Digital metering feedback and changes in water consumption – a review

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Digital metering and change in water consumption – a literature review

Abstract

This review paper investigates the way information is provided to customers through the use of digital water metering and customer engagement, and its impact on water consumption. A review of 25 published detailed customer water-use information feedback studies was undertaken, along with interviews with five water utilities located internationally with practical experience in digital metering rollouts. The results of the review revealed mean savings across all the studies of 5.5%, within the 10^{th}-90^{th}-percentile envelope of 3.0%-8.0% savings (excluding the extreme outliers). The range of savings was found to vary across each of the various parameters investigated, with no single intervention approach clearly standing out as best practice. With large scale rollouts, for which little literature is available, it is typically difficult to attribute the savings to feedback programs alone, since other factors may have influenced the outcomes, and are difficult to account for or were not included in the literature. To better understand and evaluate the impact of a feedback program, and optimise its operation, a well-designed evaluation and related implementation plan should be considered in conjunction with a digital metering rollout. Discrete interventions should be monitored against a control group (or groups) to assess uptake, response and persistence over time (of both uptake and savings), in order to refine a program over the business case period.

Keywords (max 6)

Digital metering; Smart-metering; Household water conservation; Water consumption feedback; Behaviour change;

1. Introduction

1.1. Background

Digital metering offers the benefits of remote reads and timely information on customer water use through more frequent reads in (near) real-time (Boyle et al., 2013). This facilitates leak detection, both within the customer's property and in the supply network and enables quicker repairs leading to water and cost savings. The potential also exists to provide customers with timely information on their water consumption using any of a number of possible mediums (e.g. letters, a website, mobile phone applications, text alerts and/or emails) to provide greater awareness about water usage and its impact on bills, and enable more informed choices about usage (Liu et al., 2015).

This paper specifically reviews the change in water consumption that can be expected via a rollout of digital water meters involving a customer engagement strategy that targets behaviour change in providing water usage information feedback to consumers in (near) real-time.

1.2. Theoretical underpinnings

The theoretical underpinnings for the provision of consumption information feedback in the literature typically make some form of reference to the so-called ‘information-deficit’ model of rational economic behaviour (Burgess et al., 1998). The theory suggests that imperfectly informed consumers will systematically evaluate alternative courses of action in the light of new information and respond in such a way as to promote their own self-interest. The provision of water-use consumption information feedback can therefore lead householders to change their consumption behaviours and/or upgrade their household water-using appliances to save water and achieve the associated financial or other gains. The theory presents a simple connection between information and consumption, with an immediate role for the provision of water consumption feedback to end users, but is not without its critics who cite the cognitive limitations of consumers in evaluating information and decision-making, as well as automated or habitual responses (Jackson, 2005). In addition, the concepts of individual choice, action and change have also be called into question by social practice theorists and researchers who instead view people as ‘carriers of practice’ with the effect that ‘socially, institutionally and infrastructurally configured’ practices affecting consumption patterns (for example, in terms of what is socially or culturally ‘normal’ for the practice of laundering) (Shove, 2010). However, in recent work on the provision of detailed water-use feedback, it was noted that such criticisms have not been specifically levelled at particular types of levels of detail of consumption information feedback, which it was argued could give rise to differential impacts and provide a closer link to specific water-using practices (Liu, 2016).

1.3. Current study

Two important knowledge gaps are to be addressed in this paper. First, the existing literature lacks an overview of the impacts on water consumption via the provision of consumption information feedback (i.e. percentage range of consumption savings achieved) using data collected via digital means. Second, more work is required to understand how savings impacts vary across the various different defining dimensions that have characterised detailed water consumption information feedback studies.

The key objectives of this research are to therefore:

(1) Review existing water consumption information feedback studies and the impacts on water consumption achieved;

(2) Analyse how water consumption savings achieved via the provision of water consumption information feedback vary according to their various key defining features (e.g. medium, content, duration, frequency, program scale, baseline water consumption, context (i.e. drought history); and review results in terms of the persistence of savings effects and uptake of interventions (e.g. online portals).

The research brings together available experience in order to provide an overview of the impacts of detailed water consumption information provision of relevance to a digital customer water metering strategy.

The rest of the paper proceeds as follows. Section 2 presents the literature review approach and methodology and including the analytical framework used to structure the literature review. Section 3 presents the results of the literature review. Section 4 presents the analysis of the results. Section 5 summarises the savings estimates and parameters affecting water savings. Section 6 summarises the key conclusions with a discussion of the implications for digital water metering implementations and business cases and identifies directions for future research.

2. Approach and Methodology

2.1. Analytical Framework

The research approach draws on a framework developed through our previous research (Liu et al., 2016) as a way to review approaches to customer engagement through digital data information and analyse their effectiveness. This 'feedback implementation framework' is presented in Fig. 1 and highlights key considerations in the design of detailed water consumption information feedback programs. The implementation framework is presented as four embedded concentric circles for heuristic purposes. Of specific relevance to this study is the larger circle, that is the practical design considerations, concerning the questions of 'Why', 'When', 'Who' and 'What':

- The 'Why' element considers the water utility's needs and motivations for introducing detailed consumption information feedback (e.g. customer engagement in water conservation);
- 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 concerns the target audience and whether this is population wide or a sample thereof (in which case issues of sample selection, representativeness, sample size and statistical significance are also of relevance); and whether the approach is opt-in or opt-out. Baseline consumption levels can also be used to characterise the audience.
- The ‘What’ segment refers to the information feedback itself (e.g. leak data, end-use data or comparative use data); and communication medium. Other considerations include who is directing the approach; how the information feedback will relate to other policies; and the customer narrative.

Fig. 1. Feedback implementation framework (Liu et al., 2016)

Key elements of the framework are used to categorise the literature review findings, as explained in the following methodology section.

2.2. Approach, Methodology and Activities

The research involved a review of publically available literature that will be used to understand the percentage range of water use behaviour change that might be expected through a digital metering rollout and investigates the range of impacts according to a range of defining features of feedback programs.

The central research question used to guide the literature review was: What is the range of water consumption savings that can be expected through the provision of water usage information to customers in a digital metering strategy? The sub-research questions used to inform this overarching research question included: (1) What water consumption savings have been achieved through the provision of water usage information to customers utilising digital metering? (2) What were the factors that influenced the level of savings that were achieved? (3) What was the possible influence of other factors in comparing across the different case studies?

The research approach involves a systematic literature review undertaken in four steps: (1) planning, (2) research data collection, (3) analysis and (4) synthesis.

2.3. Literature review

The literature review utilised a variety of sources that covered: academic databases; industry/trade journals; and other 'grey' (non-academic) literature (e.g. reports, newsletters, factsheets and conference presentations). The scope of the literature review focused on studies from within the water sector that reported on water savings achieved via the implementation of a consumption information feedback program in conjunction with digital water metering. The following search terms and alternative combinations thereof were used to identify relevant literature: water consumption; feedback; consumption information; customer portal; portal; report; IHD (in-home display); digital water metering; smart water metering; AMR (Automated Meter Reading); AMI (Advanced Meter Infrastructure); intervention; trial; pilot; study; water savings.

Additional data was collected on water consumption information feedback studies that did not involve data collection using digital metering. This research expanded upon a selected literature review by Byrne & Martin (2016) and the findings were considered where appropriate in relation to results obtained from our review.

Relevant literature from other sectors, including energy, was also reviewed for cross-sectoral insights in relation to the range of savings impacts, their duration and trajectory, and the influence of specific design and contextual factors.

In addition, primary research was conducted in order to obtain (additional) information on the most recent activities in digital metering not currently available publicly by conducting a handful of interviews with water utility digital metering management staff at the New York City Department of Environmental Protection (NYC DEP), San Francisco Public Utilities Commission (SFPUC), Madison Water Utility, Toronto Water, and Thames Water.

