usage, and results of a quantitative analysis of the impacts of access to information provided. In particular, impacts were measured in the longer term (over the course of one year pre- and one year post-intervention) and in relation to login records. The results highlighted the importance of actual engagement with feedback in producing water consumption savings and how these decrease over time. The chapter is supplemented with an evaluation of the portal which was based on data collected via a post-intervention householder evaluation survey.

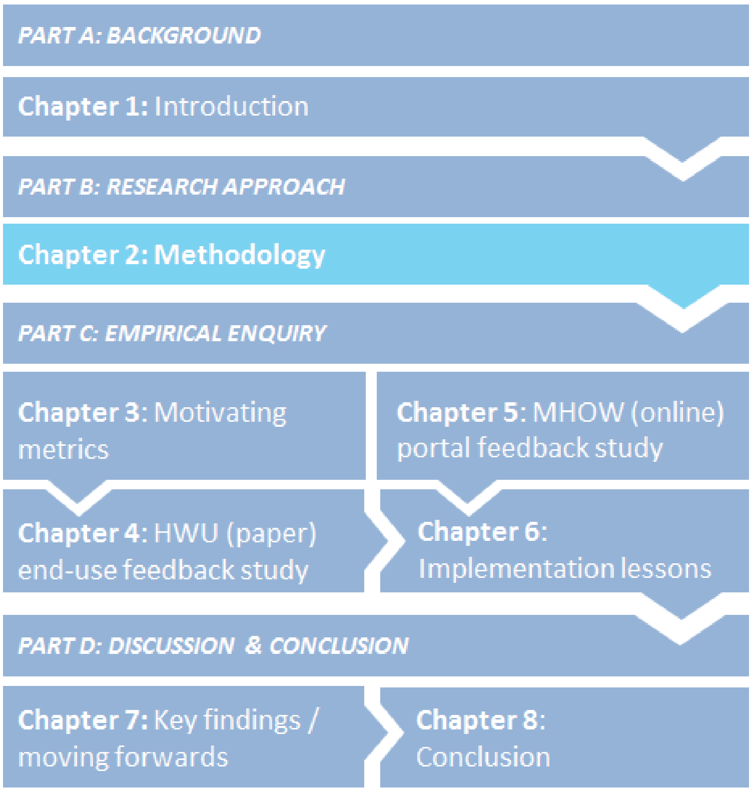
Chapter 6 presents Paper IV, which draws on the first hand experiences through the implementation of detailed water-use feedback through the HWU (paper) and MHOW (online) studies. The paper develops an 'Implementation Framework' which outlines the key elements in decision-making for detailed water-use feedback programs enabled via SW metering. The paper critically reviews current approaches to detailed water-use feedback and provides recommendations for research and practice to help foster more well-considered approaches and more widespread implementations to extend the benefits of SW metering to customers and promote greater involvement towards more SUWM.

Chapter 7 forms the Discussion section of the overall thesis. This chapter provides a synthesis if the key research findings from the individually reported studies. The discussion of these findings is particularly elevated to a consideration of the means for a greater contribution through detailed feedback and SW metering to more SUWM, with the overall conclusion that more efforts are required to enable a significant impact. The chapter also provides a summary of the conclusions, contributions, research limitations, and future research directions.

Chapter 8 summarises the research and addresses the research questions.

The Appendixes included at the end of the thesis contain additional information pertaining to the research (i.e. householder communications including project information sheets, letters and interview questions).

Chapter 2: Methodology



Introduction

This chapter details the research methodology and design adopted for this investigation. The overview of the literature in section 1.2 highlighted important knowledge gaps concerning the potential role for household SW metering to provide more detailed water-use feedback, particularly concerning the *options* for provision; understanding householders' interest in and *preferences* among alternative feedback options; and householder responses (*impacts*) and the *implications* thereof. These research gaps are addressed through empirical research, as outlined in this chapter, with the overarching goal of investigating the opportunities for detailed household water-use feedback via SW metering.

This chapter is divided into seven sections which together provide a comprehensive overview of the overall research approach. This overview aims to reflect the overall investigation. While there is some overlap with the methods sections of the papers which form the results chapters (chapters 3-6), unnecessary repetition is avoided as much as possible.

- **Section 2.1** explains how the complex nature of the overall research problem of investigating the prospects for detailed water consumption feedback via SW metering involves multiple issues and thus requires a mixed methods approach. The overarching research approach involving five phases is presented together with details on the quantitative and qualitative methods of data collection selected.
- **Section 2.2** describes the situational context of the study, providing details of the study locations and the rationale for their selection.
- **Section 2.3** provides a high level overview of the research samples including the process of recruitment and ensuing sample sizes. Further details are specifically available in the results chapters 3, 4 and 5.
- **Section 2.4** provides a discussion of the chosen method for the design of the two separate intervention mediums over alternative approaches.
- **Section 2.5** provides details of the methods used to collect the data, the rationale for their selection, and a reflective discussion of the data limitations experienced.
- **Section 2.6** describes the analytical approaches adopted in relation to the data collected, together with a discussion of their selection over alternative approaches.
- **Section 2.7** provides a summary of ethics considerations of relevance to the research.

2.1. Research approach, design and overview

The research topics concern *options* for detailed household water-use feedback, householder *preferences* and *impacts* of feedback provision. The nature of the research questions necessitated the collection of both quantitative and qualitative data to form a more complete and accurate picture. Therefore, a mixed methods approach was adopted to gain more insights from a combination of quantitative and qualitative approaches and the utilisation of their respective strengths (Creswell, 2008; Denscombe, 2010). Quantitative analysis was used to analyse water consumption data; and a mix of quantitative and qualitative methods were applied to assess for other impacts as well as householder preferences.

Detailed reviews of the literature were used to develop (i) a conceptual framework to provide a comprehensive overview of the possible options for water-use feedback enabled via household SW metering; and (ii) an implementation framework for feedback programs that outlines key decision elements to provide practical guidance to water utilities.

The overarching mixed methods design, which is separated into five phases and involves the design, implementation and evaluation of two household water-use feedback interventions and a synthesis of findings and implications, is summarised in Figure 3.

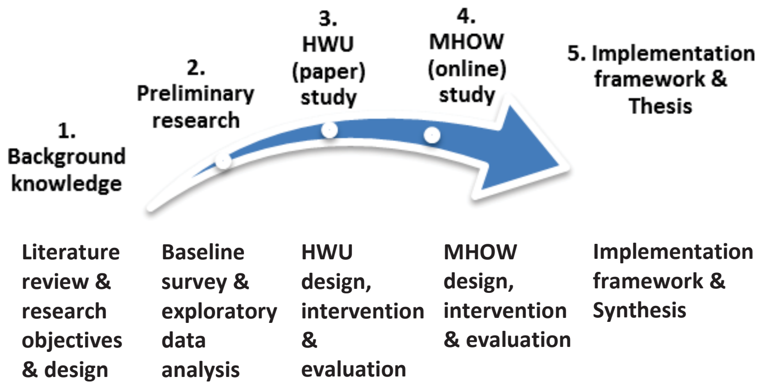


Figure 3 Overarching research approach

Further details of the activities, data collection and outputs of each of the five phases are provided in Table 3 and are summarised below.

- Phase 1 involved the acquisition of background knowledge through a review of the literature and the establishment of the research objectives.
- Phase 2 initiated preliminary research activities using quantitative water consumption data; and a mix of quantitative and qualitative data collected via a household baseline survey (Moy, Liu et al., 2012).
- Phase 3 involved the design, implementation and evaluation of the Home Water Update (HWU) study, involving paper-based reports, which provided detailed household water consumption feedback, including at end-use levels. The phase resulted in the production of two research papers which form chapters 3 and 4.
- Phase 4 involved the design, implementation and evaluation of the My Home Our Water (MHOW) online study, which involved provision of aggregated water consumption feedback in near real-time via a custom-built portal. The results of the study were presented in the paper, which forms chapter 5.
- Phase 5 involved the creation of an implementation framework for detailed household water-use feedback via SW metering, which is included in chapter 6 of this thesis. Further synthesis is provided in chapter 7; and chapter 8 concludes the overall investigation.

Table 3 Research activities, data collection and research outputs

Phase	Activities	Research data collection	Outputs
1. Background knowledge	Literature review, Research objectives and design	- Literature review I	**Chapter 1:** Introduction **Contribution to review paper:** Intelligent metering for urban water: a review (PAPER V) **Chapter 2:** Research methodology
2. Preliminary research	Baseline survey; Exploratory data analysis	- Household baseline survey data - Baseline household water consumption data • billing data (all study households); • end-use smart meter data (HWU study group)	**Baseline survey**: Know your Water **Conference / journal paper:** Smart metering and billing: information to guide household water consumption (PAPER VI)
3. HWU (paper) study	HWU design, intervention and evaluation	- Household water consumption data • billing data • end-use smart meter data - Household HWU (paper) evaluation and information preferences survey data - HWU evaluation interview data	**Chapter 3:** Motivating metrics for household water-use feedback (PAPER I) **Chapter 4:** Urban water conservation through customised water and end-use information (PAPER II)
4. MHOW (online) study	MHOW design, intervention and evaluation	- Household water consumption data • quarterly billing data • smart meter data - MHOW (online) portal household evaluation survey data	**Chapter 5:** Online water-use feedback: household user interest, savings and implications (PAPER III) **Conference paper:** Online household water portal: user interactions and perceptions of water use (PAPER VII)
5. Implementation framework and Thesis	Implementation framework Synthesis	- Review of HWU (paper) and MHOW (online) studies - Literature review II	**Chapter 6:** Detailed water-use feedback: A review and proposed framework for program implementation (PAPER IV) **Conference paper:** Household water-use feedback: moving forwards towards sustainable urban water (PAPERS VIII & IX) **Chapter 7:** Key findings/ moving forwards **Chapter 8:** Conclusions, contributions and implications

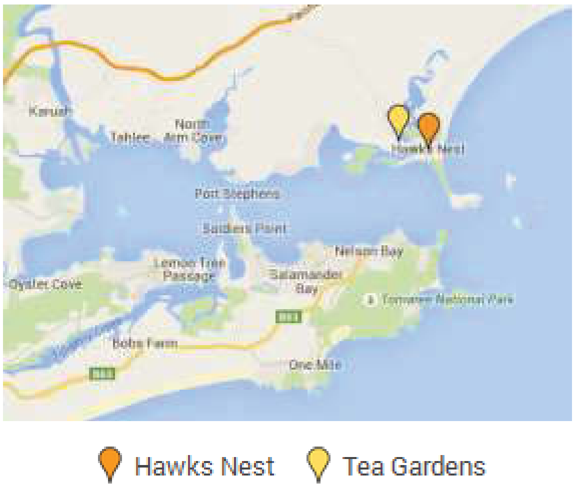
2.2. Situational context

This section provides an overview of the situational context of the research. The study locations were determined within the scope of the larger ARC Linkage Project, within which this PhD work is situated. Collaboration with MidCoast Water (MCW) as an industry partner for the research project, and the particular research study locations formed parts of the original funding proposal. MCW is a local government authority which provides water and sewerage services to some 37,000 households in the urban areas of the Greater Taree City Council and the Great Lakes within the state of New South Wales, and is situated approximately 320 kilometres north of Sydney. MCW's service area covers 10,000 km^2 from Johns River in the north, to Tea Gardens in the south, over to Gloucester in the West (MidCoast Water, 2012a). The HWU (paper) study was conducted in Tea Gardens and Hawks Nest. The MHOW (online) study was conducted within various localities of Greater Taree. The study locations are shown in Figure 4a.

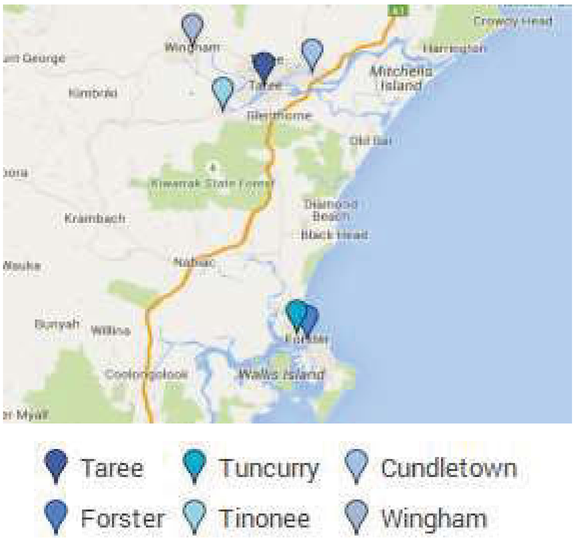
The selection of Tea Gardens and Hawks Nest for the HWU (paper) study (Figure 4b) was due to the existence of smart water meters on 141 households in the area and an ongoing collection of water consumption data at 1 min intervals every summer and winter for disaggregation at end-use levels. These meters were originally installed in mid-2009 as part of a pressure management study which involved progressive reductions in pressure in late 2010 to assess the impact on water demand at aggregate and end-use levels later in 2011. Despite the ongoing collection and detailed analysis of the data at end-use levels, this data had not previously been communicated to any of the individual smart metered homes, which presented an opportunity to test the role of communicating more detailed feedback via smart water metering to householders.

The MHOW (online) study location aimed to involve a wide demographic of participants from across a variety of localities in Greater Taree City Council (see Figure 4c). This was possible since this study required participant recruitment prior to the installation of new smart meters on recruited residents' properties. The final mix of localities and their representation in the study depended on the recruitment activities, which drew on MCW's customer database.

a.



b.



c.

Figure 4 Maps of the research study locations in NSW, Australia

Panel a. shows the two separate study locations. Panel b. shows the HWU study locations. Panel c. shows the MHOW study locations. Source: Map data © 2015 Google.

2.3. Research samples

The research samples are purposely described here in brief since the details of the individual studies are provided in the corresponding papers which form the results section of this thesis.

Samples were drawn on the aggregate household level, since it would not be possible to determine water consumption of individual household members within the scope of this research project. This sampling unit has its limitations, since households differ in terms of the number of occupants, with implications for household level water consumption, which was measure in terms of litres per household per day (L/hh/d).

Research participants for the HWU (paper) study were recruited from among the existing pool of 141 households in Tea Gardens / Hawks Nest with a smart meter, which limited the sample size. Recruitment was via informed consent in order to meet research ethics requirements. A total of 68 households were recruited (i.e. approximately half of the overall population of smart metered properties in the area). While the location offered cost advantages through the existing institutional settings of smart meter data collection and end-use analysis, the generalisability of the research findings was limited due to the narrow location specificity of households, all within an approximate radius of less than 10 km.

Research participants for the MHOW (online) study were recruited from MCW's service area, and targeted a broad demographic of households whose annual water consumption was within the second highest quartile of domestic consumers. Project budget constraints determined that a total of 120 new smart meters could be installed. The recruitment process also followed ethics requirements via informed consent and continued until this number of participants was reached. Recruitment from across a wider geographic area added to the variability of the socio-demographic groups. However, the restriction of recruiting households within the second highest quartile of users set by MCW would have worked to counter-effect this to some extent. Therefore, it is not possible to draw solid conclusions on the generalisability of the study results beyond the study areas.

Both the HWU (paper) and MHOW (online) studies involved separate intervention and control groups. In both cases, these were determined using a stratified random approach to assigning recruited participant households to either of the equally sized groups within each study. This approach aimed to capitalise on the variability within the available samples and to obtain comparable intervention and control groups for the studies.

2.4. Intervention mediums and their design

This research involved a paper-based medium (HWUs) and an online portal (MHOW). The choice of the two mediums also formed part of the original ARC Linkage Project funding proposal. The research uniquely allowed for comparisons between two commonly used mediums for the provision of household level communications. The paper-based approach (paper reports) carried the advantages of high visibility, with the reports being mailed directly to householders, and a succinct overview of household water-use. The online portal approach offered the advantages of mobile access to water-use feedback, at the convenience of householders, and user-interactivity due to the variety of features provided.

The design of the HWU study's intervention medium, the HWUs, was conducted mostly internally within ISF and in conjunction with MCW. A graphic designer was recruited for the design work once the content was determined. Other types of approaches to the design of the HWUs (paper reports) were considered, such as holding a focus group with householders to co-create the intervention medium. Such an approach was ultimately determined as unsuitable for the present research as the high level of engagement might influence the overall impacts of the HWUs (paper reports) on the study participants, and furthermore that this type of approach would be unrealistic to implement on a larger scale. In addition, the cost of this alternative approach would have gone beyond the available project budget and caused delays in the overall project timeline. Discussions were held on the possibility of customising feedback according to householders' preferences, but this was also rejected in favour of the adopted methodology which aimed to explore a low engagement strategy with greater replicability and lower costs for water utilities. Finally, due to budget, timing and data collection constraints, it was determined that the intervention group households would receive two HWUs, depicting their winter and summer data, respectively.

The design of the MHOW (online) study's portal followed a similar method to the HWU (paper) study. The content was largely determined via internal project team workshops and discussions and reviews of existing literature[3]. As with the design of the HWUs (paper reports), the design of the MHOW (online) portal did not involve any input from the study householders and thus also resulted in a low engagement approach enabled to explore the impacts of a portal to which potential users had no direct connection.

[3] The formulas ultimately used to produce the content were largely constructed by Thomas Boyle, who coordinated the design of the portal interface.

2.5. Research data (and limitations)

An overview of the data collected for the research is provided in Table 4. Further details on the types of data collection and the rationale for the corresponding methods of collection together with a discussion of their data limitations are provided in the subsections that follow.

Table 4 Overview of data collection via the two research studies

HWU (Paper) Study	Dates / Duration	MHOW (Online) Study	
Baseline Survey (*N*=68)	Round 1: Nov 2012. Follow up on non-respondents: Jan 2013.	Baseline Survey (*N*=120)	Round 1: Nov 2012. Follow up on non-respondents: Jan 2013.
SmartMon end-use data † (*N*=68)	Pre-intervention data: Winter 2012 (8/6/12-27/06/12) and Summer 2012/13 (12/12/12-15/01/13)*; Post-intervention: Winter 2013 (19/06/13-3/7/13)**; and Summer 2013/14 (28/12/13-6/1/14)	Outpost smart meter data ‡ (*N*=111)	Jan 2013 – Jan 2015
Quarterly Billing data † (*N*=68)	2012-2014	Quarterly Billing data † (*N*=120)	2012-2015
Evaluation survey (*N*=22)	Nov 2013	First login online survey ‡ (*N*=18)	Open from Jan 2014.
Evaluation interviews (*N*=5)	Sep 2014	Portal usage log ‡ (*N*=18)	From Jan 2014.
		Google Analytics data ‡ (*N*=20)	From Jan 2014.
		Evaluation via online survey ‡ (*N*=18)	June 2015

Table notes: † Data provided by MidCoast Water (MCW). ‡ Data provided by Outpost Central. All other data was collected from study householders recruited from within the MCW service area.
*** This data was provided in the first HWU, sent on 9th May 2013. ** This data was provided in the second HWU, sent on 10th September 2013.**

2.5.1. Baseline survey data

The baseline survey (Moy, Liu et al., 2012) sought to collect a novelly large amount and range of data, including on the household water appliance stock, water related practices, attitudes towards conservation and new technologies, household demographics and informational preferences. The data was used to obtain a broad and detailed understanding of the pre-intervention conditions of participant households and was used to enable categorisations and comparisons at baseline and the basis for pre- versus post-intervention assessments.

In hindsight, the baseline survey would have benefited from the use of more questions drawn directly from other relevant literature, including validated constructs, for the purposes of comparison. The survey could also have been established as a pre-requisite for MHOW (online) study participation (as with the HWU (paper) study). Unfortunately, various recruited households that were fitted with smart meters did not later return the voluntary baseline survey. Limited additional data was available for these households beyond their water consumption data, so the project may not have made the most efficient use of project resources (i.e. capital investments in smart meters and the associated project team time investments).

2.5.2. Water consumption data

In order to evaluate the SW metering opportunity, quantitative data for the research was primarily collected via smart water meters. These technologies enable water consumption data collection at high frequency intervals (e.g. every 1 min). Alternative approaches have involved more manual methods using conventional household water meters, either using utility billing data (e.g. quarterly), or by involving householders to record their own meter readings. However, the former provides data which can neither provide feedback on time of use nor end-use; and the latter requires considerable effort by householders and cannot collect anywhere close to as many data points as a smart meter. SW metering therefore offers a superior, automated approach, which far exceeds the capabilities of manual consumption recording, with direct advantages regarding the level of detail available for subsequent water-use feedback.

The HWU (paper) study involved Datamatic firefly data loggers connected via a reed switch to conventional Elster V.100 water meters. The data loggers were set to record at 1 min intervals with a resolution of 0.5 litres per pulse. Due to their limited memory and dependence on drive-by manual data downloads using a hand-held device, this data collection at 1 min intervals was limited by MCW to summer and winter periods of between two to five weeks each.[4] This method of intensive snapshots of data collection was also adopted in previous end-use studies due to the resource intensity required (Willis et al., 2010). To improve the availability of data for this research project, additional data collection was introduced at 1 hour intervals in between. Figure 5 shows a typical smart meter installation used in the HWU (paper) study.

The MHOW (online) study used Outpost WASP loggers attached to the households' existing conventional water meters. The data loggers were initially set to collect data at 1 min intervals for uploading overnight via the internal SIM card and the 2G mobile phone network. Due to transmission issues, a few loggers were later adjusted to collect data at 5 min intervals and all loggers were eventually switched over to the 3G network. Figure 6 shows an Outpost WASP logger attached to a conventional water meter.

Throughout the duration of the research project, the households' conventional water meters continued to record accumulated household water consumption data. Meter reads also continued according to MCW's regular quarterly meter reading cycle for household billing.

Figure 5 Datamatic Firefly logger

Source: MCW (MidCoast Water, 2012b)

[4] The exact duration of each period was determined independently by MCW and resulted in the following data collection: winter 2012 (20 days); summer 2012/13 (35 days); winter 2013 (15 days); and summer 2013/14 (10 days).

Figure 6 Outpost WASP logger

Source: Outpost Central (Outpost Central, 2015)

2.5.3. HWU postal evaluation survey and interviews

Evaluation of the HWU (paper) intervention involved additional data collection via a household evaluation survey distributed to all intervention group households via mail. The cover letter and information sheet provided are included in Appendices 1A and 1B, respectively. The survey approach was used as a relatively low cost method to gain a larger sample of quantitative and qualitative data on a broad range of aspects necessitated by the research questions. The survey particularly evaluated the impact of the HWUs (paper reports) by exploring how householders responded to their detailed water-use feedback. The scope of the questions included the reach and appeal of the HWUs (paper reports) and changes to household water infrastructure, water-using behaviours and awareness. Finally, the survey was also used to recruit volunteer households to participate in an additional evaluation interview for additional insights. A copy of the survey is provided in Appendix 1C.

Telephone interviews were conducted for a further qualitative investigation of how householders used, interpreted and valued their customised water-use information. Interviews were chosen for being specifically suited to the evaluation of more complex and more subtle phenomena (e.g. to gain insights into opinions, feelings and experiences, including sensitive issues) (Denscombe, 2010). A semi-structured approach was further adopted in order gain a deeper understanding of these aspects, while particularly aiming to capture descriptions by householders in their own words. A copy of the guiding interview questions is provided in Appendix 1D.

Using the strategy of recruiting interviewees via the survey led to one-third volunteering, and only five of these seven households could finally be reached for interviews. An alternative approach to recruiting more interviewees might have yielded more interview candidates beyond the limited number achieved.

2.5.4. MHOW portal first login survey, usage log, Google Analytics ™ data and online evaluation survey

Materials mailed to MHOW (online) study participants at launch included a cover letter, an information sheet, a user login postcard, a password sticker and a brochure (see Appendices 2A-2E respectively). A short online survey, administered to portal users at their first login, was subsequently used to collect additional baseline data. The survey aimed to capture householder water consumption awareness, interests, intentions and perceptions of ability to save. A copy of the survey questions is included in Appendix 2F. Reminders were later sent via a postcard (see Appendix 2G) and later email (see Appendix 2H) to encourage households to login.

Learning from the experience with the baseline survey, the decision was taken to make the short online survey administered to MHOW (online) portal users at first login a pre-requisite to accessing the detailed water-use information provided via the portal. However, three households, which appeared to have logged in, did not complete the survey and did not therefore access their detailed household water-use information.

To collect data on household user interactions with the online MHOW (online) portal, user change logs and Google Analytics ™ were set up. Google Analytics ™ was used to trace portal logins, page views and the time householders spent within the portal. The user change logs recorded responses to the first login survey questions, as well as user changes to profile settings, registrations for the various alerts, and engagement with the portal's interactive facilities. This method of automatic data collection offered the benefits of low cost, detailed portal usage data collection.

Additional evaluation data collection ensued via an online evaluation survey, administered via Survey Monkey ™, which was developed for householders to evaluate the MHOW (online) portal. The survey was designed for both households that did and did not use the portal in order to explore reasons for usage, non-usage and what types of information these householders find as useful.

An online survey method for evaluative data collection was selected for its speed and cost advantages relative to postal survey methods (Parasuraman and Zinkhan, 2002). The launch of the survey could itself be communicated via email and its online completion and data collation offered time savings for data collection and its preparation for analysis. Moreover, as the majority of MHOW (online) study participants were expected to have access to the internet, it seemed appropriate to use an online method of evaluation.

A relatively low final response rate to the online evaluation survey suggested that alternative methods of data collection might potentially have yielded greater participation, albeit at a higher cost. However, due to time and budget constraints, neither alternative methods of data collection, nor an extended deadline for the online survey could be explored within the present research.

2.5.5. Data limitations: HWU study

A number of important data limitations were anticipated during the design phase of the HWU (paper) study. Various elements of the research design defined within the larger ARC Linkage Project scope and available project budget and existing processes had implications for the timing of data collection, analysis and evaluative activities and imposed several constraints, which were beyond the influence of this PhD research. Three major concerns related to:

(i) The *timing of the detailed water consumption data collection* via the smart meters for end-use disaggregation. This data collection during short 'snapshot' periods in summers and winters only, meant that there were limited possibilities for comparing household water consumption pre- and post-intervention at end-use levels, with the HWU intervention taking place in between two snapshot periods.

(ii) The significant *time lag* in the availability of household feedback. This time lag was due to the extensive labour time commitment required by MCW to collect and analyse the data at end-uses; and the labour intensive production of the HWUs to communicate the data as household consumption feedback. The time lag implied that household feedback was delayed (e.g. by at least four months after actual consumption occurred) and together with the timing of the detailed consumption data collection meant household responses to the provision of feedback via the HWUs could only be measured relatively soon after their provision (i.e. at approximately ~5 weeks). In addition, it was anticipated that the savings impacts on consumption might itself be moderated by the time lag between the time of actual water consumption and the availability of end-use feedback since feedback has been shown most effective when provided immediately (Geller, 2002).

(iii) The moderate *sample sizes* available for the research. The relatively short length of the predetermined durations of the intensive data collection periods for end-use disaggregation (i.e. between two to five weeks each summer and winter) in conjunction with the limited available sample size of household participants was expected to have implications for the power of the study to detect statistically significant changes in relative household water consumption as a result of the HWU intervention.

Despite these concerns and recognising that limitations always exist, the research was required to proceed making the best of the available resources and constraints. The additional decision to collect one-hour data in between was also taken in order to help expand the available data from which to assess the impact of the HWU intervention. However, subsequent data loss, due to human (meter reader) error, rendered this data set incomplete which impeded additional analysis.

Logger failures and participant attrition (due to changes of property ownership as some participants moved away during the study) also reduced the final sample size for evaluation of the impact of the HWU intervention. However, the mixed methods approach to the research which involved the complementary use of an evaluation survey and interviews meant that the assessment of the impacts of the HWU intervention did not have to rest solely on the quantitative analysis of the smart meter data. Rather additional insights could be drawn from these additional sources of data in order to obtain an understanding from multiple angles.

2.5.6. Data limitations: MHOW study

The MHOW (online) study met with a number of data limitations including interruptions in data transmission, logger failures and data loss. Resolving these issues required replacement loggers, operating system upgrades, switching over to the 3G network or an increase in the length of the logging interval from 1 to 5 minutes. The issues took several months to resolve during the baseline period due to the newness of the technology and limited experience of the technology partner with these issues at other customer sites.

For the affected households, the technical disruptions resulted to varying degrees in incomplete water consumption records and delays in both the provision of access to the MHOW (online) portal as well as in updated water-use feedback via the portal. For the purposes of the research, the resulting unforeseen delays to the project timeline impacted upon the timing of data collection, analysis and evaluative activities.

2.6. Data analysis and critical discussion

2.6.1. Data preparation

Data preparation for the HWU (paper) study commenced within MCW's existing business analysis processes. This involved the disaggregation of the aggregate household water consumption data collected at 1 min intervals into end-uses via the process of end-use analysis. Details of this process are provided in Box. 1. Once the disaggregated data was obtained (i.e. at water usage event level), this was provided in the form of MS Access databases for the research project for further analysis in MS Excel to produce the HWU intervention medium; as well as for later analysis of the impact of the HWU intervention using SPSS (IBM, 2012). The details of these analyses are provided in chapter 3, which presents the design and evaluation of the HWU study.

Box 1. End-use analysis for the HWU study

While most previous water end-use research studies used Trace Wizard © software by AquaCraft (e.g. Athuraliya et al., 2012, 2011; Beal and Stewart, 2011; Roberts, 2005; Tom et al., 2011; Willis et al., 2010), MCW adopted SmartMon (Redskink Pty Ltd., 2011). The software offers the advantage of requiring significantly less data collection by logging consumption data at 1 min intervals, rather than every 10-15 seconds. Furthermore, its adoption allowed MCW to install its SW metering technology at a cost of about $250 per residence, which is lower than the costs entailed by high resolution meters and data loggers.

SmartMon is a Microsoft Access based program which is used to read CSV files of total flow data collected post meter for disaggregation using a system of tagging of events according to flow patterns (Redskink Pty Ltd. 2011). In the process of tagging, SmartMon faces comparatively more difficulties in identifying smaller water usages and requires a lot more manual analysis to separate overlapping events. However, this is of greater concern when analysing high occupancy households. Applied on Tea Gardens / Hawks Nest data, SmartMon analysis is more likely to yield an accurate picture of end-use consumption because the sampled households have an average of just two occupants. Another challenge was exemplified in the fact that a small fraction of water-using events was not assigned with any event usage tags.

SmartMon data outputs include event (i.e. shower, washing machine, toilet, outdoors, taps, bath and leaks), event date and start time, event duration (minutes), total consumption (litres), and flow rates (minimum, maximum, start, end, average and mode for flows in terms of litres per minute). This data can subsequently be extracted from SmartMon for further analysis of household water usage. A screenshot of the data collected for one household during the course of one Saturday morning is shown in Figure 7.

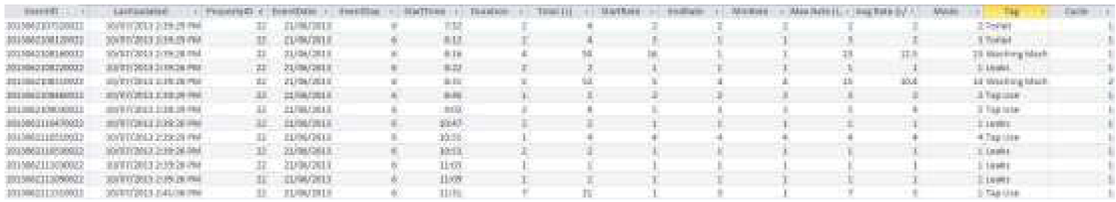


Figure 7 Screenshot of SmartMon end-use water consumption data

2.6.2. Analysis of the data

Chapter 3 presents results from the HWU (paper) evaluation and information preferences survey, together with additional insights from the semi-structured interviews that were conducted with householders who experienced the provision of detailed customised water-use feedback via the HWUs (paper reports). The survey data was also analysed in SPSS (IBM, 2012) and the recorded interviews were transcribed using MS Word. The results were compared across participants in order to obtain a range of views to the various topics that were covered.

Chapter 4 reports on the quantitative analysis of the smart meter data collected to analyse the impact of the HWU (paper) intervention, together with some insights drawn from the evaluation survey. These analyses were conducted using MS Excel and SPSS (IBM, 2012) version 21. The quantitative analysis involved descriptive statistics to identify general tendencies and inferential statistics involving a mixed analysis of variance to test for significant differences between the HWU (paper) intervention and control groups over time to improve the robustness of the analysis.

Chapter 5 presents the quantitative analysis of the MHOW study, drawing principally on the smart meter data, as well as on the portal usage log. The quantitative evaluation of the smart meter data was conducted by the ARC Linkage Project mathematician/modeller to ensure high quality analysis. The data cleaning and statistical analyses were conducted using Python (2.7.6) and the statistical package R (3.1.2).

All assumptions applied in the analyses are described in detail in the respective papers in which the results are reported in order to make the research transparent and reproducible.

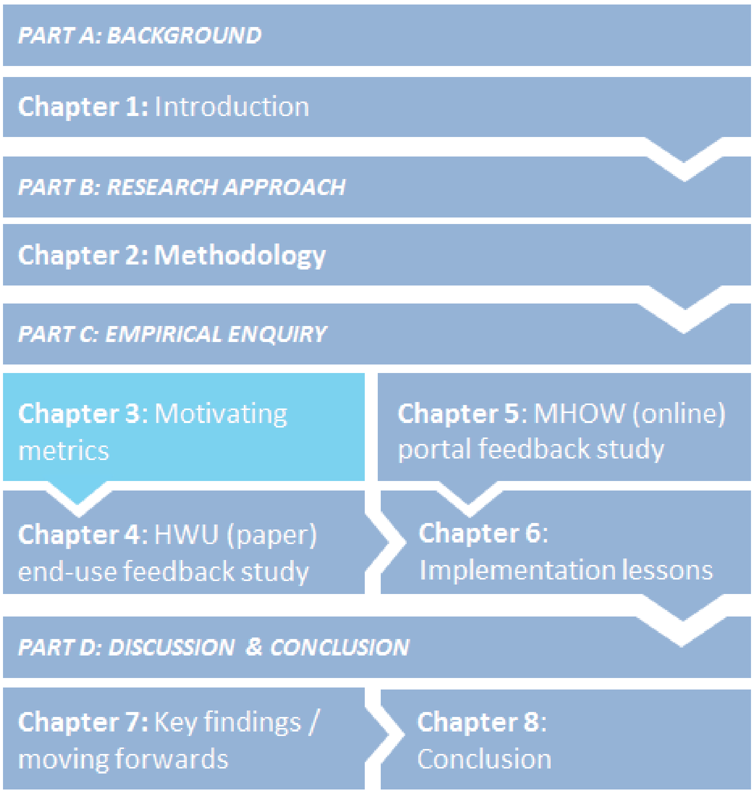
2.7. Ethics considerations

The research conducted for this thesis was covered under ISF's 'program approval' which was obtained for the wider ARC Linkage Project (LP110200767) immediately prior to the commencement of this doctoral research. The detailed 'ISF internal ethics approval form' documented details of the greater project research design and methodology. However, as the project was developed during the course of this doctoral research, all changes (including those concerning recruitment of and interactions with participant households) were documented in a second and third amendment and successively approved. As was detailed in the ethics form, interactions with participants were limited to recruitment, baseline and evaluation surveys, and a small subset of final interviews.

Informed consent was obtained by all study participants (and controls) through the provision of an information sheet about the research aims and scope and the submission of signed consent to participate. Consent was specifically obtained for water-use data to be linked to their survey responses and for information to potentially be shared with the respective household. Contact details of both MCW and ISF staff were also provided for queries, as was the opportunity to withdraw from the research at any time. Interviews involved an opt-in process and took place via telephone which provided convenience to participants and further reduced interviewer risk. Interviewees were informed they could stop the interview at any time for any reasons. Verbal consent was sought to record the interviews for data recording accuracy.

All participant data and survey responses were de-identified for analyses and interview recordings were also kept anonymous in all research publications so that householders could not be personally identified in any information collected for the research. Finally, for confidentiality, all data and information was stored on the project team's folder on ISF's digital storage infrastructure, which could only be accessed by the project team.

Chapter 3: Motivating metrics



Paper preface

This chapter includes a re-formatted co-authored peer-reviewed paper. The full bibliographic details of the paper, including all authors are:

Liu, A., Giurco, D., Mukheibir, P. 2015, 'Motivating metrics for household water-use feedback', *Resources, Conservation and Recycling*, vol. 103, pp. 29-46. DOI: 10.1016/j.resconrec.2015.05.008.

Statement of contribution

Ariane Liu was the project lead for the design, implementation and evaluation of the HWU study. Ariane wrote the evaluation survey, conducted and designed the interviews, and wrote the paper. Damien Giurco and Pierre Mukheibir provided supervisory guidance which involved reviewing drafts of the paper.

Acknowledgements are due to: Graeme Watkins (MCW) for access to the study householders and data; Candice Delaney (née Moy) & Thomas Boyle for contributions to the design of the HWU study, and for reviewing a draft of the Evaluation Survey from which results of the paper derive.

Research highlights and graphical abstract

The research article highlights and graphical abstract (see Figure 8) included in the online version of the journal article are as follows:

- Smart water metering enables detailed feedback but this needs characterisation.
- A framework for detailed household water-use feedback is thus presented.
- A household end-use feedback study is also evaluated via a survey and interviews.
- How water-use metrics are understood, preferred and motivate savings is explored.
- Heterogeneity in preferences suggests a variety of approaches to feedback is taken.

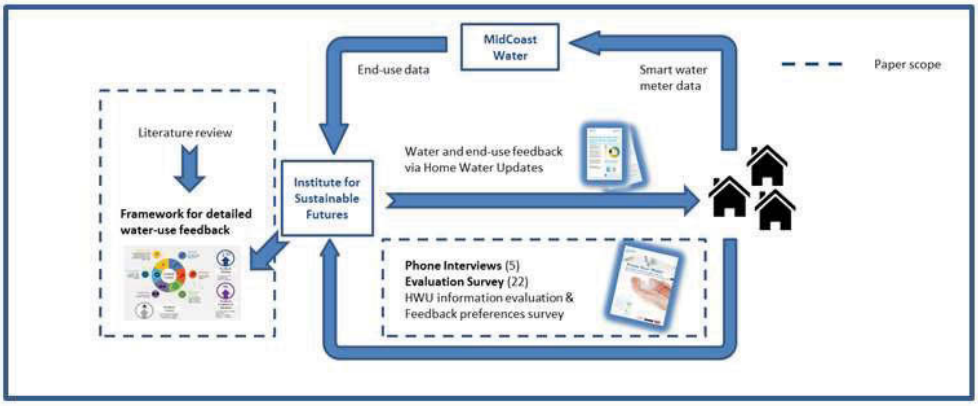


Figure 8 Graphical abstract

Motivating metrics for household water-use feedback

Abstract

Motivating more sustainable water consumption is important since population growth and climate change are placing increased pressures on water supplies in Australia and elsewhere. Smart water metering creates new possibilities for feedback of detailed water-use information to householders as a signal of potential opportunities to save water, and a number of recent feedback studies have shown water saving results. However, existing literature lacks an overview of the available options for the presentation of detailed household water-use information; and research into what households understand, and value and prefer in terms of feedback. This paper introduces a framework for the possibilities for feedback; and further explores dimensions of the framework via a detailed post-intervention evaluation of a recent smart water metering trial involving detailed end-use feedback to a sample of households in New South Wales, Australia. The householder evaluation survey and interviews investigate engagement with customised water-use metrics presented during the trial, and explore wider preferences for water-use feedback. Understanding how householders relate to different types of information has an important role to play in maximising household engagement and the potential for more detailed water-use feedback to guide household water management. Therefore, the framework and evaluative research findings carry implications for future deployments of residential smart water metering involving feedback. Particularly, the high level of interest and engagement of many study householders with the detailed water-use information highlights important potential for feedback, and lends support to the business case for utilities to pursue smart water metering trials and roll-outs. However, with heterogeneity of customer preferences and responses, more carefully considered approaches to water-use feedback are advised (e.g. more judicious feedback design, and potentially the use of tailoring and/or customer segmentation) to facilitate a greater contribution towards more sustainable water consumption.

Keywords

Smart water metering; End-use analysis; Household water conservation; Water-use feedback; Behaviour change; Sustainable water.

3.1. Introduction

3.1.1. Smart water metering opportunity

The recent advent of smart water metering enables the collection of higher resolution water consumption data than under conventional metering. By logging usage at highly frequent intervals (e.g. of seconds or minutes), smart metering creates a far larger database of water consumption according to time of use and allows for analysis of end-use patterns. Deployments of smart water meters are growing rapidly in many developed countries, with over 250,000 units either planned for, or already in operation by Australian water utilities (Beal and Flynn, 2015). The water industry is therefore now beginning to embrace new levels of data and means for its analysis and communication. However, while many water utilities are focusing on the benefits in terms of internal planning or network efficiency (see Boyle et al., 2013), not all implementations have been extended to provide more detailed water-use feedback to householders. An underexplored opportunity therefore remains for collected data to be analysed for translation into significantly more detailed water consumption feedback for household consumers.

3.1.2. Householders: feedback, responses and preferences

Householders may not be entirely aware of their water usage nor of opportunities to save. Therefore, consumption feedback may help to address these knowledge gaps. Recently, Beal et al. (2013) found that householders which received feedback on how their water consumption compared to other homes could more accurately match perceptions of their water consumption to their actual usage. Beyond raising awareness, the provision of information on opportunities to save can further improve householders' knowledge of how to save; and knowledge and water-saving skills have been found as important determinants of water conservation behaviours (Corral-Verdugo, 2002; Corral-Verdugo et al., 2012).

The provision of consumption feedback has been shown to help customers monitor and more effectively manage resource use (see Abrahamse et al., 2005), and positive impacts through feedback have been found via research across a variety of domains, including household energy and recycling behaviours (Schultz et al. 2014). Through raising awareness and changing consumption behaviours, feedback on household water-use also has the potential to contribute to more sustainable consumption patterns and practices, and potentially reduce the demand on constrained water resources.

A number of recent research studies, which particularly involve smart water meters, have shown that various different forms of water-use feedback can effectively reduce household water consumption (Anda et al., 2013; Doolan, 2010; Erickson et al., 2012; Fielding et al., 2013; Joo et al., 2014; Wetherall, 2008; Willis et al., 2010). These studies tested for quantitative changes in water consumption and reported savings ranging from 5 to 10%. The recent "Home Water Update" (HWU) study, to which this present work relates, also signalled initial savings of 8% through feedback of detailed water and end-use metrics in paper-based reports, although with the moderate sample sizes and measurement periods, these savings could not be confirmed as statistically significant (see Liu et al., 2015, manuscript submitted for publication).

Despite the reports of overall quantitative savings and some documentation of specific changes in behaviour, relatively few feedback studies have conducted a detailed post-intervention evaluation to understand how householders engaged with the different forms of water-use information provided. In the few cases where comprehensive post-trial surveys and/or interviews were actually conducted (e.g. Doolan, 2010), householder information preferences were investigated only briefly among a wider set of trial related issues. Erickson et al. (2012) took the novel approach of investigating pilot usage of an online water portal via internet click-counts, which showed where users were spending most time, and thus sheds some light on user interactions with available data and functions. However, both in this and most other studies, it is unclear what additional or alternative types of information householders might have preferred. It is furthermore uncertain in each of the studies which pieces of information specifically motivated changes in behaviour towards water conservation.

Fielding et al. (2013) took another innovative approach by using study sub-groups from the outset to compare impacts of customised end-use data against procedural information and against descriptive norms on ways to save. The distinct feedback groups obtained significant savings relative to the control group, but not relative to one another (Fielding et al., 2013). The study scope did not include an evaluation of how householders within the different groups interacted with the different forms of feedback provided, or their other preferences.

Parallel work from within the field of sensor technologies (Froehlich et al., 2012) represented a first attempt to obtain wider insights into householder information preferences for more detailed water-use information. However, the study's use of prototypes meant participants were unable to engage with any real, customised, water-use data reflecting their own household consumption.

Research is currently underway to explore alternative ways of analysing household water usage data collected via smart water meters. This includes improvements in end-use categorisation via the automation of flow trace analysis using pattern recognition and event probability functions (Nguyen et al., 2013); as well as the detection of water-use signature patterns, which cluster meter reads on the basis of calendar dates, times and volumes to identify target behaviours for reducing consumption (Cardell-Oliver, 2013). Within the energy sector, there have already been further advances in terms of automating smart meter data analysis and producing customised household energy reports for mail distribution (e.g. Laskey and Kavazovic, 2011). This suggests that further developments can well be expected within the water sector to facilitate the creation and provision of more detailed consumption feedback to householders.

Amid these growing prospects for more advanced water-use feedback, our review of existing literature found a clear need for additional work in this emerging field to understand the forms of water-use feedback that householders might prefer and could help motivate savings. This remains essential in shaping the role for feedback via smart metering to promote water conservation. While scarcely researched for the water sector, this need has been more clearly recognised within the residential energy sector, where detailed feedback is also more established.

Energy-related research has specifically cautioned that "care must be taken when choosing the information the consumers are given and with the way in which it is presented…that the information provided to consumers is relevant and enables them to make sustainable decisions about their energy use" and so "the study of what kind of consumption feedback consumers understand and prefer is required" (Karjalainen, 2011). Within the energy sector, insights from behavioural science (e.g. the fields of influence and persuasion) have also been recommended to help "develop the right ways to present the right information for maximum impact" (Laskey and Kavazovic, 2011). Such considerations also need to be applied to the design of water-use feedback, whereby well-designed feedback can help householders to better monitor their consumption and ultimately save water.

3.1.3 Current study

Our review of the existing literature highlighted two important knowledge gaps to be addressed in this paper. First, the existing literature lacks a comprehensive overview of the extensive water-use feedback possibilities specifically made possible via smart metering. Second, more work is required to understand the specific forms of information that householders prefer, and could help motivate behaviour changes toward more sustainable water use in the home.

The research topic is depicted in Figure 9 below, where one circle represents the set of household water-use feedback information that is technically possible; while the other circle represents the set of informational interests and behavioural responses of householders. The area of overlap is designated with the term "motivating metrics" and corresponds with information that is possible, and is additionally of interest and/or motivating to householders.

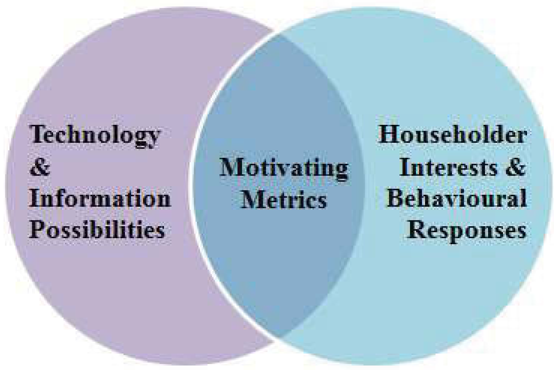


Figure 9 Research focus

The key objectives of this research are to:

(1) Develop a conceptual framework presenting the feedback possibilities enabled via household smart water metering, which therefore clarifies the first circle in Figure 9; and

(2) Present the results of an evaluation and householder preferences survey conducted in conjunction with the "Home Water Update" (HWU) smart metering feedback trial conducted in NSW, Australia (2012-2014) (see Liu et al., forthcoming), which contributes towards understanding the second circle in Figure 9 and attempts to direct discussion in the field towards the area of overlap. Here, the main aims are to:

(a) Explore how householders evaluated and valued the detailed water-use information provided in the HWU feedback trial;

(b) Explore what types of water-use information/metrics householders prefer and find useful/motivating.

The HWU study's distinctive feature was its provision of feedback involving a range of customised metrics of household water and end-use consumption not previously provided in other research. Therefore, an evaluative assessment by these particular study participants allows for a potentially more informed householder evaluation of different forms of water-use feedback. While this research is a small-scale study and cannot provide the definitive answers, the results represent a valid contribution in demonstrating the variety of responses that exist among householders and uncovering some of the key considerations in the design and presentation of more detailed feedback. The mixed method approach further combines quantitative responses from the survey with qualitative insights from the interviews, and thus explores the issues from multiple angles to gain a more accurate picture.

The rest of the paper proceeds as follows. Section 3.2 presents a framework for smart metering water-use feedback possibilities, and is used to highlight knowledge gaps requiring further exploration. Section 3.3 describes the study research methods. Section 3.4 presents the HWU evaluation survey results, further complemented with illustrative quotations from participant interviews. Section 3.5 summarises the key conclusions with a discussion of the study implications for smart water metering deployments, limitations, and directions for future research.