2.4. Data collection and classification

The data collection phase involved extracting data for the variables of interest from the collected literature that were deemed as defining characteristics of the consumption information feedback studies utilising the framework in Fig. 1. The results were tabulated against the variables of interest.

Key variables of interest included the location (city, region, country), the number of households that were provided with consumption feedback, the number of households that were assigned to a control group for the purposes of comparison, whether or not the study involved a sample only or covered an entire population and if the study was opt-in or opt-out, the feedback medium (e.g. portal, report, in-home display (IHD)), the types of consumption feedback that were provided (i.e. end-use, leak data, comparative use, (near) real-time or delayed data), the duration of feedback, the frequency of its provision, the savings that were achieved) and the context (i.e. history of drought, water-use restrictions and baseline consumption levels).

The collected literature was classified according to the method of water consumption data collection – either as 'digital metering' feedback studies (i.e. projects that specifically collected consumption information via digital water meters); or as 'non-digital metering' studies (i.e. projects that did *not* involve digital meters to collect detailed water consumption information). Most of the latter used manual meter reads. A few studies used on-device consumption displays (e.g. shower monitors), which do not require a digital water meter, but these were excluded from the analysis due to the different nature of these studies.

The literature was additionally classified within one of the following categories:

- Quality literature (i.e. academic journal articles / conference papers / reports) reporting water savings impacts;
- Grey literature (e.g. trade journals / news articles) reporting water savings impacts;
- Grey literature (about rollouts/pilots) that does *not* report on water savings impacts;

For the purpose of the present research, which focuses on water savings via the provision of consumption information collected via digital means, we focus on available digital metering studies that report savings impacts, whether from quality sources or grey literature. In part, this decision to include grey literature was due to the relatively small number of quality studies available.

It is important to note that most available studies that report water savings impacts are based on small-scale studies or pilots, with the implication that there is limited available information on the impacts that have been achieved in larger scale rollouts of digital water metering. To still draw from available experiences from the large-scale rollouts (i.e. of city or country scale), relevant findings from grey literature (and interviews) are presented where relevant, even if they do not report on water savings impacts.

2.5. Analysis

The analysis involved evaluating the literature collected to understand the range for the percentage change in water consumption through behaviour change in a digital metering rollout. We noted *a priori* that the number of available studies would be insufficient to use more advanced modelling or statistical techniques. The data was therefore analysed using descriptive statistics to determine the ranges of water savings impacts, and important influencing factors that may have shaped the results by identifying patterns and trends in the available data. Specific details are provided in Section 4.

The reliability of the calculated savings due to customer behaviour change could potentially be influenced by two considerations. Firstly, the studies surveyed did not clearly indicate if the consumption data pre and post intervention had been climate corrected prior to the calculation of savings. Changes in climatic conditions can influence the general consumption (most notably water demand for irrigation). Secondly, the distinction between water saved from repaired leaks vs changes in customer behaviour was not made explicitly clear in a significant number of studies.

3. Results

3.1. Overview of studies

This section presents a summary of the key data collected from the literature. Table A1 presents variable definitions and Table A2 presents the findings extracted from the literature.

3.2. Caveats and Outliers

3.2.1. Important caveats on the comparability of water savings results across studies

Table A2 tabulates key results from each of the digital water consumption information feedback studies. It is, however, important to note that the individual savings results are not directly comparable between studies. Each water consumption savings result is the product of a wide range of its defining factors, including those captured in the columns included within the table, such as differences in study designs (including the content, medium, duration, frequency and context of feedback provision). Differences in the methods of quantitative analysis adopted, sample selection and representativeness are also important.

It should also be noted that factors such as the number of people in each house, the age and technical knowhow of the residents, and the motivation of the residents to save water are also relevant when comparing the savings within and across a range of studies (Delaney and Fam, 2015; Jackson, 2005; Shove, 2010). This qualitative information was not readily available in the published literature reviewed.

In Section 4, key dimensions of study design are considered in turn and percentages are provided that present the range of savings achieved (i.e. the highest and lowest results arranged according to the particular dimension). Naturally, these percentage savings ranges are indicative only of the savings achieved according to that specific dimension and there is an important degree of interdependency between the various dimensions. To assist in capturing the fuller variation in results visually and identify patterns and trends, scatter plots additionally present the results of individual studies.

3.2.2. Caveat on the limited number of studies available and the newness of the approach

The limited number of studies available restricts the analysis in the report to descriptive statistics, rather than to the use of more advanced statistical techniques to quantify the influence of specific variables on water consumption savings. Additionally, the fact that longer term experience with digital water metering is also limited, particularly due to the newness of the technology and that there is limited documentation of and experience with large scale rollouts, poses various challenges for the analysis on the persistence of impacts. The research does, however, bring together available information on the range of savings impacts through behaviour change that might be achieved.

3.2.3. Outliers in terms of savings results

The results in Table A2 show a handful of outliers in terms of reported water savings figures, both positive and negative. Two studies reported particularly high water consumption savings results which need to be seen in the light of their study designs to facilitate their interpretation; and moreover, unexpectedly, some studies yielded negative savings results. The authors of these studies provided some possible explanations, which we use to tease out lessons for future pilots and/or rollouts. The outliers are discussed briefly below and the three extreme outliers are largely excluded from the analysis.

In Britton et al. (2013), consumption feedback provided in the form of leak letters was reported to have yielded 89% savings. The study sample that received feedback was particularly drawn from the 4% of the population of Hervey Bay that were identified as having a leak, of which finally less than half were informed in the study. The savings therefore relate to a communication strategy which only applied to <2% of the overall population, so the 89% savings result has to therefore be interpreted within this context – a very specific sub-sample which had large potential for water-savings. This case study has therefore been excluded from the analysis in section 4 of this report.

In Tom et al. (2011), intervention households were provided with an end-use water breakdown based on one-week of consumption data, which led to 24.1% savings relative to the control group. However, the authors noted that since the intervention group started out with much higher consumption than the control group, the relative savings achieved may have been due (in part) to the so-called effect of ‘regression to the mean’, particularly since at post-intervention, the intervention group had reached a level comparable to the control group. The study is therefore considered an ‘extreme outlier’.

Through the work of Kenney et al. (2008), it is noted that the impact of consumption information may depend on the pricing strategy. In this study, the combination of feedback and increasing block tariffs was given as the reason for a measured increase of 16.0% in water consumption in the study. The authors suggested that, through increased visibility, the intervention households were able to avoid the third most punitive tier and rather make greater use of the lower priced tiers 1 and 2 so they could increase their overall consumption. In our analysis, this study is considered as another extreme outlier.

Through the results of Doolan & Crissani (2015), it is additionally noted that savings should be interpreted in the light of the study design and uptake rate. Intervention households increased consumption by 1.0%. The authors attributed the result on the one hand to the study design, particularly the small sample size and short duration of the trial; and to an observed lack of active participation by the customers, all factors of importance in determining the likely impacts of a digital metering strategy involving the provision of consumption information to customers.

4. Analysis & Discussion

This section reports on the findings from the analysis of the data collected from the literature on water consumption savings achieved according to the key dimensions of study design investigated. The analysis is summarised in Table 1 which presents an overview of the range, mean and median percentage change in water consumption for each of the key dimensions of feedback investigated. The mean and median figures exclude the three extreme outliers discussed previously.

Table 1

Summary of range, mean and median percentage savings in water consumption according to the key dimensions of water consumption information feedback

Feedback dimension	Savings Range	Mean	Median
Medium			
In Home Display (IHD)	4.0% - 8.5%	6.4%	6.8%
In Home Display (IHD) & Portal	5.0%	-	-
Paper Report	6.6% - 8.0%	7.5%	9.0%
Post Card	7.9%	-	-
Online Portal*	(-1%) 3.0% - 10.0%	5.8%	5.3%
Online Portal & Paper report	2.8% - 4.6%	4.4%	4.8%
Letter & Phone call	6.9%	-	-

Smartphone App**	0.0%	0.0%	0.0%
Content			
(Near) real-time data	4.0% - 10.0%		
End-use data	7.9% - 8.0%		
Leak data	4.0% - 10.0%		
Comparative use data	2.8% - 10.0%		
Duration			
< 2 months	2.8% - 3.0%	2.9%	2.9%
4 ≤ 6 months	4.1% - 8.0%	5.9%	7.25%
12 - 14 months	4.2% - 8.5%	5.9%	5.2%
24 months	4.0%		
Frequency			
Once-off	24.1%		
Bi-annually	8.0%		
Bi-monthly	2.8% - 8.0%	5.3%	4.9%
Monthly	7.9%		
Weekly	3.0%		
Daily	4.2% – 6.8%	5.5%	5.5%
Real-time	4.0% – 10.0%	5.5%	5.3%
Program Scale (number of households)			
<50	3.0% – 8.0%		
50-99	4.2% – 6.8%		
100-149	(-1.0%)		
150-199	6.6% – 8.5%		
200-999	4.0% – 10.0%		
1,000-2,000	2.8% – 4.1%		
>2,000	4.6% – 8.0%		

Notes: **Most online portals typically come with the option to sign up for usage alerts sent via email and/or SMS, thereby utilising multiple feedback mediums.*

4.1. Feedback medium

The change in water consumption associated with the provision of consumption information feedback and digital metering was found to vary by feedback medium. Fig. 2 graphically illustrates the percentage change in water consumption associated with individual studies for a smaller number of categories of feedback medium (i.e. the various forms of paper mediums (paper reports, postcards) have been aggregated together as ‘paper reports’). Where two mediums have been used in parallel for the same intervention group households (e.g. letters and phone calls) these are plotted separately. Each marker represents the water consumption savings achieved in an individual study.

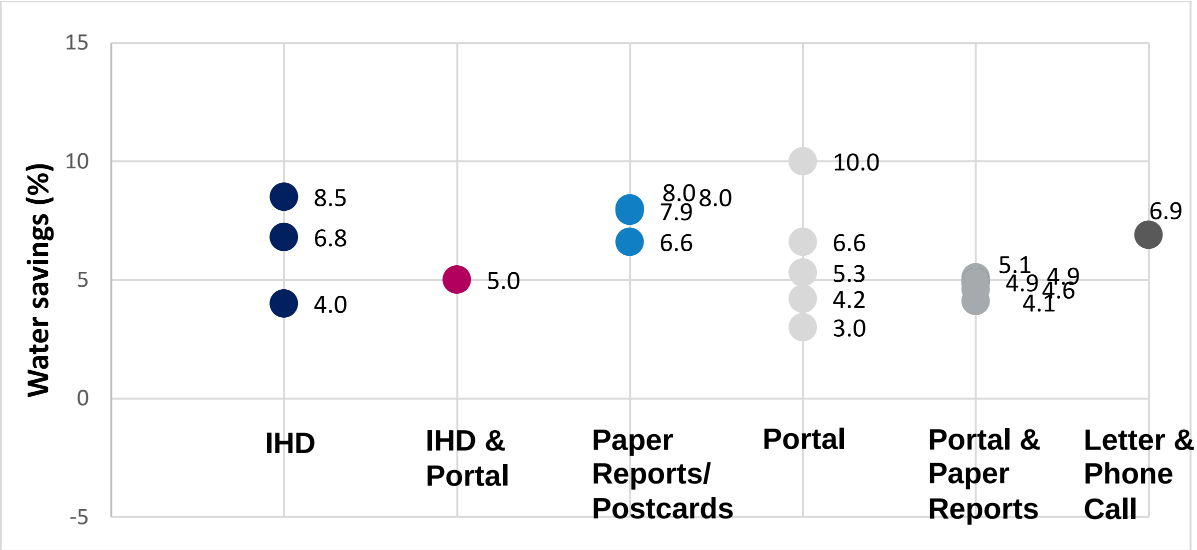

Fig. 2. Percentage savings in water consumption vs. feedback medium

As can be observed, most savings results fall within the range of 2.8%-10.0%. (This excludes the extreme outliers discussed in Section 3.2.3, as well as the outliers of 1% and 0% savings). The type of medium for providing usage information to customers appears to make little difference to the savings obtained. The four "push" studies that provided paper-based reports have the highest mean savings, whereas the "pull" mediums such as portals and IHDs appear slightly less effective. However, the combination of paper reports and a portal seemed to fair the same as just the portals. This suggests a variety of other influences are at play. Ultimately, the optimal choice of feedback medium is likely to involve choosing the most appropriate approach considering a range of criteria including costs, customer expectations and other business objectives.

4.2. Feedback content

In terms of feedback content, most studies that provided (near) real-time data also provided feedback on leaks and comparative use. It is therefore difficult to disaggregate the savings based solely on any one of the content types. However, the savings reported in Table 1 presents the savings that were associated with each type of content regardless of whether other types were provided in conjunction. Across all studies, and excluding the extreme outliers, the mean consumption savings is 5.8%, with a savings range between 2.8% - 10% across all content types.

4.2.1. End-use data

It is noted that the water end-use consumption feedback studies were based on relatively short study durations which provided breakdowns of total consumption on the basis of snapshots of usage only.

4.2.2. Leak alerts

Leak alerts form a key component of the majority of digital water metering consumption information programs and water utilities that have implemented digital metering have approached the communication of leaks in a variety of different ways. Since leaks are widely reported as a major component of residential water use, they represent an important opportunity for water savings. Once abnormally high usage over a period of typically a few days has been identified by running reports internally, some water utilities take a manual approach to alerting customers either via phone calls, emails (if available), letters or even visits by "sending a truck" if the customer cannot be reached (Pers. Comm. Madison Water, 2017). These approaches are more widespread where AMR (Automated Meter Reading) systems have been implemented and customers have not been provided with access to their consumption information. With implementations of AMI (Advanced Meter Infrastructure) systems, digital communication of leaks is more widespread with the use of online portals and the opportunities for customers to register for leaks alerts, sent either via email or SMS. Regarding uptake, leak alerts have been found to be popular widely, with for example sign-up rates of 78% among portal users (Liu et al., 2017).

4.2.4. Comparative use data

A variety of approaches have been taken in the provision of comparative feedback, including against: previous consumption; average households; and similar households (e.g. based on the number of occupants; or some forms of efficiency benchmarks).

Alternative framings have also been used including descriptive social norms (which refer to accepted rules of behaviour) and aligned norms (e.g. with 'smileys' to characterise positive or negative results).

4.2.5. Other strategies – gamification

Currently, only a small minority of digital water metering programs have introduced gamification as part of a consumption information feedback strategy. Among academic studies reviewed in this report, only the Dubuque Portal study (Erickson et al., 2012) involved elements of gamification and provided evidence of the overall savings results. The trial involved an ongoing weekly game with matched teams of four to six households created automatically with the goal being to use less than the opposing team. The portal also included a ranking feature to show how the individual household was performing against all others. Since 48% of portal users reported usually looking at the weekly game, this suggested the feature was valued. It is, however, noted that the study was only evaluated in the very short term and the savings achieved (6.6%) were not noticeably different from studies that did not include gamification.

Some evidence from the energy sector shows consumption feedback involving gamification over a longer period can yield high savings rates. The 'Reduce Your Juice' energy consumption program involved a custom-built app with a series of mini-games supported by digital communication including email, SMS and social media to engage players in learning about home energy use and the impact of their behaviours and yielded an average of 12.3% energy savings on the previous year (Swinton et al., 2016).