3.2. Conceptual framework

3.2.1. A framework for water-use feedback: content, medium, frequency and duration, and context

In order to understand the opportunities and level of interest among householders for different forms of detailed water-use feedback enabled via smart metering, a guiding framework is required to help conceptualise the problem. In this section a framework for water-use feedback is introduced. The framework emerged through a review of the characteristics of feedback described in related energy and water sector literature (particularly Fischer, 2008; Froehlich, 2009; Karjalainen, 2011), and a consideration of their relevance when specifically applied to the context of smart water metering.

In Fischer's (2008) well-cited review of feedback studies within the residential energy sector, she describes a comprehensive set of features that may determine its effectiveness, namely "frequency, duration, content, breakdown, medium and way of presentation, comparisons, and combination with other instruments." Her work covers many important defining dimensions of feedback and therefore serves as a useful basis for a characterisation of feedback in the context of household water. A reorganisation of these features is, however, applied within our framework, commencing with the characterisation of water consumption feedback in (Boyle et al., 2013) in terms of just three dimensions, namely its *mode (or medium)* of information communication, the *frequency* of information delivery, and its actual *content.* Features in Fischer (2008) are thus integrated within this basic framework, which we expand with a fourth dimension, namely *context*. "Breakdown, way of presentation and comparisons" (from Fischer 2008) are therefore grouped within *content*. Frequency and duration are combined into one category; and "combination with other instruments" is categorised within our broader category of *context*. Additionally, a visual representation is adopted rather than using a descriptive approach alone. Finally, our four dimensions are expanded through more recent contributions from Froehlich (2009) and Karjalainen (2013) as described below.

Froehlich (2009) describes ten "design dimensions of feedback technology" which discuss features identified by Fischer (2008) with some additions. An important distinction between "push" and "pull" delivery strategies is introduced i.e. between approaches in which information is always available (e.g. via a display unit); and those which only inform users when an anomaly is detected (e.g. when usage is excessive), or when explicitly navigated by the user (e.g. online portals). Froehlich (2009) also discusses location, but we consider this as part of the definition of the selected communication medium. "Social sharing" is also discussed, which we consider as part of the context. Finally, "recommending action" is introduced; which we categorise under the broader heading of interpretation, which covers tips, the inclusion of other information and the use of framing.

Karjalainen (2013) describes alternative ways of presenting household energy feedback, and thus focuses specifically on the *content* of feedback, and provides input to the *content* component of our framework. In particular, Karjalainen (2011) defines presentation format as either graphical, numeric or textual; and provides detailed options in terms of the units adopted (e.g. kilo-watt hours, watts, monetary units, environmental impacts or visual indicators). We describe the corresponding options made available via smart water metering and categorise basic options under the *content* heading of "measures" and those which add some form of elucidation under the heading of "interpretation".

The framework shown in Figure 10 provides a comprehensive overview of feedback possibilities that are being made possible through smart water metering, which we propose as a general framework for analysing current feedback programs involving smart water metering and for the design of future interventions.

Figure 10 Framework for water use-feedback via smart water metering and end-use analysis

In summary, feedback is defined in Figure 10 in terms of the *feedback medium*, the *frequency, speed and duration* of feedback; the *content* of feedback, and the *context* in which it is provided. Examples of *feedback mediums* include paper bills, web portals, in-home displays, SMSs or smart phone applications. *Frequency* is typically between quarterly for bills and (near) real-time with digital applications and *duration* might be on-going or just temporary. Regarding *context*, which refers to the setting in which feedback is applied, other instruments (e.g. pricing incentives, rebates) or competition or social sharing might be applied in an attempt to increase the impact of feedback. Finally, we propose the *content* of feedback can itself be characterised in terms of six further properties, namely, its measure, resolution, reporting period, comparison, interpretation and presentation. For example, on a typical water bill, water consumption volume (measure) is shown as a total (resolution) for a quarter (period) against consumption in the previous quarter (comparison) in the form of a chart (presentation). More sophisticated feedback might show the duration (measure) of the average shower (end-use level) for a fortnight (period), in comparison to other households in the same neighbourhood (comparison), with additional information on how to save (interpretation) and presented pictorially (presentation).

3.2.2. Feedback content enabled via smart water metering

The opportunities for more detailed and targeted household water-use feedback under smart water metering far subsume the possibilities under conventional metering particularly in terms of *content,* but also in terms of *frequency* and in exploiting different *mediums*. Given the variety of forms that particularly each feedback *content* element can take, each element is discussed in further detail in the sub-sections that follow.

3.2.2.1. Measures

Under conventional metering in NSW, household water use is typically read at three, four or even six month intervals before conversion into cost data for presentation to households via (paper) water bills. Smart water metering causes data volumes to increase exponentially (Hill, 2011) and greatly multiplies the possible data dimensions by measuring use at far more frequent intervals (typically between 10 s and hourly intervals). By recording time of use, smart meters collect the data required to understand the volumes, rates and duration of flows (Mayer et al., 2000). This provides the foundation for the provision of more detailed water-use feedback. It is, however, unclear which measures or metrics are of greatest interest to householders.

Recent work suggested householders are firstly interested in more detailed measures of water use (Froehlich et al., 2012; Liu et al., 2013). Froehlich et al.'s (2012) survey suggested householders may like multiple data representations (e.g. measures in terms of both cost and volume). Regarding measures of energy use, however, Wood and Newborough (2007) found a preference for kilowatt units over monetary units, which were ineffective due to the low daily cost; and over environmental units (e.g. carbon dioxide emission) to which householders were not accustomed. Since household water bills are typically lower than energy bills, this may be an important consideration for water-use feedback in which monetary savings may appear low relative to the corresponding volumes of water. At the same time, due to the greater visibility of water, householders may have a better understanding of litres than energy units.

3.2.2.2. Resolution

Historically, household water use has been measured at an aggregate level (e.g. total use per quarter) without the possibility of showing where water is used in the home. Smart water meters, by contrast, collect higher resolution data according to the particular technology. Data collected via smart meters at hourly intervals has already been shown able to communicate leaks effectively (Britton et al., 2013). Still finer resolution data (collected every 10-60 s) can disaggregate total flow data into individual end-use events (e.g. shower, toilet, washing machine etc.) via end-use (trace-flow) analysis software. Therefore, smart water metering in conjunction with end-use analysis offers more detailed measurements of consumption, and feedback at end-use/appliance resolutions can help householders to better understand how and where water is used in the home and to identify corresponding opportunities to save.

To date, customised end-use breakdowns (e.g. pie charts) of household water consumption have only previously been presented to householders in Fielding et al. (2013); and while householders in the Froehlich et al. (2012) study indicated interest in disaggregated water-use data, we do not know how much householders value water end-use information, which is currently costly and time-consuming to produce. Furthermore, other types of detailed end-use metrics that are also possible via smart water metering have yet to be presented to householders for evaluation, and there is a need to understand which metrics from the possible spectrum appeal most to householders.

3.2.2.3. Reporting periods

Feedback can be presented using different reference time periods. This may influence its ability to guide household water consumption and is determined and constrained by the frequency of meter reads (e.g. with quarterly reads, updated consumption feedback can only be provided four times per year). Relatedly, the speed with which data can be processed and communicated has implications for timeliness of responses. With the approximation to real-time monitoring, feedback can cover more distinct time periods (e.g. use per minute, hour, day, week etc.). Importantly, the finer the reporting period, the easier it is for users to identify events which contribute to unusually high water use, which may in turn motivate targeted responses. By contrast, reporting by week or month may show general usage patterns (e.g. for washing machine or outdoor use) more clearly (Froehlich et al., 2012).

Recent studies using electronic feedback mediums have explored householder preferences between different reporting periods. For example, Doolan (2010) found that from among the four available in-home display (IHD) screens, interviewees were more interested in the hourly screen and daily totals for the previous 14 days, than in daily totals for either the last 7 or 28 days; and in Erickson et al. (2012) the hourly usage graph was most popular. Due to the present study involving a paper rather than a digital communication mode, reporting periods is not discussed in detail.

3.2.2.4. Water-use comparisons

Historical data allows for self-comparisons and tracking of changes in water use over time. Water utilities have been enhancing water bills by integrating cost and/or volume data from previous billing periods (e.g. for the previous year). However, data collection via smart water metering at highly frequent intervals (e.g. every set number of seconds or minutes) allows for more detailed historical comparisons, far subsuming data available via traditional quarterly meter reads.

Normative comparisons (i.e. with other households) may motivate water savings in presenting a consumption reference value or benchmark. The reference requires a specific population or sample (e.g. geographic location from national, down to neighbourhood or street level). It may refer to a specific number of household occupants (e.g. average), or property size, or involve some measure of efficiency (e.g. an efficient two-person household benchmark).

In a review of international energy feedback studies, Fischer (2008) found interest in historical self-comparisons was usually reported; as was some interest in normative comparisons, which has also further been stated to motivate energy conservation if consumption was shown above average. These conditions are likely to hold for water-use feedback. Results from Froehlich et al.'s (2012) US based study found most householders were interested in historical water use (91%) and in normative or "social" comparisons (68%); with similar demographics and geographic neighbours more popular than comparisons with other cities or countries. However, since preferences have also been found to differ across countries, and possibly also in the types of information that are effective in motivating conservation, it has been cautioned that country-specific research is required (Fischer, 2008; Roberts et al., 2004).

The level of interest among householders for historical and normative comparisons requires specific customer research, as does meeting the challenge of providing comparative information or metrics that will actually motivate savings. Since discussions have been raised around whether signalling to householders that their consumption is relatively low or at the average might act to demotivate saving behaviours (Doolan, 2010); or legitimise existing practices (Strengers, 2011a), more work is required to understand how householders respond to different scenarios of comparative usage.

3.2.2.5. Interpretation

Feedback can be presented in its raw form (i.e. just the facts), or enhanced via additional information or interpretations to help householders understand or analyse the information.

Smart water metering opportunely allows for a progression from generic saving tips to significantly more customised and targeted advice, which relates to household-specific water-usage patterns. The highest water end-uses or periods of usage can be targeted with specific information. However, whether householders are interested in additional information or interpretations (e.g. water-saving tips) beyond the straightforward facts remains to be explored.

Customised tips made possible via smart water metering can involve comparisons by drawing on social norms. A distinction lies between descriptive norms, which represent typical or normal behaviour by describing what important, or relevant, people actually do (e.g. to save water); and injunctive norms, which refer to what important people (e.g. water utilities) think people should do (Cialdini et al., 1990). Regarding impacts, Goldstein et al. (2008) found that encouraging hotel towel re-use was more successful using descriptive norms than a traditional environmental appeal. Fielding et al. (2013) also showed descriptive norms of the form "what people, like you, who are low water users do to save" can be effective. However, it remains unclear whether householders are more interested in water-saving information based on injunctive or descriptive norms.

The framing of information or messages in different ways can determine how effectively savings opportunities are communicated. Indeed it is well established in the behavioural sciences that cognitive judgments are influenced by the way in which decision problems are framed (see Kahneman and Tversky, 1984). Alternative measurement units or analogies can therefore be adopted. For example, instead of referring to volumes in terms of litres, the number of (ten litre) buckets might be displayed (Anda et al., 2013; Strengers, 2011b). The reference period (e.g. per quarter or per annum) may also be attuned to promote savings since temporal framing has been shown elsewhere to affect attitudes and perception of savings (Tangari and Smith, 2012). Householders may interpret the same savings differently according to how they are framed; whereas the use of terms which are more familiar or meaningful to householders may aid interpretation.

3.2.2.6. Presentation

Feedback can be presented textually (e.g. tables), or pictorially (e.g. charts or "infographics") to engage its audience and ease understanding. Infographics are "a visualisation of data or ideas that tries to convey complex information to an audience in a manner that can be quickly consumed and easily understood" (Smiciklas, 2012) and are increasingly being used by businesses to communicate data to customers. The richer data available via smart metering increases the potential for novel representations of water usage data. Professional design services can be engaged to obtain visually appealing communication style (as in the HWU study). However, an exploration of alternative presentation formats is not the focus of the current paper.

3.3. Materials and method

3.3.1. Background to study

The study forms part of an Australian Research Council Linkage Project investigating the role for smart metering in a sustainable urban water future. The study location is Tea Gardens/Hawks Nest in regional New South Wales, Australia. The suburbs are serviced by MidCoast Water (MCW), a council-owned water utility based in Taree and Forster. Smart water meters were previously fitted to 141 properties in 2009, from which households were recruited to participate in the "Home Water Update" (HWU) study (2012-2014). The study investigated the impact of detailed water-use information obtained via smart water metering and end-use analysis on household water consumption.

The HWU study involved 68 households, of which 34 participants were provided with detailed feedback on their water consumption. The approach can also be described in terms of the framework introduced in Figure 10, as follows. The *feedback medium* was a paper based statement (see Figure 11 for an example HWU). The *feedback frequency and duration* involved two instances of feedback, presenting winter 2013 and summer 2013/14 data, respectively. In terms of *feedback content*, the HWUs contained the following customised water-use feedback: (1) an "end-use pie chart" showing disaggregated water consumption (i.e. for shower, toilet, taps, washing machine, outdoors and leaks); (2) a "neighbourhood comparison" showing total water consumption compared to the neighbourhood average; (3) total water use expressed in terms of buckets; (4) a set of ten detailed "end-use metrics" (e.g. average shower duration; number of toilet flushes per day; average litres per washing machine use); and (5) customised water-saving tips. The HWUs thus contained a variety of detailed water-use measures, including at an end-use resolution, with daily averages as the adopted reporting period. A normative comparison was also provided, as were interpretations in terms of customised tips and alternative framings (e.g. using a bucket metaphor).

Finally, regarding *feedback context*, the setting for the HWU study can be described in terms of MCW's pricing and other customer and information related initiatives, as well as the study community's background of water usage. MCW's current pricing structure includes a particularly large fixed cost component, so its volumetric pricing has a relatively small impact on customer bills. In terms of other initiatives, MCW has an ongoing rebate program, which encourages the retrofit of water-efficient devices. Unlike many other communities that have been studied elsewhere in Australia, this service area does not have a significant history of drought or restrictions, rather the interest in conservation related more specifically to the deferral of capital expenditures for supply augmentation. Since the smart water meters were installed some years prior to the HWU study, householders were provided with an information letter during the recruitment stage, which referred to their existing smart meter, and explained this could be used to enable the provision of more detailed water-usage information. Householders were informed the study purpose was to see what value households derive from additional information and whether or not this makes any difference to the way water is used.

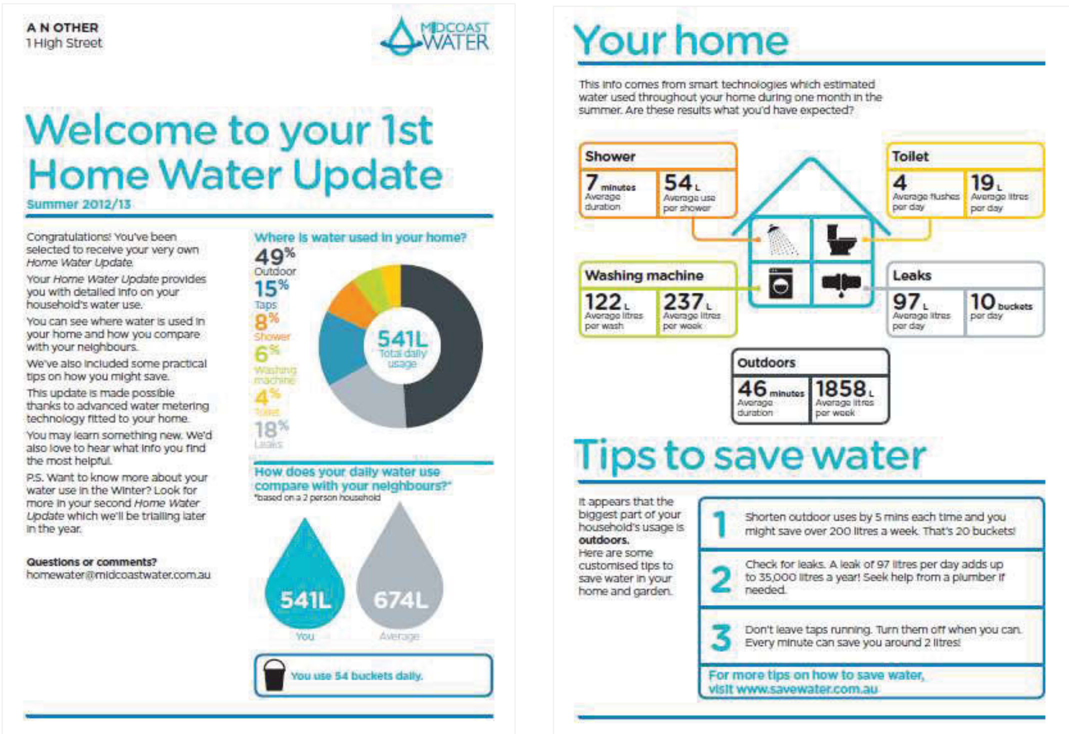


Figure 11 Example Home Water Update – front and reverse sides

3.3.2. Data and analysis

In addition to the collection of consumption data via the smart water meters, a baseline survey was completed by all households at recruitment. A mail evaluation survey, followed by a subset of telephone interviews, was further conducted with volunteer survey respondents post-intervention, and these represent the main data reported in this research.

The HWU evaluation survey began by asking households to evaluate the detailed water-use information included in their HWUs. The survey then went on to investigate wider household information preferences in terms of alternative comparisons with self and others, interpretations, tips, and communication modes, frequencies and speeds. The survey also explored how households might be motivated by various different feedback scenarios (e.g. of comparative use) and alternative framings of savings. Finally, household valuations for the main forms of feedback in the HWUs were sought.

The survey involved a series of closed questions, using either multiple choice or mostly five-point Likert-type scale response formats. Single-item Likert type scales were used where direct questioning was considered appropriate to achieve content validity, that is, where the question was expected to be clearly interpreted by the respondent and multiple items would not therefore be required to build a valid construct (Rossiter, 2008). Open-ended questions were also included to explore the richness and complexity of views held (Denscombe, 2010).

The survey was distributed to all HWU intervention group households with the offer of an AUD 20 incentive to gain an evaluative understanding from as many participants as possible. The survey response rate was 65% (22 out of 34). All survey responses were entered for analysis into an SPSS Statistics version 21 database (IBM, 2012).

The sample sizes were recognised as potentially low from the outset, given recruitment was from a limited pool of households that were already fitted with smart water meters. Therefore, to maximise on variability from among the available recruits, the participant and control groups were formed via a stratified randomisation approach, which ensured at a minimum that households which received feedback essentially represented the fuller range of consumption and occupancy profiles.

Baseline survey data for HWU evaluation survey respondents showed they represented a variety of socio-demographics. Survey respondents' ages ranged from the 35-44 to the 65+ age band, with a negatively skewed distribution, which also broadly reflected the local, more elderly population. Male respondents represented 57% of the sample. Respondents had a range of educational training with 33% having a trade or apprenticeship; 24% a diploma; and 10% a postgraduate degree. Income ranged from less than AUD 30,000 up to the AUD 90,000 – 119,000 band, with a median within the AUD 30,000 – 59,999 band. Further details are provided in the Supplementary Information to Chapter 3 (see Table 7 and Table 8, where the statistical tests show that respondents typically did not differ from non-respondents in terms of socio-demographic, attitudinal and water consumption variables).

Semi-structured telephone interviews were used for a further qualitative investigation of how householders used and interpreted their customised water-use information. Multiple attempts were made in the course of a fortnight to contact all participant households who had previously indicated a willingness to be interviewed in the evaluation survey (*N*=7). Informed consent was obtained from each prospective interviewee, as was permission to record each call for data recording accuracy. The interviews (*N*=5) were transcribed within a week of the interviews and examined recursively while noting patterns and themes. Where available, data from the interviews is either presented for all interviewees, or those showing the range of opinions, in order to provide reliable representations. Interviewees were also compared with evaluation survey respondents who were not interviewed for a further check for selection bias among interviewees and of the potential representativeness of their views. These results are provided in the Supplementary Information to chapter 3 (see Table 9 and Table 10).

3.3.3. Study expectations

An interesting trend among energy and water feedback studies is to emphasise overall and average quantitative savings measured across all households. The variation inherent in responses, and moreover, the fact that not all households in any given sample responded by reducing consumption, is usually ignored. This is, however, an important issue since it highlights the fact that feedback is not equally effective between different households (and may be simply ineffective among some). We therefore expected that householders in the current study would also show a variety of information preferences, response patterns and valuations of detailed water-use feedback.

3.4. Results

This section reports on the findings from the HWU evaluation survey and telephone interviews. All reported percentages are from the evaluation survey. The survey questions and results discussed here can also be found in Table 5. Additional insights from interviews and quotations that illustrate participant views are provided where relevant.

Table 5 Survey data on household water-use feedback preferences and responses

Section	Question	Response	Frequency	Percentage
3.4.3.1.	Which of the following is useful to know for your household?	Shower water use (litres per shower)	19	90%
		Average shower duration (minutes)	16	73%
		Toilet water use (litres per day)	16	76%
		Toilet use (flushes per day)	16	73%
		Taps water use (litres per day)	18	82%
		Taps flow rate (litres per minute)	12	57%
		Washing machine water use (litres per week)	16	76%
		Washing machine use (litres per wash)	18	82%
		Outdoor water use (litres per week)	16	73%
		Outdoor water use (minutes)	12	60%
		Leaks (buckets per day)	12	57%
		Leaks (litres per day)	17	81%
3.4.3.2.	How much information on your past water use would be most useful to you?	12 months	11	50%
		6 months	7	32%
		Not sure	3	14%
		None	1	5%
	Is it useful to be able to compare your water use in the current billing period with the same billing period last year?	No	1	5%
		Yes	21	95%
3.4.3.3.	Which comparison with other households would be useful for your household?	Both efficient and average households	11	50%
		Average household	7	32%
		Efficient household	2	9%
		Neither	1	5%
		Not sure	1	5%
	What location would you most prefer to see your household compared against?	My street	8	36%
		My suburb	8	36%
		Mid-North Coast	3	14%
		NSW	1	5%
		None	1	5%
		Not sure	1	5%
		Australia	0	0%
3.4.3.4.	What level of information would you most prefer?	Detailed water-use information with personalised tips	17	81%
		Detailed water-use information without tips	2	10%
		No detailed water-use information just personalised tips	2	10%
	Which information would interest you more?	What water utilities recommend householders to do to save	12	63%
		What other households are actually doing to save water in the home	7	37%
3.4.3.5.	Which of the following options do you prefer most?	Two HWUs per year	6	30%
		More detailed quarterly bill	6	30%
		Annual report	4	20%
		Real-time information	4	20%
	Which of the following options do you prefer second?	More detailed quarterly bill	9	50%
		Two HWUs per year	4	22%
		Annual report	3	17%
		Real-time information	2	11%
	It takes time to collect and analyse the water-use data collected by your smart water meter. This means there is a time lag between when you actually use water in the home and when detailed information might be available. What do you think is an acceptable time lag?	1 month	7	32%
		6 months	6	27%
		2 months	4	18%
		3 months	4	18%
		12 months	1	5%

3.4.4.1.	If you found out that your household's water use was higher than in your last bill and also higher than in the same billing period last year, how would you respond?	I would try to save more next period	16	76%
		I wouldn't think much of it	0	0%
		I would think about what reasons might lie behind this	17	81%
		I would think about whether the difference was justifiable e.g. due to different needs	13	62%
		I would plan how to save more water	10	48%
		I would talk to other household members about this	10	48%
3.4.4.2.	If you found out that your household uses more water than the average two-person household, what would you think?	My household should save more water	12	55%
		It would depend on how much more than the average my household was using	6	27%
		I wouldn't think much of it	0	0%
		I would think about what reasons might lie behind this	10	45%
		I would think about whether the difference was justifiable e.g. due to different needs	9	41%
3.4.4.3.	How motivated would you feel to try to save more water if you lived in the following homes: (Note: data refer to those who selected either "strongly motivated" or "motivated")	A (lowest users)	6	30%
		B (low users)	7	37%
		C (average users)	13	65%
		D (high users)	14	74%
		E (highest users)	16	80%
3.4.4.4.	Which kind of savings would you find most motivating?	Save $100 a year	8	38%
		Save $25 a quarter	5	24%
		Save 40,000 litres of water a year	5	24%
		Save 10,000 litres of water a quarter	3	14%
	Which kind of savings would you find most motivating?	Save 10,000 litres a year	18	82%
		Save 1,000 buckets of water a year	4	18%

3.4.1. Engagement / HWU information evaluation

The level of engagement of householders and the ultimate achievement of water savings through the provision of consumption feedback are likely to depend on the design and types of *feedback content* provided. Marketing and information communication sciences also explore the importance of the appeal of communication style, and while there are no hard-and-fast rules in information design, general guiding principles can still be applied based on accumulated experience (e.g. Samara, 2007; Tufte, 1990). Some specific criteria, which can guide an evaluation of water-use feedback information, can also be derived from literature on household feedback and behaviour change.

In terms of information evaluation criteria, it is likely that the feedback information provided will need to be new and/or interesting in order to elicit adequate attention or engagement. Generally, feedback information will further need to be communicated in a format that it is easily understood (Karjalainen, 2011). In practical terms, feedback should help householders to identify water-saving opportunities, such as by enabling them to see the information provided in the context of their own household and in terms of their own daily lives (Giurco et al., 2010). Beyond recognising opportunities, feedback information should motivate, or in the language of (Ajzen, 1991), help householders form “behavioural intentions” towards greater conservation.

Finally, as a measure of effective feedback, water-saving behaviour changes need to actually be enacted as a result of the information provision.

Six information evaluation criteria were selected for evaluation of the HWU feedback, namely, (i) newness of information, levels of (ii) interest and (iii) understanding, and the degree to which the information let them (iv) see new opportunities to save, (v) motivated them to save, and (vi) actually helped the households achieve water-savings. Householder engagement particularly with (a) the end-use pie chart; (b) the neighbourhood comparison; and (c) the end-use metrics, were thus evaluated via the evaluation survey. Readers should note that other criteria could equally well have been measured; but the final set of survey questions was selected by the authors through careful discussions held with a focus on keeping the overall survey to a manageable length while covering a broad range of important responses to the feedback. Based on the literature, it was expected that scores would be generally higher for the scales measuring newness of information, and levels of interest and understanding; then progressively lower for the scales representing seeing new opportunities to save, being motivated, and actually saving.

The survey results (Figure 12) showed all three information types were considered new by about two thirds of the households. The detailed information types were found easy to understand by approximately 90%. Between 80-90% found the information interesting and further found that the information let them see more opportunities to save water in the home. The majority (two thirds) of households were motivated by the detailed information and more than half reported it had helped them to save water in the home.

The survey trends were highly consistent across the three detailed information types, with differences in responses of only about 10% for each of the information evaluation criteria. This suggested that households typically evaluated each information type equally. Overall, the evaluations by householders suggest the HWUs did include motivating information and metrics for a significant proportion of households, with around 70% reporting being motivated, and more than half of respondents actually reporting a positive impact on household water savings as a result of the HWUs.

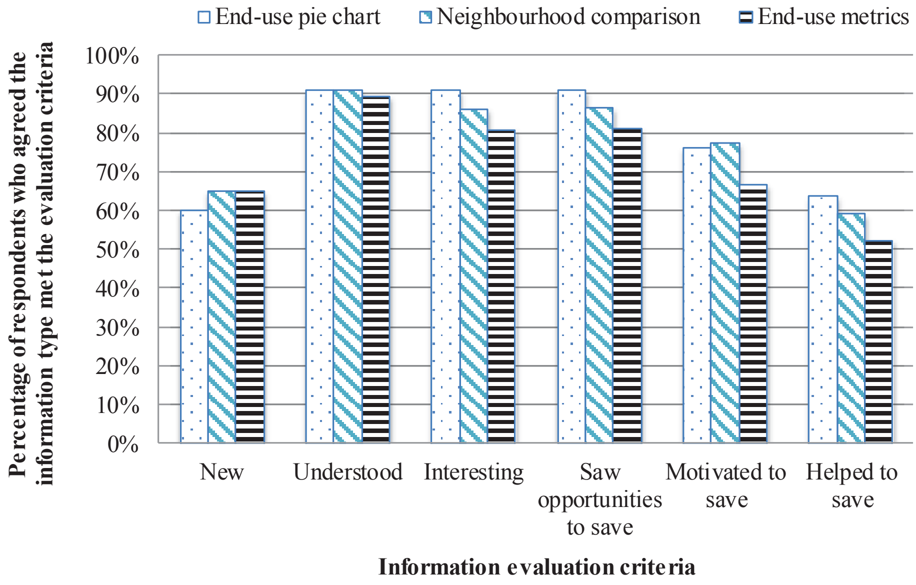


Figure 12 Householder evaluations of HWU information content (*N*=22).

Notes: For each of the three types of customised information, householders were asked to evaluate, on a five point Likert-type scale (ranging from strongly agree to strongly disagree), the extent to which they agreed with each statement (e.g. "the information was new"). To simplify the presentation and discussion of our findings, the results shown here represent the combined percentages of respondents who "agreed" or "strongly agreed" that the information type met the evaluation criteria.

Scale scores were progressively lower for those representing seeing new opportunities to save, being motivated, and actually saving. Therefore, despite most households seeing opportunities, or being motivated to save, not all reported actually taking action. This highlights an important motivation-action or attitude-behaviour gap, which has repeatedly been raised in related literature (De Oliver, 1999; Hurlimann et al., 2009; Kollmuss and Agyeman, 2002; Randolph and Troy, 2008). Even very concrete awareness of water-saving opportunities might not translate into action due to the relevance of other factors. For example, Beal and Flynn (2014) recently described utilities reported customers excusing inaction to leak alerts because repair costs would exceed paying for the leak in their water bills. Therefore, understanding non-response to information and visible opportunities is also of significance to the discussion of feedback.

From the HWU survey, explanations for no positive action by study householders also included "cost/economic factors", as well as "habits", "inconveniences" or "personal factors." Some interviewees pointed specifically to the influence of other household members e.g. "The kids, trying to train them, that's not always easy" (Interviewee 5) and "My wife! Other people!

That's the greatest barrier" (Interviewee 4). Additionally, the challenges of finding time and putting plans into action were also raised.

The high level of interest in the end-use data in the HWUs reported in the survey was confirmed by interviewees, with comments including: "I thought it was a really good idea … because [through the end-use metrics] you can tell where you're using more water and do something about it. I think it's of value to everybody actually" (Interviewee 2); "Definitely getting the breakdown on the Home Water Updates, that's a useful thing, as it shows us where in the household we could actually possibly save water … the pie chart with the percentages beside it; though actual usage on the back [i.e. the end-use metrics] was also useful. All the information on the Home Water Updates was actually very useful" (Interviewee 1). It's good to see where the water is going to. And probably it would be good to have that [pie] chart on our bill, if we could have it all the time" (Interviewee 5). Others commented that: "Anything that improves the management and people's knowledge can only be a benefit and the more information, and as long as it's information people can understand, the more information the better" (Interviewee 3) and "I do find it useful ... I suppose in all reality, that with that breakdown information, together with that information in the bill, there's not much additional information that you could provide me with to optimise water use" (Interviewee 4).

3.4.2. Valuation of detailed water-use feedback: willingness to pay

Customers may appear overly interested in products if no price is attached. Therefore, to gain an indicative valuation of the HWUs, householders were surveyed on their willingness to pay to receive the different pieces of information included in the HWUs. While straightforward, open-ended stated preference questions may be simplistic; they can nevertheless be indicative of the underlying level of interest and further allow for comparisons of alternatives (Whynes et al., 2005). With this in mind, the value of customised feedback against generic information was also estimated by asking households to state their willingness to pay for a "generic HWU" (containing no information about their particular household's water use, only averages across all households).

Within household energy research, a few studies have investigated estimates of willingness to pay for detailed energy feedback in a similar manner. Goldman et al. (1996) obtained average estimates per month of USD 0.16 for historical information, USD 0.34 for a neighbourhood comparison and again USD 0.16 for an energy appliance level breakdown. Egan (1999) found an average willingness to pay of USD 0.78 per month for a neighbourhood comparative distribution graph. More recently, for an energy smart meter, a study in Norway showed 33%

of households willing to pay 18 EUR per year for a ten-year period, with the remaining 66% not willing to pay any amount (Livgard, 2010). These estimates are all quite low and therefore interesting to compare with estimates for water-use feedback, and in an Australian context.

HWU survey results showed one third of households expressed a positive willingness to pay for the provision of the information included in the HWUs, which is similar to the share found by Livgard (2010). Estimates on the value of a HWU ranged from AUD 0.50 to AUD 10.00, with an average of AUD 2.50 across all the survey question respondents. Households explained estimates by expressing value in being able to monitor water use and identify opportunities to save. The average willingness to pay for (a) the neighbourhood comparison information was AUD 1.97; (b) the end-use breakdown was AUD 2.81; and (c) end-use metrics was AUD 2.64. Customised information was valued more highly than generic detailed information. Fewer households (25%) were willing to pay for generic information, with an average estimate of AUD 0.64 across all respondents. Notably, many households stated they would not be willing to pay for the HWUs, but expressed strong interest in the detailed water-use feedback provided. Spearman's rank-order correlations were run to test for associations between willingness to pay estimates (Table 6). The results showed a significant correlation between estimates for the different information types suggesting householders who valued one detailed type of information highly, also tended to value other detailed information types highly; or conversely, that households that were not willing to pay for one information type, were also generally unwilling to pay for the other information types.

Table 6 Spearman's rank-order correlations.

	WTP_EUPIE	WTP_NEIGHB	WTP_EUMETRICS	WTP_HWU	WTP_GEN_HWU
WTP_EUPIE	1.000				
WTP_NEIGHB	.846**	1.000			
WTP_EUMETRICS	.997**	.842**	1.000		
WTP_HWU	.902**	.897**	.897**	1.000	
WTP_GEN_HWU	.745**	.720**	.712**	.671**	1.000

Table notes: WTP_EUPIE: willingness to pay for the end-use pie chart; WTP_NEIGHB: willingness to pay for the neighbourhood comparison; WTP_EUMETRICS: willingness to pay for the end-use metrics: WTP_HWU: willingness to pay for a complete HWU for the then subsequent summer (2013/14); WTP_GEN_HWU: willingness to pay for a generic HWU containing information about the average household only.

$^{**}p<0.001$

3.4.3. Information preferences

3.4.3.1. Disaggregated (end-use) measures

Householders were asked to rate a range of possible end-use metrics as either "useful" or "not useful," or select "I don't understand this," if appropriate (Figure 13). While more water-use metrics are possible via smart water metering, a broad selection was presented to rather gain overall insights, without requiring too much from the respondents within the same question set and compromising data quality (Herzog and Bachman, 1981).

Overall results showed stronger interest in measures of volumes of water consumed per event (for shower, washing machine use), per day (toilet, taps, leaks) or per week (outdoors) than for either frequencies or duration of use. The least interest was recorded for tap flow rates, outdoor use in minutes and leaks in buckets. The flow rate metric is potentially the least intuitive for householders. Outdoor use in minutes may be uninformative. Leaks in buckets appeared less useful than in simple litre terms (see also section 3.4.4 on framing).

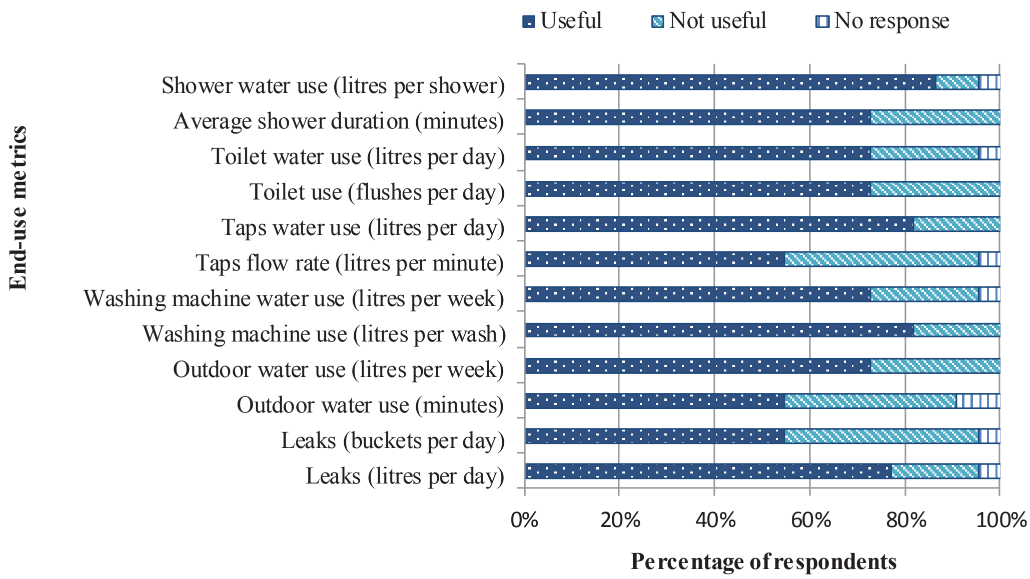


Figure 13 Householder evaluation of end-use metrics (*N*=22)

3.4.3.2. Historical self-comparisons

Householders were asked how much information on their past use would be most useful. Half the respondents preferred twelve months of historical water-use data. One third preferred just six months of previous data. A minority wished to receive no historical data, with the remainder unsure. Almost all respondents (95%) agreed it is additionally useful to be able to compare their water usage in the current billing period with the same billing period last year. The general interest among households in historical self-comparisons reflects results noted in Fischer (2008) and Froehlich et al. (2012).

3.4.3.3. Comparisons with other households

Households were asked to state their preferred comparison with others by selecting between an average and/or efficient household benchmark, or neither. Half the respondents said it would be useful to compare their household with both an efficient and an average household. One third was more interested in comparing themselves with an average household. A minority preferred only an efficient household benchmark, neither benchmark, or was unsure. The results show a preference for multiple benchmarks, with relatively more interest in the more descriptive norm (average household) than the injunctive norm (efficient household).

In terms of a geographical location for the basis of comparison, the equally highest preference was for a comparison within one's own street and for homes in the same suburb (36% each). Homes within the same region (here, Mid-North Coast) were of interest to 15% of respondents. However, comparatively few were interested in a state level comparison and none were interested in a country level comparison, which also fits with Froehlich et al. (2012). Households were not asked to explain their choices in the survey. However, in explanations given by interviewees, the relevance of a preferred comparison with "people in our street" was elaborated as involving "people in homes like ours, with similar sized blocks of lands" (Interviewee 1). Households may also perceive local areas as more relevant due to other similar external conditions (e.g. climatic, social and institutional), which could make local comparisons more meaningful. Another interviewee summarised her preference: "our area would be good, you know, we're not in the city, it's probably a similar sort of lifestyle, because we're regional, so it's lifestyle I guess" (Interviewee 5).

3.4.3.4. Information interpretations and ways to save

In response to the question of what level of information householders would most prefer, 80% selected the provision of detailed water-use information *with* personalised water-saving tips. A small minority preferred to only receive the detailed water-use information (i.e. without additional interpretation on ways to save), or the converse (i.e. only personalised tips without the details about water use) (10% each).

Households were then asked which water-saving recommendations they preferred by choosing between what water utilities recommend, and what other households are actually doing to save water. Almost two thirds preferred to know what water utilities recommend. One interviewee explained (also considering supply availability): “Personally, I think I’d go with the recommendations from the utility…because I can adjust my behaviour with reference to what is necessary for the sustainability of the resource, rather than what other people are doing” (Interviewee 4). Among the other third who were more interested in what other households are actually doing to save, it was commented: “basically what they [other households] are doing is the real deal, they are actually doing it, whereas the other people [utilities] are only suggesting it, I mean they probably are suggesting the right things, but when you can see it in black and white it’s different. It’s like someone might say “you know you can lose 10 kilos doing that,” but when you see someone has lost 10 kilos doing that, well there you go!” (Interviewee 5).

The greater interest found here in the injunctive norm (i.e. what utilities recommend) is perhaps surprising. Overall tendencies may relate to the issues of trust and information source credibility and the relative influence of peers in different cultures, communities and service supply areas.

3.4.3.5. Information communication mediums, frequency and speed

Householders were asked to rank their preferred communication medium for water-use feedback. Among first choice responses, there was broadly equal interest in each of the options which covered annual, half-yearly, quarterly and real-time data (20-30% each). However, among second choices, a more detailed-quarterly water bill emerged as the most preferred option. The results here show that householders are heterogeneous in their preferences for feedback mediums, and that potentially, a range of communication mediums would be the ideal offering by water utilities in order to reach a wider audience. However, if only one medium is feasible, an enhanced quarterly bill seems appealing to the majority of respondents in this study (see also (Liu et al., 2013). This is an interesting result in our “digital world,” showing that although the possibilities exist for advanced communication tools, it is not necessarily something everyone prefers (including potentially regardless of age).

To investigate expectations for feedback speed, the survey explained it takes time to collect and analyse data from the householders’ smart water meters, which meant there is a time lag between when water is used and when detailed information might be available for feedback. Households were then requested to state an acceptable time lag (in months). The range of answers was disparate, demonstrating the differences in customer expectations. One third felt a one-month time lag was acceptable. About one third suggested either two or three months.

One quarter thought six months acceptable, and even a twelve-month lag was put forward. Although Fielding et al. (2013) showed delayed feedback can be effective; Geller (2002) proposed feedback should be given as close as possible to behaviour. Since technologies (e.g. for end-use analysis) will most likely advance to expedite the feedback processes, it would be interesting to explore the relationship between the immediacy and effectiveness of detailed feedback, and the respective roles for paper versus digital forms of water-use feedback.

3.4.4. Responses to feedback

3.4.4.1. Responses to historical water-use comparisons

Householders were asked how they would respond to water-use information showing their household used more than in their last bill and more than in the same billing period last year. Overall, the responses suggested a high level of responsiveness to historical information. Interestingly, no household selected they "would not think much of it." The vast majority (80%) said they would think about possible reasons for the increase in water use and 60% said they would think about whether the increase was justifiable. Interestingly, three quarters felt they would want to try to save more next period as a result of feedback showing increased water use. Half said they would furthermore proactively "plan how to save more water" and a similar share would be inclined to talk with other household members about the increase in water use.

During interviews, relevant considerations were also described in detail when householders discussed their water bills: "I particularly like looking at usage compared to last year I think about if we were away and that's the reason, and congratulate myself if lower than last year" (Interviewee 2).

3.4.4.2. Responses to normative water-use comparisons: with an average household

Householders were asked how they would respond if feedback showed their household used more water than the average. Here a two-person household average was suggested since the vast majority of households in the sample had two occupants. Overall, responses suggested some responsiveness to normative comparisons. Again no respondent selected they would "not think much of it." Interestingly, more than half thought their household should save more water if using above the average. Over 40% would think about justifications and/or the possible reasons. A quarter believed the magnitude of the difference from the average might be important. Householders were finally invited to provide any other thoughts. Some respondents indicated relevant factors that influence their relative water use, with one referring to the “amount of veggie garden,” and another stating “we have children so there would be a difference.”

Overall, the results suggest households might be more responsive to information on changes in their own water use, than they are to comparisons with others. Significantly more households said they would think about the possible reasons for an increase in their own consumption than when finding their consumption higher than the average household. Similarly, more households would consider justifications for an increase in their own use than for a difference with the average household.

During interviews all householders confirmed in one way or another the relevance of a variety of important factors that have also been found as significant factors explaining relative water use in the literature on determinants of water (Grafton et al., 2011; Rathnayaka et al., 2014; Russell and Fielding, 2010). Differences in household sizes, and compositions in terms of age (e.g. children versus adults), garden types, sizes and levels of care; and ownership/use of spear points, rainwater tanks, and efficient devices were all mentioned. One reaction to comparative feedback was summarised: “We were surprised to be more than average. We did discuss how that was arrived at and who we were being compared with. I know some of our neighbours have spear points, although we do enjoy our garden and try not to water unnecessarily” (Interviewee 1). The variety of determinants demonstrate the challenge of comparing “like with like” when using normative comparisons. It may be easier for householders to consider changes in water use within their own homes over time than with others, although seasonal factors and changes in occupancy and usage patterns would have to be considered.

3.4.4.3. Responses to normative water-use comparisons: on a distribution

Householders were further shown a conceptual image of their household’s relative water use, using a spectrum of five households labelled from “lowest user” (House A) to “highest” user (House E), and were asked how motivated they would feel to save water, given the different possible scenarios. The graphic is a simplified version of work from the Energy Star Billing program (see Egan et al., 1996; Lord et al., 1995), which investigated alternative presentations of household energy feedback on informative bills.

About one third of households responded that they would be either “strongly motivated” or “motivated” to save if among the lowest (A) or low (B) users. However, two-thirds said they would be motivated to save water if theirs was an average household (C). Householder motivation to save increased if households were high (D) users, and more so if a highest (E) user. Indeed, most households responded they would be strongly motivated to save if among the highest users (E). Throughout the scale (A-E), some households remained neutral/not motivated to save, showing that not all householders are necessarily responsive to relative measures of water use. While the questions underlying these results are hypothetical in nature, the responses give an idea of how householders think about different scenarios of relative usage. The results lend some support to findings in energy related research by Laskey and Kavazovic (2011) that “most people were strongly compelled to keep up with the Jonses even if they do not realise or acknowledge it”.

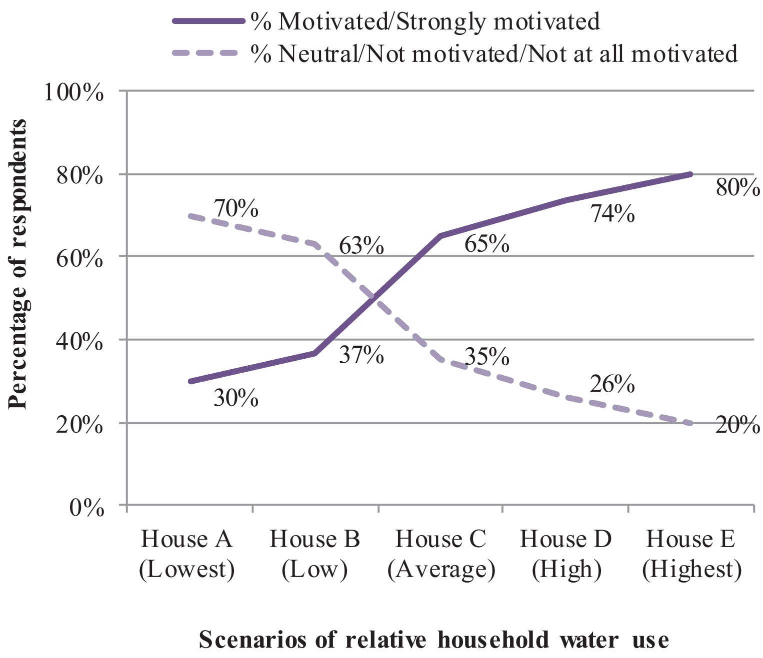


Figure 14 Motivation / Demotivation to save through normative comparisons (N=20)

Contrary to previous suggestions about comparisons potentially demotivating saving behaviours (Doolan, 2010; Strengers, 2011a), the results here may suggest the motivational benefits of communicating relatively high usage to higher users might outweigh any potential demotivation for lower/average consuming householders. This can be seen by comparing aggregated categories of strongly motivated/motivated versus neutral/not motivated/not at all motivated Figure 14.

On a related note, one interviewee volunteered “the average itself is interesting as a ball park figure, but I would still like to know if the distribution is symmetrical…I mean the distribution around the average; are there a lot of people at the low end or top end?…and where we fall within that band. I'd like the average together with some indication [of] the distribution of households and where we fall, whether we're in the top 10% of users, or in the lower 10%...a percentage band where we fall" (Interviewee 4). This suggests there also exists support for still more detailed comparative feedback.