4.2.6. Other strategies – water savings tips

Water savings tips provide the opportunity to present customers with concrete advice on how to save. A difference lies between the provision of generic tips, irrespective of how a customer uses water; and customised tips that provide more specific information on the basis of their usage patterns (Liu et al., 2015). Evidence from the wider literature on water consumption feedback outside the digital sphere provides mixed results. For example, in Schultz et al. (2016), the provision of water-saving tips (without consumption feedback) showed no impact on water consumption; but the added use of descriptive norms (about similar households' usage) led to 26% savings, or of aligned norms (which included smileys) led to 16% savings. Kurz et al. (2005) found that labels providing water-saving tips at points of consumption around the home and garden led to significant water savings (23%), while neither the provision of information leaflets nor socially comparative feedback produced an effect. Seyranian et al. (2015) also found that, specifically for high water users, information only led to an increase in usage, while the use of social norms and personal identity framings were more effective at reducing consumption.

In Liu et al. (2017) an interactive 'pledges system' was included within an online consumption portal to provide specific tips and allow users to click on each tip to say they were doing this action or would like to pledge to do it. However, the analysis of page views did not show high levels of engagement with this particular tool (Liu et al., 2017).

The provision of end-use consumption information particularly offers opportunities for more targeted advice and has been reported to be very helpful for customers (Liu et al., 2015). However, the added impact of tips and customised tips on water savings at end use levels in particular requires further research.

Overall, the evidence is mixed and further research is therefore required to understand the most effective and engaging approaches to providing water saving tips in conjunction with a customer digital water metering program.

4.3. Feedback (intervention) duration

Here, the term duration refers to the period between when the provision of feedback first commenced (i.e. the first instance of feedback) and when it finished. No distinction has been between the provision of information and actual access to it. For example, an online water consumption portal can make consumption information accessible to customers at any time; however, whether or not customers actually log on to access their consumption information is a separate issue, which is also picked up on the subsequent section which looks at the frequency of feedback. Many of the studies surveyed did not provide sufficient information on the access rates to portals for example.

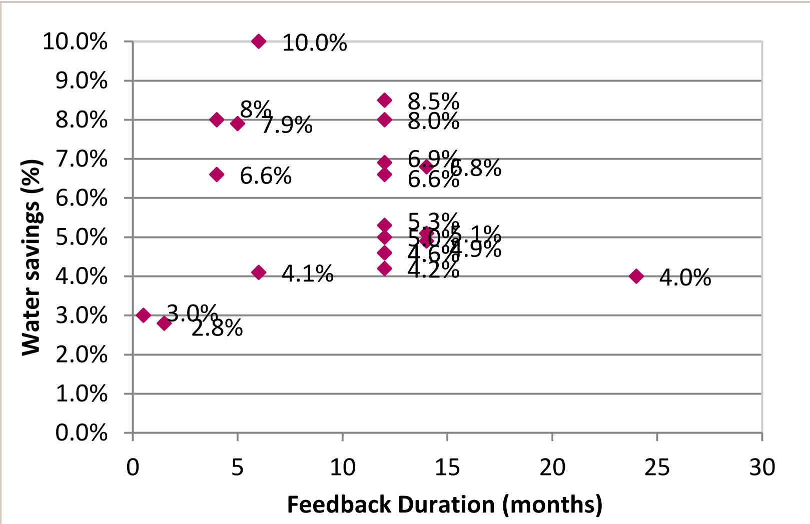

Fig. 3. Percentage savings in water consumption vs. feedback duration

Feedback studies implemented over the short term (less than 2 months) appear to have yielded half the savings of those implemented over a longer period (6 to 18 months). It is, however, noted that this observation about short term studies is based on very limited observations. Overall, there is an important lack of long-term research and experience with the provision of water consumption information via digital metering. Most studies only provided feedback in the short-term, and only a handful of studies provided information for longer than one year, and for a maximum of two years. This reality means that projections on the long term impacts of consumption information feedback have little in the way of previous experience to draw upon. Little information is provided on the ongoing savings over a longer period of time. So, while the results would indicate that customer feedback would provide savings over the short term, as a drought response measure, there is little evidence of how long the savings would be sustained, that is, the persistence of the uptake.

4.4. Feedback frequency

Here, the term frequency refers to how often new consumption data was provided to the customer, that is, the frequency of ‘data refresh’. Feedback frequency in existing studies has varied from once-off communications (reports), through to real-time communications via digital mediums. For online portals with an overnight data refresh, the frequency of feedback is categorised as being on a daily basis, even if the information content provided may be of a higher resolution (e.g. hourly intervals).

Fig. 4 presents the water consumption savings results for each individual study. For each category of feedback frequency there is a wide range of savings results, so it is not immediately obvious how savings are likely to be associated with varying frequencies of consumption information feedback provision. Real-time feedback provided the highest savings results of all. However, there are examples showing much less frequent consumption feedback information led to comparable results. Again, the mere provision of access to consumption feedback information does not equal actual exposure. It is therefore plausible that less frequent feedback (e.g. bi-monthly or monthly reports), might have comparable effects to the provision of information via an online portal accessed infrequently. Here, an important distinction exists between ‘*push*’ and ‘*pull’* approaches to the provision of consumption information feedback. In the case of reports or alerts, whether sent via traditional mail, email or SMS, these are ‘pushed-out’ to water consumers. However, with the provision of an online consumption portal or app, this information will only be accessed if the consumer actively logs on to view their usage information. Such ‘pull’ strategies require the consumer to take the initiative to access the information that has been made available to them. Importantly, our previous research also demonstrated that the impact of logging on to a water consumption feedback portal actually produced a significant impact on the level of water consumption savings (Liu et al., 2017).

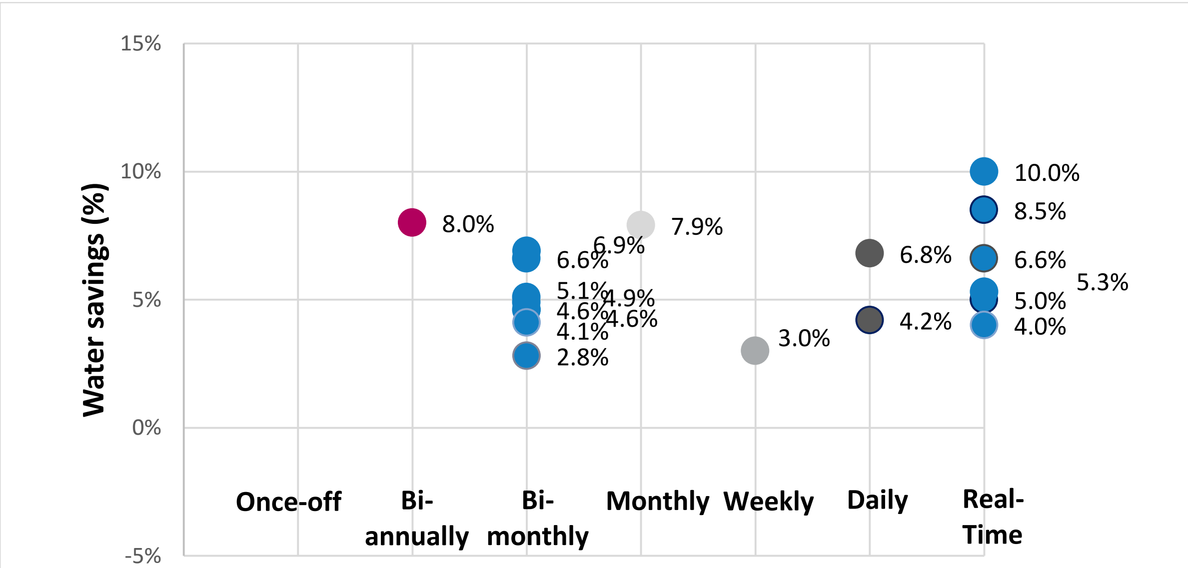

Fig. 4. Percentage savings in water consumption vs. feedback frequency

As can be observed, the mean savings is roughly the same across all frequencies i.e. 5.5%. A slight benefit would seem to be evident by having a frequency or more than bi-monthly, but this would be marginal, and might also depend on what else is going on, such as a drought.