3.4.4.4. Responses to alternative framings of savings

To explore the impact of information framing of potential water savings, householders were asked to select the most motivating option among alternatives. These allowed a comparison of savings in terms of dollars and litres; and simultaneously, a comparison of time frames (i.e. quarterly versus yearly savings). Financial savings (in dollars) were found to be more motivating than the equivalent in litres by about two thirds of respondents. Additionally, annualised savings were more found motivating than quarterly. Interestingly, some householders noticed the equivalence between the options, which they raised with annotations in their surveys. The result here might seem contrary to Wood and Newborough (2007), which suggested (low) monetary savings might be ineffective. However, in retrospect, the values chosen in our question might have been unrealistically high (i.e. requiring savings of about 100 litres per day). Smaller volumes would yield lower financial savings, which might alter the relative motivational power of a framing in dollars over volumes.

A second question on framing was used to address alternative measures of volumes. Householders were asked which was the more motivating: savings in terms of litres, or the equivalent savings in terms of buckets of water. Here, 80% found litres saved more motivating than the number of buckets saved. However, it is interesting to observe the use of buckets did appeal to the remaining 20%. So while most householders related better to standard metric terms, alternative measures still appealed to some. By contrast with alternative metrics of energy usage, householders may have a better sense of water use in litres or indeed buckets, than of energy presented in kilowatt hours.

Interview data showed perceptions of measures of water in terms of buckets varied from personally irrelevant e.g. "That doesn't impact on me, because I can easily identify what a litre is, or megaliter is" (Interviewee 4), or less preferable e.g. "I guess I prefer litres, because buckets can be any size and a litre is a litre" (Interviewee 2), through to more appreciative remarks like "That's pretty good, you can visualise what a bucket looks like" (Interviewee 5) and "That's interesting. It says we use 85. It seems like an awful lot. When we had the rainwater tank, particularly in dry times, we used to carry buckets from the tank, so you get to know how much that is. I think it's a useful tool" (Interviewee 1). This again shows heterogeneity of preferences and suggests the potential for varying responses and impacts from different ways in which information is presented.

3.4.5. Respondent segments

To determine any relationship between householder preferences and the different feedback options, cross-tabulations were run using Fisher exact tests of significance. Responses to the questions on detailed end-use metrics (section 3.4.3.1) were first combined to form three categories, namely, "high", "medium" or "low" according to the number of metrics they were interested in (i.e. 8-12, 5-8, or 0-4 metrics, respectively). This measure of interest in end-use metrics was then compared against other preferences (sections 3.4.3.2-3.4.3.5) (i.e. for historical and comparative measures and benchmarks, tips and/or detailed information, utility recommendations versus information about what others are doing to save, and acceptable time lags and preferred mediums for feedback).

The results showed that households that were interested in more end-use metrics also preferred longer histories (12 months) (Fisher's exact test, $p<0.05$), and more comparative benchmarks (i.e. both average and efficient references) (Fisher's exact test, $p<0.05$). High interest households also tended to prefer the provision of both customised tips and detailed information rather than one or the other; shorter time lags; and mediums offering more frequent feedback, albeit not significantly (Fisher's exact tests, $p>0.05$). These results show that there may be customer segments that are interested in significantly more detailed information on their household water-use, with other segments interested in fewer specific enhancements to the information currently provided on water bills.

3.5. Discussion and conclusions

3.5.1. Brief summary and discussion of results

This paper presented an overview of the extended possibilities for detailed household water-use feedback enabled via smart water metering. The need to understand householder preferences and responses to determine motivating water-use feedback was highlighted. The framework in Figure 10 thus illustrated important feedback design considerations and areas of research that might guide future implementations of smart water metering and water-use feedback programs. Dimensions of the framework were explored via a post-intervention evaluation survey and interviews which related to the HWU study. Due to the use of a paper-based intervention medium (HWU), the focus was on measures, resolution, comparisons and interpretations (and less on presentation and reporting periods).

The current research aimed to explore engagement with the detailed information included in the HWUs; household valuations of detailed water-use information; and preferences for detailed water-use feedback. The HWU evaluation survey showed overall interest in detailed water and end-use feedback. The feedback was generally evaluated as new, interesting and understandable. Householder interest was further reinforced by positive estimates of willingness to pay for customised information, which also exceeded estimates for generic information. These positive results lend water utilities some support towards the pursuit of more extended smart water metering involving detailed household water-use feedback, although more work is required to understand its contribution towards a business case.

In terms of specific measures, the study sample rated end-use metrics as useful, with general preferences towards volumes rather than durations or rates of water uses. Regarding comparisons, there was greater interest and responsiveness to historical self-comparisons than normative ones. For normative comparisons, local references (i.e. own street or suburb) were preferred, together with a variety of benchmarks (efficient and average). Most householders preferred additional interpretations of feedback to include customised water-saving tips. Recommendations from water utilities were more highly valued than advice about what other households are doing to save. Preferences varied highly between different communications mediums, though an enhanced water bill was popular among the majority. Expectations in terms of speed of information communications also varied considerably.

Beyond the detection of overall trends in feedback preferences, the survey results showed additionally that the study sample had more similar views on some dimensions of water-use feedback (e.g. interest in historical comparison with the same last year; and both detailed usage information and customised tips); but wider heterogeneity in most responses (e.g. preferred length of historical comparison; preferred normative comparisons e.g. interest in efficient benchmarks; additional interest in specific end-use metrics; most preferred medium; expectations for feedback speed; use of metaphors etc.). These results show from a small sample that householders are not only heterogeneous in terms of their water consumption patterns (Aitken et al., 1994; Cardell-Oliver, 2013), but also very much heterogeneous in their preferences for water-use information.

Within related energy literature, large variation in energy consumption between individual households has itself been considered to reinforce a need for household-specific feedback (customised according to household characteristics, preferences and needs), rather than generic information or tips based on all households (Vassileva et al., 2012). It has also been argued that a “one size fits all approach” is unsuitable to information policies if the value of residential energy information and management systems is to be maximised (Carlson et al., 2013). With the new possibilities for feedback enabled via smart water metering, it therefore seems that a variety of approaches may also be required to help realise potential benefits more fully.

Market segmentation might play a role by identifying customer groups (see e.g. Jenkins and Storey, 2012), or behaviour patterns (Cardell-Oliver, 2013), in order to tailor the design of feedback programs according to specific segment typologies. Feedback could target households with high potential for water savings, high end uses, or inefficient behaviours or appliance stock. Here the resolution of metering and involvement of end-use analysis will determine the scope for such targeting. Additional information may also be required (e.g. on the number of occupants). Different communication mediums also imply different opportunities for customisation, segmentation and user-input. For example, digital mediums, such as web portals e.g. Erickson et al. (2012) allow users to “drill down” further into content and can include self-customisation of dashboards; whereas paper-based modes would be likely to require more segmentation by the provider.

Since household water use has been found to vary according to socio-demographical, psychosocial, behavioural and water-efficient infrastructures (Aisa and Larramona, 2012; Carragher et al., 2012; Fielding et al., 2012), these factors are also likely to influence the effectiveness of detailed water-use feedback, with additional implications for any forms of targeting or segmentation. While introduced to the discussion, customer segmentation could not be explored in detail in the current study due to its limited sample size. However, statistical correlations of householder preferences between different information possibilities showed there do appear to be customer segments that would prefer a much fuller range of detailed metrics, and others which would favour fewer, specific, pieces of information from smart water metering. This suggests different levels of information will be suited to different groups, however, clearly more work is required here.

In terms of impacts, the evaluation of the HWU study showed that the recognition of opportunities to save and a motivation to save do not necessarily translate into saving behaviours. Understanding this motivation-action, or attitude-behaviour gap, which has been raised repeatedly in the literature (e.g. De Oliver, 1999), is important in furthering the success of consumption feedback programs. More work is required to understand the barriers to the effectiveness of information (and therefore how feedback can be further enhanced or tailored) and its relation with other policies (e.g. rebates, pricing structures, restrictions etc.) to support household water conservation. Our study showed important barriers to the effectiveness of limited information alone. As anticipated, not all households were motivated by or responsive to the feedback provided. Similarly, not all took action as a result of the HWUs. Consequently, a key challenge for policy makers and water authorities may be to engage the less interested or motivated, especially if particularly high water consumers. Again, more considered design and additional research is recommended towards “smarter” feedback provision.

Finally, the business case for smart water metering and more detailed feedback also merits further discussion. While this study showed significant interest in more detailed feedback, high resolution smart water metering, particularly involving end-use analysis, is currently costly. This has also raised doubts as to prospects for its scalability to larger populations and over longer time scales (Cardell-Oliver, 2013). However, work such as by Nguyen et al. (2013), shows developments are currently taking place to automate disaggregation. Therefore, costs can well be expected to come down, so scalable implementations should not be excluded from being a practical and future possibility. In the meantime, the provision of end-use feedback does not have to be nation or city-wide, but could alternatively target particular segments (e.g. high users). Another possibility is for on-demand or subscription based customer water-usage reporting services (targeting interested users). The finding of positive estimates of willingness to pay for the HWUs shows this could appeal to some customer groups; as do findings elsewhere on willingness to pay for energy smart meters and in buying additional information services (Livgard, 2010). However, the wider implications of such approaches would also need careful consideration.

3.5.2. Limitations and future work

As mentioned at the outset, this small scale study does not attempt to provide the definitive answer to the questions of household water-use feedback preferences and responses, but rather begins to uncover some of the key considerations in the design of more detailed feedback. The study sample in this paper is not necessarily generalisable, but did nonetheless involve a fairly broad socio-demographic of subjects (e.g. in terms of age, gender, education and income). Therefore, the results can be taken to suggest a variety of responses to detailed water-use information that might arise in any given population. Additionally, the research and survey methods introduced could be directly applied to larger sample studies.

The survey results are derived from self-reported data and perceptions of knowledge, and may be subject to some social desirability in responses. However, respondents were encouraged to answer the survey questions as frankly as possible to give the most meaningful results. Furthermore, both positive as well as negative responses were recorded, with comments in open-ended questions and interviews noted as remarkably frank.

The HWU study involved a paper-based intervention medium and was therefore limited in terms of the information content it could provide to householders. However, the evaluation survey incorporated a wider range of information types that could potentially be provided as water-use feedback. The use of online mediums (e.g. web portals) could, however, allow for the presentation of a wider range of content for householder appraisal and actual use.

Larger sample size survey studies might contribute to a better understanding of the variability in preferences and which metrics might motivate greater water savings. To further guide the development of feedback programs, larger samples would also allow for an exploration of customer segmentation. Finally, since results may differ according to geographical location or culture (Fischer, 2008), population-specific studies of householder information preferences are recommended to understand distinct populations.

Further questions that arise from this study relate to the cost-effectiveness of different forms of household water-use feedback and the issue of customer choice.

Regarding cost-effectiveness, important questions are:

- How much customisation of feedback is needed? / What is the minimum amount of customisation that can achieve a desired effect among specific types of subjects? [5]
- And what are the relative costs of different kinds of feedback? For example, leak detection requires less advanced smart metering and analysis than end-use disaggregation, but what are the marginal benefits of additional data collection, information processing and provision? The relative effectiveness of paper versus digital feedback also requires additional research.

Regarding customer choice, further research is required to understand:

- How much information is “too much”? Indeed, care must be taken to avoid “information overload” and achieving a balance between providing the full scope and range of metrics, and what ultimately constitutes actionable information.

[5] This was similarly proposed by Skinner et al. (1999) in relation to tailoring messages in healthcare.

- How much choice should be given to householders over what information is available/provided?; and what impacts might this have on engagement? Here, choice might involve any of the dimensions introduced in our framework (e.g. in terms of feedback content, medium or frequency etc.). Again, with digital media, the potential for tailoring information might be more readily achievable, with the options for householders to select their own preferred content, medium and frequency of feedback.
- Also, what are the bounds of privacy in the presentation and sharing of detailed water-use feedback (Giurco et al., 2010)? Householders may differ in their perceptions of privacy towards the collection, analysis and communication of detailed water-use information and this too warrants further research, as smart water metering technologies are progressively adopted.

3.5.3. Concluding remarks

Recent literature has documented experiments with various forms of more detailed household water-use feedback via smart water metering. However, more work is required to optimise approaches by understanding how householders relate and respond to the many different forms that feedback can now take. While smart water metering creates new opportunities; these may only materialise more fully through a more comprehensive approach to the provision of household water-use feedback considering household preferences and responses, as well as costs, effectiveness and customer choice. Ultimately, householders have limited attention spans due to competing demands, particularly in the information age, and utilities also have limited space to provide comprehensive information (both in paper-based, as well as electronic media e.g. dashboards). Therefore, smarter selections in the design of household water-use feedback are recommended for utilities through additional research, to more actively embrace this new age of possibilities through smart water metering.

Acknowledgements

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Supplementary Information to Chapter 3: Characteristics of respondents versus non-respondents

Method

The 65% response rate to the evaluation survey is relatively high for social science research. Noting that since for one third of participant households (n = 12), no evaluation of the HWUs or information preferences could be obtained, a series of statistical tests were applied to baseline data to analyse for any differences between evaluation survey respondents and non-respondents in terms of socio-demographic, attitudinal and water consumption variables.

An appropriate technique for categorical variables involving frequencies (e.g. for the comparison of respondents and non-respondents in terms of gender), is the use of Pearson's chi-square tests of independence. This cross-tabulation technique involves tabulating frequencies relating categorical variables within contingency tables. These tables show the relationships between the selected categorical variables, which are assessed by Pearson's $\chi 2$-statistic. For small sample sizes, as in the present study, and specifically, contingency tables in which any of the expected values of a cell are less than 5, a Fisher's exact test is appropriate. This test was therefore applied to a variety of socio-demographic characteristics (i.e. gender, age, education and income) and various attitudinal variables (i.e. interest in the provision of more detailed water use information, belief that more information would help them save and a variety of measures of awareness of water use) to examine for any differences in the characteristics of survey respondents and non-respondents.

In addition, for the continuous variables measuring the level of household water consumption at baseline (for summer and winter), respondents and non-respondents were compared using independent sample t-tests.

How the interviewees (n = 5) (who represented a subset of evaluation survey respondents) related to the wider participant group, was also analysed with respect to the above baseline attitudinal variables. Using data from the evaluation survey itself, differences were also analysed for interviewees and survey respondents who were not interviewed. These measures assessed the level of appeal and applicability of the information provided in the HWUs, thus enabling a further check for selection bias among interviewees and the potential representativeness of the views they expressed.

Results

The comparisons between respondents and non-respondents are shown in terms of the socio-demographic and consumption variables are shown in Table 7. There was no significant difference for any of the individual socio-demographic variables (i.e. gender, age, education and income) (Fisher's exact test, $p>0.05$). There was also no significant difference in either the baseline measure of household water consumption between evaluation survey respondents for winter ($M=355.41$, $SD=217.12$) and non-respondents ($M=341.18$, $SD= 198.98$); $t(31)=0.182$, $p=0.857$; or for summer between respondents ($M=728.09$, $SD=34.38$) and non-respondents ($M=672.09$, $SD=174.96$); $t(10.39)=1.051$, $p=0.317$.

Table 8 shows the results of the comparison of respondents and non-respondents in terms of attitudinal variables. Here, the level of interest in receiving more detailed water use information measured at baseline also did not differ significantly between the respondent and non-respondent groups (Fisher's exact test, $p>0.05$). However, the share of participants that believed more information about their water use would help them save was significantly higher for evaluation survey respondents than non-respondents (Fisher's exact test, $p<0.01$). This suggests that those who expected a more positive impact on their water use were more likely to later respond to the survey post-intervention. Therefore the results may over-represent households which had greater expectations towards the provision of more detailed water use information.

In terms of the awareness measures, the percentage of participants that reported knowing where most water was used in the home at baseline was significantly higher for evaluation survey respondents than for non-respondents (Fisher's exact test, $p<0.01$). However, the three other measures of awareness (i.e. knowledge of household water use and of use by appliances, and feeling informed of household water use) showed no significant differences between respondents and non-respondents (Fisher's exact test, $p>0.05$). This suggests that overall awareness was not likely to be significantly different between the respondent and non-respondents at baseline.

The analysis of differences between interviewees and non-interviewees at baseline (Table 9) showed no significant differences in terms of interest in more detailed information about water use, perceptions that more information would help save, nor in the various measures of awareness (Fisher's exact tests, $p<0.05$).

The comparison of interviewees against non-interviewees from among those participants who did respond to the evaluation survey (Table 100) also showed no statistically significant differences in terms of the level of appeal and applicability of the information provided in the HWUs (Fisher's exact tests, $p<0.05$). It was, however, noted that all five interviewees liked the HWUs (strongly agreed (2) or agreed (3) to the statement "I like the HWUs"). Therefore no one who disliked the HWUs was reached in the interview stage. At the same time, however, 86% of respondents liked the HWUs, so the views do not overly represent positive evaluations from within the sample. The same test result was noted for the applicability of the information included in the HWUs. Again, all five interviewees belonged to the categories that either strongly agreed (3) or agreed (2) that the information in the HWUs was applicable to their household, which also aligned with the opinion of 86% of the overall respondent population, hence the insignificance in the statistical test.

Table 7 HWU evaluation survey respondents versus non-respondents: socio-demographic variables

Variables	Respondents (*n*)	Non-Respondents (*n*)	Total (*n*)	*P* value
Gender				0.694†
Male	57% (12)	44% (4)	53% (16)	
Female	43% (9)	56% (5)	47% (14)	
Age				1.000†
35-44	5% (1)	9% (1)	6% (2)	
45-54	14% (3)	18% (2)	15% (5)	
55-64	9% (2)	9% (1)	9% (3)	
65+	73% (16)	64% (7)	70% (23)	
Education				0.401†
High school or less	33% (7)	30% (3)	32% (10)	
Diploma	24% (5)	20% (2)	23% (7)	
Trade/apprenticeship	33% (7)	10% (1)	26% (8)	
Bachelor/Honors degree	0% (0)	10% (1)	3% (1)	
Postgraduate degree	10% (2)	30% (3)	16% (5)	
Income (AUD) before tax				0.143†
Less than 30,000	42% (8)	13% (1)	33% (9)	
30,000 - 59,999	37% (7)	38% (3)	37% (10)	
60,000 - 89,999	11% (2)	25% (2)	15% (4)	
90,000 - 119,999	11% (2)	0% (0)	7% (2)	
120,000 - 149,999	0% (0)	13% (1)	4% (1)	
More than 150,000	0% (0)	13% (1)	4% (1)	
Baseline water consumption (L/hh/d)				
Winter 2012	355 ± 217	341 ± 199	351 ± 208	0.857‡
Summer 2012/13	728 ± 134	672 ± 175	709 ± 105	0.317‡

Note: Percentages do not always sum to 100 due to rounding.
Data are n (%) or means ± SD.
† Chi-square test and Fisher's exact test.
‡ Independent samples t-test.

Table 8 HWU evaluation survey respondents versus non-respondents: attitudinal variables

Variables	Respondents (*n*)	Non-Respondents (*n*)	Total (*n*)	*P* value
I want more detailed information				0.207†
Yes	95% (20)	78% (7)	90% (27)	
No	5% (1)	23% (2)	10% (3)	
More information would help me save				0.008†**
Strongly agree	23% (5)	0% (0)	15% (5)	
Agree	73% (16)	55% (6)	67% (22)	
Neutral	0% (0)	36% (4)	12% (4)	
Disagree	5% (1)	9% (1)	6% (2)	
Strongly disagree	0% (0)	0% (0)	0% (0)	
I know my household water use				0.635†
Strongly agree	5% (1)	9% (1)	6% (2)	
Agree	46% (10)	46% (5)	46% (15)	
Neutral	27% (6)	9% (1)	21% (7)	
Disagree	18% (4)	36% (4)	24% (8)	
Strongly disagree	5% (1)	0% (0)	3% (1)	
I know how much my appliances use				0.926†
Strongly agree	0% (0)	0% (0)	0% (0)	
Agree	31% (7)	30% (3)	31% (10)	
Neutral	27% (6)	20% (2)	25% (8)	
Disagree	36% (8)	50% (5)	41% (13)	
Strongly disagree	5% (1)	0% (0)	3% (1)	
I know where most water is used in my home				0.002†**
Strongly agree	0% (0)	20% (2)	6% (2)	
Agree	82% (18)	30% (3)	66% (21)	
Neutral	5% (1)	0% (0)	3% (1)	
Disagree	9% (2)	50% (5)	22% (7)	
Strongly disagree	5% (1)	0% (0)	3% (1)	
I feel informed about my household's use				1.000†
Strongly agree	0% (0)	0% (0)	0% (0)	
Agree	36% (8)	30% (3)	34% (11)	
Neutral	23% (5)	30% (3)	35% (8)	
Disagree	36% (8)	30% (3)	34% (11)	
Strongly disagree	5% (1)	10 % (1)	6% (2)	

Note: Percentages do not always sum to 100 due to rounding.
† Chi-square test and Fisher's exact test.
** Significant $p<0.01$

Table 9 HWU interviewees versus non-interviewed participants: attitudinal values

Variables	Interviewees (*n*)	Non-interviewees (*n*)	Total (*n*)	*P* value
I want more detailed information				
Yes	100% (5)	88% (22)	90% (27)	1.000†
No	0% (0)	12% (3)	10% (3)	
More information would help me save				0.482†
Strongly agree	40% (2)	11% (3)	15% (5)	
Agree	60% (3)	68% (19)	67% (22)	
Neutral	0% (0)	14% (4)	12% (4)	
Disagree	0% (0)	7% (2)	6% (2)	
Strongly disagree	0% (0)	0% (0)	0% (0)	
I know my household water use				0.316†
Strongly agree	20% (1)	0% (0)	5% (1)	
Agree	40% (2)	47% (8)	46% (10)	
Neutral	40% (2)	24% (4)	27% (6)	
Disagree	0% (0)	24% (4)	18% (4)	
Strongly disagree	0% (0)	6% (1)	5% (1)	
I know how much my appliances use				0.374†
Strongly agree	0% (0)	0% (0)	0% (0)	
Agree	40% (2)	29% (5)	32% (7)	
Neutral	20% (1)	29% (5)	27% (6)	
Disagree	20% (1)	41% (7)	36% (8)	
Strongly disagree	20% (1)	0% (0)	5% (1)	
I know where most water is used in my home				0.442†
Strongly agree	0% (0)	0% (0)	0% (0)	
Agree	80% (4)	82% (14)	82% (18)	
Neutral	20% (1)	0% (0)	5% (1)	
Disagree	0% (0)	12% (2)	9% (2)	
Strongly disagree	0% (0)	6% (1)	5% (1)	
I feel informed about my household's use				0.143†
Strongly agree	0% (0)	0% (0)	0% (0)	
Agree	60% (3)	29% (5)	36% (8)	
Neutral	0% (0)	29% (5)	23% (5)	
Disagree	20% (1)	41% (7)	36% (8)	
Strongly disagree	20% (1)	0% (0)	5% (1)	

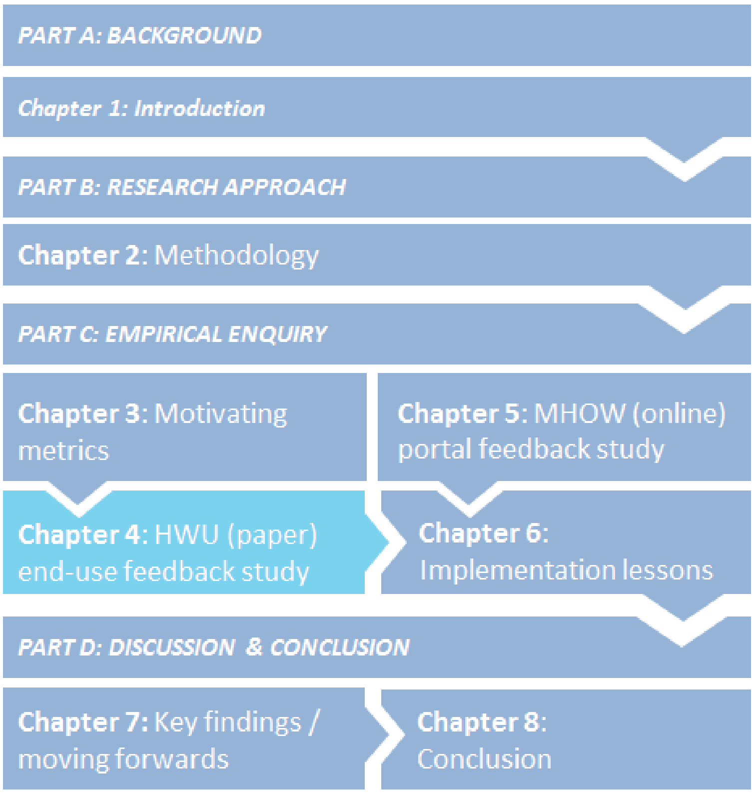
Note: Percentages do not always sum to 100 due to rounding.
† Chi-square test and Fisher's exact test.

Table 10 HWU interviewees vs. non-interviewed HWU evaluation survey respondents

Variables	Interviewees (*n*)	Non-interviewees (*n*)	Total (*n*)	*P* value
I like the HWUs				0.660†
Strongly agree	40% (2)	13% (2)	19% (4)	
Agree	60% (3)	69% (11)	67% (14)	
Neutral	0% (0)	13% (2)	10% (2)	
Disagree	0% (0)	6% (1)	5% (1)	
Strongly disagree	0% (0)	0% (0)	0% (0)	
The information is applicable				0.660†
Strongly agree	40% (2)	13% (2)	19% (4)	
Agree	60% (3)	69% (11)	67% (14)	
Neutral	0% (0)	13% (2)	10% (2)	
Disagree	0% (0)	6% (1)	5% (1)	
Strongly disagree	0% (0)	0% (0)	0% (0)	
The information made me more conscious				0.465†
Strongly agree	60% (3)	19% (3)	29% (6)	
Agree	40% (2)	63% (10)	57% (12)	
Neutral	0% (0)	13% (2)	10% (2)	
Disagree	0% (0)	6% (1)	5% (1)	
Strongly disagree	0% (0)	0% (0)	0% (0)	

Note: **Percentages do not always sum to 100 due to rounding.**
Measures are taken from the evaluation survey rather than the baseline survey.
† Chi-square test and Fisher's exact test.

Chapter 4: Home Water Update Study — paper based water and end-use feedback



Paper preface

This chapter includes a re-formatted co-authored peer-reviewed paper. The full bibliographic details of the paper, including all authors are:

Liu, A., Giurco, D., Mukheibir, P. 2015, 'Urban water conservation through customised water and end-use information'. *Journal of Cleaner Production,* vol. 112, pp. 3164-3175. DOI: 10.1016/j.jclepro.2015.10.002.

Statement of contribution

Ariane Liu was the project lead for the HWU study. She collected the end-use data from MCW; analysed the data for impacts; and wrote the paper. Damien Giurco and Pierre Mukheibir provided supervisory guidance which included reviewing drafts of the paper.

Acknowledgements are due to: Graeme Watkins and Chenxi Zeng of MidCoast Water for technical support and SmartMon data analysis, respectively; Thomas Boyle and Candice Delaney (née Moy) for overall project support, including in the design of the HWU study; the householders who kindly participated in the study; Ian Chong for HWU design work; and UTS Printing Services.

Research highlights

The research article highlights included in the online version of the journal article are as follows:

- Mixed methods study examines role of detailed water end-use feedback on water uses.
- Detailed water-use information appealed to the vast majority of householders.
- Concrete changes in water-using behaviours and infrastructure reported.
- Potential for customised water-use information to promote urban water conservation.

Urban water conservation through customised water and end-use information

Abstract

Water conservation in urban centres is an ongoing challenge in which new technologies can play an important role. Smart water metering in conjunction with end-use analysis enables the collection of more detailed information on household water consumption than was previously possible. This presents a new and currently underexplored opportunity to promote more efficient water use via the provision of detailed customised water-use information to householders. Among the variety of possible approaches, is the option of paper-based reports containing a highly detailed 'snapshot' of household water use. This paper describes a mixed methods study in which customised paper-based 'Home Water Updates' were provided to a group of households in Australia to explore the idea of providing detailed feedback, including detailed end-use consumption information on uses of water within the home. The methods used within this research are described in detail to disseminate experience in this relatively new area of research. Analysis of the post-intervention householder evaluation survey showed the provision of detailed water-use information via the Home Water Updates appealed to the vast majority of householders; and further resulted in changed behaviours (e.g. shorter showers and full washing machine loads) and installations of new infrastructure. These research findings suggest a role for customised household water and end-use information via smart metering. However, more work is required to optimise approaches to enable a significant contribution towards more sustainable urban water management.

Keywords

Smart water metering; End-use analysis; Residential water conservation; Information; Feedback; Sustainable water.

4.1. Introduction

As the need for greater sustainability in urban centres becomes increasingly apparent (Agudelo-Vera et al., 2012, 2011; McCormick et al., 2013), new technologies and behaviours which can contribute to a more sustainable consumption of important resources are becoming of increasing interest. In particular, ways to reduce consumption of energy and water require the attention of researchers, industry professionals and consumers alike.

Smart metering is an innovative measurement technology which offers the potential to contribute to a more efficient use of electricity, gas and water resources in both commercial and residential buildings. Essentially, smart metering technologies introduce new opportunities to collect more detailed information on resource consumption practices and patterns than was previously possible under conventional metering. The opportunity exists to convey this information both to the utility and the consumer to inform and guide water management (Boyle et al., 2013). Particularly in the water sector, however, comparatively less attention has been on the *communication* of the detailed water-use information to customers.

4.1.1. Water consumption data advances

Within the water sector, residential meters have traditionally been read up to once per quarter, yielding no more than four data points per meter per year (Britton et al., 2008). By contrast, smart water meters record the flow of water consumption every set number of seconds (e.g. every 15 or 60 s). The technology therefore opens the door to significantly greater data resources and the possibility of understanding water consumption according to time of use within the day, taking also variations in weather and seasonal changes into consideration. Further analysis of detailed smart water meter data can be conducted using trace flow (end-use) analysis, a process which assigns end-use tags (e.g. shower, toilet, washing machine etc.) to each water-using event (Willis et al., 2009). This allows metrics to be obtained for each individual water-using event including start and finish time, duration, flow rate (maximum, minimum, average) and volume (Liu et al., 2013; Mayer et al., 2000). This analysis of high resolution water consumption data collected via smart water metering can therefore prelude a detailed understanding of where water is used in the home (Giurco et al., 2010). This can in turn be used to support more targeted water conservation efforts as well as to assess the effectiveness of demand management interventions (Stewart et al., 2010).

4.1.2. Water conservation and the role of information campaigns and detailed feedback

Water utilities and public agencies around the world have at times used information campaigns to encourage residential water conservation. A variety of modes have been used to inform households of ways to save, including leaflets, bill inserts and websites. The particular mode of informational delivery (e.g. paper versus online) is likely to have implications for its reach. Similarly, the content of water-use information and its format may influence impacts on consumption behaviours. Here an important distinction needs to be drawn between generic information (e.g. aggregate data for a supply location) and disaggregated feedback at the household level. To date, water conservation campaigns have been based on the former, often presented in terms of averages. However, as explained by Aitken et al. (1994), customised feedback can provide a more accurate basis for assessment and action thereby enabling progress towards a (conservation) goal. Therefore, disaggregated water-use feedback may promote conservation at the individual and household levels. Moreover, the more detailed or specific that the customised feedback is, the clearer the signal of real water-saving opportunities may be.

Information-based approaches are often linked to an 'information deficit' model of rational behaviour (Burgess et al., 1998), which suggests households will respond to additional information to their own gains. However, the explanation is not without its critics, who have questioned whether the provision of information alone is effective and if additional interventional support may be required (e.g. McKenzie-Mohr and Smith, 1999); or whether a focus on information is wrong, since households may depart from the assumptions of rationality in various important ways (e.g. Shove, 2010). Yet these critiques are not specifically levelled at particular types or levels of information, which could plausibly yield varying impacts.

4.1.3. Householder smart metering opportunity

The high resolution data obtained from smart meters creates the potential for far greater informational resources than under traditional metering. The data collected can be analysed with the goal of providing significantly more detailed household-specific information to household water consumers for a potentially more effective provision of information to promote conservation (Liu et al., 2013).

Until now, however, more research has been conducted within the residential energy sector on the potential role of customised feedback via smart metering (see e.g. Darby, 2010; Faruqui et al., 2010 for reviews). While a couple of residential energy-focused studies took novel steps to incorporate real-time online water use feedback, the impacts on water consumption were comparatively small (3% in Petersen et al., 2007), or not reported (Fróes Lima and Portillo Navas, 2012). Over the past few years, a handful of studies have emerged specifically investigating the impact of more detailed, customised water-use information via smart water metering. Studies involving paper-based interventions e.g. leak notification letters (Britton et al., 2013) and feedback postcards (Fielding et al., 2013), as well as in-home displays (Doolan, 2010; Wetherall, 2008) and online portals (Erickson et al., 2012; Joo et al., 2014), have reported a positive impact of between 5 and 10% water savings. The opportunity still remains, however, to allow householders to engage with a variety of detailed types of water-use feedback, including at end-use levels.

4.1.4. Research aims

This research belongs to a larger program which investigates the potential for detailed water-use information obtained via household smart metering to promote behavioural changes towards more sustainable water consumption. Within this wider scope, this paper explores how householders respond to the provision of detailed, household-specific water and end-use information communicated specifically via paper-based reports[6]. A unique variety of detailed and water-use measures are presented within the study to specifically allow householders to experience different types of information. The study adopts a mixed methods approach in which the impacts of detailed water-use information are analysed using smart meter and end-use data, with the novel inclusion of a post-intervention householder evaluation survey. The study methods and limitations are further described in detail. Deeper insights are thus provided into the approaches adopted to guide future industry and research activities within the emerging field of household smart water metering, end-use analysis and feedback programs.

4.2. Materials and methods

4.2.1. Background

The study location is Tea Gardens/Hawks Nest, suburbs located within the service area of MidCoast Water (MCW) in New South Wales, Australia. In a prior study (2009-2011) MCW introduced smart metering to 141 homes in the area to investigate the impact of pressure management on household water demand. To compare pre- and post-intervention water use the 'Datamatic Firefly' loggers were set each summer (December/January) and winter (June to August) to record water use intensively for a period of between two to five weeks each. This water-use data, which is collected at 1 min intervals with a resolution of 0.5 L per pulse, is subsequently analysed by MCW using SmartMon software (Redskink Pty Ltd., 2011) to disaggregate the flow data into end-uses (i.e. shower, toilet, washing machine, taps, outdoors and leaks).

[6] The comparative role for online water-use information will also be investigated within the greater ongoing research project later in 2015.

While the smart metering technology has since remained in place, and moreover the detailed data is continually being collected each summer and winter and also being disaggregated to end-use levels, no detailed data had previously been communicated to the residents of the smart metered homes. This existing organisational setting therefore led to an interesting opportunity to explore the idea of communicating smart water meter information to the respective households, which forms the focus of the present 'Home Water Update' study (2012-14). Importantly, the existing setting provided a relatively low-cost research environment, since the metering and end-use analysis technologies and the data collection and analysis processes were all already in place. However, corresponding process limitations must simultaneously be acknowledged and their wider implications for future research and industry practice discussed.

4.2.2. Study design

A detailed summary of the key HWU study processes is shown in Figure 15 to provide a comprehensive overview of the requirements of the research study. However, future research programs or implementations might vary in multiple aspects from those listed (e.g. according to budgetary conditions and specific goals). Key HWU study processes are described in more detail in the sub-sections that follow.

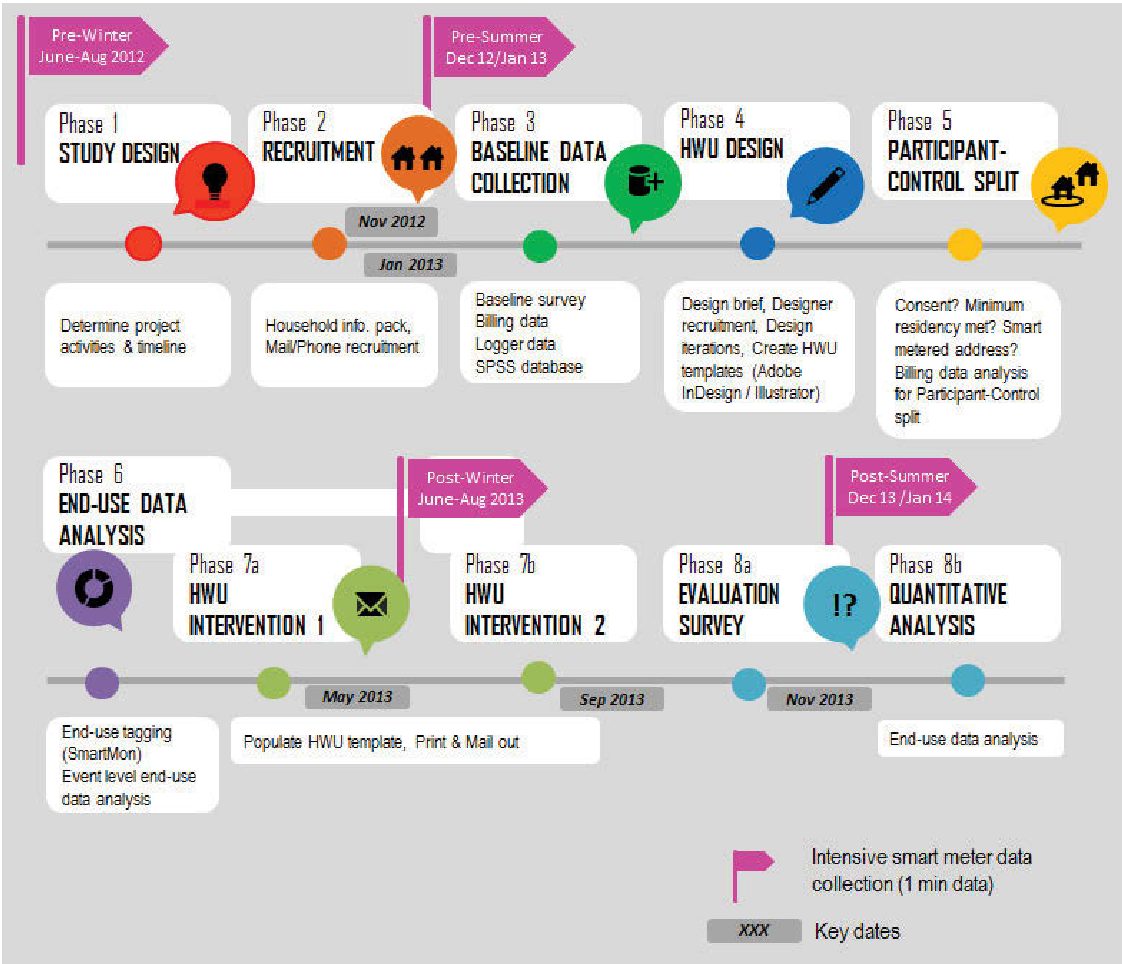


Figure 15 HWU study design

4.2.3. Study participants

Study participants were recruited via informed consent from the existing pool of 141 smart metered homes. An information pack about the research, which included a baseline survey, was mailed in November 2012 to invite participation in the study. Households willing to participate in the research were required to complete and return the baseline survey and provide written consent to the analysis of their smart meter water consumption and survey data and to potentially being selected to receive more detailed information on their water use. A second round of information packs was mailed to non-respondents in January 2013, followed by recruitment phone calls in order to increase the sample size and representativeness of a wider population. An incentive of an AUD 50 rebate on their water bill was offered to all participants to compensate for the time required to complete the baseline survey.

The recruitment processes yielded a total of 79 respondents. Several exclusions were made from the study due to: an insufficient length of residence at the smart metered address; the respondent no longer residing at the targeted address; duplicate responses from the same household; missing consent statements; and a vacant property. The overall initial sample size for the study came to 68 households.

In terms of household demographics, data collected via the baseline survey showed the study sample was characterised by:

- A median pre-tax household income within the AUD 30,000 – 59,999 bracket.
- Two occupants per household for the majority (69%); 13% had just one occupant; 10% had three occupants; 6% had four occupants; just one household had 6 occupants.
- 44% female and 47% male respondent gender, with the remainder not reported.
- Median and mode age within the more elderly category i.e. older than 65 years and consistent with demographics in the area.
- Employment status of respondents was 64% retired, 33% in employment and 3% unemployed.

In terms of household water-appliance stock:

- 79% of households' toilets were all dual-flush; 13% had only single-flush toilets; and the remainder had a mix of these.
- 58% of households were completely fitted out with efficient shower heads; 28% did not have any efficient shower heads; the remainder again had a mix.
- 88% of households had a top loader washing machine; while 10% had a front loader.

4.2.4. Treatment groups

The study involved an intervention group and a control group. A stratified randomisation approach was used to distribute the 68 households to either of the equally sized groups (N=34). The households were first divided into approximate decile groups on the basis of the previous year's water consumption using billing data, before random assignment within each decile to either group. Repeated randomisations were conducted to select approximately similar water consumption distributions between the resulting intervention and control groups. Similarly, the corresponding distributions for the number of occupants per household were compared to check for a balanced distribution between the two groups.

The paper-based intervention medium for the study was the so-called 'Home Water Update' (HWU). Each HWU was a unique A5-sized double-sided colour printed card, containing detailed information about the respective household's water use based on data collected in the previous intensive measurement period. The HWU design work was contracted to a graphic designer with the goal of producing a professional and visually clear representation of the information to be provided. Figure 16 shows a de-identified example of a data-populated HWU (Liu et al., 2015b).

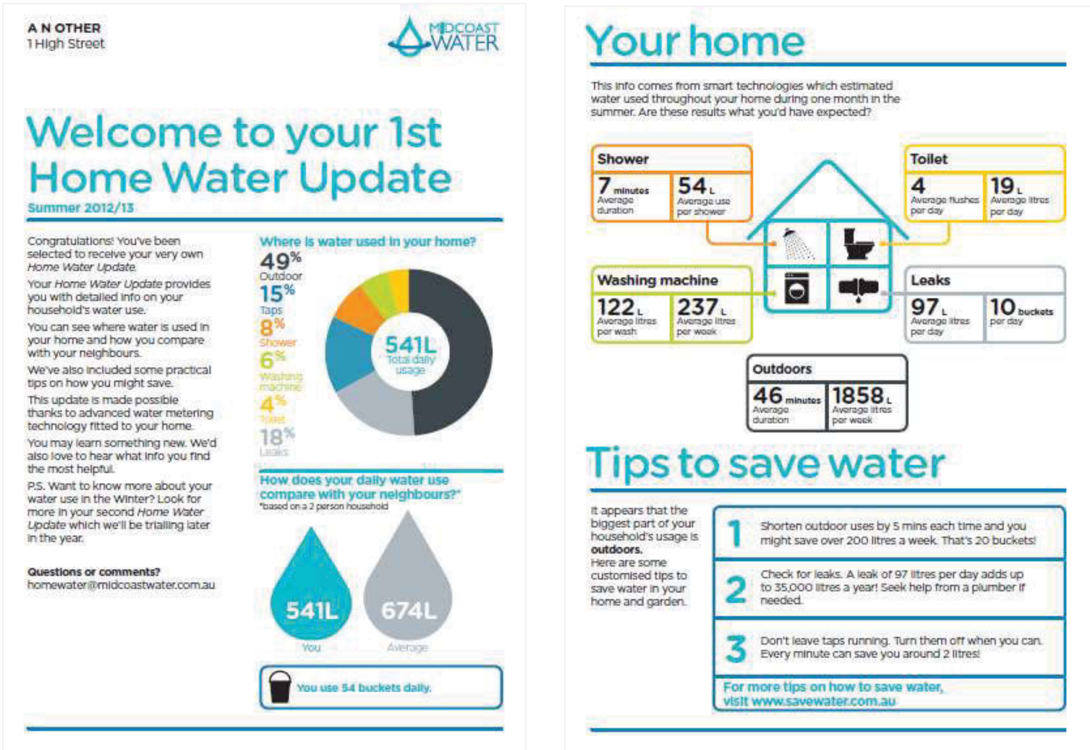


Figure 16 Example of the 'Home Water Update' intervention medium – front and reverse sides

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The information provided in the HWUs offered households a quick and detailed overview of their total and relative water use, including summarised measures at end-use levels in greater detail than previously provided. The HWUs' distinctive feature relative to other paper-based feedback mediums (e.g. Britton et al., 2013; Fielding et al., 2013) lay in the inclusion of a variety of customised metrics; and differed from online portals and in-home displays (e.g. Doolan, 2010; Erickson et al., 2012) by providing end-use data. In this way, rather than testing the impact of specific pieces of information, which small samples also do not support, the HWU study enabled households to engage with various different types of customised water and end-use feedback and thus permitted a real-life exploration of interest in different forms of information. This also contrasts with Froehlich et al. (2012), which through the use of prototypes for displays of detailed water-use feedback, did not provide participants with real actual personalised feedback.

The front side of the HWU:

- informed householders they had been selected for the study, which was framed as a trial; introduced the key features of the HWU medium and provided a contact email which was set up for any questions or feedback;
- presented an 'end-use pie chart' i.e. the breakdown of the particular household's water consumption between shower, toilet, washing machine, taps, outdoors and leaks;
- showed a neighbourhood comparison i.e. the average litres consumed daily by the household as compared with the average two-person household within the study. Two-person households represented the majority of study households and were selected as the benchmark for simplified presentation;
- summarised the household's average daily water consumption in terms of (10L) buckets so the residents could visualise volumes of water.

The reverse side of the HWU contained:
- 'end-use metrics' i.e. detailed measures of water use for specific water using appliances (e.g. average shower duration, average number of toilet flushes per day etc.);
- customised tips on how the household could save water. The customisation typically involved targeting the household's three largest end-uses. Tips were varied between households to explore framing; and care was taken to ensure tips were not repeated for the same household to allow for potential comparisons.

Data collected via the smart meters located on the properties was analysed via SmartMon (Redskink Pty Ltd., 2011) and MS Excel to provide the intervention group households with their first HWU in early May 2013, followed by a second updated HWU in early September 2013. The mailing dates were largely determined by the internal lead times required to collect and process the data and to subsequently produce the HWUs.

A decision was made to mail the HWUs separately from the households' regular quarterly bills. As automated billing is handled externally to MCW, this avoided the need to find a means to coordinate or integrate the mailing of the HWUs with the respective bills for the selected intervention group households independently of other households in the region. It was also perceived that mailing the HWUs separately might improve their visibility and reach, avoiding the HWUs being mistakenly discarded as generic bill inserts.

4.2.5 Evaluation survey

A post-intervention evaluation survey was distributed to all intervention group households in late November 2013, approximately three months after the second and final HWU. The goal of the postal survey was to evaluate the impact of the HWUs by exploring how householders responded to their detailed water-use information. In particular, participants were surveyed on: the reach and appeal of the HWUs; changes to household water infrastructure and water-using behaviours; and awareness of household water use after receiving the HWUs. An additional incentive of an AUD 20 rebate on their water bill was offered to encourage survey participation. Importantly, the evaluation survey allowed the quantitative analysis to be corroborated by insights obtained from reports of participant householders' experiences.

Of the 34 surveys, 23 were returned within the three-week completion deadline and 22 surveys were useable for the majority of questions asked, producing an evaluation survey response rate of 65%.

4.2.6. Quantitative measures and analysis

All quantitative analyses were performed using MS Excel and SPSS (IBM, 2012) version 21. Descriptive statistics were used to identify general tendencies and analyse means and standard deviations. Inferential statistics involving a mixed analysis of variance (ANOVA) were applied to the data to test for significant differences between the sub-groups over time.

Water consumption data pre- and post-intervention of the intervention group relative to the control group formed the basis of the quantitative analysis. Smart meter data collected in winter 2012 represented the baseline data, while data collected in winter 2013 represented the post-intervention period. This data was used to calculate the average litres of water used per household per day (L/hh/d) and to compare the pre- and post-intervention winters.

Several households were excluded from the analysis. One household lacked a pre-intervention winter baseline; two moved away from the smart metered properties prior to the post-intervention winter; two had no post-intervention winter data due to meter failure or reader error; and one received incorrect data.

The data sets were characterised by a significant presence of zero or near zero consumption days. To account for householder absence, all zero and near zero consumption days (defined as less than or equal to 10 L/hh/d) were excluded from the analyses. In addition, a minimum of five valid days per household per measurement period was used to ensure consumption calculations were not distorted by households for which very little data was recorded due to extended absences. These criteria led to a number of additional exclusions. Therefore, in total 11 households (16%) were excluded from the winter analysis to give 28 intervention group households and 29 control group households.

Despite the study sample drop outs, the intervention and control groups remained similar overall in terms of both the means and variance in pre-intervention water consumption and in household occupancy rates (Figure 17).

a

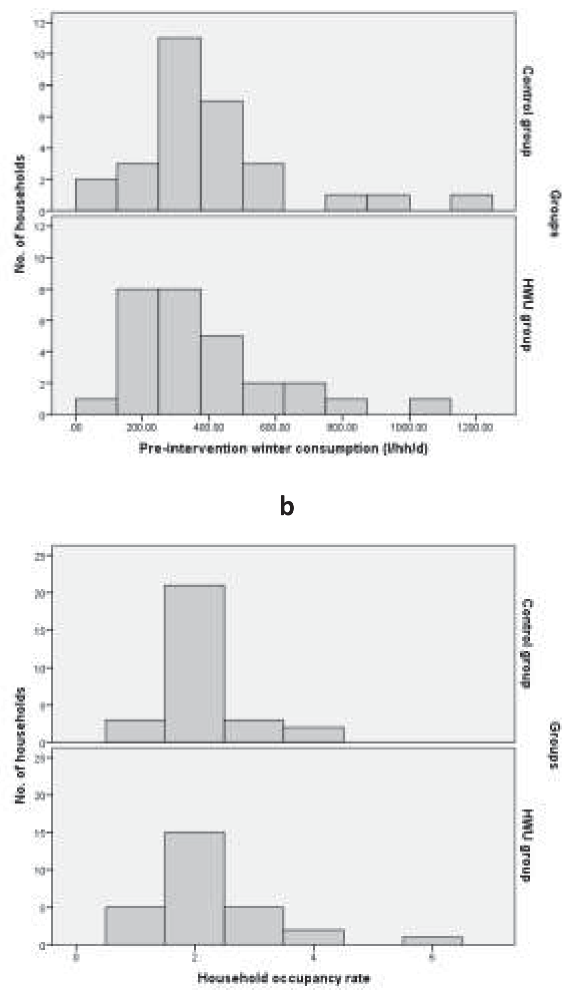


Figure 17 Histograms of (a) household water consumption profiles and (b) occupancy rates for the final intervention and control groups

The longer term impact of the HWUs was similarly assessed by comparing baseline data from summer 2012/13 with post-intervention data from summer 2013/14 (four months after the HWU intervention ceased). This analysis was conducted on 26 intervention group and 29 control group households.

4.3. Results

4.3.1. Evaluation survey results

The data obtained from the HWU evaluation survey provided specific insights into the impact of the HWU intervention among participant households. This section reports on the impact of the HWU in terms of (1) the reach and appeal of the HWUs; (2) household water infrastructure changes implemented; (3) behaviour changes enacted; and (4) impact on householders' level of awareness of household water use.

4.3.1.1. HWU program reach and appeal

The HWU evaluation survey showed that the HWUs achieved a high program reach rate, with all 22 respondents reporting having taken at least a few minutes to engage with the HWUs. Half spent 5-10 min on the HWUs, and a couple spent more than this. More than half of the respondents looked at their HWUs more than just once and almost three-quarters compared the two HWUs they received, suggesting the HWUs were used as a reference. More than two-thirds discussed the information in the HWUs on either one or more occasions, which showed the HWUs' reach extended beyond the survey respondents alone.

In terms of appeal, the HWUs were well received by the vast majority of participant households, and all but one household wished to continue to receive HWUs in the future. Some householders particularly expressed notions of value in the ability to monitor their water use and identify opportunities to save via the HWUs.

The HWUs were designed to allow households to experience a range of different types of customised water-use feedback. Responses to the evaluation survey showed that each of the key detailed measures provided (i.e. the end-use pie chart, end-use metrics and neighbourhood comparison) were found interesting by somewhere between 80 and 90% of households. Additionally, more than 50-60% of reports for each of these specific measures stated the particular type of feedback had helped them to save more water at home.

As the end-use metrics was a particularly novel feature in the HWUs, households were invited to comment on what they had thought when they saw this information in their HWUs. Here 14 out of the 22 survey respondents provided comments. The end-use metrics were generally described as "interesting" or "very interesting." Some mentioned notions of "surprise" or even "shock" at the amounts of water being used and a wish to do more to save. One household checked their taps and meter to test for leaks as a response. Another concluded they should "Reduce the washing machine usage. Always use half flush in toilets". Finally, a couple of respondents expressed either doubts about the data, or curiosity as to how the end-use data was obtained.

4.3.1.2 HWU impact: household water-using infrastructure changes

Several physical changes to household water infrastructure were reported via the evaluation survey by households after receiving the HWUs. Two of the 21 respondent households (10%) reported having installed new water-efficient appliances after receiving the HWUs. These involved one new efficient shower head and one new water-efficient toilet. In addition, three households (14%) reported repairs of leaking household water infrastructure.

4.3.1.3. HWU impact: household water-using behaviour changes

In terms of everyday water-using behaviours, eight of the 21 respondent households (38%) reported changing their behaviours after receiving the HWUs in order to conserve water used in the home. Specifically, three households were using taps differently e.g. "[we] make sure kids turn off [the] tap always" and "turn off to brush teeth and washing veggies [vegetables] and washing up". Five households reported saving water in the shower by taking "shorter showers" or "turning down" [the flow]. As for toilet flushing, two households reported they were using the "half flush when necessary" and opting to "only flush when necessary". Three households used the washing machine more conservatively, by using the machine "less often, [and for] full loads" or "only [for] full loads". Finally, three households reported saving water outdoors, with one explaining they "used the spear point [bore water] more often" than before.

4.3.1.4 HWU impact: changes in awareness of household water use

A comparison of the baseline survey (conducted at recruitment) and post-intervention evaluation survey showed a marked increase in householders' awareness of their water use after receiving the HWUs. Post-intervention awareness scores for the HWU group evaluation survey respondents were much higher than pre-intervention, and furthermore higher than the pre-intervention scores of both the non-respondents to the HWU evaluation survey and the control group (see Figure 18).

After receiving the HWUs, all 22 respondents agreed they knew where most water was used in the home. More than 80% felt they knew their water use, almost double the share pre-intervention. Knowledge of household water-using appliances consumption also increased on a similar scale. More than 90% felt informed about their water use after receiving the HWUs as compared with just one-third of households pre-intervention. From the surveys an altogether positive impact on awareness was reported, suggesting the HWUs served well as an educational tool among its recipients.

Within the HWU group, pre-intervention awareness was found slightly higher among those who later responded to the evaluation survey than those who did not. However, initial awareness was higher still among the control group. Overall, the HWUs may have reached households with mid-range awareness.

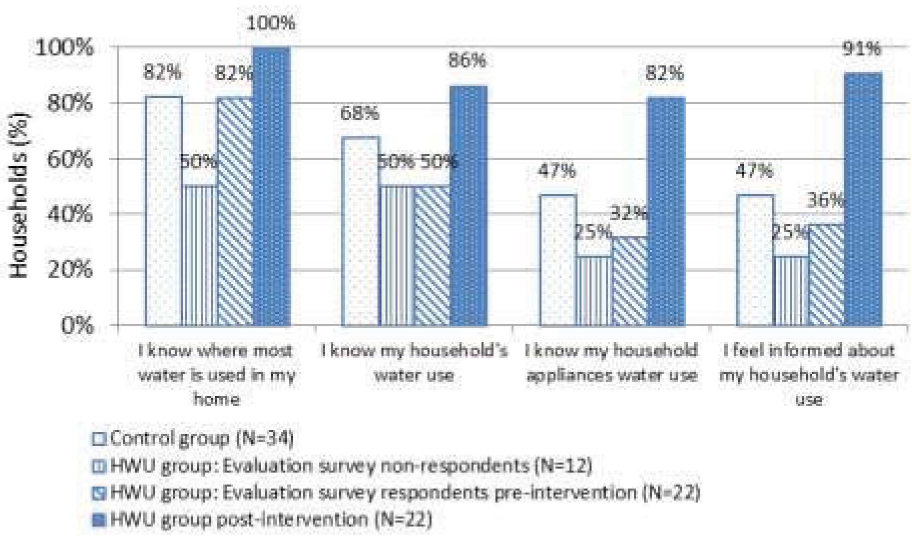


Figure 18 Awareness of household water use pre- and post-intervention.

Data presented is based on the share of respondents who either agreed or strongly agreed with each statement. HWU group post-intervention results refer to households that completed the evaluation survey. Pre-intervention results for the HWU group are shown separately for those who did not complete the post-intervention evaluation survey.

4.3.1.5 Winter analysis of total water use pre- and post-intervention

Descriptive statistics are shown in Table 11. Initially, the intervention group consumed an average of 373 L/hh/d; 8% less than the control group's average of 405 L/hh/d. Post-intervention winter consumption was lower for both groups than at baseline. The intervention group's consumption decreased by 76 L/hh/d (-20.3%); and the control group's by 52 L/hh/d (-

12.7%). Post-intervention the intervention group consumed 16% less than the control group, (compared to the initial 8% difference). Since the two groups were located in the same geographical area it is reasonable to assume other factors (e.g. weather variables) are likely to have had a similar impact on both. This impact is captured within the control group's change in consumption. The results signal a net impact of 8% water savings in the intervention group.

Table 11 Descriptive statistics for the control and intervention groups pre- and post-intervention

	Pre-intervention winter (L/hh/d)		Post-intervention winter (L/hh/d)		Pre-post difference (L/hh/d)
	Mean	SD	Mean	SD	Mean
Control group	405	239	354	211	-52 (-12.7%)
HWU group	373	220	297	184	-76 (-20.3%)
Group difference	-32 (-8%)		-57 (-16%)		-24 (-7.6%)

4.3.1.6. Inferential statistics for winter analysis

A mixed ANOVA performed on the winter data showed a significant main effect of time, $F(1,55)=5.061$, $p=0.028$, partial $\eta^2=0.084$; an insignificant main effect of group, $F(1,55)=0.827$, $p=0.367$, partial $\eta^2=0.015$; and an insignificant interaction between time and group, $F(1,55)=1.83$, $p=0.670$, partial $\eta^2=0.003$. Overall, this means that the measured effect of the HWU intervention was not significantly different between the intervention and control groups. However, the interaction test may lack statistical power as the modest trial sample size (N=57) may not have been large enough to detect differences between the subgroups.

4.3.1.7 Winter end-use analysis pre- and post-intervention

Figure 19 compares pre- and post-intervention winter consumption at end-use levels for the intervention and control groups. Pre-intervention household consumption was approximately equal between the two groups across all end-uses except leaks. The control group had an unusually high occurrence of leaks of 42 L/hh/d (10% of total water use), compared with the intervention group's 15 L/hh/d (just 4% of total water use). Excluding leak data, intervention and control group households consumed an almost equal amount pre-intervention i.e. 358 and 363 L/hh/d, respectively, or a difference of just 1%. Among the remaining end-uses, pre-intervention winter consumption was slightly higher in the intervention group households for shower and toilet uses than the control group.

Post-intervention winter consumption was lower in the intervention group than the control group for every end-use. Relative to the control group, the intervention group obtained marked savings in outdoor (-25%), washing machine (-24%), shower (-15%) and toilet (-10%) use. Water consumption via leaks was fairly stable for the intervention group across the two periods. Interestingly, however, the control group reduced their leakage by 44% compared to baseline, so a level comparable to the intervention group was recorded.

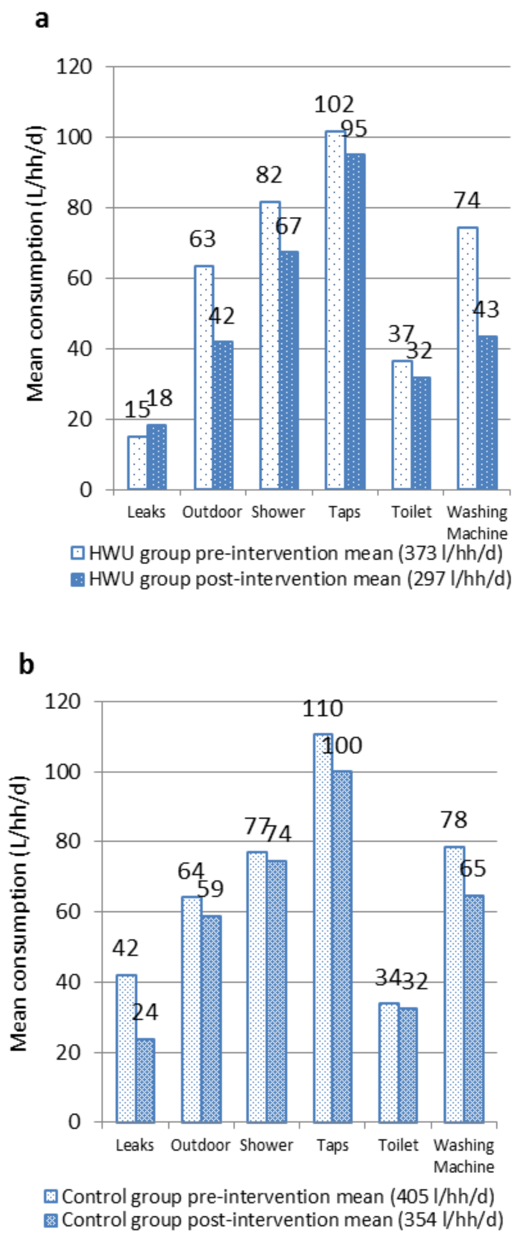


Figure 19 Pre- and post-intervention winter consumption at end-use levels for (a) HWU group and (b) control group

End-uses for the control group expressed in terms of consumption shares were very stable between the two winters, each varying by 1-3%. By contrast, consumption shares for the intervention group showed greater variance pre- and post-intervention. In particular, the share of water used by the washing machine decreased by 6% and by outdoor use by 3%. Conversely, the share represented by taps increased by 5%. However, all other end-uses retained a share of overall consumption within 1-2% of the pre-intervention shares.

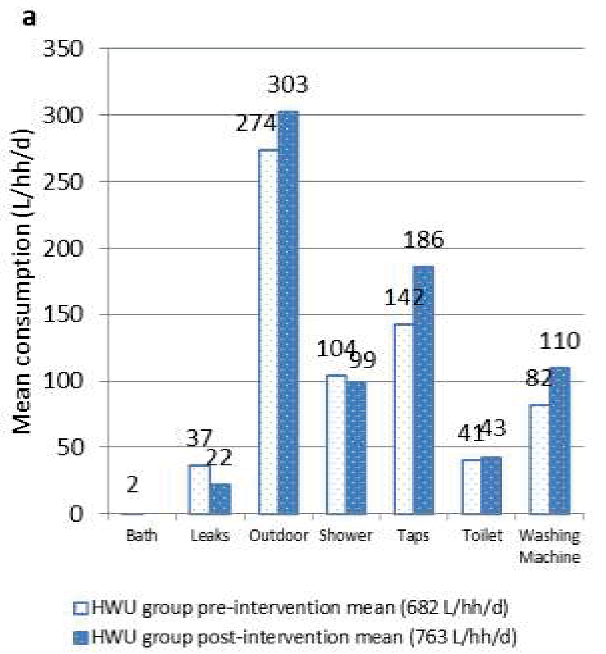
4.3.2. Longer term (summer) analysis pre- and post-intervention

In the pre-intervention summer, the intervention group's average consumption was 682 L/hh/d (SD=319), and was 7% higher than the control group's 638 L/hh/d (SD=293). Post-intervention summer consumption increased for both groups, to 763 L/hh/d (SD=298) in the intervention group (+12%), and 655 L/hh/d (SD=325) in the control group (+3%). The intervention group's consumption was therefore 16% higher post-intervention than the control group; representing an overall net increase of 9% relative to the control group.

A mixed ANOVA for the summer data revealed similar results as for winter, but with an insignificant main effect of time, $F(1,53)=1.667$, $p=0.202$, partial $\eta^2=0.031$; in addition to an insignificant main effect of group, $F(1,53)=1.051$, $p=0.310$, partial $\eta^2=0.019$; and an insignificant interaction between time and group, $F(1,33)=0.709$, $p=0.403$, partial $\eta^2=0.013$. Again, the measured effect of the HWU intervention was not significantly different between the intervention and control groups.

Figure 20 shows pre- and post-intervention summer consumption at end-use levels for the intervention and control groups. The higher level of consumption in the intervention group at baseline applied across most end-uses, with the greatest disparities in tap (+16%), shower (+15%) and outdoor use (+6%); but toilets and leaks consumption was almost equal between the two groups. Only washing machine use was initially lower among the intervention group (-9%).

End-use data sheds light on the relative increase in the intervention group's water consumption and reveals the intervention group consumed more than the control group for most uses, with the exceptions of showers and toilets. Compared to pre-intervention, the intervention group saved 21% in the shower and 17% in the toilet relative to the control group. A notably large difference of 66 L/hh/d in outdoor use in the post-intervention period accounts for most of the final overall difference in consumption between the two groups. Baseline survey data showed the control group had relatively more bores and fewer swimming pools and spas than the intervention group, which may have contributed to this result.



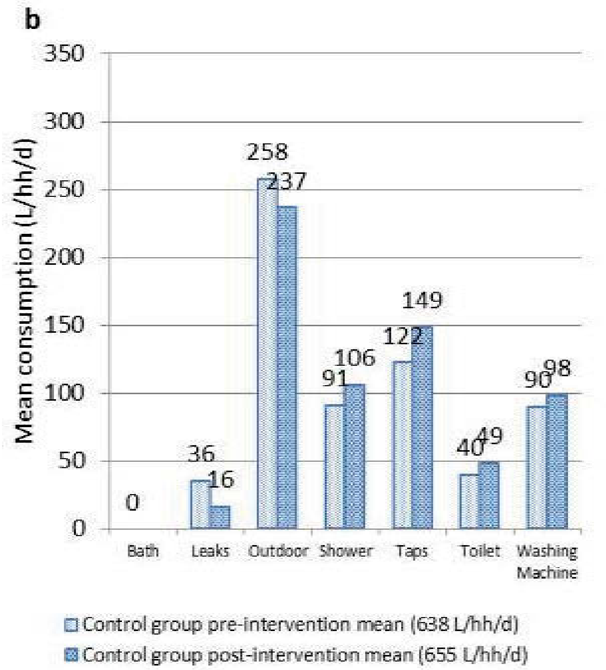


Figure 20 Pre- and post-intervention summer consumption at end-use levels for (a) HWU group and (b) control group.

4.3.3. Limitations of the study

The HWU study was conducted within a pre-existing organisational setting of smart metering, data collection and end-use analysis, which allowed for a relatively low-cost research environment to explore the provision of detailed household water-use feedback. However, several research design constraints were experienced as a result of these existing processes.

Due to the data collection process involving intensive measurement only in summers and winters, the HWU study could only capture snapshots of water use pre- and post-intervention. Particularly the baseline data was recorded for only a limited number of days. While due to resource constraints this is not uncommon among intervention studies conducted using smart water metering (e.g. Willis et al., 2010), it is noted that Fielding et al. (2013) were able to collect three months of baseline data. Nevertheless, the HWU study's use of a control group with similar characteristics (i.e. similar previous consumption levels from billing data, the same geographic location and a similar number of occupants) to the intervention group, should have compensated for other external influences, likely to impact equally on both groups (e.g. climatic changes, MCW's other communications e.g. regular billing and rebate program).

The HWU study sample was limited from the outset due to its recruitment from a limited population of households already fitted with smart water meters and the research ethics requirement of informed consent. In retrospect, the statistical power of the analysis could have been improved via additional recruitment efforts to increase the sample size for the quantitative analyses. Alternatively, since the manual production of HWUs for additional households would have been costly, longer measurement periods might have offered a better approach by reducing the variation in average daily consumption, thereby increasing the statistical power of the trial. Nevertheless, and despite sample size attrition, the HWU study sample was not very small, so the idea of providing detailed water-use information could be tested among a fairly heterogeneous group of households. Additionally, for the main purpose of exploring a new method, the overall study sample (N=68) provided ample experience to gain process learning and identify relevant issues.

Unfortunately, due to meter reader error and consequent data loss, hourly consumption data could not be collected throughout the study. This would have allowed for a more direct analysis of the quantitative impact of the HWUs on water consumption over time, in addition to the results from the detailed end-use snapshots. Increased use of more reliable automated meter reading technologies should reduce meter reading errors (Arregui et al., 2006) and support future research into the effectiveness of demand management interventions. In addition, nearer real-time metering and monitoring or analysis will enable faster detection of meter-failures, rather than discovering this only when meters are read through drive-by, as in the present study, and we note is still a method which is commonly used by many utilities.

In addition to detecting completely missing smart meter data for some households, the data analysis met with the challenges of handling zero and near zero consumption days (as in Fielding et al., 2013). While some vacancy of properties is normal, their inclusion would have distorted the analysis. Zero consumption days suggest the householders were simply absent, so for comparability were excluded from the analysis. Near zero consumption days are more challenging and a lower threshold was set for any days in which consumption was equal or below 10 L/hh/d. Low consumption may signal the presence of a leak, which needs to be counted as water consumption. However, if occupants are absent, counting the days as a positive consumption day would impact on average consumption for the household since other daily uses (e.g. shower, toilet or taps) are zero. Again, the recording of short snapshot periods of detailed data, inherent in the research design, could have altered the impact of zero and near zero consumption days on specific households depending on the particular dates measured, so longer periods are recommended. However, the availability of end-use data can in itself provide useful insights for interpretations of low consumption and the presence of householders.

4.4. Discussion

The sustainable supply of water to the urban residential sector is a constant challenge for the water industry and more effective ways to promote conservation or more efficient use among users are continuously being sought. On the one hand, the HWU study lent support to results from other similar studies (Fielding et al., 2013) that smart water metering and end-use analysis can contribute to the greater goal through better informing householders of their specific uses of water and practical opportunities to save. On the other hand, by exploring the opportunity to provide detailed customised water-use information, the HWU study raised a number of methodological issues relating to current practice, with important implications for the future of household smart water metering and feedback. These issues are elaborated in this discussion section.

Current practice with smart water metering actually varies tremendously between (and even within) water utilities in terms of the technology, scale and data analysis, and depends heavily on project goals and available budgets. However, important trade-offs exist between the resolution of data collected (e.g. typically between 1 min and hourly data); its suitability for the application of end-use analysis (this is rarely practised since it requires 1 min data or finer); the measurement periods adopted (i.e. intensive snapshots versus continuous measurement); and the sample size of study households. Without sufficient consideration of the trade-offs new sample-specific insights can still be attained, but as experienced in the current study, high variation in water consumption between households and over time may result in studies which are underpowered to confirm the impacts of interventions.

With regards to the analysis of the interventions, it is worth noting that the use of descriptive statistics is often relied upon when reporting results of smart water metering feedback interventions (e.g. Erickson et al., 2012; Petersen et al., 2007). However, taking the additional step to perform analyses using inferential statistics, as in the HWU study, produced valuable insights into the underlying variation in household water consumption and the statistical power required to detect impacts that might apply at population levels. This is an important consideration, often overlooked in trial-scale water utility projects, but one that warrants further attention.

The HWU study demonstrated that the type of smart metering selected is important in determining the availability of data and the speed of information transmission to customers. The meters used in the present research recorded more detailed water use (at 1 min intervals) for just a few weeks each summer and winter due to the logger's limited memory to store the large quantity of data thus collected. In addition, the study experienced a significant lead time between the water consumption events themselves and the related information communication. The use of more advanced metering technologies capable of storing and transmitting in near real-time enables more complete and timelier information for consumers, which may promote more immediate responses to unusually high consumption, such as leaks (Doolan, 2010; Erickson et al., 2012). However, for other uses, near real-time feedback may not be required and a one-off or periodic communication, such as the HWUs, could suffice to inform householders on their potential for water savings. More work is required to understand the role of the frequency and continuity of water-use feedback in promoting conservation. Also, since impacts on household water use can diminish over time, particularly after an intervention ceases (as in Fielding et al., 2013), the longer term impact of a sustained HWU-type program requires further exploration.

End-use analysis can open the door to a greater understanding of water use within the home, but current end-use software is not without its challenges and new processes need to be developed for integration with existing information systems. End-use analysis itself requires some manual tagging of water-using events, which is time-consuming and requires industry expertise. Some events can be difficult to interpret, particularly if occurring simultaneously (although this was less of an issue for the low occupancy homes in this study). As costs come down, higher resolution smart water metering may improve the accuracy of end-use analyses and further developments in automating end-use disaggregation (e.g. Nguyen et al., 2013) will improve the prospects for end-use feedback. Since the HWU study further met with the not unusual challenge of changes in occupancy, as two properties changed ownership during the study, the automation of smart water metering data processes and services would have to ensure data is linked to the correct owner, something which was more challenging in a manual process of analysis.

The HWUs presented householders with a quick overview of a range of detailed measures of water and end-uses (i.e. an end-use breakdown, neighbourhood comparison, end-use metrics and customised tips). The approach differed from other paper-based mediums (e.g. Britton et al., 2013; Fielding et al., 2013) by including a variety of customised metrics; and from online mediums (e.g. Doolan, 2010; Erickson et al., 2012; Joo et al., 2014; Wetherall, 2008) in providing data categorised by end-use. While the provision of different measures to subgroups of participants allows comparisons of impacts (as in Fielding et al., 2013), further work is required to understand how householders interact with specific and different forms of information. Which information is most useful to householders and what specifically motivates water savings is therefore explored in conjunction with the HWU study in Liu et al. (2015).

The impact of more detailed water-use information such as in the HWUs may also vary according to householder profiles. Recent work involving end-use data has shown end-use consumption (Makki et al., 2013), awareness of water use (Beal et al., 2013) and savings via water-efficient devices (Willis et al., 2013) differ according to socio-demographic variables. Therefore, still more work is required linking the responses of householders at end-use levels to more detailed water-use information according to householder socio-demographic characteristics. It is fully conceivable that the HWU approach might be better suited to specific demographic groups and more work is required to better understand target audiences. Paper-based customised reports may offer a viable alternative or complement to feedback approaches which make use of in-home or web-based displays accessed via computers and smartphones. Paper reports may offer greater accessibility and familiarity for specific customer segments, including those which still have difficulties accessing digital alternatives (e.g. no computer, smartphone or internet access), or cities which cannot afford to provide in-home displays.

The HWU study adopted a low engagement strategy whereas other studies (e.g. Anda et al., 2013) used more active approaches in an attempt to encourage householders to conserve water via additional communications (e.g. a more visible program launch or local community engagement event, or phone calls to participants during the trials). Therefore, the impact of HWUs on water consumption might be increased if a higher engagement strategy were implemented. The present study showed the potential impact of a low-cost strategy for a water utility involving limited additional interactions with the participants.

The analysis of the smart water meter data in the HWU study revealed some interpretation and analysis by householders will be required since not all relevant information will be available to the utility (see Kempton and Layne, 1994 for a parallel in the energy literature). For example, zero and low consumption days may be difficult for a water utility or data analyst to interpret. However, the respective householders would be better placed to interpret unusual usage (e.g. due to them being away). Similarly, any changes in occupancy (e.g. due to changes in family circumstances) would be unknown to the utility. These fluctuations in activities will influence water consumption and might need to be considered when viewing and comparing water-use data. This issue was exemplified in one evaluation survey comment that "it would be useful to know the dates that the evaluation of use was carried out - this would allow the household to adjust its use for holidays etc." Alternatively, the more continuous and complete data that is made accessible, the greater may be the capacity for householders to detect important influences on their water use. The presence of unusual events, which can distort averages within a short measurement period (e.g. just two weeks), could be less significant if data is collected during a longer period, or indeed continually. However, the inclusion of dated feedback for shorter periods could be a low-cost improvement to the HWU program.

Finally, analytical challenges identified via the HWU trial are of acute relevance to handling the data that is currently being generated by other applications of smart water metering and water sensors. Accompanying this rapid growth of data availability are the challenges of data cleaning and exploratory data analysis, which precede the application of advanced analytics. Therefore, issues we detected with the more manageably sized HWU study's data sets will also need to be considered when analysing the data sets which are now emerging through larger scale implementations of smart water metering.

4.5. Conclusions

The HWU study investigated the potential role for detailed water-use feedback via smart water metering and end-use analysis. The study's mixed method approach involved an original combination of smart meter data and end-use analysis in conjunction with a householder evaluation survey to analyse the role for the paper-based intervention medium.

The evaluation survey showed detailed household-specific water-use information (i.e. end-use breakdown, neighbourhood comparison, end-use metrics and customised tips) was well received by participating householders. Householders expressed value in monitoring their water use via the HWUs and in being able to identify opportunities to save. Awareness of water use increased considerably among HWU recipient households and many reported concrete behaviour changes. These observations suggest a role for customised, detailed water-use feedback, at least for some if not all customer groups. Clearly, further work is required to optimise approaches and understand target audiences to enable a more significant contribution towards residential water conservation.

Quantitative analysis, which was limited to snapshots of data collected pre- and post-intervention, initially signalled 8% savings in water consumption relative to the control group, but this could not be confirmed as statistically significant. Therefore, how significant effects on consumption can be achieved clearly requires additional research involving larger sample sizes and/or more extended measurement. Future work is also required to more fully understand the types of information required by householders to better manage water use, and how householders interact with and interpret these. This would inform the water industry of how best to meet these information demands through smart water metering technologies and associated information services to maximise the potential for water conservation.

Smart water meters are now rapidly being rolled-out in Australia and internationally; increasingly with data resolutions suitable for end-use analysis. However, to date, relatively little data has been disaggregated, so the opportunity for its communication to household customers remains largely unexploited. International conferences are currently demonstrating progressive improvements in smart grid technologies and smart meter data collection, storage, transmission, analysis and communication. Their exploitation may help enable end-use feedback in future, such as provided in the HWU approach and/or via online mediums, and thereby involve customers more fully in the new opportunities being afforded in the digital age.

Finally, the marked variation in household water use found among the study households reinforces that household water use is a complex phenomenon with multiple forces in play. As more data becomes available through more extensive smart water metering and end-use analysis, further research may support a greater understanding of these complex factors to further inform water demand intervention policies.

Acknowledgements

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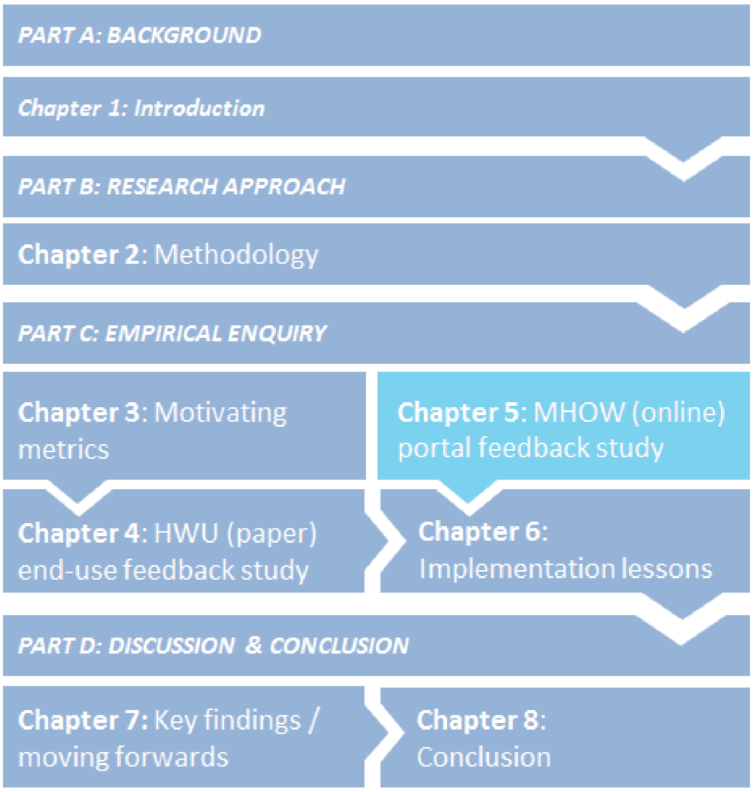
Chapter 5: My Home Our Water — Online portal feedback study



Chapter preface

This chapter comprises of two main parts. The first part contains Paper III entitled 'Online water-use feedback: household user interest, savings and implications', which is preceded by a paper preface. The second part contains the analysis and results of the post-intervention evaluation survey which was conducted to evaluate the MHOW online feedback portal.

Paper preface

This chapter includes a re-formatted co-authored journal submission which is currently under review. The full bibliographic details of the paper, including all authors are:

Liu, A., Giurco, D., Mukheibir, P., Mohr, S., Watkins, G., White, S. 'Online water-use feedback: household user interest, savings and implications', submitted manuscript.

Statement of contribution

Ariane Liu effectively took over as the MHOW project lead from December 2013 onwards and coordinated the activities leading up to the launch of the MHOW online portal. Ariane Liu coordinated the data collection and analysis and wrote the paper. The statistical analysis was provided by Steve Mohr. Damien Giurco and Pierre Mukheibir provided supervisory guidance and reviewed drafts of the paper. Graeme Watkins and Stuart White also reviewed the paper.

Acknowledgements are due to: Chenxi Zeng (MidCoast Water), and James Riddell and Robert Yin (Outpost Central) for their collaboration during this study. Thanks are also due to Thomas Boyle (who initially was the MHOW project lead) and Candice Delaney (ISF) for their contributions to the study and portal design and to Ian Chong for design work. The involvement of the household study participants is also gratefully acknowledged.

Research highlights

The research article highlights included in the submission of the article are as follows:

- This study reports the longer term impacts of an online water-use feedback portal
- Water use was analysed one year pre- and one year post-intervention with login data
- Measured over one year the intervention group saved 24.1 L/hh/d (4.2%)
- Regression analysis found significant savings related specifically to portal logins
- Significant short-term effects of logins persisted 42 days averaging at 63.1 L/hh/d

Online water-use feedback: household user interest, savings and implications

Abstract

Smart water metering together with advanced information and communication technologies create expanded opportunities for the feedback of consumption information to householders. Few studies have shown the impacts of consumption feedback via online household water portals. Moreover, longer term impacts and the persistence of savings over time have not been explored, neither has the relationship between water-savings and actual engagement with online water-use feedback. This paper reports on the impact of online feedback provided via a smart water metering trial involving 120 households in New South Wales, Australia. Near-real time feedback was provided to half of the sample (i.e. the intervention group), while the remainder served as a control group. Water consumption data was collected for one year pre- and one year post-intervention and analysed in conjunction with login data collected during the post-intervention year. Measured over the course of one year, the intervention group as a whole saved an average of 24.1 L/hh/d (4.2%). Importantly, however, regression analysis showed that significant savings achieved by active users related to portal login activity, whereby significant short-term effects persisted for 42 days, averaging at 63.1 L/hh/d. The article concludes with a discussion of the implications of the results for research and practice.

Keywords

Smart metering; Feedback; Online portal; Water conservation; Sustainable water; Water savings.

5.1. Introduction

5.1.1. New opportunities via smart water metering and the internet

Water resources management has seen a generational shift from a focus on supply side augmentation towards a greater consideration of demand-side options to meet projected demands for water (Dawadi and Ahmad, 2013; Turner et al., 2008; White et al., 2006). The search for effective demand management policies is of particular interest to water authorities under water stress, either seeking to delay supply augmentations or facing water shortages including conditions of drought. New technologies may offer hopeful promises, but the interactive behaviours of users has been recognised as equally influential in ultimately determining impacts on water consumption (Beal et al., 2013b; Stewart et al., 2013).

Smart water metering presents new opportunities for improved collection and analysis and communication of water consumption data to monitor and manage usage. Despite rapid growth in the market of smart water metering technologies, including in Australia (Beal and Flynn, 2015), the extension of smart water metering to incorporate household feedback is lagging behind these wider deployments (Boyle et al., 2013; Liu et al., 2015b). At the same time, however, a variety of advanced information and communication technologies exist which can be used to communicate feedback far beyond what is currently practised.

The internet provides a convenient platform to convey consumption information to end-consumers, as well as to managers of water resources. Online portals can be used to provide feedback to householders on their consumption of water in near real-time, and enhanced with additional features, or information, such as on how to save water at home. Online mediums offer the advantage of access via any web-enabled device, at the convenience of users, whether at or outside of the home, and further permit interactivity e.g. with other households.

While new opportunities are presenting themselves via smart water metering, including expanded means for improved feedback to end-consumers, research particularly investigating the impacts and usage of online feedback currently remains very scarce. Understanding householders' use of advanced feedback is important, as water utilities remain reluctant to invest time and financial resources in new approaches and services without the confidence that householders will value these new technologies and services. In addition, utilities also need to understand the likely impacts of more detailed feedback on water consumption patterns and behaviours and the potential contribution towards improved water resources management.

In this study, smart water meters were installed on 120 residential properties New South Wales (NSW), Australia to analyse the impacts of the provision of detailed water-use feedback on household water consumption. Half the households were provided with feedback via an online water consumption portal, whereas the remainder served as a control group. Portal usage was measured via a website user change log and Google Analytics ™. Statistical analysis of the smart meter data collected for one year pre- and one year post-intervention was used to test for quantitative impacts on water consumption.

5.1.2. Research objectives

This paper reports on the impact of householder access to a custom-built online water consumption portal, My Home Our Water (MHOW), which provides detailed feedback on household water use in near real-time. The research analyses portal usage and both short- and long-term changes in household water consumption.

The key objectives of this research are to:

1) Determine use of the MHOW portal in terms of householder logins and the use of its various features.
2) Compare longer term water consumption between the intervention and control groups during the first year pre- and post-intervention.
3) Evaluate the water-savings potential of actual access to MHOW by comparing the changes in relative water consumption of active portal users against the control group.
4) Analyse how household water savings vary according to portal logins over time.

The research outcomes provide water authorities and governing bodies with empirical and qualitative evidence on the impacts of online household water consumption feedback.

The paper proceeds as follows: Section 2 briefly describes the theoretical background of the current study. Section 3 describes the trial in detail, including the feedback provided. Section 4 presents the results and section 5 concludes with a discussion of study limitations and implications of the results for research and practice.

5.2. Theoretical background

Published research on householder interest and usage of online water consumption feedback portal opportunities and its impacts remains very scarce. Moreover, longer term impacts and the persistence of savings over time have not been explored, neither has the relationship between water-savings and actual engagement with online water-use feedback. Hence, there is a need to enrich the existing literature to address these knowledge gaps. This section discusses (i) how theory suggests feedback might work; (ii) approaches to feedback; (iii) the distinction between short- and long-term impacts; and (iv) the application of different evaluation methodologies.

5.2.1. How feedback works

Literature on consumption feedback proposes a number of theoretical mechanisms by which feedback might change consumption behaviours. The 'information-deficit' model of rational behaviour (Burgess et al., 1998; Wilhite and Ling, 1995) suggests that when imperfectly informed consumers are provided with new information, they will systematically evaluate alternative courses of action and respond in a way that pursues their self-interest. It is assumed householders will revise their consumption behaviours or upgrade appliances to pursue financial (or other) gains. However, rational models ignore cognitive limitations of consumers to process and evaluate information and alternatives, and to act accordingly. In addition, consumers respond unconsciously, with automaticity using mental short-cuts e.g. habits and routines, as well as emotionally (Jackson, 2005).

Attitude-behaviour models, such as the Theory of Planned Behaviour (Ajzen, 1991), suggest that feedback may specifically change consumers' attitudes towards their consumption, which in turn leads to changed behavioural intentions and then behaviours. However, applied literature repeatedly reports an 'attitude-behaviour' or 'attitude-action gap' and that for various reasons actual consumption behaviours may not conform to attitudes or intentions (Kollmuss and Agyeman, 2002). Therefore, impacts of feedback on consumption may be moderated by various other influences beyond those purported by rational behaviour models.

5.2.2. Approaches to feedback

Explanations for the way in which feedback works tend to point towards a role for educating consumers and increasing awareness in order to inform their behaviours. However, particular approaches to feedback can vary widely. Liu et al. (2015) proposed characterising feedback in terms of its *content, medium of communication, frequency and duration*, and *context.* For example, the *content* of feedback can be presented in very different ways with respect to the measures, resolution, reporting periods, comparisons, presentation style and interpretations, whereby the choices adopted in each application of feedback are likely to shape its impacts (see Liu et al., 2015).

A mix of feedback strategies may be adopted in an attempt to achieve a greater impact by targeting different mechanisms. Bonino et al. (2012) distinguish between *antecedent* and *consequent strategies,* in which the former aim to induce user behaviours, and the latter inform users after the behaviour has occurred. So, rather than simply providing (previous) consumption information, additional strategies such as goal setting via a target or budget can be introduced in parallel. Greater levels of information detail (e.g. end-use resolution, fine grained time steps, or tailored advice) may also help consumers to more easily identify water-saving behaviours (Fielding et al., 2013; Liu et al., 2013). In each case, the choices adopted in the design and provision of feedback involve varying underlying assumptions as to how feedback might work and thus target different methods of informing consumers of their consumption behaviours. Also, the *medium of communication* presents different opportunities and limitations. For example, online mediums particularly offer the advantages of user interactivity and greater flexibility for multiple representations of data.

5.2.3. Impacts of feedback over time (rebound-effects) and long-term success

Impacts of water demand management interventions including consumption feedback may vary, or more specifically, diminish over time. According to the Technology Acceptance Model, usage of a technology (e.g. an online portal) will depend on its acceptance, defined as a function of its 'Perceived Usefulness' and it 'Perceived Ease of Use' (Davis, 1986). Relating to this theory, Martinez-Torres et al. (2008) point out a relevant distinction between first use and continued use of a technology as a measure of long-term success. Therefore, on the one hand, initial and continued usage of an online water consumption feedback portal may vary over time, according to its acceptance among householders. On the other hand, actual (behavioural) responses to the provision of feedback via the portal may also vary over time. In particular, household water consumption savings may be linked to actual usage and exposure to feedback via specific acts of logging on to the feedback.

Various studies have reported on the possibility of rebound-effects, in which initial consumption savings return to pre-intervention levels over time. Possible explanations for this phenomenon can be found in studies involving energy in-home displays (IHDs), which reported information fatigue, with devices 'fading into the background'; and household users have been described as simply losing enthusiasm and interest over time (Faruqui et al., 2010). However, overall empirical results on the persistence of feedback effect are mixed in the energy sector (see Schleich et al., 2011). More long-term research has particularly been called for, noting that most residential energy feedback studies lasted less than 4 months (and many much less than this) (Van Dam et al. 2010); with Buchanan (2014) elucidating that "it is crucial that data is collected over a long enough period of time to control for initial novelty effects and to allow for long-term energy use adjustments to be revealed". The same need generally applies to the water sector and specifically across different types of feedback mediums.

Limited longer term analysis of interventions using alternative feedback mediums in the water sector has also shown mixed results on the persistence of savings. Some interventions targeting household water use via paper-based feedback mechanisms found short-term reductions which did not appear to continue in the longer term, particularly after feedback ceased (Fielding et al., 2013; Liu et al., 2016). By contrast, Davies et al. (2014) recently reported long-term savings in household water-use via an IHD measured over 5 years.

Specifically regarding online water-use feedback, an early study in Dubuque, US, which also involved smart metering and an online portal, measured a 6.6% decrease in water consumption over 9 weeks among participants relative to a control group (Erickson et al., 2012). The study extrapolated savings for one year on the basis of these short-term impacts, but in the absence of an understanding of how savings might vary over time, it may not have been reasonable to assume the same savings would continue. Other similar projects involving online water portals for the provision of feedback are currently being developed or deployed elsewhere. However, these are either in their infancy, or their results have not been reported publicly, so more work is required to understand impacts of online feedback over time.

In modelling post-drought 'bounce-back' in water consumption, Giurco et al. (2013) suggested that while water usage behaviours (e.g. shower length) may relax after water-use restrictions are lifted, an accelerated installation of efficient appliances (e.g. water-efficient shower heads) can help limit this effect. Therefore, the persistence of household water-savings impacts through feedback may also depend on whether they derive from behaviour change or the installation of more water-efficient appliances.

Based on available literature, reductions through an online household feedback portal may only be short-lived, with consumers reverting to pre-intervention behaviours and consumption levels over time. This may depend on portal usage and hence the continuity of actual access to available feedback. While the longer term impacts of water-use feedback interventions generally require further investigation, especially more work is required to understand the role and impact of online feedback mechanisms over time and relative to portal usage.

5.2.4. The role of different evaluation methodologies

Analyses of the impacts of a variety of different types of feedback on household consumption vary widely in terms of the methodologies applied. Naturally, some differences in evaluation methodologies arise from the study design and associated limitations, for example, whether or not the evaluation involved comparison with a control group; and participant and control group sample sizes. Some studies adopted a pre-post design, only reporting descriptive statistics at the end of the trial (Erickson et al., 2012; Petersen et al., 2007); and such approaches may lack the robustness of other studies which additionally report inferential statistics. There is also a tendency to analyse how consumption changed among participants from when the feedback intervention began and then for the aggregate period which the trial lasted, in some cases as short as just several weeks (e.g. Erickson et al., 2012). In general, there is little in the way of analyses of how impacts on consumption might change over time and particularly immediately after actual access to feedback (rather than just after access is granted, but not necessarily utilised). This is also the case for feedback trials involving an online feedback portal.

In short, a review of the literature reveals a clear need for longer term analyses of impacts involving an intervention and control group to investigate relative changes in consumption over time and relative to logins, rather than just before versus after the intervention date and rather than for all intervention group households, irrespective of whether or not they accessed available feedback.

5.3. Material and methods

5.3.1. Study context

The study was conducted within the local government areas of the Greater Taree City Council and the Great Lakes, approximately 320 kilometres north of Sydney, Australia, where some 37,000 households are supplied by MidCoast Water (MCW). MCW currently operates five water supply systems in the area and facing projected demand from 50,000 households by 2050 (MidCoast Water, 2015) is thus in pursuit of greater efficiencies in both water supply and use in order to defer capital expenditure on new infrastructure. It is within this context that the potential role for residential smart water metering and the provision of detailed water-use information via an online portal is explored.

5.3.2. Study design overview

A total of 120 households were recruited into the study which involved an intervention and control group. Following recruitment, installation of Outpost WASP loggers at the recruited residences took place during the last quarter of 2012 so the loggers could collect baseline smart meter data throughout 2013. The loggers were initially set to collect household usage data at 1 min intervals and to transmit the consumption data overnight via the internal SIM card and use of the 2G mobile phone network. Due to transmission issues all were replaced with 3G. After installation, baseline surveys were distributed to collect additional data on the householders and their water consumption. In parallel, during the baseline year, My Home Our Water (MHOW) was developed as the online intervention medium for the study that would be provided to the intervention group.

The main study hypothesis was that households in the intervention group (i.e. with access to My Home Our Water), would show relative reductions in household water consumption in comparison to the control group. In addition, it was hypothesised that intervention group households would achieve greater reductions immediately following access to MHOW; and that measured savings impacts would decrease with time from households' last logins.

5.3.3. Study participants

The 120 participants were recruited from six towns in the study region, namely, Taree, Wingham, Forster, Tuncurry, Tinonee and Cundletown (see Figure 21). Recruitment into the study was via informed consent and targeted households whose water consumption over the previous year was in the 50th to 75th percentile of users, which had a meter capable of digital pulsed output. A multi-staged process of letters was used to invite householders to be part of the study. Participants agreed to the installation of a smart water meter that would collect their water usage data more frequently and the possibility of being selected for the online provision of more detailed feedback about their water consumption.

Figure 21 Maps of study locations in NSW, Australia

Source: Map data ©2015 Google

In terms of demographics, the study sample was characterised by an average of 2.78 (SD = 1.38) occupants per household. 6% were single occupancy, the majority (55%) had two occupants, 9% had three occupants, 19% had four occupants; and 11% had five or more occupants. Median pre-tax household income was within the AUD $30,000 – 59,999 bracket; with 24% earning less than AUD $30,000, 33% earning AUD $30,000 – 59,999, 22% earning AUD $60,000-89,999, 10% earning AUD $90,000-119,999 and 10% earning $120,000 or more. Baseline household survey respondent gender was 53% male and 38% female, with the remainder not reported. Median and mode respondent age was within the 44-64 age group category. 51% were in employment, 41% were retired, and 2% were unemployed. One third (33%) had achieved less than a high school certificate and 13% completed high school. One quarter (23%) had attended a trade school, 13% had earned a diploma, 9% an undergraduate degree and 5% a postgraduate degree.