The frequency of feedback (data refreshes) carries cost implications associated with the collection and transmission of data. Therefore, while the technology is available to provide highly frequent data refreshes, both in research and in practice, many times water utilities have opted for less frequent updates. For example, the NYC DEP's customer portal was initially updated four times per day, but this was later adjusted to just one refresh overnight, with battery power cited as an obstacle to the provision of more frequent data collection and customer feedback (Pers. Comm. NYC DEP, 2017). Some utilities cited the need to check the quality of data before providing it to customer portals. At SFPUC, rather than showing blanks for missing data reads, which could cause customers to distrust the system and their bills, the utility provides 'evenly distributed usage' figures (Pers. Comm. SFPUC, 2017).

4.5. Feedback program scale (pilot or full-scale)

Table 1 showed the percentage range of consumption savings that were reported for individual studies according to categories of scale i.e. sample sizes. There does not appear to be any immediate pattern in the table on the basis of scale.

Water utilities that were interviewed revealed that with full scale rollouts it is often difficult to isolate the impact of user consumption feedback from other impacts taking place in parallel (Pers. Comm. NYC DEP, 2017; Pers. Comm. SFPUC, 2017). However, for water utilities that (first) undertook a small-scale trial, it was possible to quantify the impact of consumption feedback, particularly via the use of a randomised controlled trial (RCT) that utilised a control group whose only difference was no access to consumption information while the intervention group was granted access. This approach was mostly adopted where studies were conducted via university research partnerships. One managed service provider, WaterSmart Software, however, usefully encourages water utilities to begin with a small-scale trial that involves a control group in order to measure the impact of their business service which involves reports (paper and/or email) and access to an online consumption portal (Holleran, 2016). Importantly, the approach adopted by WaterSmart Software is typically introduced on a larger scale, that is, thousands rather than just a few hundred household customers.

Due to the lack of empirical data for large scale implementations, the strategy of utilising a RCT involving a pilot plus a suitable control group may provide one of the best possible indications of the likely impacts that might be achieved through access to detailed water consumption information feedback in a large-scale rollout of digital metering. However, more publicly available research is required specifically in this regard beyond the currently limited available studies.

4.6. Baseline water consumption

In the majority of studies, baseline consumption was reported at the household level (L/hh/d) so we adopted this measure, excluding studies that used per capita measures or that did not report baseline consumption. Theory suggests that households with a high level of water consumption pre-intervention could have greater potential for water savings, including through the provision of water consumption information feedback. For example, Brent et al. (2016) found that 'heavy users' saved more.

A comparison between water consumption savings for each study against its respective baseline measure of household water consumption showed that contrary to expectations, there does not appear to be any relationship between the two variables. This suggests that the overall average savings achieved via digital metering and water consumption information feedback program may not necessarily depend on existing average levels of usage. One possible explanation could be that the average figures mask significant variation and that in any implementation there will be both higher and lower users. It does not, however, always stand to reason that high water consuming households use more water for discretionary uses such as irrigation and swimming pools. In many cases, it is also possible that these households have more people residing in the residence, potentially using the same per capita volume as those living in smaller family units.

4.7. Feedback context

Theory suggests that recent experience of drought may bring about drought priming with a heightened awareness about conservation, such that consumers might be more responsive to the provision of additional water consumption information feedback than would otherwise be the case.

A comparison of the percentage savings in water consumption achieved within the context of either recent experience of drought or no recent experience did not appear to show any distinction in savings impacts as a function of drought history. Neither did there appear to be any distinction due to the imposition of water usage restrictions.

4.9. Engagement by customers (uptake)

Engagement levels can be measured in terms of initial uptake, which is most commonly reported, as well as engagement over time. Engagement can vary according to the feedback medium. For example, paper based interventions (i.e. paper bill amendments, additional reports, sent either with or separate to the bill) were reported to have high uptake rates, possibly due to their high visibility. For example, in Liu et al. (2016) all households evaluated reported having taken at least a few minutes to engage with the paper reports that they were mailed to provide end-use water consumption feedback.

In terms of online portal uptake, our review supplemented by interviews found registration rates varied from 30-45% Therefore, a significant share of consumers never log on. In addition, of those that do log on, around 40% have been found to not return (Pers. Comm. SFPUC, 2017). Importantly, however, if users sign up for alerts, they will remain alerted to abnormally high usage even if they do not continue to log in to the portal regularly (Liu et al., 2017). With online portals, there are greater opportunities for usage tracking, although our interviews revealed this is not always monitored for various reasons including capacity constraints. However, a good example of usage tracking is by SFPUC whereby a regular dashboard report is run to provide information on new registrants, return rates, usage types (i.e. registrations versus logins), usage by hour of the day, and top users; with the information on registrants provided in aggregate and for different user types – commercial, residential – multiple, and residential – single) (Pers. Comm. SFPUC, 2017).

Customer engagement in terms of registrations and logins can be promoted using competitions and prizes. For example, at Madison Water Utility, a quarterly prize draw was offered with iPad giveaways to encourage sign-ups (Pers. Comm. Madison Water, 2017). Keeping customers engaged with their water consumption information is a key challenge to be addressed as a rollout of digital metering progresses. As mentioned previously, ongoing engagement with the information provided, for example, by logging on to view a portal, may be required to help maintain water saving behaviours (Liu et al., 2017). There is therefore an ongoing role for water utilities to 'push' out information to customers. A variety of approaches can be used to maintain customer engagement. For example, in order to remind customers to login to their portal, WaterSmart Software has been tracking email 'open rates' using different email subject lines in order to try to understand what approaches could provide the best results[1] (Holleran, 2016).

An interesting question requiring further exploration concerns a consideration of which customers to target and when. WaterSmart Software, for example, charges its utility clients on the basis of the number of consumption feedback reports to be provided; and utilities are

[1] For example, email subject lines such as '{firstname}, you're using {gpdchangeT12M} {interjectionT12M} water this year than last year. Curious? Look inside' that are personalised and incorporate details about daily water use (e.g. over the last 12 months in gallons per litre per day) achieve a 62% open rate; while a more 'spam-like' subject line like {3 Ways For You to Save Money & Water}, even if personalised with the customer's name and with a mention of the current month, achieved the worst open rates of 46% (Holleran, 2016).

given the option to either send reports to all customers, or more frequent reports to higher (e.g. above average) users (Holleran, 2016).

While customer uptake rates were found to vary across different approaches, if they could be increased through additional marketing/advertising and reminders, there exists the potential to increase the overall savings achieved. For example, in the MidCoast Water trial, the 30% portal uptake rate yielded 4.2% water savings (Liu et al. 2017). This overall savings rate applies to the entire sample of intervention group households, so if portal uptake were to be increased, then higher overall savings would be plausible.

4.10. Persistence of savings

The impacts of consumption information can endure if consumers adopt new water-saving behaviours and form new habits and/or invest in more water-efficient appliances. However, many studies have found evidence of 're-bound effects' (especially for post restrictions), with the effects on consumption reverting to pre-intervention levels over time, particularly if feedback ceases. At the same time, however, there is evidence to suggest that renewed exposure to feedback can help savings impacts to persist. There is therefore a case for strategies that seek to periodically re-engage customers in interacting with their water consumption information e.g. via additional communications such as to promote portal logins.

Our literature review showed there are very few longer terms studies available to inform the goals of the present research. Among the literature, half of the studies provided consumption information feedback for less than one year and only one study provided feedback for two years. In most studies once feedback was stopped, then measurement was also stopped in most cases, or shortly thereafter. Therefore, there is little evidence on the persistence of savings effects.

In the absence of longer term studies in the water sector, some indication of persistence can be found in studies undertaken in the energy sector. Work by Fischer et al. (2011) indicated that for nine studies that they analysed that were between 1-3 years long, feedback induced energy savings persisted over time. This was especially true for studies where the feedback interventions were maintained across all the years of the study. They did not evaluate any cases post intervention however, so there is no documented evidence of sustained savings post the study period, that is, beyond three years.

5. Summary of savings estimates

The results of the literature review and analysis are summarised in this section. The overall mean water consumption savings achieved across all studies was 5.5% (excluding the extreme outliers). Similarly, the median savings rate was 5.1% (again excluding the extreme outliers). The expected savings based on the average of all the studies can be estimated to be 5.5%, within the 10th-90th percentile envelope of 3.0%-8.0% (excluding the outliers). While the range of savings achieved varied across the various parameters investigated, the difference between them is likely to be within the error bounds of the analysis. Most of the available literature related to smaller scale pilots which used control groups to estimate impacts. With large scale rollouts, for which less literature is available, it is typically more difficult to attribute water savings to feedback programs alone, since many other factors are at play, which are either difficult to account for or have not been included in the literature.

Table 2 provides a summary of each of the study parameters in terms of mean savings and the 10th-90th percentile range. Brief conclusions are provided that summarise the implications for each specific dimension to detailed water-use information feedback provision.

Table 2

Summary of the parameters affecting water savings

Dimension	Mean and 10th-90th Percentile Range	Conclusions
Medium	Mean 5.5% Range 3.0% - 8.0%	No medium stood out as most effective. Water utilities would therefore be advised to choose the most appropriate approach.
Content	Mean 5.5% Range 3.0% - 8.0%	Feedback was generally in the form of a combination of formats e.g. leak alerts, comparisons and near-real time data. The best approach is likely to involve combining a range of content types.
Duration	Mean 5.9% Range 4.2% - 8.5%	The longer the duration of the intervention, the higher the savings.
Frequency	Mean 5.5% Range 3.0% - 8.0%	Near-real-time data provides marginally higher savings than less frequent options, however, this comes at additional cost.
Program scale	Mean 5.5% Range 3.0% - 8.0%	No difference is program scale was obviously evident.
Context	Mean 5.5% Range 3.0% - 8.0%	No difference between drought and non-drought contexts was obviously evident.
Water consumption	Range 4.2% - 8.5%	No noticeable difference due to the baseline level of water consumption.
Uptake	Range 30% - 45%	The reported uptake across the studies was within a similar range.
Persistence	100%	Based on a review of energy studies, persistence of longer term programs can be expected to be maintained through a continuation of the consumption feedback program.

6. Conclusion and recommendations

This section summarises the range of percentage water consumption savings documented from the literature and provides preliminary recommendations based on the literature review and analysis to help maximise the level of water consumption savings that might be achieved via a digital water metering rollout that involves a customer engagement program that provides detailed water consumption information feedback.

5.1. Expected percentage savings in consumption

Based on the available literature reviewed in this research, and particularly the results that are based on the intervention *duration* parameter, it appears that the range of potential water consumption savings is in the range from 4.2%-8.5% and that savings might persist due to the provision of an ongoing feedback program.

5.2. Recommendations to maximise savings

In order to maximise the level of savings from water consumption information feedback programs, the following recommendations are made:

5.2.1. Medium

A combination of push and pull approaches is recommended. This will provide access to water consumption feedback at the convenience and timing desired by the customer and will provide utilities with the flexibility to provide additional information to targeted customers (e.g. high users, customers with leaks) and to also re-engage customers periodically. The collection of email addresses and (mobile) phone numbers will further facilitate communications and provide a greater range of options for communications.

Cost will, however, also be an important factor and the benefits of alternative approaches and combinations of approaches will require detailed investigation.

5.2.2. Content

A range of content is recommended in order to provide more detailed information to customers. Feedback on leaks is particularly important, and real-time information offers the advantage of ongoing availability. The evidence on comparative information is mixed, but customers have been found to respond to a variety of comparisons including with other customers as benchmarks. Historical self-comparisons are standard, and providing alternative views (e.g. of daily, weekly and monthly resolutions) offers customers the opportunity to explore their usage as required. The jury is out on the role for end-use information, particularly due to its costs; however, its provision may be more suited to specific customer groups with the highest potential for savings.

5.2.3. Frequency

Near real-time data offers the benefits of providing continuous, access although the results may be comparable to up to bi-monthly approaches. This may be due to the actual engagement by customers. Again, a combination of approaches is recommended that provides ongoing access as well as periodic and timely additional communications or nudges at varying frequencies.

5.2.4. Context

During drought conditions, the feedback frequency could be ramped up to help drive down consumption for the period that that the drought is present, and then let the consumption bounce-back marginally thereafter.

5.2.5. Uptake

Uptake rates, particularly at the launch stage, can generally be promoted using engagement strategies such as prize draws. Ongoing or periodic engagement is likely to require ongoing strategies that aim to re-engage customers. Here, there is a role for ongoing public relations and communications and additional programs to promote engagement with consumption feedback.

5.2.6. Persistence

To maintain the level of residential savings, the ongoing provision of feedback information is likely to be required. Again, the there is a role for ongoing campaigns and communications and potentially additional programs to promote engagement with consumption feedback.

5.2.7. Learning opportunity

As has been demonstrated by this literature review, there are not many well-constructed and documented feedback studies that have sought to measure specific interventions. The global water industry would benefit from a best-in-class rollout of digital metering and customer water information feedback provision that is carefully designed and documented. This would help other water utilities around the world with the construction of their own business cases, many of which are struggling to quantify the likely benefits and to build a case for digital metering. Particularly with a view to understanding the likely impacts of digital water consumption information provision to customers, it would be especially helpful, if a digital metering rollout were designed and introduced using the approach of a robust research trial. In such a way, the results could be used to confirm the likely impacts at an earlier stage in the rollout and the findings could also be communicated rapidly. The opportunity would also exist to be able to further develop the associated communication strategy, as required, as the rollout is underway.

There are many lessons to be learnt from existing large scale rollouts, as uncovered via our interviews with five water utilities that have already embarked on digital water metering programs involving customer water usage information feedback a few years ago. Each interview provided insights to various aspects, which could aid in the planning and evaluation phases of a consumption information feedback program.

From the interviews, a recurring theme was how the water utilities adapted their strategy as they proceeded with the rollout. There, therefore, exists the opportunity to commence with a 'basic' digital metering customer information feedback provision strategy which can later be enhanced and refined by adding/amending functionality, and/or by involving a specialist managed service provider of which there are a growing number available.

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Appendix A1

Table A1

Key variables and definitions

Variable	Definition
Reference	The source document and name of the water utility if a collaborative study was undertaken.
Location	City and State/Region where the feedback intervention was implemented.
Country	Country where the consumption information feedback intervention was implemented.
Intervention households	The number of households that received consumption information feedback.
Controls	The number of households that did not receive consumption information feedback and used to evaluate the relative impact among the intervention household.
Sample	'X' means the consumption feedback intervention was applied to a sub-set of the population.
Population	'X' means the consumption feedback intervention was applied to an entire population.
Opt-in	'X' means the households were required to 'sign up' for the consumption information feedback.
Opt-out	'X' means the households were automatically selected to receive the feedback intervention and required to withdraw from the intervention.