In terms of household water-appliance stock, 78% of each households' toilets were all dual-flush and only 7% still had only single-flush toilets. The remainder had a mix of dual and single flush toilets. 59% of households were completely fitted out with water-efficient shower heads, 26% did not have any efficient shower heads; and the remainder again had a mix. 70% of households had a top loader washing machine, while 30% had a front loader.

5.3.4. Intervention groups

After approximately one year of pre-intervention consumption data collection via the smart meters, households were randomly assigned to either the intervention or control group (each N=60). A matched pairs design approach was applied to take baseline water consumption, household occupancy and specific locality (town) into consideration and ensure broadly similar study subgroups. After establishing the matched pairs, households without internet access were initially assigned to the control group for the sake of resource efficiency (i.e. to first provide access to households with internet access given the moderate overall sample size). In addition, several households with technical issues (e.g. with data transmission) were assigned to the control group, since it would not be possible for these householders to view their consumption data if they were part of the intervention group. A further balance was attempted between the intervention and control groups in terms of the assignment of households (n=104) for which baseline survey data was available.

Independent *t*-tests confirmed that there was no statistically significant difference between the ensuing intervention and control groups in terms of average baseline consumption, household occupancy rate or locality. Average consumption was 602 L/hh/d (SD = 251) for the intervention group, and 571 L/hh/d (SD = 242) for the control group (t = 0.692; df = 118; p = 0.490). Excluding households that did not complete the voluntary baseline survey, the average occupancy rate was 2.84 (SD = 1.41), and 2.71 (SD = 1.35) occupants, respectively, for the 55 intervention and 49 control group households for which baseline survey data was available (t = 0.449; df = 102; p = 0.654). A Fisher's Exact Test showed furthermore that the intervention and control groups did not differ in terms of their compositions according to the localities of their households (Fisher's exact test, p = 0.345).

5.3.4.1. My Home Our Water

During the baseline period, MHOW was developed between the Institute for Sustainable Futures, MidCoast Water and Outpost Central. The interface design was published under the terms of the Creative Commons Attribution-ShareAlike 3.0 Australia Licence, which allows the freedom to share and adapt the work (see https://creativecommons.org/licenses/by-sa/3.0/au/). Since the portal was specifically created to serve as a customer interface for householders to view and track their water consumption, professional design services were enlisted in order to achieve a visually appealing communication style for residential customers (rather than water utility operators or commercial customers, which previously available information services had targeted). The MHOW 'Dashboard', 'My Usage' and 'Ways to Save' screen is shown in Figure 22.

Figure 22 My Home Our Water internet portal – Dashboard, My Usage, and Ways to Save screens

Information provided via the portal includes customisable displays of historical water use, comparisons with others, a water-budget feature, access to various usage alerts, and an interactive water-saving pledges facility. The portal content therefore adopted a variety of feedback strategies. The key features of MHOW are summarised in Table 12.

Table 12 Features of My Home Our Water

Key feature	Description
Dashboard page	The dashboard provides a quick overview of household water use. - Users can view total litres consumed during the last 30 days and a daily average for the same period. Users can compare these figures with the same period last year. - Users can compare their consumption with efficient and average benchmarks based on households with the same number of occupants. - Users can further see how their household ranks among all households included in the trial. - Users can set a monthly budget and track progress. - Users can be alerted to the detection of possible leaks.
My Usage page	- Users can view their household's water consumption using selectable reporting periods (i.e. daily consumption for the last 30 days, the last week, month or year; or in hourly intervals for each day). - Totals can be viewed in litres, dollars, or bucket measures of unit. - Comparisons are also provided with homes in the neighbourhood and an efficient home.
Ways to save page	- An interactive savings pledges facility shows users a menu of different ways to save water in the home and garden. - Users can select what they are already doing or have done, and make additional pledges to save according to the tips provided. - Users can also view what pledges are being made by other users.
My profile page	Users can update the number of occupants, set-up or adjust the monthly water budget, and select and manage water usage alerts (i.e. sign up for email and/or SMS alerts relating to leaks, usage relative to neighbours, and usage relative to their water budget).
Help/FAQ page	Users can find more information about the project and answers on how to use the portal. Contact details are provided for feedback or additional help.

5.3.4.2. Intervention

From January 2014 onwards, the 60 intervention group households, were granted access to the MHOW portal. Intervention group households were sent a mail information pack which contained a cover letter, project information sheet and a fold-out brochure explaining the portal's key features. A magnetic postcard was also provided as a handy reference to the customer's unique login details. The username was printed on a sticker which was affixed to the postcard; whereas the password sticker was sent via separate mail in order to improve water customer security.

Some communication issues were experienced initially with some loggers failing to transmit new data and a consequent unavailability of new data for householders to view via MHOW. Therefore, login reminders were put on hold until these issues were rectified. After logger issues were resolved, either via replacements or switching over to the 3G network, postcard reminders were delivered to all 60 intervention group households in September 2014 to encourage them to log on to the portal. Finally, an email reminder was sent in October 2013 to 51 out of the 60 households for which an email address had been provided.

5.3.5. Data collection

Data collection followed a mixed methods approach involving both quantitative and qualitative data. Consumption data was collected via the smart water meters throughout the trial. Initially loggers were set to log usage at 1 min intervals, however, during the trial a few were adjusted to record at 5 min intervals in order to preserve battery life and increase the reliability of daily data transmission. Quarterly billing data was also collected, as per MCW's regular billing cycles.

Householders were requested to complete a paper based baseline survey in November/December 2012, with a follow-up with non-respondents in January 2013. The survey collected information on the households' water appliance stock, water-related practices, attitudes towards conservation and new technologies, information preferences and household demographics. To encourage participation, a $50 AUD incentive was offered to survey participants.

A short online survey was additionally administered to portal users using a series of web light-boxes for completion at their first login. The survey was completed immediately prior to access to household consumption information and captured householders' water-use awareness and confidence in their awareness, interests, and intentions and perceptions of potential ability to save. Analysis of this data is presented in Liu et al. (2014). Users were also given the option to register for various usage alerts and/or to set a monthly water budget (or they could return to these features at a later date).

User change logs and Google Analytics ™ were also set up in order to collect data on householder interactions with the portal. Google Analytics ™ was used to track portal logins, page views and time spent within the portal. The user change logs recorded responses to the first login survey as well as registrations for the various alerts, pledges, and profile settings.

This paper focuses on the impacts of the portal in terms of portal usage using the change logs and Google Analytics ™ data; and the quantitative impacts on consumption by analysing the smart meter data in conjunction with the portal login data.

5.4. Results

5.4.1. MHOW portal usage

5.4.1.1. Portal logins

Portal usage data collected via Google Analytics ™ and the user change log signalled that a first key challenge was getting householders to take the initial step of actually logging on to MHOW for a first time. Out of the 60 intervention group households, 20 appear to have attempted to log on; and only 17 (28%) appear to have actually proceeded to view their household's water use data[7]. Revisits to the site proved to be a further challenge and half of the user households only logged on once. One quarter logged in just twice. A couple of households used the portal every few months; and a couple of users logged in relatively frequently (i.e. once or twice every few weeks).

5.4.1.2. Usage of portal features

Portal usage data collected via Google Analytics ™ recorded where active users spent their time in the portal. Figure 23 shows the data collected for the first year of access (excluding page views and time spent completing the first login survey). The data in Figure 23(a) show that in terms of page views, the dashboard was viewed most (103 times; 41%), followed by the 'My Usage' page (75 times; 30%) and 'My Profile' page (42 views; 17%). Figure 23(b) shows how much time users spent on each page. Here 'My Usage' came top (1806 minutes; 59%), followed by the 'Dashboard' (626 minutes; 20%). Comparatively little time was spent on the 'Ways to Save' page or engaging with 'My Pledges'.

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[7] One additional household responded to an offer to have water usage alerts set up via a phone call to MCW's Customer Service, rather than by logging on to the portal. This household's registration for alerts is included in the analysis in section 5.4.1.3.

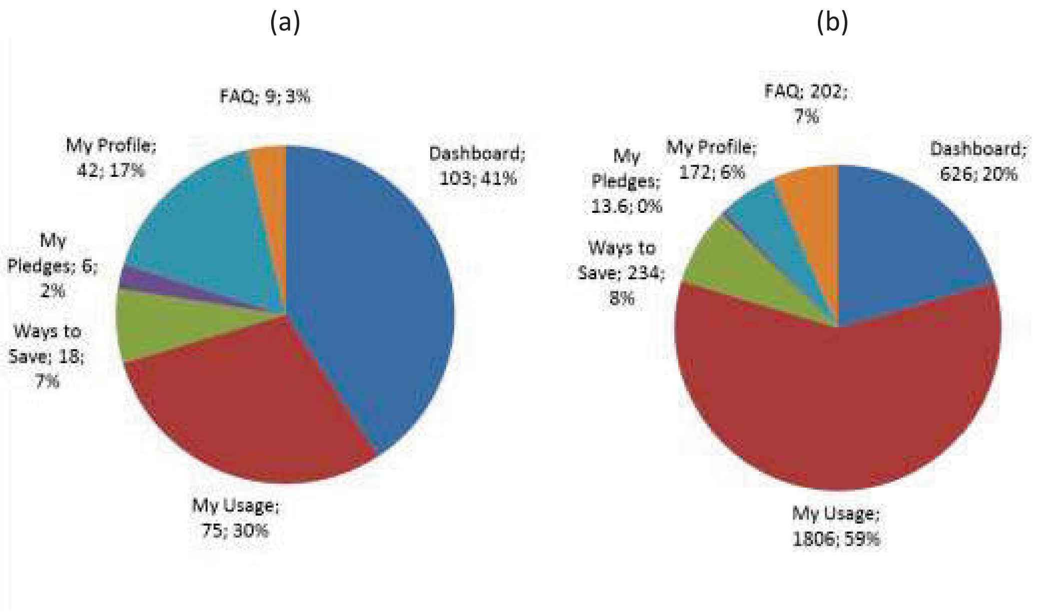

Figure 23 (a) Number of page views by page; (b) Time spent on each page in minutes

5.4.1.3. Usage alerts registrations

Water usage alerts were found to be very popular among householders that engaged with the portal[8], with 15 out of the 18 households (83%) signing up for one or more kinds of alerts. Only three user households did not take advantage of the opportunity to sign up for alerts. Among the alert options, portal users showed particularly strong interest in 'leak alerts' (78%). There was also significant interest in 'water budget alerts' (50%), which were activated once 80% of a household user's self-determined budget for water was consumed. By contrast, there was relatively low interest in the 'neighbour alerts' which were activated when a user's consumption was over 80% that of its neighbours (22%). In terms of communication medium, email alerts were generally preferred over SMS alerts. A variety of sign-up patterns were also noted varying between mediums and alert types. For example, some users selected all three alert types for one communication mode; both email and SMS for the same type of alert; or only leak or budget alerts).

Importantly, by registering for usage alerts, participant householders would remain alerted to high water usage even if they did not use the portal regularly, or even make a second website visit. Analysis of a three-month sample log of user alerts showed that nine users (50%)

[8] This data includes the household that registered for alerts by contacting MidCoast Water Customer Service rather than directly logging on to the portal.

received one or more usage alerts during this period. In particular, eight households received leak alerts (44%), four received budget alerts (22%), and two received neighbour alerts (11%). Some households received multiple alert types almost simultaneously, which demonstrated the interrelationships that exist between the alerts. That is, a leak can cause water use to exceed a user's monthly budget and to activate the neighbour alert if use becomes relatively high.

5.4.2. Smart meter data preparation and analysis

Smart meter data logged at either 1 or 5 minute time-steps for January 2013 to January 2015 was downloaded in bulk in the form of csv files for analysis in R (3.1.2) and Python (2.7.6). The two years of data were then checked for consistency with quarterly billing data records collected via conventional water meters.

Raw consumption values (logged at the 1 or 5 minute time-steps) were aggregated to 30 minute periods for more manageable analysis and then cleaned to remove implausible values. Outliers were defined as either (i) days for which less than 80% of the 48 half hourly records existed; or (ii) days where consumption was greater than 3 standard deviations above the mean. This process of data checking produced a 'cleaned' smart water meter data set.

Figure 24 shows importantly that the cleaned smart meter data and the billing data records generally aligned. Panel (a) shows that in the majority of cases where the data differed, the smart meter had recorded less than the conventional meter. The box plot in panel (b) compares the value of consumption reported via the smart meter relative to the billing data against categories for the percentage of billing period days that the smart meter recorded positive consumption during the quarterly billing period. There were 119 household quarters for which the smart meter had operated on 100% of the corresponding billing period days, and only 4 of these records had an error between the two measurements of more than 5%. For the 356 household quarterly records where the smart meter recorded data for at least 90% of the days, two thirds (237) were within a 10% error margin.

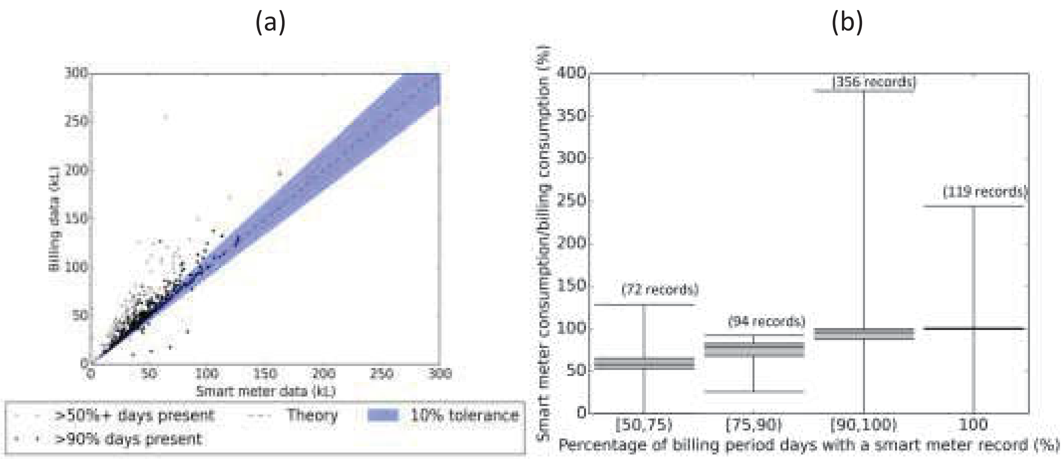

Figure 24 Comparison of smart meter and billing data

Notes: Data represent water consumption for each household's billing quarters.

To estimate water savings, quantitative analysis was performed on both the raw and cleaned smart water meter data sets. Importantly, all results on the raw data were insignificant. Therefore, all data presented in the results section are based on the cleaned smart meter data.

Descriptive statistics were performed to compare water consumption for one year pre- and one year post intervention between the intervention and the control group. As not all intervention group households used MHOW, a distinction was drawn between 'active' and 'inactive' participants, depending on whether or not the individual households actually logged in and used the portal. A Welch's t-test was used to test for the statistical significance of differences. Analysis of the overall intervention group was therefore complemented with separate comparisons for the active and inactive intervention group participants with the overall control group. Ordinary Least Squares (OLS) regression analysis was subsequently performed to analyse the impacts on daily household water consumption of logging on to MHOW.

5.4.3. Impacts on consumption over one year post-intervention

During the baseline year, intervention group households consumed an average of 571.7 L/hh/d, while the control group consumed a slightly lower average of 548.1 L/hh/d. Compared to the pre-intervention year, water consumption had decreased in the intervention group by 41.9 L/hh/d (7.3%) to 529.8 L/hh/d. Consumption decreased less steeply in the control group by 17.8 L/hh/d (3.3%) to 530.3 L/hh/d. Therefore, the intervention group achieved a significant overall average saving of 24.1±13.6 L/hh/d (4.2%) relative to the control group.

A Welch's unequal variances t-test performed on the mean daily consumption data of each of the intervention and control group households divided into pre- and post-intervention periods of 365 days either side of the intervention date (7 January 2014) signalled these average daily savings were highly significant (Welch's t = 3.47, df = 720, p = 0<0.001).

In terms of portal usage, the user change log showed that out of the 60 intervention group households, only 17 (28%) appeared to have actually logged onto MHOW and actually accessed their detailed household water consumption information on either one or more occasions. Additional analysis on the resulting subgroups of active versus inactive participants and relative to the pre-intervention period showed absolute consumption savings among active participants (20.3±19.7 L/hh/d or 3.7%) were only slightly lower than among inactive participants (25.7±14.6 L/hh/d or 4.4%). This insignificant difference suggested that the chosen period of comparison of an entire year post-intervention against one year pre-intervention was potentially too long relative to the actual persistence of significant effects of portal logins on water consumption. Therefore, the subsequent regression analysis was required to explore the impacts of portal usage over time. The significant savings detected among inactive participants may also be explained by the well-known Hawthorne (or observer) effect in which research participants modify their behaviour as a result of their awareness of being observed. While also possible among the control group, this may have been even more relevant to the inactive participants since they were provided with access to the portal and additional associated customer engagement. Interestingly, this act of provision and engagement seem to have been sufficient to reduce water consumption in the longer term, regardless of whether the portal and available feedback were actually accessed.

5.4.4. Regression analysis

This section presents the results of the OLS regression analyses used to estimate the impacts on consumption relative to portal logins and the duration of impacts over time. The analyses make use of all the logins made by each active intervention group household. A first set of regressions estimated the presence of savings among active participants relative to controls over time and explored their underlying functional structure. A second set of regressions estimated short- and long-term savings and the duration of these impacts relative to when households last logged in to MHOW.

5.4.4.1. Duration of water consumption savings and functional form

To detect the presence of savings among active participants relative to controls a regression equation of the following form was estimated:

$$
\begin{aligned}
\text{ActiveParticipantCons} \\
\approx\ & \text{AverageControlCons} + \text{range\_0\_14} + \text{range\_14\_28} + \text{range\_28\_42} \\
& + \text{range\_42\_56} + \text{range\_56\_70} + \text{range\_70\_84} + \text{range\_84\_98} \\
& + + \text{range\_98\_112} + \text{range\_112\_156} + \text{range\_126\_140} \\
& + \text{range\_140\_154} + \text{range\_154\_182} + \text{range\_182\_210} + \text{range210\_252} \\
& + \text{range\_252\_294} + \text{range\_294\_336} + \text{range\_336\_378}
\end{aligned}
$$

Where *ActiveParticipantCons* is the consumption on a given day of an individual active participant; *AverageControlCons* is the average of the control group's consumption on the given day; and *range_X_Y* are 0, 1 dummy variables for specific periods of time which incorporate when households last logged on to MHOW. (These ranges were set to increase slowly from 14 to 28 and then to 42 day periods, with 14 day periods chosen initially to provide sufficient data for the regression model).

Table 13 shows this first set of regression results, which estimate water savings of active participants relative to controls for ranges of days that incorporate when households last logged on. For example, active participant households that logged on to MHOW, saved an average of 54.1±37.9 L/hh/d relative to the control group, when their last login was between 0 and 14 days ago.

Savings achieved by active users relative to controls continued to be statistically significant at the 95% confidence level for each period up to 42 days after logging in to MHOW, after which the difference in household water consumption generally became insignificant for subsequent ranges of time, and it is assumed that any significant savings or losses in the period after 70 days were caused by noise.

Table 13 Water consumption savings relative to when households last logged in to MHOW

Term		Value (L/hh/d)	Confidence %	P value %
Intercept		150.5±43.8	99.99	<0.01
Avg. Control Consumption		0.7±0.1	99.99	<0.01
Active Participant Consumption (for last login range of days)	(0,14]	-54.1±37.9	99.49	0.52
	(14,28]	-68.3±47.1	99.55	0.45
	(28,42]	-57.6±48.0	98.11	1.89
	(42,56]	-18.0±50.1	51.79	48.21
	(56,70]	-20.5±51.6	56.42	43.58
	(70,84]	26.1±55.2	64.64	35.36
	(84,98]	-45.7±58.2	87.63	12.37
	(98,112]	-39.3±58.4	81.30	18.71
	(112,126]	-86.4±60.2	99.51	0.49
	(126,140]	-43.9±67.1	80.01	19.99
	(140,154]	-91.3±70.9	98.84	1.16
	(154,182]	1.7±49.9	5.31	94.69
	(182,210]	37.3±51.0	84.85	15.15
	(210,252]	-5.7±50.1	17.56	82.44
	(252,294]	227.7±58.6	99.99	<0.01
	(294,336]	83.7±60.3	99.35	0.65
	(336,378]	63.4±78.1	88.83	11.17

Note: The last login range of days (0,14] means households that last logged on to MHOW somewhere between 0 and 14 days ago (inclusive).

5.4.4.2. Short- and long-term impacts on consumption relative to time from last portal login

The second set of regression results, which distinguish between short- and long-term impacts are shown in Table 14. The regression equation estimated is:

$$\text{ActiveParticipantCons} \approx \text{AverageControlCons} + \text{IntvDateDummy\_Xlong} + \text{IntvDateDummy\_Xshort}$$

Where *ActiveParticipantCons* is the consumption on a given day of an individual active participant; *AverageControlCons* is the average of the control group's consumption on the given day; *IntvDateDummy_Xlong* is a 0, 1 dummy variable, the value is zero if:

- The day is before the intervention date (7^{th} of January 2014) or
- The household has logged onto the portal in the last X days

Otherwise the value is 1. Similarly, *IntvDateDummy_Xshort* is a 0, 1 dummy variable where the value is zero if:

- The day is before the intervention date (7th January 2014) or
- The household has not logged onto the portal in the last X days

Otherwise the value is 1, which means the household has logged onto the portal in the last X days. Note the regression has been performed on 365 days prior to the intervention date and 365 days post the intervention date, with the intervention date excluded.

These results estimate how long impacts on household water consumption lasted relative to when households last logged on to the portal. By contrast to the previous set of results, the savings reported here refer to the entire period since last login. Short-term savings are estimated by *IntvDateDummy_Xshort*, which measures relative daily household savings within X days of last logging on. Long-term savings are estimated by *IntvDateDummy_Xlong*, which measures additional savings lasting beyond X days.

Based on the previous set of savings estimates over time a significant effect of logging onto MHOW appeared to last 42 days. Table 14 reports regression results for X = 42. The short-term savings parameter estimates for *IntvDateDummy_Xshort* estimate average savings across the 42 day period of 63.1 ± 27.4 L/hh/d.

The long-term savings parameter estimates for *IntvDateDummy_Xlong* were statistically insignificant. The results suggest that (significant short-term) consumption savings were approximately consistent for up to 42 days, after which savings underwent a step-change and became noise.

Table 14 Regression results: short- and long-term water consumption savings among active participants when last login was up to 42 days ago.

X	Intercept		AverageControlCons term		IntvDateDummy_Xshort		IntvDateDummy_Xlong	
	Term	Conf.	Term	Conf.	Term	Conf.	Term	Conf.
42	125.9 ± 42.8	99.999	0.8 ± 0.1	99.999	-63.1 ± 27.4	99.9994	-0.8 ± 19.0	6.9

5.5. Discussion and conclusion

5.5.1. Discussion and implications

The aims of this research were to explore use of the MHOW portal which provided detailed household water-use feedback, and to analyse the longer term quantitative impacts of provision of access, including how water-savings vary with portal logins over time.

Results showed significant savings among the intervention group (with access to the MHOW portal) relative to the control group, using data collected one year pre- and post-intervention. However, results from the OLS regressions indicated that the magnitude of the savings varied significantly over time. These results highlighted the importance of accounting for the actual engagement of householders with feedback interventions, here, actually logging on to and accessing water-use feedback MHOW.

Another important contribution of the present research is its elevation to the discussion of the issue of evaluation methods in the calculation of savings impacts from feedback interventions. Generally greater caution needs to be exercised in measuring savings impacts. This work demonstrated that even comparing an entire intervention group against the entire control group can be simplistic, since not all intervention group households may actually experience the intervention (i.e. logon to MHOW and access their household water consumption information). This paper took a first step towards addressing the previously unexplored opportunity to make use of actual login data capturing which participant households actually logged on and when.

Since the literature on household resource consumption feedback calls for more long-term studies of impacts, another important contribution of the MHOW study lies in its collection and analysis of household water consumption data for one year pre- and one year post-intervention. The results showed that impacts varied significantly with time, and additionally that it could be inaccurate to simply extrapolate savings calculations based on very short intervention studies, as has been done previously.

Results indicated that access to MHOW reduced household water consumption significantly in the short term, with significant effects lasting up to 42 days (6 weeks). Significant long-term effects of logging on to the portal were not detected. Rather, highly significant short-term effects led to the appearance of longer term significance (among the intervention group relative to the control group, though not between active and inactive participants), even when spread over one year. These results lend support to findings of rebound effects after paper-based water-use feedback interventions ceased (Fielding et al., 2013).

A key policy implication of these research results for urban water policy makers is that access to online household water-use feedback via smart water metering can be an effective means of reducing household water demand among active users, particularly in the short term. However, the result that two thirds of intervention group households never actually logged on to the portal, which corroborates the US based finding of Erickson et al. (2012), reinforces that this particular approach is unlikely to reach all segments of the population. Additionally, given participation in the MHOW study was voluntary and the participants were self-selecting, they may also have had a greater interest in the topic.

In order to achieve greater impacts, policymakers will have to consider how to better engage household water consumers. Returning to Liu et al. (2015a), the context may be of particular importance. For example, different water pricing conditions or the application of water-use restrictions in times of drought which incentivise or enforce conservation may raise the attractiveness of this type of technology. The short-term savings following actual logons particularly suggests MHOW as an effective approach in times of water crisis in which individual information via a portal could be promoted alongside awareness campaigns via alternative media.

Specific enhancements to the design of the portal, and the wider program could potentially improve its overall acceptance, usage, and therefore impacts. In terms of the design of the portal, multiple opportunities remain for optimisation. Further evaluative work will shed light on the householders' experiences with the portal. The program itself also leaves room for possible improvements. Open questions remain regarding the approaches taken with the launch and subsequent communications with participant householders. The approach taken in the MHOW study was a relatively low engagement strategy. A more highly visible launch or greater marketing communication type efforts might have created additional interest to engage with the portal both among active and inactive users.

5.5.2. Study limitations

The MHOW study has a number of important limitations. Particularly, a number of technical issues were experienced that were later rectified during the trial. Communication issues with the loggers initially meant that data could not always be uploaded as scheduled. This may have had a negative impact on portal usage since it meant that updated data might not have been available for householders to view. Login reminders sent via post and email were also delayed due to the issues with the loggers. Therefore, these initiatives may have had a less fruitful impact than may have otherwise been the case. Regarding usage alerts, there were also some initial issues with alerts not actually being sent out to customers. This again meant that householders (at least in earlier phases) were not as well informed of their water use as they had expected. With the correction of these aforementioned technical issues, it is plausible that the use and impacts of MHOW could potentially have been greater than was experienced in this first trial of the portal. It is also possible, that the particular sample may have had greater interest in the opportunity to receive online feedback and might also be more forgiving of the initial technical issues that were experienced during this trial.

5.5.3. Implications for future research

Further research on the role for online household water-use feedback portals is required to address a number of important issues. First, more work is needed to understand how to promote engagement with the portal, both for active as well as inactive users. Regarding non-participation, questions arise as to who are the inactive users and what are the reasons for them not using the portal. There may be specific barriers which can be overcome to reach certain segments. For example, water usage alerts via alternative mediums such as email, SMS or post might be required to reach different population segments. To illustrate, when householders were later given the opportunity to register for usage alerts by calling MCW customer service (rather than by logging on to the portal), this led to one additional participant calling and registering in this manner.

Stimulating engagement for portal users also remains a challenge. The majority of users logged in to MHOW relatively infrequently over the first year of access. The development of the interactive ‘My Budget’ and ‘My Pledges’ features represented attempts to additionally deploy antecedent strategies of goal setting and making commitments. However, these features do not appear to have been used very actively, and only by a minority of users. The question therefore remains as to other ways to motivate interest (Liu et al., 2015b) and to engage users e.g. via gamification and more social networking functions (as in Erickson et al., 2012).

A second question relates to where the MHOW type feedback technology might be of most use; especially if continuous and widespread engagement is unlikely to be achieved. To explore the specific role that a portal such as MHOW could play in drought conditions, further research is required. This would ideally involve a larger scale deployment in order to explore impacts with a wider demographic.

A third opportunity for future research lies in combining the kinds of household water-use feedback provided by MHOW into an integrated household online platform, which incorporates relevant data from other sources (e.g. weather data), other forms of consumption feedback (e.g. on household energy consumption) and/or with additional practical functions (e.g. billing). Greater technology acceptance, participation and responses among household consumers may be promoted by suitably increasing the levels of information and functionality provided.

5.5.4. Conclusion

In the current study, MHOW was used to provide detailed online water consumption feedback to householders in near real-time. The analysis of impacts using data collected for one year pre- and one-year post intervention contributed towards wider calls for longer term research into consumption feedback. Analysis of water-savings in conjunction with portal login data further enabled a novel exploration of the duration of impacts. The results showed that active MHOW online portal users achieved significant water-savings relative to the control group in the short term (i.e. 6 weeks) following specific acts of logging on to the portal.

More extensive and continuous engagement remains a key challenge for policy makers and future research is needed to maximise the potential involvement of end-customers in the opportunities for improved water-use management afforded by the age of smart water metering. Further research is specifically required in terms of promoting household user engagement, understanding the potential role for online feedback portals in varying contexts (e.g. drought) and in expanding functionality.

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5.6. My Home Our Water evaluation survey results

This section reports on an additional analysis of the MHOW online portal, which draws on an analysis of the results of the evaluation survey. The survey was administered to MHOW (online) study participants to understand the usage, interests and experiences of householders. Changes in behaviours, water-using infrastructures, and awareness are reported in a similar manner as was conducted for the previous HWU (paper) study. The results also show the appeal of the portal and how it and its features were valued by participant householders, and suggestions for improvement.

The evaluation survey was completed by a total of 18 households, of which 12 (67%) had logged in and used the portal and 6 (33%) had not, thus providing views from both users and non-users. Section 5.6.1 reports on impacts. Section 5.6.2 reports on the appeal of the MHOW portal. Section 5.6.3 reports on challenges and possible improvements. Section 5.6.4 concludes.

5.6.1. MHOW evaluation of impacts

Impacts were evaluated in terms of (1) the reach of the MHOW portal and motivations for usage; (2) changes implemented to household water-using infrastructure; (3) behaviour changes enacted by portal users; (4) responses to alerts; and (5) changes in householder awareness of their water use.

5.6.1.1. MHOW program reach and motivations for portal usage

The previously reported analysis of MHOW portal usage and login data (in Paper III) showed approximately one third of participants actually logged on to use the portal. (This figure is based on an analysis of one year data for the initial group of 60 participant households). The evaluation survey also investigated *who* used the portal to assess its reach, whether the portal was discussed and why the portal was used to understand why it reached certain households.

Usage of the portal was mostly confined within the respective households, with only one participant having shown the portal to other relatives who were not members of the immediate household. The portal was not shown to friends, neighbours or colleagues. The portal led to discussions within most user households (83%) and with some non-user households (50%). Topics discussed are shown in Table 15.

Table 15 Discussion topics among user and non-user households

Topics discussed among users	Topics discussed among non-users
Usage, leaks and lack of warnings	Must get on and have look
The way the system operated with my family	The value of having access to knowledge about our water usage.
Just that it had been set up	Not much
Mostly in a curious way about how it can be used for us. Used to check for leaks mostly.	
If it had any relevance to our usage of water.	
Outcomes	
Water leak alerts	
Being able to compare our usage.	
The portal and the information available	
How much information we would learn	

In terms of why householders used the portal, all users reported this was "To have a look at my household's water use". Half also reported doing so "To participate in the 'Know Your Water' Project run by MidCoast Water" and "To see how much information is available via the portal". Only one third of users logged on "To find ways to save water". No one logged on just "To try a new internet service" and no other reasons were mentioned.

5.6.1.2. MHOW impact: household water-using infrastructure changes

Several physical changes to household water-using infrastructure were reported via the evaluation survey. Four out of the 12 user households (33%) reported having installed one or more new water-efficient appliances after accessing the MHOW portal. These changes involved a total of three new shower heads, two new toilets and two new washing machines. In addition, seven user households (58%) reported having repaired leaking household water-infrastructure through reports such as "[we] fixed dripping taps" or [we] "replaced leaking washers".

5.6.1.3. MHOW impact: behaviour changes

In terms of everyday water-using behaviours, six out of the 12 user households (50%) that responded to the evaluation survey reported changing their behaviours after accessing the MHOW portal. Specifically, four households reported using taps differently e.g. "[we] controlled the amount of times used" and "[we] made sure all taps are turned off". Five households reported saving water in the shower. Three explained they were taking "less time" or "shorter showers" and one had "installed a 4-minute timer". As for toilet flushing, four households reported changes with explanation such as "[we] always use [the] half flush when required" or "we didn't flush every time, only when required". Three households used their washing machines more conservatively, through “fuller loads” or reducing usage frequencies to “once a week” or “…a bit less”.

5.6.1.4. Responses to water usage alerts

Five of the respondent households reported having received water-usage alerts, seven did not, and one user had not registered for any. Positive responses to the alerts were: “[I] fixed [a] leaking toilet cistern”; “[Due to a] leak alert [I] turned [the] garden tap off”; and “initial leak alerts gave me the ability to repair a serious water leak in the line to the house and have the line replaced. This enabled us to avoid an ongoing cost”. This last beneficiary also commented however that “there appears to be ongoing problems with all alerts except [the] neighbourhood alert”. Another respondent also shared that “[I] had to contact MidCoast Water to stop sending alerts as I could not find any good reason for the alert. I could not find any leaks and the meter had not move[d] when checked over time”; while another reported that the “suspected leakage was due to the number of visitors staying with us”.

5.6.1.5 MHOW impact: changes in awareness of household water use

A comparison of the baseline survey (conducted at recruitment) and post-intervention evaluation survey showed a marked increase in householders’ awareness of their water use after logging on to the MHOW portal. Changes in awareness scores are shown in Figure 25. Post-intervention awareness of household water use for MHOW portal users was much higher than their scores pre-intervention, and furthermore higher than the pre-intervention scores of both non-respondents to the evaluation survey, as well as non-users that did respond.

After accessing the MHOW portal, the vast majority of respondents agreed they knew where most water was used in their homes. The vast majority also agreed they felt informed about their household’s water use, almost double the share prior to logging in. Knowledge of consumption by household appliances also increased with almost twice as many users reporting this post-intervention. Almost three-quarters felt they knew their household’s water use after logging in, as compared with under 60% pre-intervention. From the surveys, an altogether positive impact on awareness was reported, which suggested the MHOW portal served well as an educational tool among users.

Interestingly, reported awareness scores among non-users also increased for three measures (i.e. knowledge of where most water is used, knowledge of household appliances’ water use, and feeling informed of household water use). However, general reports regarding knowing household water use remained constant.

Comparing pre-intervention awareness levels, scores were found higher among those who later logged on to the MHOW portal than those for both non-users and non-respondents. Overall, MHOW may have been used by households with slightly higher perceptions of their household water-use awareness.

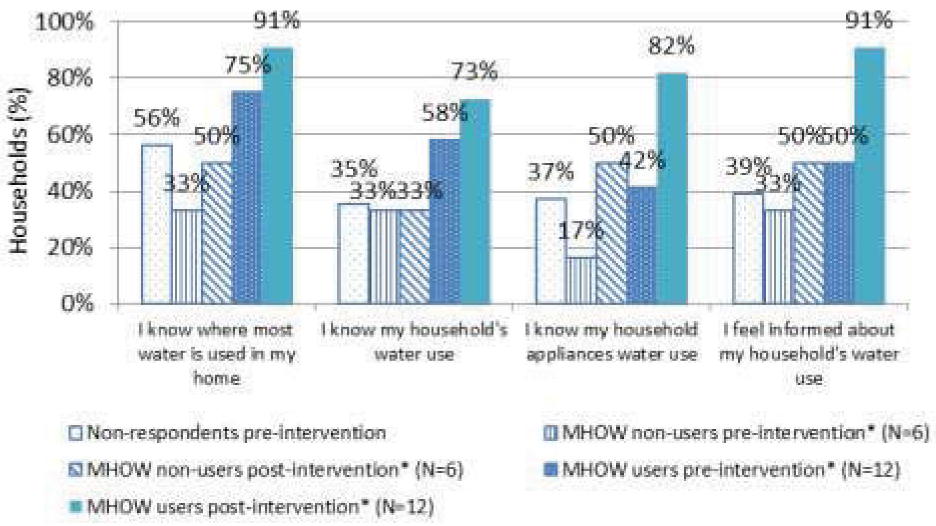


Figure 25 Awareness of household water-use pre and post-intervention.

Data presented is based on the share of respondents who either agreed or strongly agreed with each statement. Households which did not respond to the evaluation survey (non-respondents) are shown at baseline only. Pre- and post-intervention scores for evaluation respondents are shown separately for MHOW portal users and non-users.

5.6.2. MHOW program appeal

The evaluation survey also measured the appeal of the MHOW portal both among householders that logged in as well as those that did not. Appeal was assessed by asking householders (1) how much they liked MHOW overall; (2) how they valued access in terms of willingness to pay; and (3) how they rated the different features.

5.6.2.1. Like of MHOW

Across all respondents almost three-quarters agreed with the statement 'I like MHOW'. The vast majority of users (>90%) agreed, of which one third strongly agreed. Among non-users, ratings were lower, with one-third liking MHOW and two-thirds expressing neutrality. No household reported disliking the portal.

The availability of the MHOW portal produced a variety of different reactions across different household participants. For example, one respondent's evaluation was highly positive: "Make [it] an ongoing service - the benefit to the community is extensive" also commenting "this tool is very useful"; whereas another simply stated: "[I'm] not interested in the application.

5.6.2.2. Valuation of access to MHOW: willingness to pay

To understand householders' valuation of access to the MHOW portal, the survey included questions on willingness to pay to gain an indicative valuation.

The MHOW evaluation survey results showed that half of respondents expressed a positive willingness to pay for access to MHOW. Estimates on the value of access to MHOW for one year ranged from AUD 1.00 to AUD 20.00, with an average of AUD 5.75 across all the survey respondents. Among those who were not willing to pay, one respondent commented: "…if a charge is forthcoming for this service I would want it removed". Portal usage was unrelated to estimate of WTP, with the most active users also unwilling to pay any amount. Also, three non-users also gave positive estimates of willingness to pay, ranging from AUD 1.00 to AUD 10.00, with one apologising for not having logged on, commenting: "lack of time and simply forgot sorry".

5.6.2.3. Evaluation of portal features

The evaluation of specific MHOW portal features asked householders to assess specific features provided on individual portal pages (i.e. dashboard, 'My Usage', 'Ways to save') as well as the alerts. The evaluation of the features on the dashboard and 'My Usage' pages provided an understanding of householders' preferred metrics for household water-use feedback.

The specific features of the MHOW portal dashboard were evaluated in terms of their usefulness. The results are shown in Figure 26. The leak detection feature was evaluated most highly with 71% rating this as very useful. 'My usage this time last year' was also rated as very useful by more than half of respondents. All other features were rated as very useful by about 30-40% of respondents. All features were considered either somewhat or very useful by more than three-quarters. Only the budget feature and the efficiency measures (household ranking and efficient home comparisons) were rated as not useful by any households.

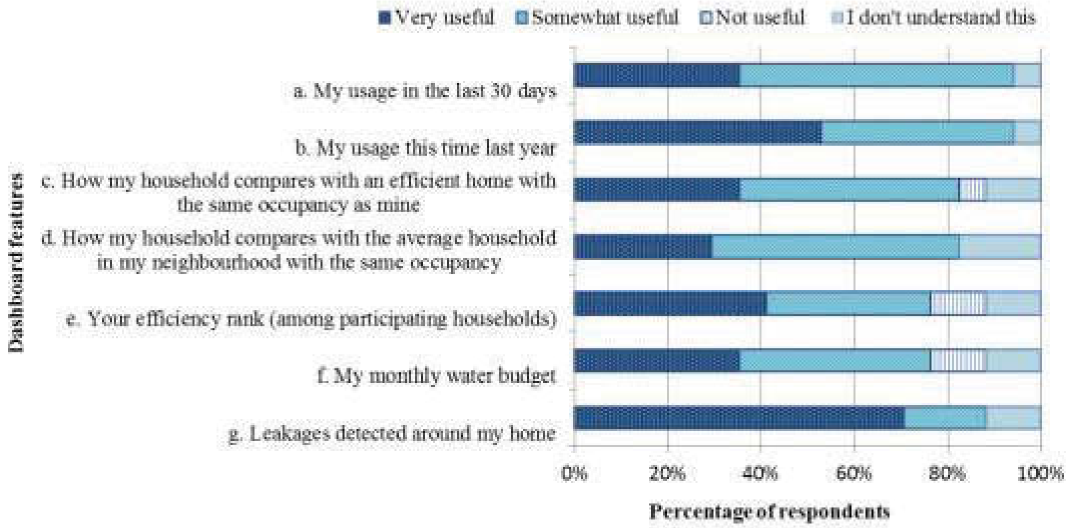


Figure 26 Householder evaluation of the MHOW portal's dashboard features

Based on the three alternative metrics provided for household water consumption on the "My Usage' page, householders were asked in which terms they would be interested in seeing their water usage described. 82% responded with dollar terms, 71% with litres, and none selected buckets or other terms.

Householders were asked to evaluate the alternative displays of household water consumption presented in the 'My Usage' page and the opportunities presented by the 'My Pledges' page in terms of their usefulness using a rating scale from 1 to 5, where 1 = "Not at all useful", and 5 = "Very useful". Householders were also requested to evaluate the various leaks alerts available via MHOW, in terms of interested they were (again rating from 1 to 5, where 1 = "Not at all interested", and 5 = "Very interested". The combined results are shown in ranked order in Table 16 for comparative purposes.

Leak and budget alerts were most highly ranked, followed by customised end-use information (not currently available via MHOW). The displays of household water consumption were generally rated more highly than the opportunities that the 'My Pledges' page offered. Among the alternative displays of household water consumption, daily consumption blocks were preferred over monthly blocks. Household respondents showed greater interest in viewing their own usage, rather than comparisons with others (e.g. efficient households or average neighbours). Householders also preferred to pledge or track their own water-saving activities than to see what others were doing.

Table 16 Ratings of My Usage, Ways to Save and Alerts

Feature	Mean	Std. Deviation	Min	Max
Leak alert (signalling that you suspect my household has a leak)	4.35	1.115	1	5
Budget alert (signalling when my household reaches 80% of a self-determined water budget for the month)	4.06	.899	3	5
Customised information, like in the pie chart, showing a breakdown of the uses of water in my home *	4.00	1.000	2	5
Daily consumption blocks shown in a view of the last 30 days	3.94	1.144	2	5
Daily consumption blocks shown in a view by month	3.94	1.144	2	5
Daily consumption blocks shown in a view of the last 7 days	3.82	1.131	2	5
General information, like in the pie chart, about where water is typically used in homes in my area	3.65	1.272	1	5
Monthly consumption blocks shown in a view for the 12 months in a year	3.59	.870	2	5
The opportunity to track which water-savings activities I am doing/plan to do	3.59	1.064	1	5
My household compared to the average household	3.35	1.222	1	5
My household compared to an efficient household	3.29	1.312	1	5
Neighbourhood alert (signalling when my household's water-use exceeds average use in my neighbourhood	3.29	1.213	1	5
The opportunity to pledge new water-saving actions	3.24	1.033	1	5
The opportunity to see what other households are pledging	3.18	1.185	1	5
A water-savings pledges feature	3.12	.993	1	5

* End-use information was not available in MHOW, but this question was introduced to understand how householders might value this information were it to be made available.

5.6.3. Challenges and possible improvements

Householders were asked if they experienced any technical difficulties logging on to MHOW; if they experienced any difficulties in trying to save more water at home; what their suggestions for improvement were; and finally their thoughts in terms of who should be given access to MHOW and which kind of access they would prefer in future.

5.6.3.1. Technical issues

Householders were asked if they experienced any technical difficulties logging on to MHOW. Two households reported having forgotten their passwords and one reported not having a computer at home. No one selected having forgotten their username, having no internet connection, or that the process to log on was lengthy, which were also provided within the possible response set.

5.6.3.2. Barriers to saving water

Householders were asked if they experienced any difficulties in trying to save more water at home and asked to select a response(s) from a list (adapted from the 'Who cares about the environment survey' (Department of Environment and Conservation NSW, 2007)). The results are show in Table 17. The majority of respondents selected "I'm doing what I can" as a challenge to saving more water. Habits were selected by almost half. Personal factors and "already doing the water-saving tip(s) or water-saving alternative(s) were also selected by about one-third of respondents.

Table 17 Barriers to saving more water in the home

Barrier	Frequency
I'm doing what I can	10
Habit	7
Personal factors (e.g. laziness, forgetfulness, didn't think about it)	6
I'm already doing the water-saving tip(s) or a water-saving alternative(s)	5
Impact of others (e.g. children)	4
Time / convenience	4
New water-saving actions are a low priority for my household	2
Economic / cost factors	2
The water-saving alternative is less satisfactory	1
Lack of information	0
Technically not feasible	0
No other alternative	0
Lack of opportunity	0
My activities don't impact the environment	0
Other (please specify):	0

5.6.3.3. Suggestions for improvement

Householders were reminded that MHOW is currently only a trial service and asked if there is any way to make MHOW more accessible; if they had any suggestions for improvement; if there is a better way to communicate detailed water use to their household; and anything would have made them log on more frequently.

The vast majority of households could not think of a way to make MHOW more accessible. The only two suggestions were: "make [this] an ongoing service – the benefit to the community is extensive" and another suggested 'allow [this] as part of water billing', which signalled an opportunity for combining information communications. In terms of possible improvements, the only suggestion was to "make sure the alerts work at all times as expected". Regarding communications, 80% thought there was no better way to communicate detailed water-use information with comments such as “no – this tool is very useful’ and [I’m] happy with the system”. Two respondents both proposed communicating water-use via email, with one specifically proposing “via monthly email”. One respondent suggested “expand the information on the bill”. Regarding improving login frequencies, more than half had no suggestions. Others suggested “more rebates”, “regular communication via email” and “suspected leaks[s]” would have made them log in more. One commented that “remembering to do it” would help and another explained “Time and priority. Sorry we have been slack all round!”

5.6.3.4. Access for whom and of what kind?

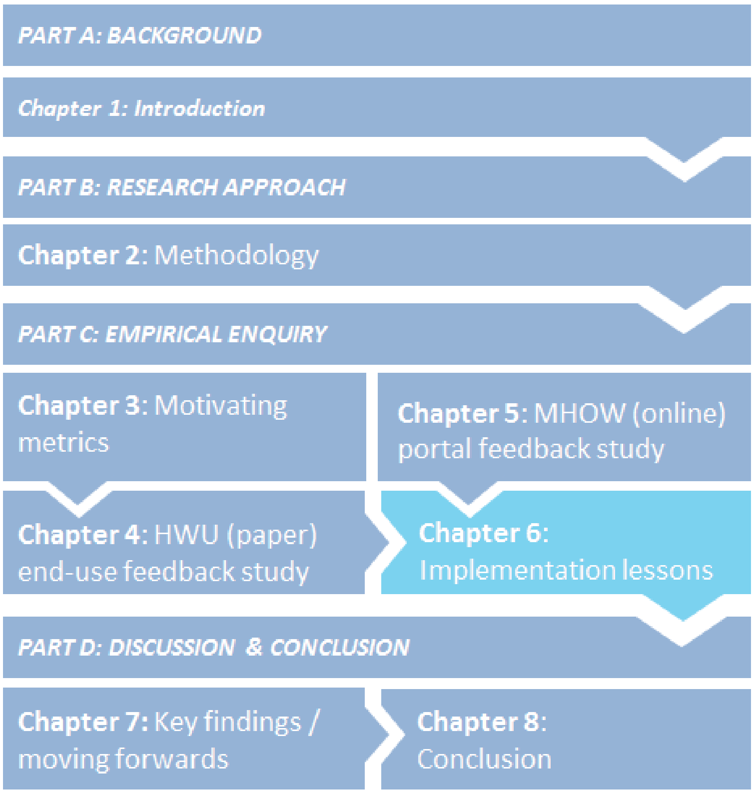
44% of respondent households selected that access should be given to ‘every household’; 56% however felt that access should only be given to ‘interested households’. No one selected ‘only high water-using households’ or ‘no households’.