Medium	The means of communication used to provide consumption information feedback e.g. portal, paper report, in-home display (IHD) or some combination thereof.
End-use data	'X' means that disaggregated consumption information feedback was provided i.e. by end-use, e.g. shower, toilet, washing machine, taps, leaks, outdoors.
Leak data	'X' means that consumption information feedback on leaks was provided.
Comparative use	'X' means that consumption information feedback was provided with some form of comparison e.g. with average or efficient benchmarks.
(Near) real-time data	'X' means that consumption feedback was provided in (near) real-time i.e. high frequency feedback such as every hour and updated continuously and at least overnight.
Delayed data	'X' means that consumption feedback was provided with a delay from when actual consumption took place of more than one day.
Feedback duration (months)	The number of months during which consumption information feedback was provided (i.e. from the first instance of feedback through to the last).
Feedback frequency	How often consumption feedback was provided e.g. once-off, real-time (RT), daily, weekly etc.
Savings %	Water consumption savings reported as a percentage reduction and refer to the average treatment effect (ATE) relative to the control group where applicable.
Baseline water consumption (L/hh/d)	Average household water consumption pre-intervention in litres per household per day (L/hh/d). [Or per person (pp) if not reported at household level].
Recent Drought Experience	'X' means the locality had recent experience of drought for some period within the last 20 years.
Restrictions	'X' means water usage restrictions were in place (as documented in the respective literature).

690 **Table A2**

691 Matrix of digital water consumption information feedback studies reporting savings effects

Reference	Location	Country	Intervention households	Controls					Medium			Comparative use	(Near) real-time data	Delayed data	Feedback duration (months)	Feedback frequency	Savings %	Baseline consumption (L/hh/d)	Recent Drought Experience	Restrictions
Petersen et al. (2007)	Oberlin, OH	US	18 dorms	-	-				Portal			X	X		0.5	weekly	3.0%	[140 pp]		
Aurora Water (Kenney et al., 2008)	Aurora, CO	US	-	-	X				IHD				X		N/A	RT	-16.0%	-	X	X
South East Water (Wetherall, 2008)	Melbourne, VIC	Australia	50	-	X		X		IHD & Portal				X		12	RT	5.0%	468	X	X
Sydney Water (Doolan, 2010)	Westleigh, NSW	Australia	161	20	X		X		IHD		X	X	X		12	RT	7-10%	561		X
Sacramento County Water Agency (Tom et al., 2011)	Sacramento, CA	US	50	50	X		X		Report	X	X			X	(once)	once	24.1%	-	X	
City of Dubuque (Erickson et al., 2012; Naphade et. al. 2011).	Dubuque, IA	US	151	152	X		X		Portal		X	X	X		4	RT	6.6%	496	X	
Fielding et al. (2013)	Brisbane, Ipswich, Sunshine Coast & Gold Coast, QLD	Australia	24+65+66	66	X		X		Postcards	X	X	X		X	5	monthly	7.9%	[143 pp]	X	X
Wide Bay Water Corporation (Britton et al., 2013)	Hervey Bay, QLD	Australia	332+40	100	X				Letters		X			X	3	monthly	89.0%	-	X	
WaterSmart Software Castro Valley experiment (Mitchell & Chesnutt, 2013)	Castro Valley (Dingee as Controls), East Bay Municipal District	US	8000 (later 10,529)	1300 (later 13,765)	X				Reports			X			12	bi-monthly	6.6%	989	X	
WaterSmart Software Random group experiment (Mitchell & Chesnutt, 2013)	East Bay Municipal District, CA	US	1,710	1,576	X				Reports			X			12	bi-monthly	4.6%	-	X	
Joo et al. (2015)	Incheon City	S. Korea	80	100	X		X		Portal				X		12	RT	5.3%	205	X	
Sydney Water (Davies et al., 2014)	Westleigh, NSW	Australia	Initially 109. After dropouts, 82	Initially 109. After dropouts, 82	X		X		IHD		X	X	X		14	daily	6.8%	-		

MidCoast Water (HWU study) (Liu et al., 2015, 2016)	Tea Gardens/Hawks Nest, NSW	Australia	34	34	X		X		Reports (paper)	X	X	X		X	4	bi-annually	8.0%	373		
Sydney Water (Doolan and Crissani, 2015)	Ku-ring-gai & Auburn, NSW	Australia	135	yes	X		X		Portal (Water & Energy)		X		X		5	RT	-1.0%	-		
WaterSmart Software (Brent et al. 2015)	3 utilities "A", "B" and "C"(*confidential*), CA	US	992; 1.545; 1,180	897; 1,547; 1,200	X				Reports & portal					X	14	bi-monthly	5.1%; 4.9%; not reported	765; 1068; 1321		
MidCoast Water (MHOW study) (Liu et al., 2014, 2017)	Greater Taree, NSW	Australia	60	60	X		X		Portal		X	X	X		12	daily	4.2%	572		
South East Water (Byrne & Martin, Apr 2017)	Melbourne, VIC	Australia	89	78	X		X		App	X	X				4	RT	0.0%	-	X	
Townsville City Council	Townsville, QLD	Australia	200	-	X		X		Portal		X	X	X		6	RT	10.0%	-	X	
Anglian Water (Glass, 2015)	East England	UK	429	-	X		X		IHD		X	X	X		24	RT	4.0%	-	X	
Water Corporation Perth H2ome Smart Program (Anda et al., 2013)	Pilbara & Kimberley regions, WA	Australia	12,256	-	X	X	X		Letters & phone calls			X		X	12	bi-monthly	6.9%	-		
WaterSmart Software Oakdale Case Study (2017)	Oakdale, CA	US	6,800						Reports			X		X	12	bi-monthly	8.0%	-	X	
WaterSmart Software Roseville; Western Governors' Drought Forum (2015)	Roseville, CA	US	18,000	700	X		X		Reports & portal		X	X	X		12	bi-monthly	4.6%	-	X	
WaterSmart Software Greeley Case Study (2017)	Greeley, CO	US	2,600			X		?	Reports & portal			X			6	bi-monthly	4.10%	-	X	
WaterSmart Software, Santa Margarita Water District (2016)	Santa Margarita, CA	US	Initially 2,000; later ~27,000 (single family) homes; 4,000 commercial	Year 1: 2,000		X		?	Reports & portal			X		X	1.5	bi-monthly	2.8%	-	X	
WaterSmart Software review (Holleran, 2016)	27 Utilities (All CA except 1 UT and 1 FL)	US	Various						Reports & portal		X	X	X			bi-monthly	1.3-5.1% (avg. 3.3%)	-		

References

Anda, M., Brennan, J., Paskett, E., 2013. Combining smart metering infrastructure and a behavioural change program for residential water efficiency: results of a trial in Perth, Western Australia, Water Journal of the Australian Water Association, 40(5), 66-72.

Brent, D.A., Cook, J.H., Olsen, S., 2015. Social comparisons, household water use, and participation in utility conservation programs: evidence from three randomized trials, Journal of the Association of Environmental and Resource Economists, 2(4), 597-627.

Boyle, T., Giurco, D., Mukheibir, P., Liu, A., Moy, C., White, S., Stewart, R., 2013. Intelligent metering for urban water: a review, Water 2013, 5(3), 1052-1081, doi:10.3390/w5031052.

Brown, L., Kriz, E., 2014. City of Roseville California Council Communication, WaterSmart Software Program, Meeting date: March 19, 2014. Available at: http://roseville.granicus.com/MetaViewer.php?view_id=2&clip_id=2745&meta_id=104902 (accessed 06.07.2017).

Britton, T.C., Stewart, R.A., O'Halloran, K.R., 2013. Smart metering: enabler for rapid and effective post meter leakage identification and water loss management, Journal of Cleaner Production, 54, 166-176.