Householders were also asked what kind of access to the MHOW portal they would be interested in in future. Half selected ‘ongoing and indefinite access’; one third preferred ‘unlimited access during one year’. ‘Monthly’ access was also proposed, as was ‘no access’.

5.6.4. Discussion and conclusion

The appeal, engagement and concrete changes in water consumption observed among some portal users demonstrate effectiveness among some households. However, the current approach is clearly not a ‘one size fits all’ solution; particularly exhibited by the finding that not all households actually took the opportunity to log on to use the portal and many did not continually use the portal (as in Erickson et al., 2012). While it is acknowledged that the sample sizes for the evaluation of the MHOW online portal are small, and it is further unclear how scalable these findings are, the results of the MHOW (online) evaluation nevertheless provide some detailed examples of the variety of possible perceptions of householders regarding the provision of detailed water-use feedback in near real time via an online portal.

Chapter 6: Lessons learned for implementation



Paper preface

The final analysis of this thesis provides a synthesis of key considerations in the design, analysis and implementation of detailed water-use feedback programs in conjunction with SW metering.

This chapter is based on a re-formatted co-authored journal submission. The full bibliographic details of the paper, including all authors are:

Liu, A., Giurco, D., Mukheibir, P. and White, S. (in press), 'Detailed water-use feedback: A review and proposed framework for program implementation', *Utilities Policy*. DOI: 10.1016/j.jup.2016.09.002.

Statement of contribution

Ariane Liu conducted the review of the two pilot studies and the critical review of the literature and wrote the paper. Damien Giurco and Pierre Mukheibir provided supervisory guidance which involved reviewing drafts of the paper. The paper was also reviewed by Stuart White.

Research highlights

The research article highlights included in the paper are as follows:

- Smart metering presents new opportunities to engage householders about water-use.
- Experiences from two household water-use feedback trials are structured.
- The literature on smart metering for water and feedback is reviewed.
- A program implementation framework for detailed water-use feedback is developed.
- Water utilities can target efforts that contribute to sustainable water usage.

Detailed water-use feedback: a review and proposed framework for program implementation

Abstract

Smart water metering (SWM) introduces new opportunities to engage householders about water use based on detailed information. Water utilities must decide how to embrace these opportunities, but remain hesitant due to limited available experience and knowledge, which risks delaying the benefits of involving householders more fully in SWM and more sustainable water consumption. An implementation framework is developed outlining the key strategic, practical and evaluative elements in decision-making for detailed water-use feedback programs by drawing on the literature and first-hand experiences of two feedback trials involving SWM. Existing approaches are reviewed and recommendations are provided to advance more well-considered approaches and realise benefits regarding sustainable water use.

Keywords

Smart metering; Program implementation framework; Water-use feedback.

6.1. Introduction

6.1.1. Smart metering: an opportunity for customer involvement yet a challenge for water utilities

Smart water metering (SWM) and advanced information and communication technologies in the digital age present new opportunities for customer engagement based on detailed and customised information about water usage and efficiency measures (Boyle et al., 2013; Liu et al., 2013). Water utilities, however, face the challenge of deciding how to embrace these new opportunities.

Water utilities demonstrate growing interest in the availability of new SWM technologies through active participation in SWM-related conferences and meetings. According to recent surveys conducted in the US (Neptune Technology Group, 2015) and Australasia (Beal and Flynn, 2015), water utilities expressed significant plans for increasing their SWM-related activities. Interest in expanding SWM to achieve additional customer benefits, including the provision of more detailed consumption feedback (i.e. customised information on how much water is used, when, and how) is also growing. In the US, 50% of surveyed utilities reported the wider opportunity for "improved customer service" as one of the main benefits of SWM (Neptune Technology Group, 2015). However, this interest in detailed feedback still lags significantly behind the wider interest in SWM. In the Australasia region, only 12% of surveyed utilities engaging in SWM projects involved "information sharing with customers" (Beal and Flynn, 2015).

Beyond the concern regarding the return on investment, important barriers to SWM relate to the current lack of information and experience. According to Beal and Flynn (2015), a key challenge to planning SWM projects included "limited industry knowledge from previous smart metering projects". Also, regarding implementing SWM projects, "limited industry experience in rolling out smart metering" was identified as the greatest challenge (Beal and Flynn, 2015). These challenges apply all the more so to detailed water-use feedback programs enabled via SWM, for which there is still less industry knowledge and experience from which to learn.

In practical terms, water utilities have to grapple with many issues that surround the design, implementation, and evaluation of detailed water-use feedback programs and no general guidelines or framework are currently available. In addition, there is no detailed overview of the studies that have been conducted to date, and limited documentation exists concerning how projects were designed and what considerations were taken into account. As a result, water utilities lack a comprehensive understanding of how to provide detailed water-use feedback with SWM. Given this lack of knowledge about relevant issues and approaches, together with the need for clearer business-case evidence, it perhaps is unsurprising that many water utilities currently remain hesitant about SWM implementations involving detailed household water-use feedback programs.

Inaction regarding detailed water-use feedback implementations will limit, or at least delay, the role for householders that are willing to engage more actively in household water management and the new opportunities afforded by SWM in the digital age (Liu et al., in press-a). Active engagement of householders regarding their water use nevertheless remains a potentially important opportunity for promoting sustainable usage and resource management, and various trials have demonstrated water-savings over longer periods of time (e.g. Davies et al., 2014; Fielding et al., 2013). While inaction risks missed opportunities, uninformed action may also result in disappointing outcomes. For example, water utilities risk incurring large sunk investment costs and technological 'lock-in' (obsolescence) to approaches that yield insignificant engagement and impacts. There is thus an important need to identify the key issues for consideration and to review and summarise the state of the art in providing detailed water-use feedback, as well as to offer recommendations based on what is known, along with suggestions for addressing the unknowns.

6.1.2. Research aims

This research builds on collaboration between the Institute for Sustainable Futures (ISF) at the University of Technology Sydney and MidCoast Water (MCW) in New South Wales (NSW) and Griffith University in Queensland (QLD), Australia (2012-2015), which through two distinct trials, explored the role for detailed water-use feedback via SWM to promote behavioural changes toward more sustainable urban water usage. This paper aims specifically to draw out key elements in decision-making for detailed feedback enabled via SWM based on the in-depth experiences of the ISF-MCW research along with a review of the existing literature.[9]

The overarching aim of this paper is to develop an implementation framework that outlines key decision elements to provide practical guidance to water utilities considering detailed

[9] The ability to draw on first-hand experiences through continuous full-time involvement by the first author as a doctoral researcher throughout the three-year ISF-MCW research program is a distinctive feature of this research, offering detailed insight into the many decisions taken, alternatives, practical challenges, and limitations.

customer water-use feedback. The framework can add significant value by bringing the various considerations together at a conceptual and strategic level, particularly at a time when detailed water-use feedback programs are still relatively few in number and guidance to water utilities is much needed. An implementation framework can help utilities plan their own approaches and evaluate the growing number of offerings by managed service providers. While new issues may emerge over time, the present framework represents an important contribution by mapping out key issues identified thus far and can therefore serve as a comprehensive foundation upon which future work can eventually build. The additional discussion of the framework in relation to existing practice further aims to provide a comprehensive and up-to-date overview, with recommendations for research and practice to advance implementations to promote more sustainable water resource consumption. The research thus aims to address important knowledge gaps concerning (i) the issues water utilities should consider when undertaking detailed water-use feedback programs; (ii) the current state of detailed water-use feedback; and (iii) research needs.

In order to justify an investment by water utilities, the cost-effectiveness of detailed water-use feedback would require a detailed assessment, including against alternative approaches to communicating and managing water-use. This is identified as a future research direction, which goes beyond the scope of this analysis and review.

The rest of the paper proceeds as follows. Section 2 describes the research study methods. Section 3 presents the implementation framework for detailed water-use feedback programs enabled via SWM. Section 4 discusses the framework in relation to previous literature, provides recommendations and identifies directions for future research. Section 5 closes by summarising the implications of the research.

6.2. Methods

6.2.1. Research approach

The implementation framework, which provides a detailed overview of the key considerations for the design, implementation, and evaluation of water-use feedback programs in conjunction with SWM, was developed following the process shown in Figure 27.

Figure 27 Implementation framework development process

A review of experiences from our two recent feedback studies involving SWM in NSW, Australia, was used as the starting point for development of a draft of the implementation framework.[10] Our revisiting of the decisions taken and lessons learned was enhanced by a review of the literature on detailed water-use feedback to capitalise on additionally available experiences and increase the validity of the framework.

6.2.2. Two recent detailed feedback studies

Both feedback studies were located within MCW's service area in NSW, Australia, about 320 km northeast of Sydney. The 'Home Water Update' (paper reports) study (n = 68), involved the provision of detailed end-use feedback to household customers via paper-based reports and was undertaken in two small coastal towns, Tea Gardens and Hawks Nest, which have a combined population of 4,449 (Australian Bureau of Statistics (ABS), 2011a). The 'My Home Our Water' (online portal) study (n = 120), involved access to a custom-built online portal providing water-use feedback in near real-time to households in Greater Taree, which has a total population of 46,541 spread across a number of towns and localities (ABS, 2011b). Both studies adopted a mixed methods research approach and involved an intervention and a control group, with smart water meter consumption data (logged at 1 min intervals) and surveys and/or interviews used to assess impacts.

Figure 28 shows a sample 'Home Water Update' paper report and Figure 29 shows screenshots of the 'My Home Our Water' online portal, which serve as examples of recent forms of detailed household water-use feedback enabled via SWM. The interested reader is also referred to Liu et al. (2016, 2015) for more detailed descriptions of the methods and results of the 'Home Water Updates' (paper reports) study; and to Liu et al. (2014) regarding the 'My Home Our Water' (online portal) study.

[10] The first author's 'hands-on' involvement during all stages of both studies (i.e. from design to implementation to evaluation) resulted in rich exposure to the issues and a solid foundation for meeting the present research objectives.

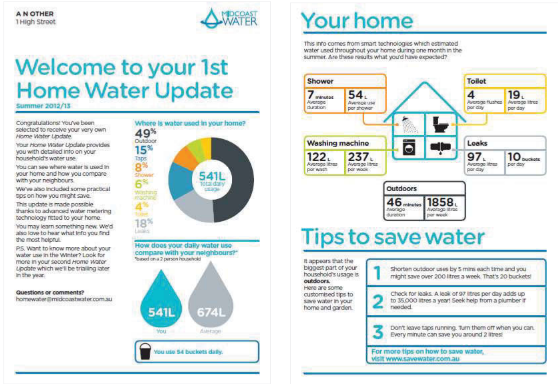


Figure 28 Example of the 'Home Water Update' intervention medium – front and reverse sides

Figure 29 'My Home Our Water' online portal – Dashboard, My Usage, and Ways to Save screens

The experiences and lessons in decision-making drawn from the two cases helped to structure the research at hand. For example, underlying issues were noted relating to who the subjects were, how they were selected, how many there were, what their characteristics were, and so on. One finding was that the 'Home Water Update' study's moderate sample size may not have been large enough to detect statistically significant impacts (Liu et al., 2016). Therefore, the question of sample size, its representativeness, and the conclusions that could be drawn were noted for inclusion in the draft framework. Continuing to the other defining aspects of the studies, in turn, helped to identify additionally relevant considerations for detailed feedback programs.

6.2.3. Implementation framework development

The program implementation framework was developed by identifying defining issues and elements to decision-making encountered during the various phases of our two research studies. These considerations were subsequently organised according to whether they related to the '*Why*', '*When*', '*Who*' or '*What*' of detailed water-use feedback program implementation. These guiding questions have been applied to organise an issue in a variety of other fields including in the social and medical sciences literature (Morris and Teevan, 2009; Sherrod et al., 2002), but not to the design of detailed water-use feedback programs.

We structured the analysis of our case experiences around these core questions. The question of *'Why'* was adopted as concerning the driver(s) or motivation for a water utility to introduce detailed water-use feedback via SWM. '*When*' referred to issues surrounding timing. '*Who*' referred to the target audience and the means for its selection, as well as its location. Finally, '*What*' was taken to refer to the design of the feedback and the adopted approach as well as the adopted means for providing the feedback. It became apparent during this work that these questions were particularly suited to identifying the *practical* considerations related to implementing a feedback program.

Other themes identified as relevant, but not specifically related to one of the four core questions, were noted down for separate organisation later in the framework. These items were later grouped as either *strategic* or *evaluative* considerations that fell outside of the more *practical* issues initially identified. The *strategic* considerations were further organised into four categories: '*Tactic*', '*Technology*', '*Theory of change*' and '*Resources*'. The *evaluative* considerations were further organised into three categories: '*Data collection*', '*Analysis*' or '*Knowledge sharing*'.

6.2.4. Literature review

The results of our literature review and analysis are provided in the Supplementary Information to Chapter 6.[11] Table 18 shows an overview of research studies/implementations organised according to the four *practical* questions (i.e. '*Why*', '*When*', '*Who*' and '*What*').

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[11] The literature review commenced with searches of a number of databases (Elsevier Science Direct, Taylor and Francis Online, IEEE, and Google Scholar) using pre-defined keywords relating to SWM, SWM trials and implementations and the provision of detailed water-use feedback to householders. Combinations of keywords were used including: "smart meter", "smart water meter", "feedback", "information", "water consumption", "household", "residential", "intervention". This search yielded reports of detailed feedback studies in high-quality international peer-reviewed journal articles.

Table 19 shows the literature according to the *strategic* and *evaluative* considerations. and Table 20 shows a detailed overview of information content by study.

To expand the scope of the academic literature review, the applied and grey literature was sourced via web searches. This search yielded various water utility reports and more general water industry-wide reports as well as online industry magazines and other news reports, which led to the identification of additional studies and experiences using detailed water-use feedback via SWM.

We found that most reports of detailed water-use feedback studies focused on presenting the particular approach adopted, which could inform the *practical* questions of '*When*', '*Who*', '*What*' and to a lesser extent the '*Why*'.[12] Many of the choices, possibly a function of the research or program designs, however, were not put into perspective by, for example, discussing why alternative approaches might have been rejected. Left undescribed, it is unclear whether or not these issues were considered, and with which level of detail. By comparing and contrasting different approaches across the literature, it was possible to identify the alternative design options and considerations and to establish strategic-level questions and broader considerations for inclusion in the framework. The literature review also helped us identify broader considerations, including research gaps in feedback strategies.

6.3. Implementation framework for detailed water-use feedback enabled via SWM

Based on our research, Figure 30 graphically presents our program implementation framework, highlighting key considerations in the design of detailed water-use feedback programs involving SWM. The implementation framework is presented as four embedded concentric circles for heuristic purposes. The order chosen here places the *objective* at the centre (detailed feedback for sustainable water-use); with *strategic* considerations in the next circle (theory of change, tactic, resources, and technology); and more *practical* design considerations, concerning the '*Why*', '*When*', '*Who*' and '*What*' questions in the next wider circle; finishing with overarching *evaluative* issues concerning data collection, analysis and the dissemination of results in the outermost circle. Each of the layers and categories in the framework are discussed in more detail in the following section.

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[12] This observation is important and highlights the need for further research into the business case and economics (i.e. costs relative to benefits) of detailed water-use feedback enabled via SWM.

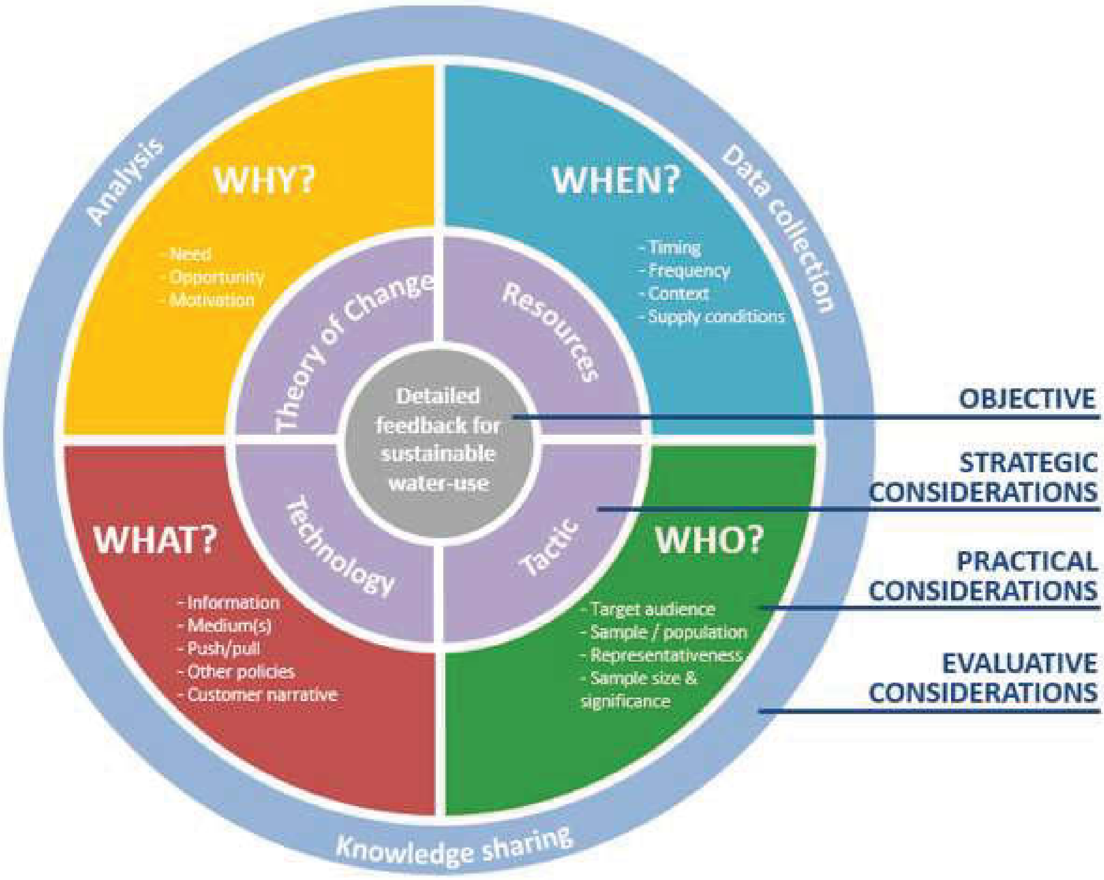

Figure 30 Program implementation framework for detailed water-use feedback programs involving SWM

6.4. Current approaches to feedback and recommendations using the implementation framework

This section presents the various elements of the program implementation framework as developed through our research and literature review. The section aims to provide an overview of the current state of work related to detailed water-use feedback as well as practical advice to guide water utilities to advance SWM and detailed feedback programs in the pursuit of sustainable urban water management. This analysis also signals areas in need of further research. While the business case is not the focus of this work, the framework elements introduced below should also be integral to a detailed cost-benefit analysis of detailed water-use feedback via SWM.

6.4.1. Objective

At the centre of the program implementation framework, the *objective* of ‘detailed feedback for sustainable water use’ is placed. This objective derives from a desire to provide detailed water-use feedback in conjunction with SWM deployment in a manner that aligns with the pursuit of sustainable urban water management.

6.4.2. Strategic considerations

The second innermost, *strategic* level circle includes the ‘*Theory of change*’, ‘*Tactic*’, ‘*Technology*’ and ‘*Resources*’. Here, ‘*Theory of change*’ refers to the underlying beliefs about the relationships between actions (e.g. information provision) and targeted outcomes (e.g. water conservation behaviours). ‘*Resources*’ refers to the human capital, time commitment, and financial resources as well as budgetary and other constraints. ‘*Tactic*’ refers to the approach to be taken in order to reach the goals and objectives (e.g. a trial versus full-scale roll-out). Finally, ‘*Technology*’ refers to the SWM technology, including the metering device, communications between the device and the utility’s system, and technologies required to produce customer water-use feedback.

A ‘*Theory of change*’ concerns the question of what change does the water utility want to bring about and what model is most appropriate in this context. This issue clearly relates to the *practical* consideration of ‘*Why*’, discussed in section 4.3.1 below. Most previous work tends to align broadly with the rational ‘information-deficit’ model (Burgess et al., 1998), which suggests that customer feedback can address gaps in customer knowledge and awareness and promote water-saving behaviours. Other relevant theories of behaviour change include Ajzen’s theory of planned behaviour (Fielding et al., 2013) and community based social marketing (Anda et al., 2013). While it is not suggested that water utilities should be driven by theory alone, the provision of detailed water-use feedback in pursuit of goals has theoretical underpinnings.

Regarding ‘*Resources*’, funding of SWM projects is obviously important. While many water utilities have fully funded their wider SWM projects, external funding contributions (especially funding via federal government grants) have provided important support (see Beal and Flynn, 2015), including for much of the current activity in the area of detailed feedback. Utility workforce skills are another important resource in feedback implementations, and for this, many projects have involved university partnerships to secure additional human capital and ensure robust approaches to evaluation research (e.g. Britton et al., 2013; Fielding et al., 2013).

In terms of the '*Tactic*', approaches differ regarding whether projects begin with a pilot, or with the plan for a full-scale implementation; and whether water utilities have targeted a more 'in-house' solution or opted for an outsourced, 'managed service'. Most research studies have involved SWM and feedback pilot projects. Some have also been opportunistic trials, whereby a need to replace an existing fleet of water meters offered the occasion to trial smart meters (Beal and Flynn, 2015). The role of a strong champion within water utilities favouring their adoption also appears to be a key factor, as was also the case with the two trials with MCW.

Regarding '*Technology*', approaches vary according to the type of SWM, data capture, storage, transmission, and customer communications. In most cases, water utilities have first adopted a particular form of SWM, to which processes of providing feedback have been subsequently added. However, some have taken a more integrated approach, such as Mackay Regional Council (2015), by developing the feedback mechanism (an online portal) in conjunction with their SWM solution. Planning an approach at the start can help ensure suitable SWM technologies are implemented to support feedback (e.g. targeted speed, frequency and resolution) (Liu et al., in press-a). The authors note that in-house approaches may grant water utilities greater control and flexibility over feedback, at least with the initial design, but suggest that any commitment, including to an outsourced service offering, might benefit from negotiated flexibility for adaptations. This flexibility would allow utilities to develop approaches as new insights emerge on better ways to present feedback and to promote customer involvement (for example, to go beyond the observed participation rate of around 30% in Erickson et al. (2012) and Liu et al. (2014)). In all cases, water utilities must be prepared for data communication issues, including with signal strength, and plan how to address them in advance since this was a recurring theme in recent research (e.g. Doolan, 2010).

6.4.3. Practical considerations

The next layer of the circle is dedicated to specific *practical* requirements of detailed water-use feedback programs. Here, the '*Why*' element considers the water utility's needs and motivations for introducing detailed feedback, and how the SWM opportunity might satisfy these, i.e. "what's in it for them?" The '*When*' element refers to the timing of feedback, its frequency and duration as well as the context and water supply conditions (e.g. normal supply or scarcity as during droughts). The '*Who*' element requires identification of the target audience, whether population wide or targeting specific segments. Regarding sampling representativeness, sample size, and statistical significance all require consideration. The '*What*' segment refers to the information feedback; the communication medium; who is directing the approach; how the information-feedback will relate to other policies (e.g., water demand management, rebates, pricing etc.); and the customer narrative to be used.

6.4.3.1. Why

SWM has many potential advantages for water utility resource and infrastructure planning and operational management, including automated meter reads and possibilities for improved network monitoring and management through increased data availability (Boyle et al., 2013). A logical next step for utilities is to more directly extend the benefits of SWM to customers, including householders, by providing them with access to detailed water-use information created and engaging them more actively in water management. In a recent research priority paper, the Water Services Association of Australia (WSAA) also noted customers are demanding more from water utilities (e.g. self-service and individual control) as a result of technology trends; and the need to involve customers in decision-making, and for greater integration into 'customers' digital lifestyles and permanent connectivity' (WSAA, 2016).

While SWM affords all water utilities with new opportunities and challenges, each circumstance is unique. Therefore, the main '*Why*' for embracing the SWM and particularly detailed water-use feedback could vary, at least initially. For example, water utilities under water stress may face a more urgent need to reduce water demand to defer capital expenditures and avoid a costly supply augmentation, so programs to induce greater household water conservation could be more appealing (Turner et al., 2010).

An alternative motivation for introducing detailed feedback could be the availability of funding resources, either internally or through government incentive programs and support (see Beal and Flynn, 2015). Another possible motivation concerns the 'reputational benefits' that many be conferred by establishing oneself as a leader or 'best-in-class' among water utilities through innovative customer engagement or a sustainability strategy (Young and Mackres, 2013), which could promote the standing of the water utility both with its customers and within the water industry.

Each water utility faces different needs, and so to do their customers. Detailed feedback could be linked to the needs of certain customer segments (e.g. to specifically target high water users or hardship customers struggling to pay their water bills) since detailed water-use feedback has been found to improve water literacy by reducing the discrepancy between actual and perceived water consumption (Beal et al., 2013).

6.4.3.2. When

Regarding '*When*' to provide detailed water-use feedback, the issues of timing, frequency, and context are particularly relevant. A difference exists whether targeting efficient water use (i.e. using the same amount of water to perform the same function) or conservation (i.e. using less water).

Previous research has shown that water-savings achieved through detailed feedback can change over time and diminish when feedback ceases (e.g. Fielding et al., 2013). We further found that savings effects are linked to specific acts of engagement, such as logging on to an online feedback portal. Therefore, the timing and continuity of feedback are important.

Regarding context, there may be specific conditions under which special conservation efforts may be required, such as under supply constraints (in which case the question of '*When*' will be closely linked to '*Why*'). In times of drought, householders could be encouraged via a campaign to log on to view their consumption information online or mailed end-use consumption reports to advise them about specific water-saving opportunities. These approaches have led to both water-saving behaviours and investments in more water-efficient appliances even under normal supply conditions. However, such approaches would require water utilities to plan ahead and have the SWM and feedback infrastructure in place in order to be 'drought-ready' and thus able to achieve an immediate response. Therefore, water utilities should already include plans for detailed water-use feedback when planning SWM implementations (Liu et al., in press-a) and not limit feedback opportunities when selecting their SWM technology (Liu et al., 2016).

6.4.3.3. Who

The target audience of detailed water-use feedback should be considered both for feedback trials and full program implementation. If provision is not (initially) population wide, then sample selection is relevant. Sample selection criteria in a customised approach relates to the objectives (the '*Why*') if particular segments are targeted (e.g., high-volume users, hardship customers, or properties with leaks) as well as locational considerations.

'Opt-in' approaches risk sample self-selection bias. If a trial is to be conducted first, with the intention of full roll-out later, then scalability should be ensured via selection of a representative sample for the trial. 'Opt-out' approaches have the advantage of first providing the opportunity to all customers; however, depending on 'opt-out' rates this may result in important losses in participation as well as sample bias. Sample size also has implications for evaluation and tests to detect significant differences in water consumption (either pre- versus post-intervention; or against a control group), as raised in Liu et al. (2016). The concept of sustainable urban water management may argue for all households to eventually receive detailed water-use feedback from their water utilities (Liu et al., in press-a). However, research on the costs, benefits, and impacts of different approaches to providing detailed water-use feedback on a system-wide basis remains very limited.

Customer information privacy is an issue is a potential concern with SWM and the gathering of detailed water consumption data (Giurco et al., 2010). This issue is directly relevant when considering to whom feedback will be provided. Due to privacy concerns, some householders may oppose being fitted with a smart meter. In the UK, SWM can be mandated by water utilities in areas of water stress, including the imposition of maximum water charges to any households that refuse an installation. This approach may motivate households to accept SWM. If not, refusal could mean no feedback. Based on currently available information, it is unclear what share of the population might be opposed to SWM installation.

6.4.3.4. What

SWM creates a variety of options for the presentation of detailed water-use feedback information to householders. An important finding in evaluating these options in Liu et al. (2015) was that a 'one-size-fits-all' approach is unlikely to achieve optimal benefits in view of the variations in customer preferences for feedback; a variety of approaches and customer segmentation were recommended.

Different approaches carry different relative advantages, with implications for program reach, access, content, customisation, interactivity, and specificity of feedback, which ultimately shape customer impacts. For example, online water-use feedback portal mediums have achieved usage rates of around 30% (Erickson et al., 2012; Liu et al., 2014). Therefore, rather than simply offering one option, alternative options or a combination thereof may achieve greater customer involvement and benefits. For example, WaterSmart Software in San Francisco, California, now offers both online and paper-based feedback (WaterSmart, 2014). A combination of 'push' and 'pull' approaches can also be used. 'Push' refers to communications directed or timed by water utilities (e.g. campaigns), whereas 'pull' refers to more customer driven access (e.g. by logging on to an online water-use feedback portal). For example, through an online portal, customers can access 'pull' information at their convenience, whereas through various campaigns or alerts, feedback can be 'pushed' out to customers by the utility. We recommend that water utilities aim to retain a balance to 'push' information according to supply and demand needs, particularly in situations of water stress, rather than exclusively limiting feedback to customer initiative.

Opportunities also exist to combine feedback with other policy tools. While most previous studies and implementations have focused on information feedback, incentives have also been offered in parallel. Examples include $100 rebates to assist with the costs of leak repairs (Britton et al., 2013); and competitions (Erickson et al., 2012; Wetherall, 2008) offering prize incentives for householders to act upon water-use feedback. While both time-of-use and seasonal pricing have also been discussed in the water sector, these have not yet been widely field-trialled in conjunction with SWM and feedback.

Finally, attention must be given to the narrative, story, or message to be communicated to householders when providing detailed water-use feedback. Research suggests experimentations with alternative message framing as this may influence outcomes (Fielding et al., 2013; Liu et al., 2015).

6.4.4. Evaluative considerations

The outer layer of the framework refers to *evaluative* considerations, which must be managed throughout the implementation of detailed water-use feedback programs. These are categorised here as considerations of '*Data collection*', '*Analysis*' and '*Knowledge sharing*'.

6.4.4.1. Data collection

The chosen resolution of data as well as the means for its transmission, analysis, and communication will shape the options for detailed water-use feedback. Currently, for water end-use analysis, consumption data collected at a minimum of 1 min intervals is required, whereas leak detection is based on an assessment of night flows using hourly data. Although higher resolution data offers greater options for detailed feedback, it also requires additional software and (currently) significant time for manual disaggregation. Medium-resolution data (e.g. hourly) has been proposed as an option for indicating water-use patterns to householders in terms of when most water is used according to the period of the day or season (Cardell-Oliver, 2013). Naturally, the insights and advice this can provide are less specific than with higher resolution data disaggregated at end-use levels. Research into the impacts of feedback associated with medium resolution data beyond leak alerts has yet to be conducted. We recommend that water utilities implementing SWM maintain flexibility to adjust the logging interval as has also been required in previous trials, albeit in response to communication issues (Doolan, 2010).

6.4.4.2. Analysis

Analysis is critical to understanding the impacts of detailed water-use feedback programs and measuring the extent to which established goals are met. An analysis of water consumption data before and after feedback is likely to be the most important component of a quantitative evaluation. A variety of statistical approaches have been used, including comparisons of means, and usually against a control group. While SWM data has usually been analysed, quarterly billing data collected via a conventional meter has in some cases been used to assess long-term usage patterns (Davies et al., 2014). Comparing conventional meter records pre- and post-intervention can be used when baseline SWM data are not available through billing records. Ideally, however, a baseline of consumption data should be collected via SWM prior to the provision of detailed feedback in order for a more accurate assessment of interventions, as in the MHOW online portal study. The optimal duration of a baseline measurement period has not been established, with current practice varying from no baseline, to just a few weeks to more than one year (which can be used to capture seasonality). The choice may also depend on the 'why' of introducing feedback in the first place.

In addition to SWM data, water utilities may also want to collect other forms of data for program evaluation purposes. Current approaches have involved householder surveys and interviews. Alternatively, focus groups could be also used. These additional evaluation methods, including qualitative assessments, can be used to identify opportunities for program improvements.

6.4.4.3. Knowledge sharing

SWM and detailed water-use feedback projects have largely been conducted independently, with limited information sharing regarding projects, status, approach, decisions, and recommendations. However, recent projects such as DAIAD (Athanasiou et al., 2014) and iWIDGET (Ganhao et al., 2015), represent more collaborative approaches between researchers and a few water utilities in Europe. A more coordinated approach to project trials and implementations could maximise the opportunity for shared learning and associated benefits (Liu et al., in press-a).

Based on the available literature on SWM implementation, we note that there is much activity for which little knowledge or findings have been disseminated publicly. Wider reporting represents an important underexploited opportunity for the water industry to improve knowledge and understanding, including of actual effectiveness, and to build and improve upon existing practice, rather than 'doing more of the same'.

The formation of some local research and industry networks can help facilitate information sharing. However, sharing on a more global scale is required to more fully understand programs, progress, and new insights as they emerge. At the same time, international experiences should be conveyed in a manner that is transferrable and relevant to local contexts.

6.4.5. Overall recommendations and directions for future research

This paper argues that water utilities should be well informed of the options for implementing detailed water-use feedback programs and have a clear understanding of the relative merits and implications of alternative approaches. An understanding of previous and current SWM feedback projects is important. Available knowledge also should be harnessed and continually developed to optimise impacts in terms of customer involvement, water-use awareness, and water consumption. Water utilities should aim to integrate, within their vision for SWM, the provision of detailed water-use feedback that supports sustainable urban water management.

Based on our proposed framework, the following gaps in the literature and practice suggest priorities for future research:

- Regarding '*Why*', an investigation of as yet unexplored motivations for detailed household water-use feedback programs, such as targeting low-income groups and customers in arrears with their bill payments; or with the introduction of new tariffs.

- Regarding '*When*', an investigation of the provision of detailed water-use feedback (e.g. high-volume uses) in contexts of water stress (such as droughts) to explore opportunities for greater collaboration between water utilities and customers to overcome scarcity.
- Regarding '*Who*', an investigation of the impacts of the provision of detailed water-use feedback for an entire population (rather than only with self-selected trial participants). This research could be conducted opportunistically in

conjunction with a new smart meter roll-out or upgrade across a district metered area. Specifically targeted audiences also warrant further explorations, which relates to the '*Why*' of feedback, discussed above.

- Regarding '*What*', an investigation of detailed water-use feedback in conjunction with customer segmentation, such as according to householder preferences, possibly including other forms of consumption feedback (e.g. related to household energy use). While designed for the consideration of detailed water-use feedback in conjunction with SWM, we suggest that our framework is also applicable to energy-use feedback.

Investigating these research topics would help to further the understanding of the role of detailed water-use feedback and help optimise its beneficial impacts.

6.5. Conclusion

A framework for understanding detailed water-use feedback programs in conjunction with SWM was developed based on first-hand experiences with two household trials. The framework presents a comprehensive overview of key considerations for the design, implementation, and evaluation of water-use feedback programs in conjunction with SWM and serves as an overarching guide to water industry practitioners and researchers. The framework was used to review current approaches and provide recommendations based on our research as well as the literature. This research will help foster more well-considered approaches and implementation, furthering opportunities for advancing knowledge and extending the potential benefits of SWM to households by engaging them in sustainable urban water management.

Acknowledgements

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Supplementary Information to Chapter 6: Results of the literature review and analysis

Table 18 Research studies/implementations: practical considerations

	WHERE	WHERE	WHO						WHAT	HOW							WHEN			WHY
Reference	Location	Country	Households	Controls	Sample	Population	Opt-in	Opt-out	Medium	Time-of-use data	End-use data	Total use	Leak data	Comparative use	(Near) real-time data	Delayed data	Study dates	Feedback duration	Study duration	Conservation
Sydney Water (Davies et al., 2014)	Westleigh, NSW	Australia	82	82	X		X		IHD	X		X	X	X	X		Jun 08 - Sep 13	14 mths	5 yr follow-up	X
(Fielding et al., 2013)	Brisbane, Ipswich, Sunshine Coast & Gold Coast, QLD	Australia	24 + 65 + 66	66	X		X		Postcards		X	X	X	X		X	Jun 10 - Sep 11	5 mths	1.3 yrs	X
Water Corporation (Anda et al., 2013)	Perth, WA	Australia	12,256	-	X	X	X		Letters and phone calls			X		X		X	Jul 11 - Aug 12	-	1 yr	X
Water Corporation (Anda et al., 2013)	Perth, WA	Australia	10	-	X	X	X		Portal & phone calls	X		X		X	X		Feb-May 12	1mth	2 mths	X
City of Dubuque (Erickson et al., 2012; Naphade et. al. 2011).	Dubuque, CO	US	151	152	X		X		Online portal	X		X	X	X	X		Sep - Dec 10	15 wks	9 + 6 weeks	X
Sydney Water (Doolan, 2010)	Westleigh, NSW	Australia	161	20	X		X		IHD	X		X	X	X	X		Dec 08 - Jun 10	1 yr	1.5 yrs	X
Wide Bay Water Corporation (Britton et al., 2013)	Hervey Bay, QLD	Australia	332 + 40	100	X				Letters	X			X			X	Jun 08 – Jun 09	3 mths	1 yr	X

South East Water (Wetherall, 2008)	Melbourne, VIC	Australia	50	-	X		X		IHD & website	X		X			X		Apr 07 - Mar 08	Mar 07	1 yr	X
(Petersen et al., 2007)	Oberlin, OH	US	18 (dormitories)	-	-				Portal	X		X		X	X		Feb 05 – Apr 05	2 wks	3 mths	X
MidCoast Water (HWU study) (Liu et al., 2016, 2015a)	Tea Gardens/Hawks Nest, NSW	Australia	34	34	X		X		Paper reports		X	X	X	X		X	Jun 12 - Jan 14	4 mths	1.5 yrs	X
MidCoast Water (MHOW study) (Liu et al., in press-a)	Greater Taree, NSW	Australia	60	60	X		X		Portal	X		X	X	X	X		Jan 13 - Jan 15	1yr	2 yrs	X
Townsville City Council	Townsville, QLD	Australia	200	-	X		X		Portal	X		X	X	X	X		2013	6 mths	-	X
Mackay Regional Council (Mackay Regional Council, 2015)	Mackay, QLD	Australia	36,000	-		X	X		Portal	X		X	X	X	X		From 2013 onwards	-	-	X
Global Water Fathom U2You	Various	US	-			X	X		Portal & smartphone app	X		X	X	X	X		From 2011	-	-	X
WaterSmart (WaterSmart, 2014)	Park City, Utah	US	4,200	-	X	X			Portal & paper or email reports					X			From May 2014	-	-	X
WaterSmart (Granger and Yolles, 2014)	Sacramento	US	5,000	6,400					Reports & portal	X	O	X	X	X	X		Sep 13 – Aug 14	-	6 mths	X
iWIDGET (Ganhao et al., 2015)	S. England, Barcelos, Athens	UK, Portugal Greece	650 86 20	650 - -	X		X		Portal	X		X		X			2012-2015	1 yr	3 yrs	X

Table notes: “X” Feature provided. “O” means estimate only

Table 19 Research studies/implementations: strategic and evaluative considerations.

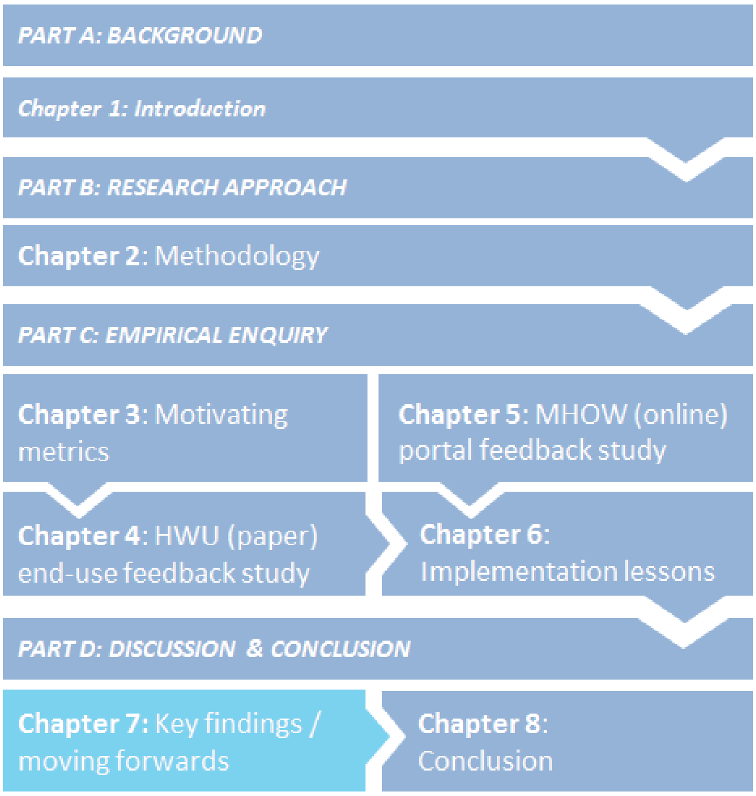
	DATA COLLECTION	EVALUATION				KNOWLEDGE SHARING			RESOURCES		STRATEGY					THEORY OF CHANGE		TECHNOLOGY		
Reference	Logging interval	Survey	Interviews	SWM data	Quarterly data	Journal	Report	News	University collaboration	External funding	Trial	Full-scale rollout	Tech device purchase	In-house solution	Managed service	Information-deficit/ behaviour change	Additional theory	Logger	AMR	AMI
Sydney Water (Davies et al., 2014)	Initially 5 min, increasing up to 60 min			X		X					X		X			X			X	
(Fielding et al., 2013)	5 s			X		X	X		X	X	X			X		X	Social norms, detailed end-use	X		
Water Corporation (Anda et al., 2013)	60 min					X								X			Community Based Social Marketing			
Water Corporation (Anda et al., 2013)	5 min					X					X			X						
City of Dubuque (Erickson et al., 2012; Naphade et. al. 2011).	15 min	X	X	X		X	X				X				X				X	
Sydney Water (Doolan, 2010)	5 min; later up to 60 min	X	X	X			X				X		X						X	
Wide Bay Water Corporation (Britton et al., 2013)	1 hour	X		X		X			X	X	X			X				X		
South East Water (Wetherall, 2008)	-	X			X		X				X		X			X				
(Petersen et al., 2007)						X					X									
MidCoast Water (HWU study) (Liu et al., 2016, 2015a)	1 min	X	X			X			X	X	X			X		X	Detailed end-use; Social norms	X		
MidCoast Water (MHOW study) (Liu et al., in press-a)	1 - 5 min	X				X			X	X	X		X	X		X	Goal setting; social norms		X	
Mackay Regional Council (Mackay Regional Council, 2015)	I hour											X		X						X
Global Water (Hill, 2015)	Various											X			X					
WaterSmart (Granger and Yolles, 2014)	Various			X						X	X	X			X		Social norms			X
iWIDGET (Ganhao et al., 2015)										X	X									

Table 20 Research studies/implementations: detailed overview of information content.

	Medium				Frequency (update)				Duration		Content																														Context				
	Paper		Digital								Measures					Resolution					Reporting period							Comparisons						Interpretation											
	Letter/Report	Postcard	Online portal	IHD	Bi-annually	Hourly	Near real-time	Delayed	Temporary	Continuous	Volume	Cost	Flow rate	Duration	Counts of use	Total volume	Indoor	Outdoor	Leaks	End-uses / appliances	Yearly	Quarterly	Monthly	Weekly	Daily	Hourly use	Minute(s) / near real-time	Historical	Normative: Average	Normative: Efficient	Normative: Quintile	Normative: Ranking	Goal setting	Chart (bar, pie)	Infographics	Pictorial	Numerical	Customised tips	Link to other information	Use of framing / metaphors	Rebate offer	Game / Competition	News / chat	Weather info	General tips
Davies et al. (2014); Doolan (2010)				●		●	●			●	●					●			●						●	●		●		●			●	●			●								
Fielding et al., (2013)		●						●	●											●																									
Anda et al.(2013) (letters)	●							●								●															●					●				●					
Anda et al. (2013) (portal)			●				●																				●				●													●	●
Erickson et. al.) (2012)			●				●		●	●	●	●				●			●					●	●	●		●				●		●						●		●	●		
Britton et. al. (2013)	●							●	●				●						●															●							●				
Wetherall (2008)			●	●			●		●							●							●	●	●			●														●		●	●
Petersen et al. (2007)			●					●	●		●					●																						●				●			
Liu et al. (2016, 2015b) (HWU reports)	●				●			●	●		●		●	●	●	●	●	●	●	●									●						●			●		●					
Liu et al. (in press-a) (MHOW portal)			●				●			●	●	●				●			●				●	●	●		●	●	●	●			●	●			●			●					●
Mackay Regional Council (2015) (portal)			●			●	●			●	●					●			●						●	●		●						●											
Hill (2015) (Global Water portal)			●																				●	●	●	●		●	●	●				●											
Granger and Yolles (2014) (WaterSmart reports)	●							●			●					●													●	●				●			●	●							
Granger and Yolles (2014) (WaterSmart portal)			●				●			●	●								●	o									●	●								●							
Makropoulos et al. (2014) (iWIDGET portal)			●								●					●				o	●		●	●	●	●	●	●	●	●															

Table notes: "o" means estimated end-use on

Chapter 7: Key research findings and implications — moving forwards



Introduction

The research in this thesis has been directed at investigating the prospects for detailed water-use feedback enabled via SW metering. The thesis focused on exploring options, householder preferences and impacts, together with their wider implications for customers, utilities and SUWM.

The Discussion chapter in this chapter is divided into four main sections which align with the representation of the main thesis topics introduced in Figure 1, respectively, as follows:

- Section 7.1 presents the *options* for the provision of detailed water-use feedback enabled via SW metering.
- Section 7.2 summarises the research findings regarding householder interests and *preferences* for detailed water-use feedback information provision.
- Section 7.3 discusses the various *impacts* of detailed water-use feedback on householders regarding water-use awareness and consumption of water.
- Section 7.4 discusses the *implications* of the research, lessons learned and SUWM
- Section 7.5 provides a research agenda and recommendations for future work.

7.1. Options

(Paper I)

7.1.1. Possible Options

SW metering creates new possibilities for feedback of detailed water-use information to better inform householders on their consumption of water and signal concrete opportunities to save. Prior to this work, however, the existing literature lacked a comprehensive overview of the available options for the presentation of detailed water-use information to householders specifically enabled via SW metering.

Understanding the options for detailed water-use feedback provision is important for various reasons. First, an overview of options is useful for water industry decision makers in considering the alternatives when planning detailed water-use feedback programs, as well as SW metering projects. Second, understanding the available options is an important precursor to asking householders to evaluate alternative means for the presentation of feedback and share their corresponding preferences, which in turn have implications for the design and impacts of feedback programs.

Through the research for this thesis, a 'framework for water-use feedback' was developed (originally in Figure 10 (Paper I), and reproduced below) through a review of the characteristics of feedback described in related energy and water sector literature, considered in the context of SW metering. The framework provides a comprehensive overview of feedback options being made possible through SW metering, and is proposed as a general framework for analysing existing programs and the design of future ones. Feedback was specifically defined in terms of the *feedback medium*, its *content*, the *frequency, speed and duration* of feedback and the *context* in which it is provided. Later, in Paper IV the framework elements were used to review the existing literature and approaches to the provision of detailed water-use feedback through SW metering, providing a first and highly comprehensive overview of activities to date in the field.

(Figure 10) Framework for water-use feedback

7.1.2. Practical Approaches

From a review of the literature and practice it is possible to identify the adoption of three main *practical* approaches to detailed household water-use feedback provision enabled via SW metering, namely: (i) leak detection; (ii) (near) real-time online; and (iii) end-use feedback (Fielding et al., 2013; Paper II). These three approaches differ in terms of SW metering requirements, the speed with which the information can be provided, the level of detail each entails and naturally also cost. These alternatives are discussed below.

End-use feedback requires water usage data to be captured at the highest resolution (at least at 1 min intervals) and is also currently very costly. However, end-use data offers the advantage of enabling very specific insights into how and where exactly water is being consumed and might therefore be saved. Leak data requires medium resolution data (e.g. 1 hr) and can address a clear opportunity for water-savings. (Near) real-time feedback has been provided using either high or medium resolution data. (Near) real-time feedback offers rapid communications which can also show householders the impact of a particular water-using event and according to the time of use, but may be less easy to interpret in terms of the impacts of any specific water-using appliance than end-use information is able to demonstrate.

While a detailed analysis of cost information is beyond the scope of this thesis, it is certainly also an important further consideration in evaluating the relative merits of these three approaches to detailed water-use feedback provision. Currently end-use analysis technologies are relatively expensive and this had previously raised some concerns as to the scalability of this approach (Cardell-Oliver, 2013). However, with continued technological advancements, this could also make scalable implementations of end-use feedback a practical and cost-effective option in the future. In the meantime, end-use feedback could be adopted as an option for targeting particular customer segments e.g. high water users. It could also be offered as a temporary service, applied to different households at different times, such as in Tom et al. (2011), where the temporary installation of a data logger for one week was offered as a customer service to provide one-off end-use feedback to interested households in Sacramento, US.

Due to the clear benefits of very specific feedback, and especially the appeal and motivational characteristics of both end-use data and end-use metrics found in this research, developing the means to enable this type of feedback provision is highly recommended. While many water utilities are currently focusing their approaches on providing customer leak alerts, it would be disappointing if other end-uses are not also targeted, since opportunities to save water exist beyond just addressing leaks and leaks are not experienced by all households.

Potentially, in order to maximise the value and benefits of end-use feedback, the speed with which it can be made available may be critical. Therefore, means to expedite its provision should also be sought. Ideally, detailed end-use feedback could be provided in near real-time, to give householders greater visibility and control over their household water use, and this is perhaps not something too distant from the present (see for e.g. Nguyen et al., 2013).

7.2. Preferences for detailed water-use feedback

(Paper I & Section 5.6)

7.2.1. Preferences

This thesis proposes that gauging householder *interest* in more detailed water-use feedback is important, rather than being simply taken as assumed. There is value in seeking to understand householder *preferences* and *responses* to different types of feedback. While the need to understand householder preferences had previously been raised in household energy literature (Karjalainen, 2011; Laskey and Kavazovic, 2011), this had scarcely been considered within water sector literature.

In this thesis, householder interests are suggested as an important precursor to engagement with detailed water-use feedback; and that confirming interest would lend support to utilities to pursue more extended SW metering which involves the provision of more detailed water-use feedback. Moreover, it was argued that understanding householder preferences could help shape the role for detailed feedback via SW metering and influence levels of user engagement and the extent to which feedback is able to promote water conservation.

To meet the important gap in knowledge regarding householder preferences between alternative ways of presenting detailed water-use information, research data was collected via feedback study participant householder surveys and interviews. The questions drew from options in the 'framework for water-use feedback' in Figure 10, and targeted an understanding of householder levels of interest, their valuation, and perceptions of the effectiveness of different forms of feedback information and means for it provision in motivating water conservation measures. The evaluation of different options by study participants, which had experienced a variety of metrics of detailed water-use and end-use information through the provision of customised HWUs (paper reports), allowed for a potentially more informed householder evaluation of different forms of water-use feedback. The key results from across the distinct studies and their implications are discussed in the following subsections, in which particularly the finding of significant variation among householders is considered further.

Significant interest in access to more detailed water-use information was found in the research. Householders that received customised feedback via the HWUs (end-use feedback) were highly appreciative of their consumption reports and particularly expressed value in the ability to monitor their water use and identify opportunities to save. The provision of detailed feedback in near real-time via the MHOW online portal produced more varying reactions. The portal was found to appeal to the majority of actual portal users (i.e. those who logged on), although non-users generally displayed more neutrality towards the portal.

Comparing feedback *mediums*, the HWUs (paper-based reports) achieved a high reach rate and many householders demonstrated high levels of interest and engagement with the detailed end-use feedback provided in this manner. MHOW online portal usage, by contrast, was recorded by only about one-third of participants to which access was extended. However, the availability of water-usage alerts via SMS or email proved to be popular among portal users through overall very high sign-up rates.

In terms of feedback *content*, the vast majority of HWU recipients reported finding the end-use pie chart, end-use metrics and neighbourhood comparison interesting. Regarding online feedback provided in near real-time, alerts regarding leaks and self-determined budgets were the features rated most highly. Further householder preferences for a wide range of alternative metrics were also evaluated.

This research has also confirmed that detailed water-use feedback can *motivate* household water savings and that different forms of information produce distinct (motivational) effects on individual householders, and that one form of feedback information could produce varying responses among different householders.

Participants in both feedback studies revealed, either through the preferences survey or portal evaluation survey, greater levels of interest in historical comparisons and changes in their own water consumption than in normative comparisons with other households, presented either in terms of average or efficient benchmarks. This finding is important since many current approaches in both research and practice are placing emphasis on the role for normative comparisons, founded on assumptions that householders will aspire to keep to social norms and/or be motivated by a sense of competition with others. The results of the present research lend some support to these current approaches, but signal moreover that changes in one's own use may be perceived to be of greater relevance and therefore a greater motivation for action. This important finding offers fresh insights concerning the possible mechanisms of feedback approaches with implications for future design.

The levels of interest and engagement with different feedback *mediums* and types of *content* as well as reported preferences via the survey all signalled wide variety among householders. However, another new finding detected was that there appear to be some customer segments which would prefer a much fuller range of detailed metrics and others which would favour fewer specific pieces of information from SW metering, such that different levels of information will be suited to different groups.

The results of this research in this thesis are important since significant householder interest in more detailed water-use feedback demonstrated by the vast majority of the study householders provides a strong encouragement to water utilities to further advance efforts in this direction. At the same time, the results showed much variation in householder preferences for detailed water-use feedback, which requires further consideration in the design and implementation of feedback programs, as discussed in the following sections.

7.2.2. Heterogeneity of consumers and the role for segmentation

The results of the research are of interest since they demonstrate that householders are very much heterogeneous in terms of their preferences for water-use information. This suggests that a variety of approaches may need to be taken to help realise the benefits of SW metering more fully. It was particularly suggested that *customer segmentation* may have a role to play in the future of detailed water-use feedback provision, with alternative approaches for different customer groups. In this section, the opportunity for customer segmentation is discussed further, taking into consideration the dimensions across which it may be feasible to segment customers and the practicalities thereof. Opportunities for both 'top-down' segmentation directed by water utilities and a 'bottom-up' approach from customers are considered.

7.2.3. The future of water utility customer data

While a wide range of options for feedback provision to which SW metering can contribute were identified in this research, it is noted that the availability of customer data might be required to realise some of the opportunities more fully. At present, however, water utilities collect and maintain very limited data records on their customers. Utility consumer information systems show minimally the (owner) name, property address and phone number (usually a landline), which can then be linked to information on their water consumption data (e.g. quarterly meter read values in the absence of SW metering). Additional, but again limited, details may be stored if a customer has payment issues (e.g. hardship), makes additional contact (e.g. general billing queries), or participates in a rebate program, which gives a further indication of the appliance stock of participating consumer households. Beyond these records, water utilities typically have little access to any further customer data. In view of this limited data, water utilities have performed little in the way of customer segmentation for the provision of more detailed water consumption information. Other than recruiting 'interested' consumers as volunteers for pilot studies, targeting consumers on the basis of water consumption levels seems to represent the only approaches taken (e.g. MCW decided to target the second upper quartile of household water consumers in the MHOW (online) study).

Just as the collection of water consumption data is increasing through SW metering, the question remains to what extent could additional information on customers be collected or accessed and integrated in future? Indeed, seen more generally within the wider context of the digital age, exponential increases in data collection are being observed to be penetrating into almost every other corner of our daily lives, so why might this also not be the case for water given the importance of water resources management?

For a water utility, additionally relevant customer data could comprise of, but would also not have to be limited to, any of the known determinants of household water consumption, including those identified in residential water consumption literature (e.g. number of occupants, property size and characteristics, garden size, household appliance stock, and socio-demographic information such as income, education, employment status etc. (Grafton et al., 2011; Jorgensen et al., 2009; Makki et al., 2013; Russell and Fielding, 2010)).

The availability of additional customer data would broaden the prospects for possible customer segmentation beyond the information that is currently available (e.g. water consumption levels, geographic data through the locality, and payment history). Here, related questions concerning information privacy laws are also pertinent. Also, to what extent would additional customer information be collected by and held at the water utility, could this be volunteered by householders, or might this be the business of third parties?

7.2.4. Self-selection and self-customisation

An alternative approach to segmentation could be based on a more bottom-up or 'pull-approach', in which utilities could provide a menu of information services, from which customers could *self-select*. For example, consumers could be granted the opportunity to sign up for their preferred feedback *medium*, in the same way that consumers are now more widely being given the opportunities to choose online access to bills and statements (e.g. for banking, and other utility services including for telecoms, energy, as well as water). In the MHOW (online) study, participants could optionally sign up for water usage alerts to be sent either by email or SMS, which led to a variety of different sign-up patterns as householders customised feedback receipt according to their preferred medium(s) of communication (Paper III).

Another level of self-customisation could allow consumers to also select their own feedback *content*. Again, in the MHOW study, householders could choose any combination of leak, budget, and neighbourhood comparison alerts, which further revealed difference information preferences. It is noted that different mediums offer different possibilities for self-customisation. Online mediums could offer self-customisable dashboards and it is even foreseeable that paper-based mediums could be designed to present customers' preferred content. Customer self-customisation is also conceivable across any of the other dimensions of feedback as identified in the 'framework for water-use feedback' (Paper I), including the *frequency* of provision. Self-customisation could therefore have a role to play in helping to meet different customers' interests and indeed circumstances (e.g. ease of access to the internet).

An important question is to what extent should customers be granted the power of *choice* across the various possible dimensions of feedback versus to what extent this decision should remain with water authorities, or indeed the domain of technology vendors? Should consumers be empowered to themselves choose what information they are exposed to? Or are there reasons for which a more paternalistic and even 'forceful' approach might be beneficial since consumers may have a limited understanding of how to choose what is 'for their own good', or indeed in the presence of externalities 'for the good of society'. The information some householders prefer may not produce desirable outcomes; and 'motivating metrics' may not appeal to all customers, but their provision could produce overall desirable outcomes. The acceptability of alternative responses to these questions may also vary in specific contexts. For example, in drought conditions, there may be a wider acceptance of a more active 'push-approach' by water-utilities in the fight to convey water consumption information and engage consumers in working together to conserve water. However, what scope should there be for customers to opt-out under these circumstances?

The work in this these identifies these important questions concerning customer choice as priority areas for future research. However, in the interests of SUWM it seems advisable that water utilities should aim to maintain their rights to provide detailed feedback information as deemed required to operate effectively under varying conditions, and perhaps especially under water supply constraints.

7.3. Impacts of detailed feedback via SW metering: implications

(Papers I, II and III)

7.3.1. Impacts

Studying the impacts of the provision of detailed water-use feedback enabled via SW metering is important for water resource managers interested in SW metering and the introduction and development of detailed feedback programs. For water utilities, it is particularly important to have a detailed understanding of the likely impacts of, and responses of householders to, different approaches and the potential contribution towards more sustainable water resources management.

Various recent studies involving SW metering have shown positive impacts of detailed water-use feedback (e.g. Erickson et al., 2012; Fielding et al., 2013), however, more research was required into the wider impacts of different approaches to feedback provision. Therefore, the research in this thesis involved the implementation of two distinct SW metering trials in which detailed water-use feedback was presented to householders via paper-based reports (HWUs) and an online portal (MHOW), respectively, and enabled a detailed exploration of impacts. Both empirical trials yielded positive results according to a broader variety of measures of impacts than evaluated previously, as discussed in this section.

Regarding water consumption *savings* through paper-based end-use feedback reports (HWUs), descriptive statistics signalled positive savings of 8% in the short term. Short-term effects of consumption feedback are generally accepted in the wider literature, so a reduction was expected. Despite the inferential statistical analysis not being able to confirm this measured change in water consumption as statistically significant at the 95% confidence level, the result was considered as positive in the light of reported changes in household water-using behaviours and appliances by study participants and the knowledge of customer behaviour in the short term in other feedback studies. It was rather considered plausible that the moderate household sample sizes and limited periods of end-use data collection may have been important determining factors.

The longer term result showed a 9% relative increase among the intervention group that was also statistically insignificant. This result was interpreted to suggest that savings did not persist in the longer term, a result which has repeatedly been reported in the wider consumption feedback literature, especially once an intervention has ceased (e.g. Fielding et al., 2013). The insignificance of this latter result also lends support to the sample size explanation, and is also possibly indicative of the wide variability in household water consumption, with other factors influencing overall water consumption in any one period. As the net difference was largely accounted for by variation in water consumption via leaks, this suggested the result was nothing unusual. Unfortunately, due to budget constraints, the control group could not be surveyed to investigate this further. The statistical issues aside, the wide appeal of end-use feedback found in the research nevertheless suggests the HWU approach warrants further attention by water utilities.

The more continuous online provision of feedback in near real-time was able to demonstrate statistically *significant water-savings,* even in the longer term (as measured throughout one year relative to the control group). Interestingly, significant savings were also detected among inactive participants that did not log in to the portal, signalling wider benefits of provision of access and the associated customer engagement, regardless of actual access to feedback and supporting the theoretical notion of the Hawthorne (or observer) effect—that research participants modify their behaviour as a result of their awareness of being observed. The savings effects among active participants were additionally found to particularly be related to actual engagement with the available feedback (i.e. actual portal usage as measured via login activity). This novel analysis demonstrated the importance of actual and continuous (or at least regular) exposure to consumption feedback. Much of the focus or rationale for water utilities to pursue SW metering feedback programs has been centred on consumption savings and these research results suggest a positive contribution is to be made in this regard.

Additional benefits of detailed feedback via SW metering were also produced in both the HWU and MHOW studies. The program evaluation design allowed for additional impacts of the provision of more detailed water consumption feedback to also be measured in terms of changes in awareness, water-consuming behaviours and household water-using appliances, something that has rarely been undertaken in previous literature, which has concentrated on measuring water consumption savings.

Regarding *awareness*, positive impacts were noted relative to the respective control groups in both feedback trials. In particular, following exposure to detailed water-use feedback, the overwhelming majority of study participant households reported feeling informed and having a good level of awareness of their water use, end uses and highest uses in their homes. In terms of changes in *behaviour*, both post-intervention evaluations signalled important impacts as a result of participation in the feedback trials. Significant proportions of the samples had adopted new water-saving behaviours to conserve more water at home. Regarding water-using infrastructure, significant shares had also retrofitted water-efficient appliances in order to save more water in their homes. New water-efficient shower heads, toilets and washing machines were fitted and leak repairs performed. While awareness appears to have been promoted leading to changes in water-use, these did not always carry over into the longer term. Behaviours may have reverted in the absence of continuous feedback, however, it is noted that the installations of more water-efficient appliances that were reported by study householders would carry benefits that do persist.

Taken together, the results of the two studies provide empirical evidence of the positive influences on household water consumption and water-use awareness through the availability of more detailed, customised water-use information. The results present a positive role for facilitating access for consumers to the detailed data resources created through SW metering. At the same time, scope for improving the overall impacts was identified in a number of regards. These are discussed further below.

7.3.2. Variation in impacts

An important finding was one of *variation* in responses of householders to detailed water-use information, which ultimately was further reflected in terms of differences in its measured impacts. The reach of feedback is an important factor, since this will automatically limit its impacts. Therefore, more work is required to understand how to improve the levels of householder involvement and therefore the potential scale of impacts. Also, the relationships between the types of feedback provided from among the various possible approaches and the variety and magnitude of specific impacts produced also requires further investigation.

The evaluation of the HWU study shows that recognition of opportunities to save and a motivation to save do not necessarily translate into saving behaviours. Understanding this motivation-action, or attitude-behaviour gap, which has been raised repeatedly in the literature (e.g. De Oliver, 1999), is important in furthering the success of consumption feedback programs. More work is required to understand the barriers to the effectiveness of information (and therefore how feedback can be further enhanced or tailored) and its relation with other policies (e.g. rebates, pricing structures, restrictions etc.) to support household water conservation.

Our study shows important barriers to the effectiveness of limited information alone. As anticipated, not all households were motivated by or responsive to the feedback provided. Similarly, not all took action as a result of the HWUs. Consequently, a key challenge for policy makers and water authorities may be to engage the less interested or motivated, especially if particularly high water consumers. Again, more considered design and additional research is recommended towards “smarter” feedback provision.

In order to achieve greater impacts, policymakers will have to consider how to better engage household water consumers. Returning to Liu et al. (2015a), the context may be of particular importance. For example, different water pricing conditions or the application of water-use restrictions in times of drought which incentivise or enforce conservation may raise the attractiveness of this type of technology. The short-term savings following actual logons particularly suggests MHOW as an effective approach in times of water crisis in which individual information via a portal could be promoted alongside awareness campaigns via other media.

7.3.3. The effectiveness of feedback

The research explored the impacts of different forms of detailed water-use feedback and showed key opportunities and barriers to the effectiveness of feedback.

The differences in *preferences* found (Paper I) suggested householders could be given access to their preferred *mediums* in order to improve reach and engagement, and therefore improve impacts. The preferences survey showing variation in preferences for *content* also signalled opportunities for customisation (Paper I). The analysis of impacts over time in the MHOW (online) study showed the frequency and continuity of exposure to feedback is highly important (Paper III), and as shown in previous work (Fielding et al., 2013) that effects may diminish over time. Therefore, the goal of a water utility is important and the targeting of short- or long-term effects requires consideration.

An underlying proposition of this research is that the types of detailed water-use information and manner in which feedback is conveyed to customers will have implications for its impacts, including its effectiveness in reducing water consumption. The design of feedback programs carries implications for its reach, the levels of engagement of customers, and the ways in which they respond. Therefore, the approaches adopted by water utilities will have important consequences for the effectiveness of feedback in meeting underlying goals. The specific objectives of water utilities is also a related issue and was covered in Paper IV, which reviewed the status quo of water utilities and considered possible '*Whys*' for detailed water-use feedback provision, which it is noted may include additional purposes beyond water conservation.

7.3.4. Short- versus long-term impacts

Most intervention studies have focused on short-term impacts of feedback (e.g. (Erickson et al., 2012; Petersen et al., 2007). However, in the energy sector there have been various calls for longer term research, since impacts may dissipate over time (van Dam et al., 2010). Due to novelty factors, a return to previous habits and behaviours, consumption levels may undergo a 'rebound effect'. Where water-using appliances have been retrofitted, changes in behaviour may also undermine the efficiency gains available through the new technologies. For example, people have been reported to end up taking longer showers are consuming more water after installing water-efficient shower heads (Inman and Jeffrey, 2006). Study participants may change their behaviours in a desirable manner only temporarily while under observation, reverting to previous behaviours and water consumption patterns, according to the Hawthorne effect once this attention ceases. There are therefore various different reasons why impacts may not be durable in the longer term.

Both the HWU and MHOW studies attempted to investigate the longer term impacts of access to more detailed household water consumption information. Water savings in the HWU study (Paper II) did not carry over to the longer term. This result should, however, be interpreted in light of the fact that this longer term measurement was taken four months after the intervention had ceased. In addition, the participant households were only exposed to two instances of feedback (two HWUs) and there was a considerable delay in their provision. Since more instantaneous and more frequent feedback has been recommended as determinants of impacts (Fischer, 2008), there is likely to be scope for improving the approach taken during the HWU trial, which was subject to various limitations in its design from the very outset. In the MHOW study (Paper III), longer term impacts were statistically significant, even across one year of post-intervention measurement. However, it was confirmed, as hypothesised that water savings were highly linked to actual exposure to feedback (i.e. portal visits), such that it was actually the large savings impacts achieved in the short term and after each login that resulted in the savings which were measured over the course of one year post-intervention being statistically significant. Linking savings to specific acts of logging in to the portal showed actual significant impacts lasted an average of 40 days (7 weeks). These results highlighted the importance of actual engagement with feedback once it has been made available, and further suggesting the need for regular interactions to produce sustained outcomes.

7.3.5. Scalability and participation

Of relation to the impacts of detailed water-use feedback, the issue of scalability also requires further attention. Pilot and small-scale experimentations conducted to date may have inherent selection biases in the recruitment of study participants. In most detailed water-use feedback studies, participants were recruited voluntarily (Doolan, 2010; Fielding et al., 2013; Wetherall, 2008), meaning study households may exhibit higher levels of interest than in the population at large. At the same time, however, recruited participants may already be implementing more household water conservation measures than is practiced in the wider population, so the potential for additional savings could be lesser (Naphade, 2011). Therefore, the ways in which implementations of detailed water-use feedback programs are to include or select households in future needs further consideration. This will also carry important implications for the manner in which water consumption data can be analysed and the results interpreted, particularly concerning the scalability of effects detected among subsets of a population and the representativeness of results.

Due to research ethics requirements for human research, household participants had to be recruited via the process of informed consent in both the HWU and MHOW studies. However, in a number of wider scale implementations, access has in principle been granted to all households within a targeted service area. In the cases of both Mackay Regional Council (see https://myh2o.qld.gov.au/) and the Water Corporation (https://mywater.com.au/) in Australia, households were required to register themselves online in order to log on and view their detailed water-use information via the water utilities' self-service portals, which in practice represented an 'opt-in' approach.

Alternative options for selecting participants in any future detailed water-use feedback trials or implementations could involve compulsory inclusion of all households; or an 'opt-out' approach, in which every household is provided with detailed information such as usage alerts by default, until they take the physical step to unregister from the program.

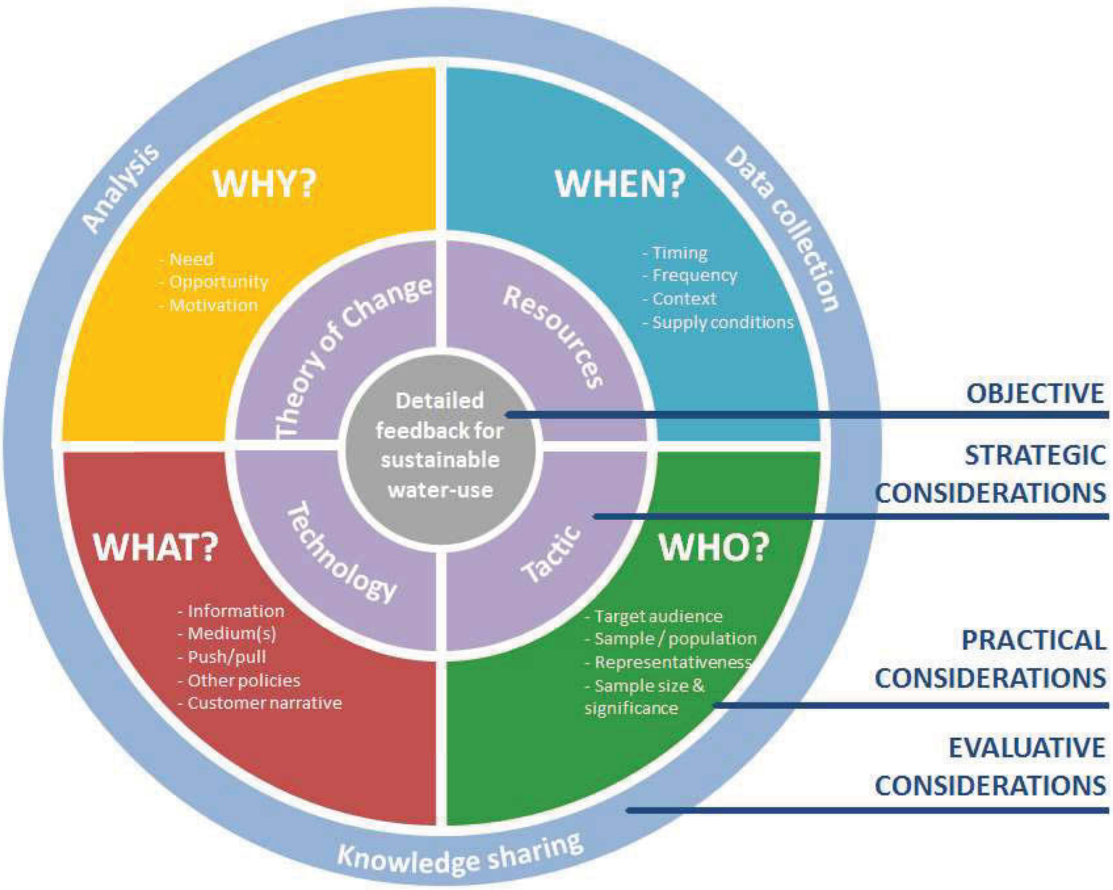
Each of the approaches, opt-in and opt-out and their variants have implications for both the representativeness of final participants of the wider population. Also any interpretation of final impacts of access to more detailed water-use information would have be seen in the light of the chosen approach e.g. through opt-in approaches, conclusions can be drawn regarding the impacts of more detailed water-use information among the 'interested' segment of the population, but inferences cannot be made regarding the impacts of access among the 'disinterested'.

7.4. Implications of the research

(Paper IV)

7.4.1. Implications for water utilities

In addition to investigating *options*, *preferences* and *impacts*, the research process itself met with various important decisions and challenges that required consideration at the various stages. This was found to additionally produce a wealth of experience from which water practitioners can benefit. These issues were presented in Paper IV through the development of an 'Implementation Framework', which presented the *strategic*, *practical* and *evaluative considerations* in decision making for detailed water-use feedback enabled via SW metering (originally in Figure 30 (Paper IV), and reproduced below). A critical discussion of the framework in relation to existing literature and current approaches provided clear guidance to water utilities to plan and implement their own approaches to water-use feedback provision and evaluate offerings by managed service providers.



(Figure 30) Implementation framework for detailed water-use feedback programs involving SW metering

Overall, findings and outputs from this thesis provide much helpful and practical guidance to water industry practitioners regarding detailed water-use feedback enabled via SW metering. The thesis argues that water utilities firstly need to be well informed of the alternative *options* for detailed water-use feedback provision and secondly have a clear understanding of the relative merits and implications of particular approaches. Far greater industry wide knowledge sharing is thus required through the dissemination of reports and results and more global networks. Available knowledge needs to be harnessed to maximise impacts in terms of involvement, and changes in water-use awareness, knowledge and water consumption; and current knowledge also needs to continually be furthered to achieve greater impacts towards SUWM. Particularly, a coordinated approach to new trials and implementations could take full advantage of this opportunity for shared learning and benefits (Liu et al., 2015a).

Built-in flexibility is also highly recommended so that detailed water-use feedback provision can be enhanced as new knowledge on better approaches is gained. So whether developing in-house solutions or opting for a managed service approach, water utilities should opt for technology offerings and services which may be adapted later as required.

Finally, regardless of the chosen approach, water utilities should aim for a vision for SW metering and detailed water-use feedback provision which includes a greater pursuit of SUWM objectives in order to maximise benefits.

7.4.2. Lessons learned

A conclusion espoused in this thesis is that SW metering requires *greater involvement* and customer-utility integration in order to achieve overall greater outcomes. The provision of detailed water-use feedback enabled via SW metering takes an important step forwards in extending the opportunities afforded by SW metering to involve end consumers including householders. However, beyond the adoption of SW metering and detailed feedback by a minority of water utilities, more widespread involvement of all water utilities is required. In addition, rather than taking approaches which may only reach limited customers and/or for a limited period, much more is required to enable detailed water-use feedback enabled via SW metering to produce significant impacts, as well as continued contributions towards SUWM.

On the basis of the results of this research and in the light of the current water utility context, utilities are cautioned about adopting the following approaches due to their negative consequences for the future of detailed water-use feedback its potential contribution towards SUWM:

i) (Large scale) roll-outs and implementation which are not accompanied by quality research (i.e. robust design and evaluation). This would result in a lost opportunity to understand the fuller contribution of detailed water-use feedback and expand existing knowledge, particularly in this early implementation phase.
ii) Conducting small scale trials and analyses which largely duplicate existing results without significantly adding to the existing knowledge base.
iii) Uncoordinated approaches which do not allow for generalisability or transferability of findings.
iv) Inaction by water utilities that continually delay decision making and implementation to indefinitely 'wait and see'.
v) Resting on unfounded assumptions about customer interest or disinterest in (certain types and approaches to) detailed water-use feedback in the absence of customer research (e.g. 'our customers won't want this – we're different').
vi) A lack of collaboration, information sharing and dissemination of results which leaves water utilities 'in the dark' concerning what is being done and what has been found.
vii) Ill-informed approaches (e.g. based on looking at a limited number of technology vendor offerings and/or independently of current knowledge).
viii) A lack of built-in flexibility in a chosen technology offering, which due to technology lock-in will result in an inability to adapt an approach in the light of new knowledge on best practices, and therefore sub-optimal impacts.
ix) Considering detailed water-use feedback as an optional add-on for later, since SW metering program designs will carry implications for what will be possible later.
x) 'One size fits all' type approaches to detailed water-use feedback, which will have a limited customer reach and impacts.
xi) Ignoring considerations of the context and opportunities for greater integration with other policies on the one hand and potentially with other sectors on the other.

Key recommendations for wider industry adoption of detailed water-use feedback programs enabled via SW metering based on the implications of this research are as follows:

- The importance of quality, robust research is underlined. There are therefore implications for water utility resources including:

    - The need for appropriate levels of utility worker skill sets and time availability; and value in outsourcing the required level of analytics skills (e.g. via partnerships with universities).
    - The allocation of capital resources to future projects and the need for greater attention to sample sizes, study duration and the generalisability of results.
- Knowledge sharing will further industry's understanding and experience in terms of methods and impacts of different approaches to detailed water-use feedback provision. An online knowledge-sharing platform is therefore recommended to promote the dissemination of knowledge (e.g. list of projects and roll-outs, results and lessons learned), which is continually updated with the latest insights. In addition, a tool-box for approaches and best practice is recommended for development.
- The water industry needs to build knowledge on how to address heterogeneity among customers by customising approaches to feedback provision. A large-scale customer preferences survey, which builds on the survey implemented in this research would provide important insights into the interests of householders at scale. The data could subsequently be used for experimentation with greater levels of customisation of feedback.
- The business case for detailed water-use feedback provision via SW metering requires development. Existing and future projects should fully document methods and make business case details available for a wider evaluation and industry recommendations and improvements.

7.4.3. Implications for SUWM

The topic and challenge of SUWM is now revisited. On the one hand, the key research findings in this thesis contributed evidence to support the positive findings in other recent research (e.g. Davies et al., 2014; Doolan, 2010; Fielding et al., 2013) that SW metering can lead to behavioural and structural changes that promote water savings and in this manner contribute to a more sustainable consumption of water resources. On the other hand, it was made apparent that the current approaches are limited in regards to their impacts, both in terms of the actual scale of customer involvement achieved and also the duration and magnitude of savings effects.

Figure 31 depicts alternative states of detailed water-use feedback enabled via SW metering. Here, the *scale* of feedback provision (i.e. inclusivity) is shown against the achievement of householder *involvement*. Small scale projects which achieve low customer involvement result in low sustainability impacts, yet present opportunities for learning ahead of upscaling. Broad provision at the water utility level on a wide scale (i.e. city or district scale) may achieve overall limited involvement if there is insufficient customisation (e.g. not all householders logging on to access their information). By contrast, some approaches taken in some smaller scale pilots have in some cases (e.g. the HWUs) achieved a higher program reach rate and therefore greater householder involvement, although these approaches require validation on a larger scale.

A vision for 'smart sustainable urban water' necessitates both feedback provision on a wide scale and the achievement of 'full' involvement. It therefore follows that there is a need to re-think the role of the water utility and water consumers enabled by SW metering and the digital age in order to achieve greater contributions towards more SUWM.

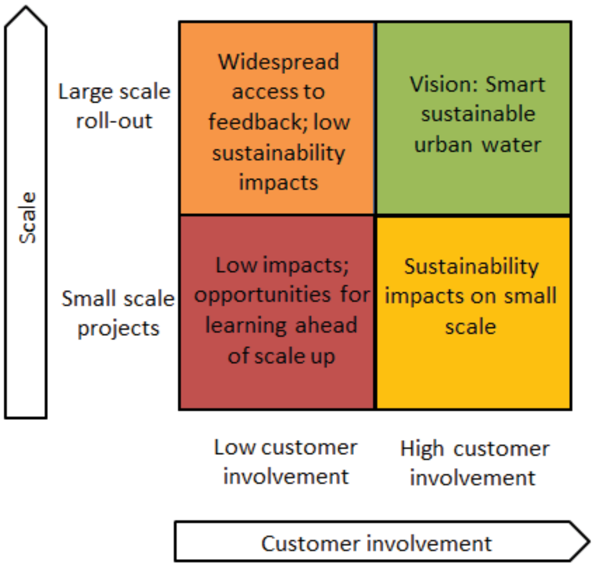


Figure 31 Towards the vision for smart sustainable urban water

The conclusion that current approaches to SW metering feedback are limited in impacts is most certainly to an extent *context dependent*. Greater outcomes are foreseeable if the policy mix were to be adapted to incentivise user interest in water consumption, water-use information or water conservation. Regarding policy options, Inman and Jeffrey (2006) have suggested that significant price increases and mandatory restrictions would be required to more generally improve the success of demand management programs. Fielding et al. (2013) have therefore advocated the use of voluntary water demand management strategies such as informational strategies, since price increases are politically and socially less acceptable and water demand has been found relatively price inelastic (Espey et al., 1997).

SW metering can be interpreted as an opportunity to combine both *'top-down'* and *'bottom-up'* approaches to promote more SUWM. From the 'top-down', water utilities and water policy makers carry responsibility for providing the enabling conditions for their customers (e.g. SW metering infrastructure, SW metering, communications and feedback mechanisms). At the same time, SW metering technologies and advanced ICT in the digital age create opportunities to enable an approach which simultaneously allows for greater 'bottom-up' contribution and innovation.

A 'top-down' approach in itself is unlikely to achieve the fuller benefits of SW metering and even in terms of engagement. As also articulated by Naphade (2011), "to realise the full potential of a smarter metering solution, it is essential to engage consumers". A variety of engagement techniques were therefore trialled in the Dubuque smart water portal pilot as well as in the present research. The criticality of customer involvement is also an idea which is further propagated in this thesis. Greater attention needs to be paid to fostering greater involvement by water utility customers, including householders.

Current approaches taken with detailed feedback enabled by SW metering have been introduced largely with narratives of 'engagement' and may appear collaborative in approach. However, when seen more closely, these approaches are actually very 'top-down' in nature. Water utilities (and researchers) have themselves determined what particular approach to adopt, with very little consideration of householders' interests or preferences. This is exhibited in the 'one-size-fits-all' approaches which have, for example, tended to offer a single communication medium with pre-determined features, with little room for householders to select according to their preferences. To some extent the nature of these approaches relates to the newness of the technologies, in which case the studies represent a first experimentation and analysis. However, 'one-size-fits-all' approaches are unlikely to achieve the scale of impacts that would make a significant contribution towards more sustainable water consumption. Therefore, there is a requirement for greater flexibility. In addition, SW metering and advanced ICT actually present far greater opportunities for customisation than have currently been investigated. The research in this thesis which showed heterogeneity of customers in terms of preferences, interests and responses lends support to the possibilities for a more user-driven than simply 'top-down' approach to detailed water-use feedback provision.

7.5. Research agenda and recommendations for future work

The HWU and MHOW studies demonstrated that there are important intangible benefits through customised smart water meter feedback. Seen in the current context, the roll-out of SW metering within the water industry is expected to gather momentum. This means, the opportunity to extend access to the new data resources to household water consumers will increase. However, delays in implementing detailed feedback means that the benefits will be postponed and the understanding of best approaches will become increasingly urgent as SW metering implementations take effect.

Opportunities for coordinated research regarding the design, implementation and evaluation of impacts exist, so that if exploited now, will facilitate a smoother and faster implementation of feedback when SW metering becomes more mainstream. Here, collaboration between research and industry can make an important contribution. Many projects both in Australia and overseas have to date involved small scale trials (Britton et al., 2013; Erickson et al., 2012; Fielding et al., 2013; Joo et al., 2014). However, larger and more widespread implementations will carry overall greater amounts of engagement and water-saving impacts due to the increased scale of customer coverage. This will offer greater conservation and sustainability impacts relating to the scale of roll-outs. What is now required is more in the way of a best-in-class type model implementation which can be used as an industry benchmark. In this way, utilities will be able to integrate the design and plans for advanced feedback programs at the outset of smart meter implementations.

This research project focused on the opportunities on the customer side in terms of the potential impacts on customers and their consumption of water via detailed water-use information. The two pilot feedback studies particularly demonstrated how SW metering is enabling more detailed household water consumption feedback and its impacts. However, the detailed research was conducted with moderate sample sizes and limitations in terms of how the study samples were selected. Similar research is recommended which builds on the approaches adopted, using both larger, as well as representative samples to truly understand the role and scope of the opportunity.

Moreover, since the moderate sample sizes showed messages of variety in a number of regards, including water consumption; water-use information preferences; interest in more detailed water-use feedback; motivations for accessing information; responsiveness to the information; engagement; and behaviour change, this heterogeneity suggested a variety of approaches to the provision of feedback needs to be taken in order to attain greater engagement and contributions towards greater sustainability. There is a need for further research in this area, which investigates the relationships between different types of information, different population segments (e.g. according to various socio-demographics; preferences) and impacts (e.g. on household water consumption and other variables of interest). Again, larger sample sizes are required. Once impacts on a larger scale are established, this will help prepare the way for more widespread and guided adoption.

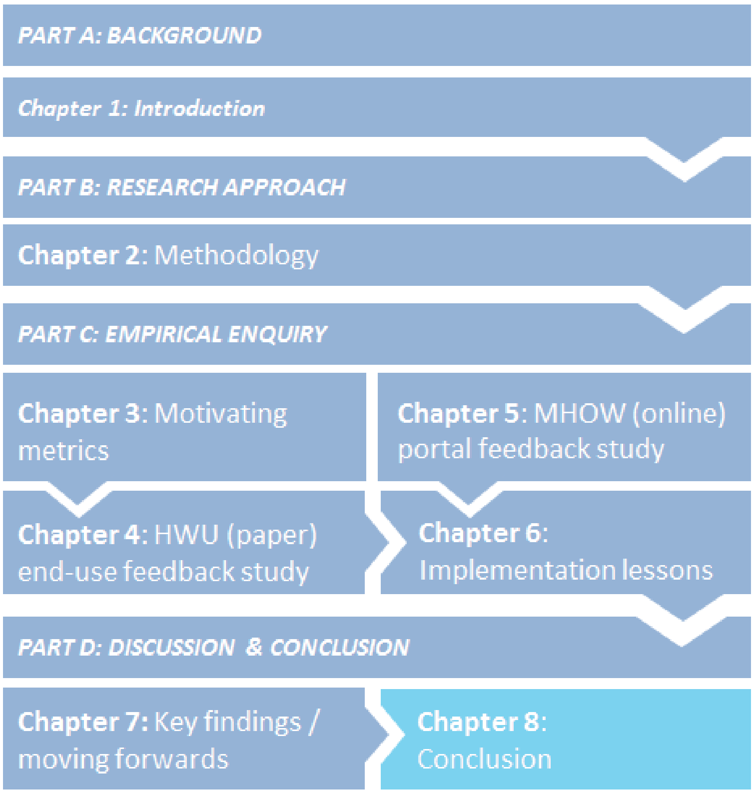
To achieve a greater contribution towards sustainable urban water, the role for detailed water-use feedback needs to be raised from pilot, independent or secondary implementations to expedite overall progress by water utilities with SW metering. At the same time, engagement and uptake by householder water consumers in new feedback opportunities need to be maximised through varying approaches.

A further opportunity exists to deepen current understanding of how water consumers specifically learn with SW metering and detailed feedback provision; and how water utilities learn during program implementation. Future research investigating both water customer and organisational learning using the 'learning journeys' concept after Deakin Crick et al. (2015) could—in identifying informational needs along learning journeys from 'purpose to performance'—be used to develop a learning infrastructure for proficient digital water users and managers.

Research recommendations for potential future studies are summarised as follows:

- Large scale (e.g. city or service area wide) feedback provision and evaluation;
- Customer segmentation for experimentation with more customised approaches to feedback provision according to the dimensions of the framework for water use-feedback developed in this research;
- Robust scaled research trials to understand the scalability of interventions;
- Investigation of water utility customer and organisational learning journeys with SW metering and detailed water-use feedback provision;
- Evaluation of the implementation framework developed in this research;
- Business case development for detailed water-use feedback provision via SW metering to meet a need identified at the outset, but outside the scope of this work.

Chapter 8: Conclusions



8.1. Summary of the research

This thesis has investigated the new opportunities for detailed household water-use feedback enabled via the implementation of SW metering. Through the implementation and analysis of two detailed water-use feedback trials involving SW metering, the research improved knowledge of the issues and effects of exploiting this opportunity.

The research investigated *options* for presentation of detailed water-use feedback to householders; householder *preferences* and *responses* from among the alternative approaches and the various impacts of provision of detailed water-use feedback. The research addressed an urgent need for improved knowledge and experiences of the issues relating to the provision of detailed water-use feedback enabled via SW metering. The findings of this thesis cover a broad range of aspects which are critical to the design of future large scale SW metering roll-outs and of detailed water-use feedback.

In addition to investigating options, householder preferences and impacts, an 'Implementation Framework', which presented the *strategic*, *practical* and *evaluative considerations* in decision making for detailed water-use feedback enabled via SW metering was developed. This framework lays out for water utilities the key issues for consideration; and was used to critically review and to summarise the state of the art of detailed water-use feedback programs, together with the provision of recommendations for action and suggestions for addressing the unknowns.

8.2. Answers to the research questions

RQ1: What are the possible and practical <u>options</u> for presenting detailed household water-use feedback in a digital future?

Through a review of the literature and the practical implementation of two trials, this thesis explored the options for the provision of more detailed water-use feedback to householders in conjunction with SW metering.

A framework for water-use feedback was introduced (Figure 10), which provided a comprehensive overview of the *possible* options for feedback enabled via SW metering and was proposed as a general framework for analysing existing programs and the design of future ones. Feedback was specifically defined in terms of the feedback medium, its content, the frequency, speed and duration of feedback and the context in which it is provided. Content of feedback was characterised in terms of six further properties, namely, its measure, resolution, reporting period, comparison, interpretation and presentation.

Regarding *practical* options, water utility practice and research have signalled three main approaches, namely, (i) leak detection; (ii) total (near) real-time online; and (iii) end-use feedback. These alternatives offer different levels of information details, and therefore target different means for achieving water-savings. Naturally, the cost and the technical challenges need to be addressed. Detailed end-use data was approved to be very popular among householders, showing specific opportunities to save, which subsumes the mere provision of leak-alerts, which is currently more predominant in utility practice. Ultimately a combined and multi-modal approach is likely to offer the greatest benefits due to the variety among customers and specific benefits of each type of feedback. At the same time, enabling expedited end-use feedback is highly recommended, noting that at present its application may be best suited to targeting certain customers.

RQ2: What are householders' preferences in terms of detailed feedback enabled by SW metering?

In this thesis, householder's preferences were investigated in terms of access to detailed feedback enabled by SW metering. It was argued that understanding householder preferences could help shape the role for detailed feedback via SW metering and influence engagement and the extent to which it is able to promote more SUWM.

Significant interest in more detailed household water-use feedback was determined in the research which lends support to utilities to pursue more extended SW metering involving the provision of more detailed water-use feedback. In addition, different approaches to feedback were found to appeal to different households. End-use information was found widely appealing. Near real-time information also appealed to others. In terms of feedback mediums, paper-based reports (HWUs) achieved a very high reach rate, whereas the online medium (MHOW) was suited to a specific population segment. Via the preferences and evaluation surveys, householders demonstrated a wide variety of preferences for different forms of water-use feedback information content. Some householders were interested in access to all types of water-use metrics, whereas others preferred fewer specific types of detailed feedback information content.

The results of the research are of interest in demonstrating that householders are very much heterogeneous in terms of their preferences for water-use information. This was interpreted to suggest that a variety of approaches may need to be taken to help realise the benefits of SW metering more fully. It was particularly suggested that *customer segmentation* may have a role to play in the future of detailed water-use feedback provision, with alternative approaches for different customer groups. Opportunities for both 'top-down' segmentation directed by water utilities and a 'bottom-up' approach from customers were considered. Regarding the latter, an alternative approach not yet investigated could involve self-customisation, in which utilities could provide a menu of information services, from which customers could select their own feedback content and means of provision, which would enable householders to receive detailed feedback enabled via SW metering according to their specific preferences.

Householders revealed different motivations for engaging with their water-use feedback, especially financial, environmental and informational interests. Finally, reports of being motivated by some forms of detailed feedback did not automatically translate into action, so various important barriers exist that prevent greater impacts and that go beyond the provision of information according to present approaches.

RQ3: What the <u>impacts</u> of the provision of detailed water-use enabled via SW metering to householders in terms of water savings, behavioural and infrastructure changes and awareness?

The research in this thesis involved the implementation of two distinct SW metering trials in which detailed water-use feedback was presented to householders via paper-based reports (HWUs) and an online portal (MHOW), respectively, and enabled a detailed exploration of impacts. Both empirical trials yielded positive results according to a broader variety of measures of impacts than evaluated previously.

The provision of detailed water and end-use feedback via the HWUs (paper reports) led to behaviour and infrastructure changes and improvements in householder water-use awareness. While a decrease in water consumption was detected, this could not be confirmed as statistically significant due to the moderate sample size and limited measurement periods. However, the wide appeal of end-use feedback found suggests this approach warrants further attention by water utilities.

The more continuous online provision of feedback in near real-time was able to demonstrate statistically significant water savings, even in the longer term. The savings effects were found to particularly be related to actual engagement with the available feedback (i.e. actual portal usage as measured via login activity). This analysis demonstrated the importance of actual and continuous (or at least regular) exposure to consumption feedback. In addition to the saving effects, positive impacts in terms of changes in awareness, water-consuming behaviours and household water-using appliances were found.

Taken together, the results of the two studies provide empirical evidence of the positive influences on household water consumption and water-use awareness through the availability of more detailed, customised water-use information. The results present a positive role for facilitating access for consumers to the detailed data resources created through SW metering.

At the same time, scope for improving the overall impacts was identified in a number of regards. Firstly, an important finding was one of variation in responses of householders to detailed water-use information, which ultimately was further reflected in terms of differences in its measured impacts. The reach of feedback is an important factor, since this will limit its impacts. Therefore, more work is required to understand how to improve the levels of householder involvement and therefore the potential scale of impacts. Secondly, the analysis of impacts over time in the MHOW (online) study showed the frequency and continuity of exposure to feedback is highly important, that effects may diminish over time. Therefore, the goal of a water utility is important and the targeting of short- or long-term effects requires consideration. There may be opportunities for increased 'push' efforts with detailed feedback by water utilities in drought conditions. Lastly, the issue of scalability also requires further attention. The ways in which implementations of detailed water-use feedback programs are to include or select households in future needs further consideration since this has implications for the manner in which water consumption data can be analysed and the results interpreted, particularly concerning the scalability of effects detected among subsets of a population and the representativeness of results.

RQ4: What are the <u>implications</u> of the research for the future of SW metering for utilities and customers and for SUWM?

The research in this thesis has provided important evidence of a positive role for detailed household water-use feedback in contributing towards more SUWM. However, to achieve more significant impacts towards sustainability objectives, a greater scale of detailed water-use feedback provision is required, which simultaneously fosters large scale customer involvement. In this manner the future of SW metering would involve 'smart water utilities' and 'smart water consumers'. Through widespread provision involving 'smart customisation' together with a suitable policy mix, large scale involvement should be targeted.

Further and coordinated research is required regarding the design, implementation and evaluation of the impacts of more detailed water-use feedback in order to facilitate a smoother and faster implementation of feedback when SW metering becomes more mainstream. Particularly the ‘implementation framework’ developed in this thesis (Figure 30) outlined the key elements in decision making for detailed water-use feedback programs enabled via SW metering. By outlining the *strategic*, *practical* and *evaluative considerations*, the framework and its discussion concerning existing approaches to detailed feedback provided clear guidance to water utilities to plan and implement their own approaches to water-use feedback provision and evaluate offerings by managed service providers.

Now the water industry is in very much need of a best-in-class model type of large-scale implementation which takes full advantage of the customised options made possible via SW metering and the digital age, by combining and building upon the wide range of existing approaches identified, to serve as an industry benchmark through wider dissemination of the approach, results and recommendations.

8.3. Concluding remark

It is anticipated that that the contributions to knowledge and the research agenda in this thesis will help water utilities and researchers make further progress in the development and implementation of improved detailed water-use feedback initiatives. Water utilities should strive to take full advantage of the opportunities of SW metering technologies to facilitate a more rapid and widespread transition towards a more sustainable form of urban water management which involves customers more fully in the digital age of information communications and decision making.