Burgess, J., Harrison, C., Filius, P., 1998. Environmental communication and the cultural politics of environmental citizenship, Environment and Planning (30), 1445–1460.

Byrne, D.P., Martin, L.A., 2016. Water Market Interventions. Report prepared by the University of Melbourne for South East Water.

Bryne, D.P., Martin, L.A., 2017. mySEW Evaluation, Draft Report of April 26, 2017 prepared by the University of Melbourne for South East Water.

Davies, K., Doolan, C., van den Honert, R., Shi, R., 2014. Water-saving impacts of smart meter technology: an empirical 5 year, whole-of-community study in Sydney, Australia. Water Resources Research, 50, 7348–7358.

Delaney, C., Fam, D., 2015. The 'meaning' behind household rainwater use: An Australian case study, Technology in Society, 42, 179-186.

Doolan, C., Crissani, R., 2015. Smart Grid Smart City – Challenges for integrating smart water meters, OzWater 2015 proceedings.

Doolan, C., 2010. Smart metering residential project 2008-2010. Sydney Water. Parramatta, NSW.

Erickson, T., Podlaseck, M.E., Sahu, S., Dai, J.D., Chao, T., Naphade, M., 2012. The Dubuque Water Portal: evaluation of the uptake, use and impact of residential research water consumption feedback, in: CHI 2012, May 5-10, 2012, Austin Texas, USA, ACM, 675–684.

Fielding, K.S., Spinks, A., Russell, S., McCrea, R., Stewart, R., Gardner, J., 2013. An experimental test of voluntary strategies to promote urban water demand management, Journal of Environmental Management, 114, 343-351.

Fischer, C., 2008. Feedback on household electricity: a tool for saving energy? Energy Efficiency, 1(1), 79-104.

Glass, P., 2015. Real-time water use information….could it make a difference? Anglian Water presentation (accessed 05.07.2017).

Hendrickx, H., 2015. Objective measurement of UK showering behaviour and a behavioural intervention to reduce water use in the shower. Research funded by the UK Water Industry Collaborative Fund and Unilver R&D. Available at: http://www.futurewaterassociation.com/sites/default/files/public/event_documentation/Hilde%20Hendrickx%20-%20Unilever.pdf (accessed: 28.06.2017).

Holleran, W., 2016. Water Savings Clustering: Impact of Social Norms at Household Level, WaterSmart Software presentation. Available at: http://www.widest.eu/images/downloads/summer_school/pdf/Holleran_WaterSavings-Clusters-and-Determinants.pdf (accessed 20.06.2017).

Jackson, T., 2005. Motivating Sustainable Consumption: A review of evidence on consumer behaviour and behavioural change, Centre for Environmental Strategy, University of Surrey, Guildford, Surrey.

Jeong, S., Gulbinas, R., Jain, R., Taylor, J., 2014. The impact of combined water and energy consumption eco-feedback on conservation, Energy and Buildings, 80, 114-119.

Joo, C.J., Oh, H.J., Ahn, H., Ahn, C.H., Loo, S., Ko, K., 2015. Field application of waterworks automated meter reading system and analysis of household water consumption, Desalination and Water Treatment, 54, 1401-1409.

Kenney, D.S., Goemans, C., Klein, R., Lowrey, J., Reidy, K., 2008. Residential water demand management: lessons from Aurora, Colorado, Journal of the American Water Resources Association, 44(1), 192-207.

Kurz, T., Donaghue, N., Walker, I., 2005. Utilizing a social-ecological framework to promote water and energy conservation: a field experiment, Journal of Applied Social Psychology, 35(6), 1281-1300.

Liu, A., 2016. Smart Water-use Feedback: Options, Preferences, Impacts and Implications for Implementation. PhD thesis. Institute for Sustainable Futures, UTS.

Liu, A., Giurco, D., Mukheibir, P., 2014. Online household water portal: user interactions, and perceptions of water use. In Book of Abstracts, 2014 SWGIC, Smart Water Grid International Conference. 25-27 November, 2014. Incheon, South Korea, 102-108.

Liu, A., Giurco, D., Mukheibir, P., 2015. Motivating metrics for household water-use feedback, Resources, Conservation and Recycling, 103, 29-46.

Liu, A., Giurco, D., Mukheibir, P., White, S., 2016. Detailed water-use feedback: A review and proposed framework for program implementation, Utilities Policy, 43, Part B, 140-150.

Liu, A., Giurco, D., Mukheibir, P., 2016. Urban water conservation through customised water and end-use information, Journal of Cleaner Production 112, 3164-3175.

Liu, A., Giurco, D., Mukheibir, P., Mohr, S., Watkins, G., White, S., 2017. Online water-use feedback: household user interest, savings and implications, Urban Water Journal.

Mitchell, D.L., Chesnutt, T.W., 2013. Evaluation of East Bay Municipal Utility District's Pilot of WaterSmart Home Water Reports. Report prepared for California Water Foundation & East Bay Municipal Utility District.

Naphade, M., 2011. Smart Water Pilot Study Report. IBM Research. Dubuque, IA.

Petersen, J.E., Shunterov, V., Janda, K., Platt, G., Weinberger, K., 2007. Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives, International Journal of Sustainability in Higher Education, 8(1), 16-33.

Santa Margarita Water District, 2016. Agenda: Santa Margarita Water District Engineering and Operations Committee Meeting, June 10, 2016. Available at: http://www.smwd.com/assets/downloads/meeting-agenda/2016-06-10_EOC.pdf (accessed 23.06.2017).

Schultz, P., Messina, A., Tronu, G., Limas, E.F., Gupta, R., Estrada, M., 2016. Personalized normative feedback and the moderating role of personal norms: a field experiment to reduce residential water consumption, Environment and Behavior, 48(5), 686-710.

Seyranian, V., Sinatra, G.M., Polikoff, M.S., 2015. Comparing communication strategies for reducing residential consumption, Journal of Environmental Psychology 41, 81-90.

Shove, E., 2010. Beyond the ABC: climate change policy and theories of social change. Environment and Planning A (42), 1273–1285.

Swinton T., Little, J., Russell-Bennett, R., Mulcahy, R., McAndrew, R., Passion, C., 2016. Reduce Your Juice Digital Social Marketing Program (LIEEP), Final Report, CitySmart, Brisbane, Australia. Available at:

https://www.environment.gov.au/system/files/energymog/files/citysmart.pdf (accessed: 13.07.2017).

Tom, G., Tauchus, G., Williams, J., Tong, S., 2011. The role of communicative feedback in successful water conservation programs, Applied Environmental Education & Communication, 10(2), 80-90.

WaterSmart Software, 2017. Managing Demand Collaboratively, Oakdale Case Study. Available at: https://www.watersmart.com/partner-story/managing-demand-collaboratively/ (accessed 15.06.2017).

WaterSmart Software, 2015. Consumer Engagement: Saving water & money through analytics and behavioural science, Roseville Case Study. Western Governors' Drought Forum (2015). Available at: http://westgov.org/news/?option=com_content&view=category&id=321&Itemid=231 (accessed 06.07.2017)

WaterSmart Software, 2017. Right-sizing budgets with analytics. Greeley Case Study. Available at: https://www.watersmart.com/partner-story/right-sizing-water-budgets-with-analytics/ (accessed 07.07.2017)

Wetherall, B., 2008. Final report of the Eco-Pioneer pilot program. South East Water. Heatherton, VIC.

Yip, D., 2014. Smarter Water: How data is making water smarter from the utility to the user, Inter-Water Australia, 15-16 Oct 2014 MCEC. Available at: http://blog.inter-water.com.au/wp-content/uploads/2014/10/DavidYipSLR.pdf (accessed 21.06.2017).