The external context of water resources management will most certainly continue to place increasing pressures on water resources through population growth, economic development and climate change, so it is likely that all water utilities will soon have no choice but to pursue greater sustainability ever more actively. If water utilities can adopt detailed water-use feedback with SW metering with greater intents and purposes for sustainability now, this could serve as a best practice example for the industry for others to follow suit, and thus expedite progress and benefits of transitioning to sustainable smart digital cities characterised by ‘smart utilities’ and ‘smart water consumers’ in addition to smart technologies.

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Appendix

Appendix 1A. HWU evaluation survey cover letter

IMPORTANT NOTICE November 2013

Dear customer,

You may recall in late 2012 MidCoast Water invited you to participate in the ***'Know Your Water'*** project with the University of Technology, Sydney. We would like to thank you again for your participation in the project, which has involved you completing a household water use survey and agreeing to receive more detailed information about your household's water use.

As your household was selected to receive more information about your water use, MidCoast Water was pleased to provide you with two ***'Home Water Updates'*** in the months of May and September.

We would now like to gain your feedback on the ***'Home Water Updates'*** and your views on different kinds of water use information for householders by kindly requesting you complete and return the enclosed survey. Your responses along with those of other households participating in the project will help us to understand what water use information our customers find useful.

By returning a completed survey <u>by Friday 6 December, 2013</u> you will automatically receive $20 off one of your next water bills. The survey will take about 15-20 minutes to complete. A reply-paid envelope is enclosed for you to return your completed survey.

Your information will remain strictly confidential and at no time will your name or personal details be disclosed. **Your full name and address must be provided (on page 1 of the survey) in order for us to allocate your $20 subsidy** to your customer account and for your survey to be included in the research.

For more information on the project, please refer to the enclosed information sheet.

Thank you for your continued participation in this exciting research.

Warm regards,

Graeme Watkins
Strategic Operations Manager
MidCoast Water

This research project is supported under Australian Research Council's *Linkage Projects* funding scheme (project number LP110200767).

Research ethics
Studies undertaken by the Institute for Sustainable Futures have been approved in principle by the University of Technology, Sydney, Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research you may contact ISF Research Directors Emma Partridge (tel: 02 9514 4964) or Chris Riedy (tel: 02 9514 4964), or ISF Institute Manager Carroll Graham (tel: 02 9514 4975).

You may also contact the UTS Ethics Committee through the Research Ethics Officer (tel: 02 9514 9615). Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 1B. HWU evaluation survey information sheet

Information Sheet

November 2013

About the project

MidCoast Water, together with the Institute for Sustainable Futures at the University of Technology, Sydney, are collaborating on an exciting research project from 2012-2015 looking at the potential impact of detailed smart water meter information on household water use. In the most recent phase of the project, selected participating households have been provided with more information about the way in which they use water in the home through the ***'Home Water Updates'***.

The success of our project depends on the continued participation of households in now sharing feedback on the ***'Home Water Updates'***. The more participants who continue to be involved by completing the enclosed survey, the more valuable the research will be.

What is a smart meter?

Smart water meters are a new, innovative technology that read your household's water use multiple times per day. As you know, your water bill usually arrives quarterly with a bulk amount of how much water was used, and how much it costs. With no further detail available to the household, it may be difficult for households to understand their water use. The ***'Home Water Updates'*** that we're trialing provide detailed information from your smart water meter and show you where water is being used and detecting leaks that might otherwise go unnoticed.

What is the research project about?

The project aims to investigate what information best helps households to understand their water consumption. The aim of the research is to see what value households derive from additional information about their household water use and whether or not this makes any difference to the way water is used at home.

Will participating cost me anything?

No, there will be no cost to you. Your household already has a smart meter installed and the trial ***'Home Water Updates'*** have been provided at no cost to you.

How can I participate?

Simply complete the enclosed survey and return by <u>Friday 6 December</u> using the reply paid envelope provided. The survey will take approximately 15-20 minutes to complete. By returning the completed survey you will automatically receive $20 off one of your next two water bills. There are no other requirements of you for agreeing to participate in this project. You are free to withdraw your participation from this research project at any time without giving a reason.

Confidentiality

All information gathered as a result of this research project will remain confidential and will only be used in general terms for the research purpose of this study. Any published research findings as a result of this study will ensure anonymity of all participating households.

If you have any questions regarding your participation in the research please contact Graeme Watkins at MidCoast Water on (02) 6592 4812 or graeme.watkins@midcoastwater.com.au, or Damien Giurco at the Institute for Sustainable Futures on (02) 9514 4978.

Thank you for taking the time to read this information.

This research project is supported under Australian Research Council's *Linkage Projects* funding scheme (project number LP110200767).

Research ethics

Studies undertaken by the Institute for Sustainable Futures have been approved in principle by the University of Technology, Sydney, Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research you may contact ISF Research Directors Emma Partridge (tel: 02 9514 4964) or Chris Riedy (tel: 02 9514 4954), or ISF Institute Manager Carroll Graham (tel: 02 9514 4975).

You may also contact the UTS Ethics Committee through the Research Ethics Officer, (tel: 02 9514 9615). Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 1C. HWU evaluation survey questions

Return this survey by Friday December 6 to automatically receive $20 off your water bill

About this survey

This survey is part of the '***Know Your Water'*** research project conducted by MidCoast Water and the Institute for Sustainable Futures at the University of Technology, Sydney.

You may recall that we sent you two ***'Home Water Updates'*** like the ones pictured on the front cover. This survey will ask you about your impressions of the Home Water Updates and different kinds of household water use information.

Your responses will help us to gain important insights into the value of different types of detailed water use information to householders. We highly appreciate your participation in this important research project and thank you in advance for taking the time to share your views.

Please remember, answering the questions as frankly as possible will give us the most meaningful results. All information gathered for this research will remain confidential and any published findings will ensure anonymity of participating households.

Please enter your details below before completing the survey:

Name ________________________________

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Your overall impressions of the Home Water Updates

*This section will help us understand your impressions of the **Home Water Updates** we sent you in May and September this year.*

1. How **much** time did **you** spend in total looking at the Home Water Updates we sent you? *(Please tick one in each row):*

	I didn't look at it	A glimpse	A few minutes	Between 5 and 10 minutes	More than 10 minutes
1st Home Water Update (May)	◯	◯	◯	◯	◯
2nd Home Water Update (September)	◯	◯	◯	◯	◯

2a. How **many times** did **you** yourself look at the Home Water Updates? *(Please tick one in each row):*

	Just once	Twice	More than twice
1st Home Water Update (May)	◯	◯	◯
2nd Home Water Update (September)	◯	◯	◯

2b. Did you compare the two Home Water Updates? *(Please tick):*

Yes ◯ No ◯

3. Who else had a look at your Home Water Updates? *(Please tick all that apply):*

◯ Other member(s) of my household
◯ Other relatives (not in my household)
◯ Neighbour(s)
◯ Colleague(s)
◯ Friends(s)
◯ Other *(please specify):* ______________________________
◯ None of the above

4. How often did you **discuss water usage information** from the Home Water Updates with any other members of your household? *(Please tick):*

Never	Once	Twice	More than twice
◯	◯	◯	◯

5. How often would you ideally like to receive new Home Water Updates? *(Please tick):*

Never	Once per year	Every six months	Every three months	Every month
◯	◯	◯	◯	◯

6. Please indicate the level to which you agree or disagree with the following statements about the Home Water Updates. *(Please tick the appropriate box in each row):*

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I like the Home Water Updates	◯	◯	◯	◯	◯
The information is applicable to my household	◯	◯	◯	◯	◯
The information made me more conscious about my household's water use.	◯	◯	◯	◯	◯

7a. Did your household **install** any new water-efficient devices or appliances **after** reading the Home Water Updates? *(Please tick):*

Yes ◯ No ◯

If yes, please tick the appropriate item(s) below:

- ◯ Water-efficient shower head
- ◯ Water-efficient toilet
- ◯ Water-efficient washing machine
- ◯ Fixed a leak
- ◯ Other(s) *(please specify):* ______________________________________

7b. Did your household **use** any of your existing water appliances **differently** **after** reading the Home Water Updates? *(Please tick):*

Yes ◯ No ◯

If yes, what did you do differently? *(Please specify actions taken for the following water uses where applicable):*

Water use		**New actions taken** *(Please comment)*
Taps	◯	
Shower	◯	
Toilet	◯	
Washing Machine	◯	
Outdoors	◯	
Leaks	◯	
Other(s)	◯	

More on the Home Water Updates

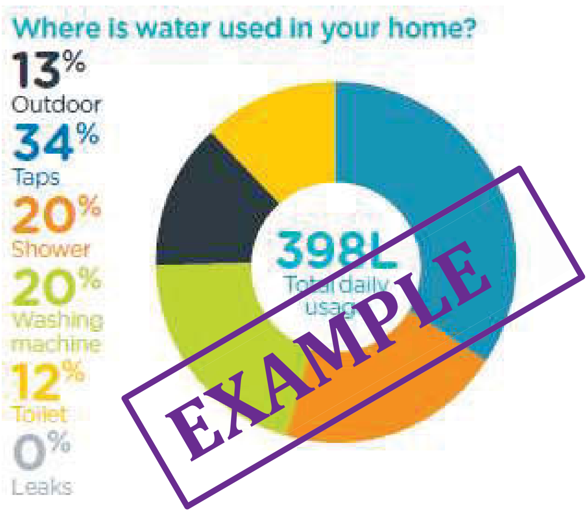
Questions 8-11 will help us to understand how you found specific information items in your Home Water Updates.

The pictures in this section are **examples only**. The pictures do **NOT** represent your own household's water use.

Please answer the questions reflecting on the information we provided in your own Home Water Updates about your own household.

Information on where water is used in your home

8. Your Home Water Updates showed **where water is used in your home**, like in Example A below.



8a. Please indicate the level to which you agree or disagree with the following statements about **this information in <u>your</u> Home Water Updates.** *(Please tick the appropriate box in each row):*

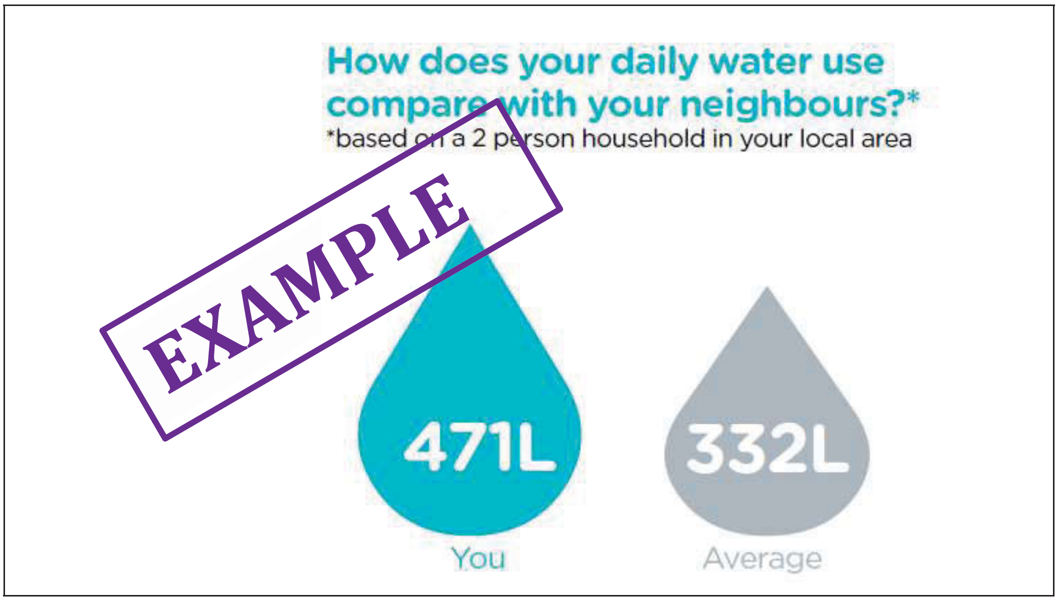
	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The information is new to me	◯	◯	◯	◯	◯
The information is interesting to me	◯	◯	◯	◯	◯
The information is easy to understand	◯	◯	◯	◯	◯
The information let me see more opportunities to save water in my home	◯	◯	◯	◯	◯
The information made me feel more motivated to try to save more water in the home	◯	◯	◯	◯	◯
The information has helped my household use less water than before.	◯	◯	◯	◯	◯

8b. Were you surprised by the share of water used by your household for any of the following? *(Please tick all that apply):*

Shower	Toilet	Washing Machine	Taps	Leaks	Outdoors	No, no surprises
◯	◯	◯	◯	◯	◯	◯

Information on how your home compares

9. Your Home Water Updates showed how your daily water use **compares with your neighbours**, like in Example B below.



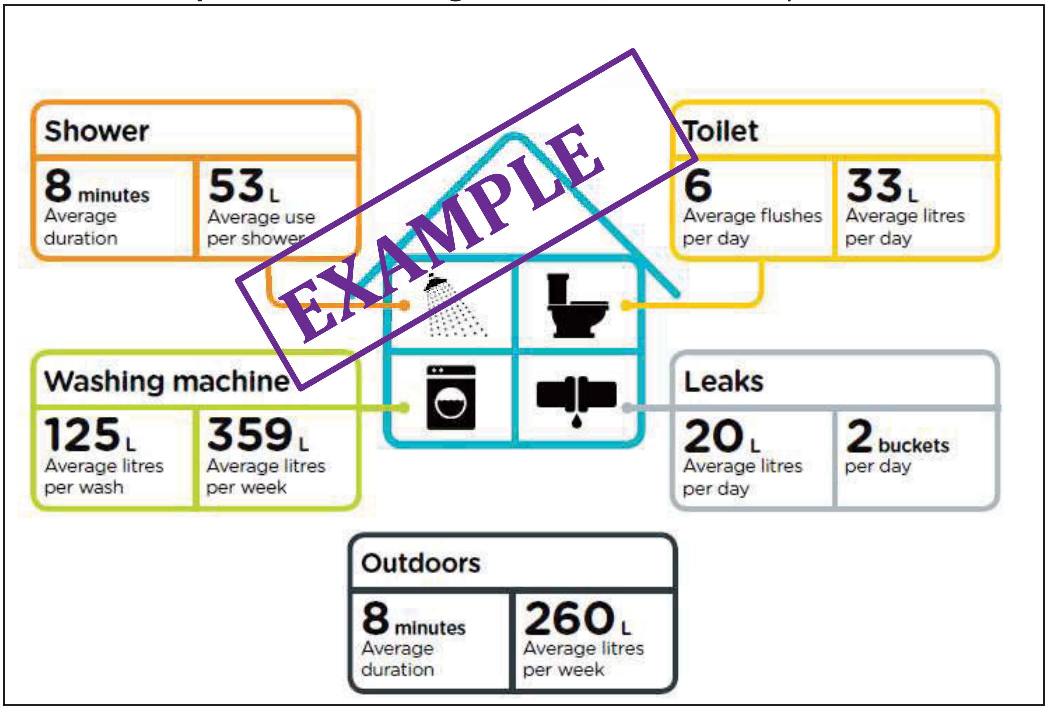
9a. Please indicate the level to which you agree or disagree with the following statements **about this comparison information in <u>your</u> Home Water Updates.** *(Please tick the appropriate box in each row):*

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The comparison information is new to me	◯	◯	◯	◯	◯
The comparison information is interesting to me	◯	◯	◯	◯	◯

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The comparison information is easy to understand	○	○	○	○	○
The comparison information let me see more opportunities to save water in my home	○	○	○	○	○
The comparison information made me feel more motivated to try to save more water in the home	○	○	○	○	○
The comparison information has helped my household use less water than before.	○	○	○	○	○

Information on specific water uses in your home

10. Your Home Water Updates included detailed information on your household's **specific water using activities**, like in Example C below.



10a. What did you think when you saw this detailed information for **<u>your</u>** home in your Home Water Updates? *(Please comment):*

____

____

____

____

10b. Please indicate the level to which you agree or disagree with the following statements **about this detailed information in <u>your</u> Home Water Updates.** *(Please tick the appropriate box in each row):*

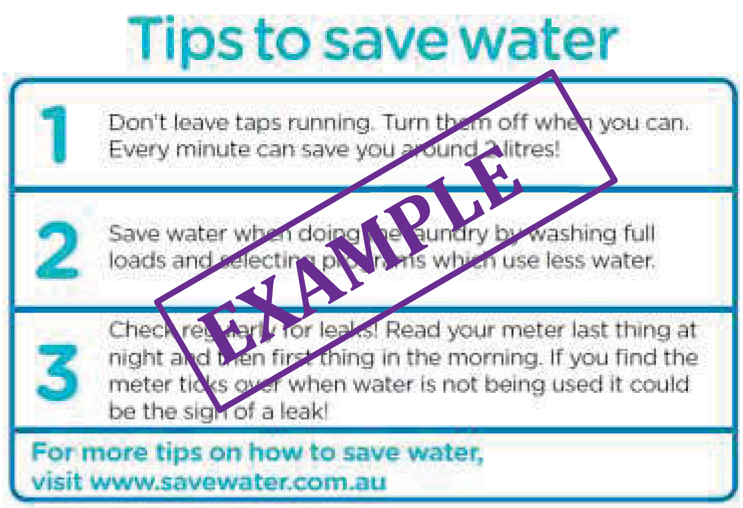
	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The information is new to me	○	○	○	○	○
The information is interesting to me	○	○	○	○	○
The information is easy to understand	○	○	○	○	○
The information let me see more opportunities to save water in my home	○	○	○	○	○
The information made me feel more motivated to try to save more water in the home	○	○	○	○	○
The information has helped my household use less water than before.	○	○	○	○	○

10c. Would it be more helpful if you were also provided with information for the **average household** so you could make comparisons? *(Please tick one only):*

Yes	No	Not sure
○	○	○

Information on how to save water in your home

11. Your Home Water Updates included customised **tips to save water** (like in Example D below).



11a. Please indicate the level to which you agree or disagree with the following statements **about the tips in <u>your</u> Home Water Updates.** *(Please tick the appropriate box in each row):*

	Agree	Partly agree	Disagree	I don't know
The tips were new to me	○	○	○	○
The tips were relevant for my household	○	○	○	○
I felt that it would be good to follow the tips	○	○	○	○
I felt the tips were do-able	○	○	○	○

11b. For the **tips you followed,** what were your reasons? *(Please tick all that apply):*

To save water	◯	No reason	◯
Environmental concern	◯	Other *(please specify):* ______________________	◯
N/A - I did **not** follow any tips	◯		

11c. For the tips you did **not** follow, what were your reasons? *(Please tick all that apply):*

Habit	◯	Economic / cost factors	◯
Lack of information	◯	Lack of opportunity	◯
Personal factors (e.g. laziness, forgetfulness, didn't think about it)	◯	My activities don't impact the environment	◯
Technically not feasible	◯	I'm doing what I can	◯
The water-saving alternative is less satisfactory	◯	I'm already doing this or a water-saving alternative	◯
Impact of others e.g. children	◯	No reason	◯
Time / convenience	◯	Other *(please specify):* __________________________	◯

N/A - I followed **all** the tips	◯

11d. What do you think would make the tips more useful? *(Please comment):*

____

____

Your water use plans & awareness

This section will help us understand your intentions for engaging in water saving activities at home both before and after receiving the Home Water Updates.

12. Think back six months ago, to the time **before reading the Home Water Updates.** To what level would you agree or disagree with the following statements? *(Please tick the appropriate box in each row):*

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I wanted my household to save more water	◯	◯	◯	◯	◯
I planned to do more everyday actions at home to save more water	◯	◯	◯	◯	◯
I planned to install more water efficient devices / appliances to save more water at home	◯	◯	◯	◯	◯

13. Now, having read the Home Water Updates, to what level would you agree or disagree with the following? *(Please tick the appropriate box in each row):*

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I want my household to save more water	◯	◯	◯	◯	◯
I plan to do more everyday actions at home to save more water	◯	◯	◯	◯	◯
I plan to install more water efficient devices / appliances to save more water at home	◯	◯	◯	◯	◯

14. Do you now agree or disagree with the following statements? *(Please tick the appropriate box in each row):*

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I know how much water my household uses	◯	◯	◯	◯	◯
I know how much water my household appliances use	◯	◯	◯	◯	◯
I know where most of the water in my home is used	◯	◯	◯	◯	◯
I feel informed about my household water use	◯	◯	◯	◯	◯
My water bill gives me all the information I need	◯	◯	◯	◯	◯

Your information preferences

Smart water metering could provide more detailed information than is on your water bills. The following questions will help us to understand your information preferences.

15a. How much information on your past water use would be **most useful** to you? *(Please tick one):*

No past information	Information on my last 6 months of water use	Information on my last 12 months of water use	Not sure
◯	◯	◯	◯

15b. Is it useful for you to be able to compare your water use in the current billing period with the same billing period last year? *(Please tick one):*

Yes	No	Not sure
◯	◯	◯

16a. Which comparison with other households would be useful for your household? *(Please tick one):*

Efficient household	Average household	Both efficient and average households	Neither	Not sure
◯	◯	◯	◯	◯

16b. What location would you **most** prefer to see your household compared against? *(Please tick one):*

Homes in my street	Homes in my suburb	Homes on the mid-north coast	Homes in NSW	Homes in Australia	No comparison	Not sure
◯	◯	◯	◯	◯	◯	◯

17. Which uses of water in your home are you **most interested** to know about? *(Please **rank from 1-6**, where 1 is the most important to you and 6 is the least important to you):*

Outdoors	Washing Machine	Taps	Toilet	Shower	Leaks

18. What level of information would you **most** prefer? *(Please tick one only):*

Detailed information about my water use without any tips.	Both detailed information about my water use and personalised water saving tips.	Just personalised water saving tips, without all the details about my water use.
◯	◯	◯

19. It takes time to collect and analyse the water use data collected by your smart water meter. This means there is a time lag between when you actually use water in your home and when detailed information might be available.

What do you think is an acceptable time lag? *(Please indicate the number of months):*

________ months

20. Which information would interest you more? *(Please tick one only):*

What other households are actually doing to save water in the home	What water utilities recommend householders to do to save water
◯	◯

21. Which of the following is **useful** to know for your household? *(Please tick the appropriate box in each row):*

	Information	Useful	Not useful	I don't understand this
SHOWER	Average shower duration	◯	◯	◯
	Average litres per shower	◯	◯	◯
WASHING MACHINE	Average litres per wash	◯	◯	◯
	Average litres per week	◯	◯	◯
TOILET	Average flushes per day	◯	◯	◯
	Average litres per day	◯	◯	◯
TAPS	Average flow rate	◯	◯	◯
	Average litres per day	◯	◯	◯
OUTDOORS	Average duration per use	◯	◯	◯
	Average litres per week	◯	◯	◯
LEAKS	Average litres per day	◯	◯	◯
	Average buckets per day	◯	◯	◯

22a. Which kind of savings would you find **most** motivating? *(Please tick one):*

Save $100 a year	◯
Save $25 a quarter	◯
Save 10,000 litres of water a quarter	◯
Save 40,000 litres of water a year	◯

22b. Which kind of savings would you find **most** motivating? *(Please tick one):*

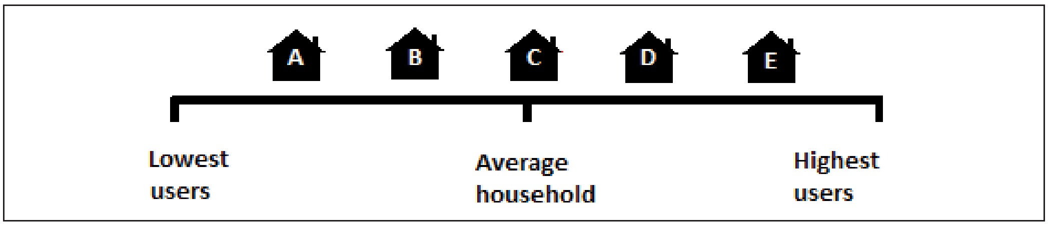
Save 10,000 litres a year	◯
Save 1,000 buckets of water a year	◯

Your responses to water use information

23a. If you found out that your household uses more water than the average 2 person household, what would you think? *(Please tick all that apply):*

Responses	
My household should save more water	◯
It would depend on how much more than the average my household was using	◯
I wouldn't think much of it	◯
I would think about what reasons might lie behind this	◯
I would think about whether the difference was justifiable e.g. due to different needs	◯
Other *(Please specify):* ____	◯

23b. How motivated would you feel to try to save more water if you lived in the following homes? *(Please tick the appropriate box in each row):*



	Strongly motivated	Motivated	Neutral	Not motivated	Not at all motivated
If I lived in house A	◯	◯	◯	◯	◯
If I lived in house B	◯	◯	◯	◯	◯
If I lived in house C	◯	◯	◯	◯	◯
If I lived in house D	◯	◯	◯	◯	◯
If I lived in house E	◯	◯	◯	◯	◯

23c. If you found out that your household's water use was higher than in your last bill and also higher than in the same billing period last year, how would you respond? *(Please tick all that apply):*

Responses	
I would want to try to save more next period	◯
I would not think much of it	◯
I would think about what reasons might lie behind this	◯
I would think about whether the difference was justifiable e.g. due to different needs	◯
I would plan how to save more water	◯
I would talk with other household members about this	◯
Other *(Please specify):* ____	◯

23d. What factors do you take into account when considering whether or not to install more water-efficient appliances? *(Please comment):*

____

____

____

____

Your water use

24. In comparison to other households in your area, what do you now think your household's current water usage is? *(Please tick the appropriate box in each row):*

	Very low	Low	Average	High	Very high
Total water use	◯	◯	◯	◯	◯
Shower	◯	◯	◯	◯	◯
Washing machine	◯	◯	◯	◯	◯
Toilet flushing	◯	◯	◯	◯	◯
Taps	◯	◯	◯	◯	◯

	Very low	Low	Average	High	Very high
Outdoors	◯	◯	◯	◯	◯
Leaks	◯	◯	◯	◯	◯

25. Do you agree or disagree with the following statements? *(Please tick the appropriate box in each row):*

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Water conservation is important to me	◯	◯	◯	◯	◯
Water conservation is important to others in my household	◯	◯	◯	◯	◯
I am confident I could save more water if I wanted to	◯	◯	◯	◯	◯
I am confident my household could save more water if I wanted it to	◯	◯	◯	◯	◯
There is a social pressure to save water	◯	◯	◯	◯	◯
Most people I know have water efficient appliances	◯	◯	◯	◯	◯
Most people I know save water around the home and garden	◯	◯	◯	◯	◯
I am interested in my household's water use	◯	◯	◯	◯	◯

26. Where do you think it would be **(a) the easiest** and **(b) the hardest** for your household to save more water? *(Please tick ONE in each column):*

(a) Easiest to save more water *(tick one)*		(b) Hardest to save more water *(tick one)*
◯	Shower	◯
◯	Toilet	◯
◯	Washing machine	◯
◯	Taps	◯
◯	Outdoors	◯
◯	Leaks	◯

26c. How could the **easiest** water savings in **Q26(a)** be achieved? *(Please tick one only):*

Installing a water-efficient appliance/infrastructure	Change in behaviour
◯	◯

Your communication preferences

27. Which of the following options do you prefer most? *(Please **rank from 1-4**, where 1 is your most preferred option and 4 is your least preferred option):*

Options	Rank (1-4)
An annual report on your water usage	
Two 'Home Water Updates' per year ***(one for the summer and one for the winter)***	
A more detailed water bill every three months	
Real time information on your water use ***(via a website / smart phone app)***	

28. Which households do you think should receive more detailed information about their household's water use? *(Please tick ALL that apply):*

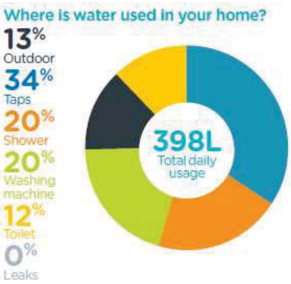
Every household	Only high water using households	Only interested households	No households
◯	◯	◯	◯

Your valuation?

The Home Water Update trial has now come to an end. This section asks how much you value the information provided.

29. What is the **maximum amount of money** you would be **willing to pay** to receive each of the following for Summer 2013/14? *(Please state the amount in dollars/cents):*

i. Information on where and how much water is used for different uses within my home



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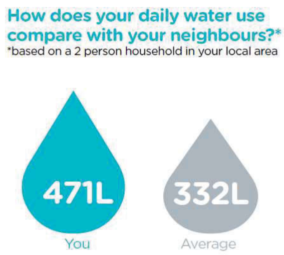
ii. Information on how my household compares with other households



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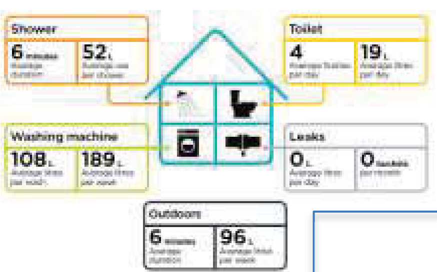
iii. Detailed information on my household's different water using activities



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iv. A complete Home Water Update for Summer 2013/14

$

v. A generic Home Water Update which only contains detailed information about the **average household** in your area (i.e. no information about your own household's water use).

$

30. Why would you be willing to pay those amounts for detailed water use information? *(Please tick all that apply):*

Reasons	
It helps me monitor my household's water usage.	◯
It will help me save water.	◯
It will help me save money.	◯
It is interesting to receive.	◯
Other *(please specify):* ____________________________________	◯

Your final comments?

Do you have any suggestions on how to improve the Home Water Updates?

____

____

____

Do you have any other comments about water use information?

____

____

____

Extra participation?

*To further understand household water use and the role of information we are seeking **volunteers** to participate in a short interview. All information collected during the interviews will remain confidential and un-identifiable.*

Would you be willing to participate in an interview?

Yes ◯ No ◯

Please kindly indicate the best phone number / email should we need to contact you to discuss possible interview arrangements.

Phone: ____

Email: ____

End of survey

We greatly appreciate you taking the time to complete this survey.

Don't forget that by returning this survey you will automatically receive $20 off your water bill.

PLEASE NOTE:

You must provide us with your contact details (see page 1)

or else we will be unable to process your subsidy.

Reply-paid envelope provided

Appendix 1D. HWU evaluation interviews – sample guiding questions

The following sample questions were used to guide the semi-structured interviews. Some of the questions were omitted or revised according to how the interviews unfolded.

Part I: About the HWUs

- Do you remember the Home Water Updates?
- What information can you recall?
- How did you use that information?
- Do you still have the HWUs? Would you be able to fetch one?
- How did you read the HWUs? What did you look at? What kinds of thoughts came to mind?
- The HWUs contained a pie chart of different uses of water in your home (shower, toilet, washing machine, taps, outdoors and leaks). How do you read such kinds of pie charts?
- What do you think about being told your water usage in terms of buckets, for example "your household consumes 15 buckets of water a day"?
- The HWUs contained a comparison of your water use with other households. Some households prefer to see how their water use compares with other households in their own street or own suburb, rather than with a regional or state level comparison. Why do you think that is? What do you think is the ideal comparison for your household?
- The HWUs contained measures of your use of each of your specific water appliances? Like duration, total volume, no. of times used. What do you think of such kinds of information?

Part II: Behaviours

- Do you think the HWUs changed any of your beliefs about your water use?
- Do you think about how much water you are using as you go about your day to day activities at home?
- Some households said the HWUs made them see opportunities to save more water or made them feel motivated to save more water, but not everyone did always actually save. Why do you personally think this is?

Part III: Privacy

- Who would you be willing to share information with about your household's water usage?
- Do you have any concerns about the collection or provision of more detailed water-use information through smart water metering? Does this depend on the types of information?
- Is privacy about your water usage an issue for you, or do you think it might be for other households?

Part IV: Regular bill reading

- How do you normally read your quarterly water bill?

Part V: Information needs

- What information do you need to best manage your household's water use?
- What kinds of information / measures of your water use would motivate you most to save more water?

Appendix 2A. MHOW household information pack: cover letter

Institute for Sustainable Futures | UNIVERSITY OF TECHNOLOGY SYDNEY | MIDCOAST WATER

December 2013

Dear Resident,

You may recall in late 2012 we invited you to participate in '***Know Your Water***', a project that aims to provide you with more detailed information about your water use. This involved completing a survey and agreeing to the upgrade of your water meter.

Over the past year we have been collecting water use information more regularly from households that agreed to participate in the trial. We have also been developing an online website called '***My Home Our Water***' that allows you to access this more detailed information about your water use, safely and securely, in partnership with our technology provider *Outpost Central*. The purpose of the website is to explore which types of water use information our customers find useful.

We are pleased to inform you that your household has been selected to trial '***My Home Our Water***'. The enclosed leaflet shows how to access the website and some of the key features available. Also enclosed is a magnetic postcard which you may find a handy reference.

Your **username** is already provided on the postcard. You may notice, your username is your home address, all lower case letters and no spaces. For example, the address 35 Example Road would be: "35examplearoad".

Your **password** will be mailed to you separately. When it arrives in the mail, you may wish to stick it on the space provided on the postcard.

If you experience any difficulties logging in, please call the MidCoast Water customer service desk on **1300 133 455** and ask for either Graeme Watkins or David Bowland.

Please remember, the '***My Home Our Water***' website is part of a trial project. We encourage you to report any issues you come across via the 'Feedback' box, which can be found under 'Help/Frequently Asked Questions'. We hope you enjoy using the site and learning more about your household's water use.

For more information on the project, please refer to the enclosed information sheet.

Warm regards,

Graeme Watkins
Strategic Operations Manager
MidCoast Water

Research ethics
Studies undertaken by the Institute for Sustainable Futures have been approved in principle by the University of Technology, Sydney, Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research you may contact ISF Research Directors Emma Partridge [tel: 02 9514 4954] or Chris Riedy [tel: 02 9514 4954], or ISF Institute Manager Carrol Graham [tel: 02 9514 4975].

You may also contact the UTS Ethics Committee through the Research Ethics Officer, [tel: 02 9514 9615]. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 2B. MHOW household information pack: information sheet

Know Your Water Project Information Sheet

January 2014

About the project

MidCoast Water and the Institute for Sustainable Futures at the University of Technology, Sydney are collaborating on an exciting research project looking at the potential impact of smart water meters on household water use. In this, the most recent phase of the project, selected households are being provided with access to detailed information on their water use via a specially developed online website, '***My Home Our Water***'.

What is a smart water meter?

Smart water meters are a new and innovative technology that reads your household water use multiple times per day. As you know, your water bill usually arrives quarterly with a bulk amount of how much water was used, and how much it costs. With no further detail available to the household, it may be difficult for householders to understand their water use. The website '***My Home Our Water***' that we're trialing provides detailed information from your smart water meter in near real time, also detecting leaks that might otherwise go unnoticed.

What is the research project about?

MidCoast Water has partnered with the Institute for Sustainable Futures, at the University of Technology, Sydney to investigate what information best enables households to better understand and act on their water consumption. The aim of the research is to see what value households derive from the additional information about their household water use, and whether or not this makes any difference to the way water is used at home.

This pilot study will be trialing a number of ways to deliver water use information to households. As a selected participant, your household will be provided with the opportunity to track your household water use on a daily basis via the '***My Home Our Water***' internet website, which you will be able to access on your desktop computer or laptop, smart phone or tablet computer.

This research project is supported under Australian Research Council's *Linkage Projects* funding scheme (project number LP110200767).

Will participating cost me anything?

No, there will be no cost to you. In fact, you may even save money on your bills.

When will the research be taking place?

Smart meter data loggers were already installed on the existing water meters of all participating households in spring 2012. Over the past year your newly configured meter has been recording water use information just like your old meter did, but data has been collected more frequently. In this next phase of the research, selected participant households are being provided with immediate access to an online website which allows you to continuously track your own household's daily consumption in 2014.

What is required for you to participate?

Other than having access to this online information, there are no requirements for you to make any changes to your household water use. If you wish to engage with the online information provided, we encourage you to do so, but this engagement is purely optional. You are free to choose how frequently, if at all, you view your consumption information. The research is interested in understanding how useful and relevant you find this additional information. You are free to withdraw your participation from this research project at any time without giving a reason.

Confidentiality

All information gathered as a result of this research project will remain confidential and will only be used in general terms for the research purpose of this study. Any published research findings as a result of this study will ensure anonymity of all participating households.

If you have any questions regarding your participation in the research, please contact Graeme Watkins at MidCoast Water on (02) 6592 4812 or graeme.watkins@midcoastwater.com.au, or Damien Giurco at the Institute for Sustainable Futures on (02) 9514 4978.

Thank you for taking the time to read this information.

Warm regards,

Graeme Watkins
Strategic Operations Manager
MidCoast Water

Research ethics

Studies undertaken by the Institute for Sustainable Futures have been approved, in principle by the University of Technology, Sydney, Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research you may contact ISF Research Directors Emma Partridge [tel. 02 9514 4954] or Chris Riedy [tel. 02 9514 4954], or ISF Institute Manager Carol Graham [tel. 02 9514 4976].

You may also contact the UTS Ethics Committee through the Research Ethics Officer, [tel. 02 9514 9615]. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 2C. MHOW magnetic postcard

Co-designed by: Thomas Boyle & Ariane Liu

Appendix 2D. MHOW password letter and sticker

January 2014

Dear Resident,

We are pleased to inform you that your household has been selected to trial the ***'My Home Our Water'*** website as part of the '*Know Your Water*' project.

Full details about the site will be mailed to you separately. The purpose of this letter is to simply provide you with your secure **password** to access the site.

Your password is printed on the attached sticker. We recommend you stick this on the space provided on the magnetic postcard, which you will receive separately in the mail.

For ease of reference, you may notice that your password also matches your MidCoast Water account number, which can be found at the top of your water bills.

If you experience any difficulties logging in, please call the MidCoast Water customer service desk on **1300 133 455** and ask for either Graeme Watkins or David Bowland.

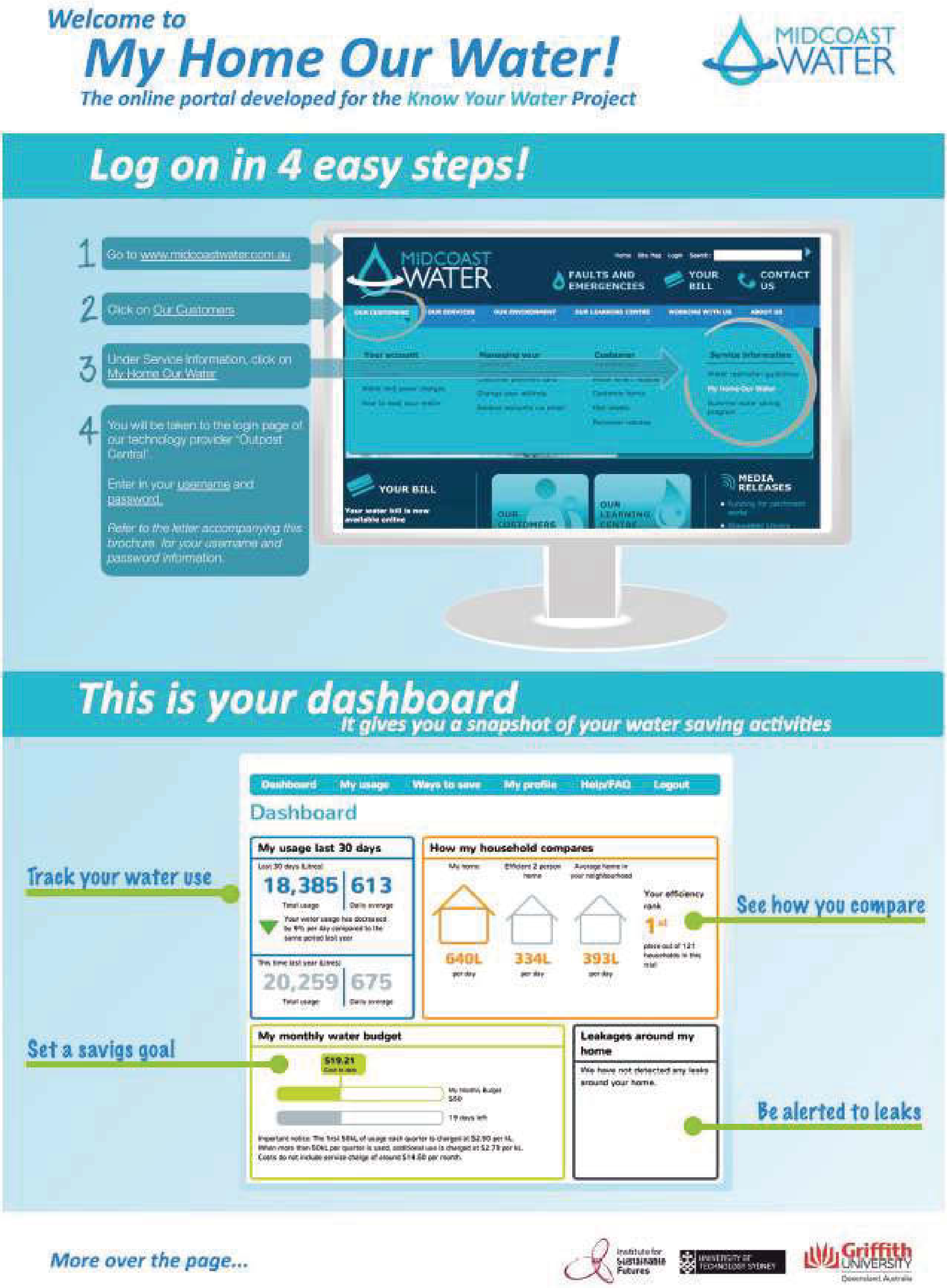
Warm regards,

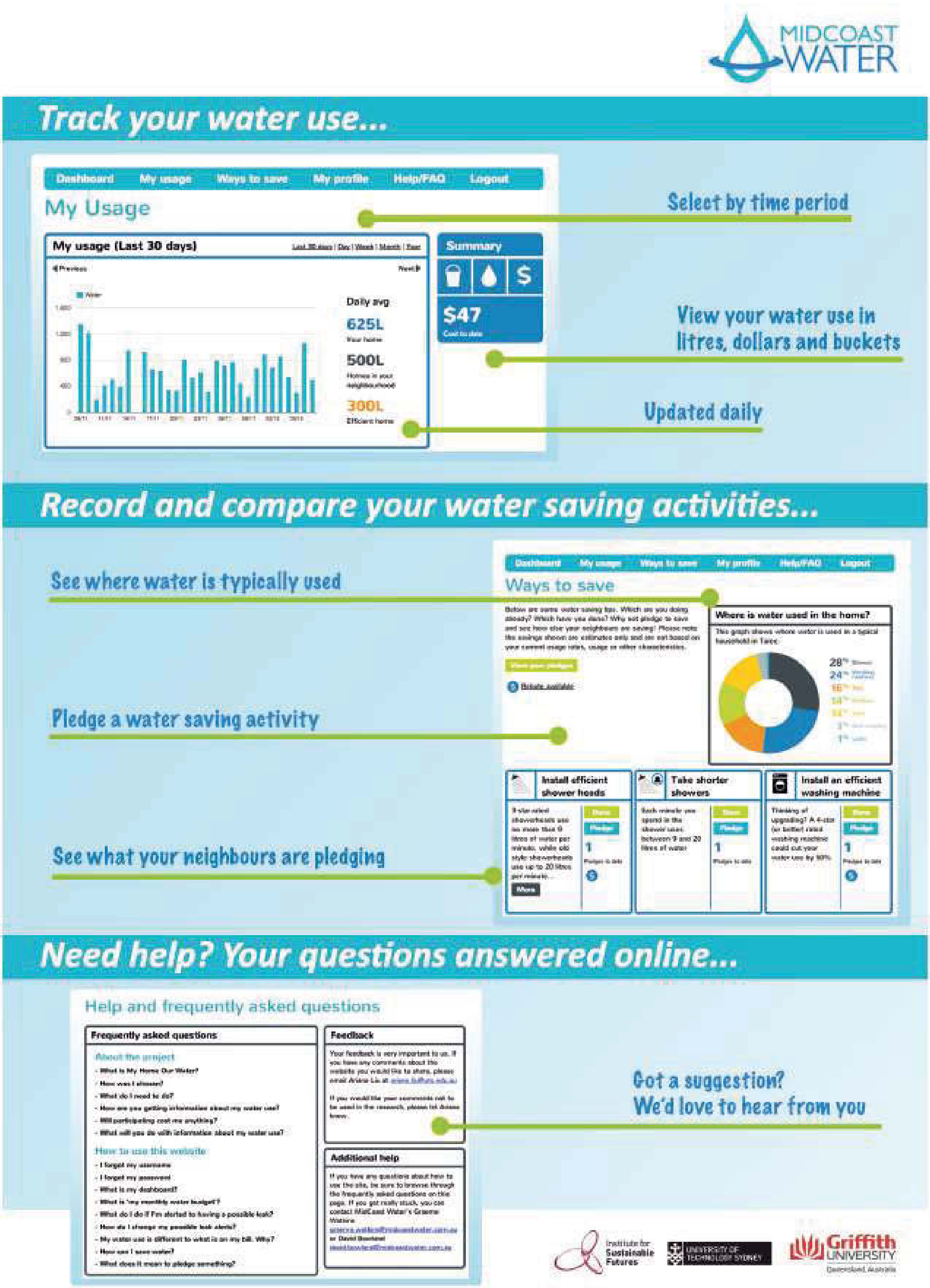
Graeme Watkins
Strategic Operations Manager
MidCoast Water

Research ethics
Studies undertaken by the Institute for Sustainable Futures have been approved in principle by the University of Technology, Sydney, Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research you may contact ISF Research Directors Emma Partridge [tel: 02 9514 4954] or Chris Riedy [tel. 02 9514 4964], or ISF Institute Manager Carroll Graham [tel: 02 9514 4975].

You may also contact the UTS Ethics Committee through the Research Ethics Officer, [tel: 02 9514 9615]. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 2E. MHOW portal brochure





Co-designed by: Thomas Boyle & Ariane Liu

Appendix 2F. MHOW first login online survey questions

1. How much water do you believe your household uses on average per day? (Just give your best guess!)

_____ litres per day

2. How confident are you about your guess?
Not at all confident Somewhat confident Confident Very confident

3. In comparison to other households in your area, what do you think your household's water use is?
Very low Low Average High Very High

4. How confident are you about your response above?
Not at all confident Somewhat confident Confident Very confident

5. To what level do you agree with the below?
a. *"I am interested in learning more about my household's water use".*
Strongly disagree Disagree Neutral Agree Strongly agree

b. *"I want my household to save more water".*
Strongly disagree Disagree Neutral Agree Strongly agree

c. *"I believe my household is already doing all it can to save water".*
Strongly disagree Disagree Neutral Agree Strongly agree

Appendix 2G. MHOW postcard reminder

Designed by: Ariane Liu.

Appendix 2H. Email reminder

From: Ariane Liu [mailto:Ariane.Liu@uts.edu.au]
Sent: Friday, 5 June 2015 9:04 PM
To: Ariane Liu
Subject: MidCoast Water – 'My Home Our Water' – have you logged on?

Dear project participant,

Have you logged on to '**My Home Our Water**' recently? Our online portal specially developed for the '**Know Your Water Project**' lets you:

- Track your household's water use,
- See how you compare with others,
- And shows you how you might save.

Also, did you know you can set up your own **leak alerts**? This means you will automatically be notified if we detect a possible leak in your property. You can choose email and/or SMS alerts, as you prefer. Household leaks often go unnoticed and can add unnecessary costs to your water bills. Leaks can cause damage, as well as significant water losses. So, a timely alert can make an important difference.

How do I set up leak alerts?
You can either log on to '**My Home Our Water**' to select your own alerts (see below). **Or if you prefer, we can set them up for you.** Just call our **MidCoast Customer Service** on **1300 133 455** and we'll be glad to help.

How do I log on to 'My Home Our Water'?
1. Go to www.midcoastwater.com.au. ***2.*** Click on **Our Customers.** ***3.*** Under **Service Information**, click on **My Home Our Water.** ***4.*** You will be taken to the login page of our technology provider, Outpost Central. Enter your **username** and **password.** (Please call Customer Service if you need help with your username or password).

Hope you find '**My Home Our Water**' useful.

Warm regards,

Graeme Watkins	Ariane Liu
Strategic Operations Manager	Doctoral Researcher
MidCoast Water	Institute for Sustainable Futures, UTS