Effectiveness of smart-meter based consumption feedback in curbing household water use: Knowns and unknowns

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Abstract

Adaptive approaches are required to counteract the mounting threats to water security. Demand management will feature centrally in such adaptation. The increase in use of smart meter technology offers an improved way for utilities to gauge consumer demand and to supply consumers with consumption feedback in (near) real-time. Such feedback can decrease the discrepancies between perceived and actual water usage. In contrast to the energy sector, however, where the advantages associated with smart meter consumption feedback are extensively documented, few studies have focused on the usefulness of such feedback when it comes to managing water consumption. This review assesses the evidence base for the effectiveness of water usage feedback technology in encouraging water conservation. The review highlights the potential value of high-granular smart-meter feedback technology in managing domestic water consumption. Findings from the papers included in this review (N = 21) indicate that feedback was associated with decreases of between 2.5% and 28.6% in water use, with an average of 12.15% (SD = 8.75). A single paper reported a 16% increase in consumption associated with smart-meter feedback. The benefits for water utilities are highlighted, but the costs for utilities need to be considered further. Overall, more work is needed to conclusively pinpoint the most effective type of feedback in terms of information content and granularity, frequency of delivery and medium, and how water consumption is linked to energy consumption. This information is needed to make concrete recommendations to the water industry about the costs and benefits of investment in smart metering and consumer feedback.

Keywords: Demand management; smart technology; water meter; feedback; behavior change.

Background

Water shortage is an increasing global problem, with approximately 500 million people currently living in areas where the potable water available is insufficient to support the local population (Evans and Sadler, 2008). Global population levels have tripled and water demand for domestic and industrial purposes has increased six-fold, putting intense stress on an already depleted and decreasing global water supply (Evans and Sadler, 2008). In addition, the consequences of climate change will continue to impact negatively on global usable water sources (Saghir, 2008), with the potential that over four billion people – more than half of the world's population – will be chronically short of water by 2050 (Evans and Sadler, 2008; Saghir, 2008). Rather than increasing fresh water production (e.g., through desalination or additional abstraction from ground/surface water) to meet current demand, better supply and demand management and conservation efforts are needed to avert water crises in the near future.

Generally, the balance between water supply and demand can be managed in two ways: (1) large-scale regulatory and infrastructural action, and (2) individual conservation efforts in the home and community. The former method can involve water use restrictions, pricing schemes, leakage reduction/control efforts and water rates tailored to specific consumer habits, as well as the installation of more efficient appliances, centralized and decentralized water reuse and recycling technologies. For example, in terms of structural and technological efforts to conserve water, rainwater harvesting and grey water recycling can be effective (Liu et al., 2013). Centralized water purification methods circumvent many problems associated with traditional means of accessing clean water, including limited groundwater reservoirs and non-stationary rainfall patterns. However, water purification efforts such as desalination are extremely cost ineffective, requiring large amounts of energy for a relatively small yield (Liu et al., 2013). Thus, simply increasing the amount of potable water through water purification efforts alone is unlikely to be a sustainable solution in all countries.

In terms of water pricing, past research has shown that, like most other commodities, water consumption is linked to cost, such that consumption decreases as price increases (Arbues et al., 2003; Campbell et al., 2004; Hoffmann et al., 2006; Olmstead and Stavins, 2007). However, there is some variation in terms of water usage. While water has been shown to be price elastic (Hoffmann et al., 2006), measures such as increasing taxes on consumption may only work in certain circumstances (Dean et al., 2016; Ghimire et al., 2015). This is because water is no ordinary commodity, but rather a (life sustaining) necessity and therefore relatively resistant to simple price fluctuations (Hoffmann et al., 2006; van den Bergh, 2008). Further, Barrett (2004) notes that because the cost of water is so low compared to other amenities in countries like Australia and the USA even relatively large price increases or restructuring of water billing go unnoticed by the average consumer. Pricing interventions are also politically difficult to implement and/or constrained by regulation in the water industry and may not be effective in the long-term (Duke et al., 2002; Espey et al., 1997; Steg, 2008). Although regulations and pricing impact water consumption, it is important to consider other strategies.

Another way to address potential future water scarcity is through grassroots community and domestic water conservation. This makes sense given the fact that in many parts of the world, more water than needed is used for everyday domestic purposes (Grafton et al., 2009). Moreover, even within relatively similar industrialized countries, there is dramatic variation in levels of household water use, ranging from an average per capita water consumption of 382 liters in the USA to 110 liters in France (Grafton et al., 2009). Given the similarity of lifestyles and water availability in Western countries, this highlights the potential for significant water savings through changing individual behavior.

The purpose of this article is to review the existing evidence base on how to expand domestic water conservation efforts by use of different feedback technologies (e.g. smart meters and in-home consumption displays) and methods (e.g. consumption feedback) designed to encourage consumers to curb their water use. Although these approaches are relatively new in the domain of water consumption, but such techniques have been widely applied and evaluated in the context of domestic energy use. In fact, there is solid evidence for the efficacy of ‘smart’ feedback methods in managing energy use, with reductions in consumption ranging from 5% to 20% (Gans et al., 2013; Houde et al., 2013; Vine et al., 2013). Nonetheless, there are limitations in the knowledge base on reducing consumption via smart meter feedback – chiefly in relation to the most effective feedback method, whether the effect is sustained over time, as well as the costs and benefits of feedback (Vine et al., 2013). Here we evaluate the existing evidence on the effectiveness of consumption feedback in reducing domestic water use and identify avenues for future research. The specific objectives of this paper are to:

(i) Critically review existing research on water consumption feedback to identify current knowledge about the effectiveness of such feedback in reducing domestic water consumption;

(ii) Draw on broader research in the application of smart metering for household energy feedback to identify what is yet to be understood in the context of water consumption feedback;

(iii) Based on the review, make recommendations for further research to address any knowledge gaps and discuss the implications for the water industry.

Using smart-meters to provide consumption feedback to consumers

Conventional water meters are typically read manually in monthly or yearly intervals to record water consumption for the utility company and the user. Smart-meters, on the other hand, record consumption in real-time or near real-time (e.g. every hour or 15 minutes), and communicate this information to the utility and consumer (Federal Energy Regulatory Commission, 2013; FERC). This enables instant up-to-date information on consumption, with the benefits of accurate, site-specific readings, easier and faster identification of leaks and water waste, as well as greater transparency about consumption for the consumer (e.g. bills based on actual rather than estimated use) (FERC, 2013). Governments and water utilities are increasingly focused on the installation of smart meters, largely because smart meters are expected to lead to reductions in water consumption beyond those associated with conventional meters (Anda et al., 2013; Beal and Flynn, 2015; Britton et al., 2013; Lima and Navas, 2012). One way that smart meters can be used to promote greater water savings is by using the data recorded and transmitted by smart meters to provide more frequent and detailed consumption feedback to consumers (Boyle et al., 2013; Cardell-Oliver et al., 2016). However, it is critical to evaluate whether this feedback does change consumer behavior. What do we know about using smart meters and feedback to reduce water consumption?

Given the infancy of smart-metering in the water domain, there is little research on its effectiveness in managing water consumption. In a recent study, Fielding et al. (2013) recruited 221 households in South-East Queensland, Australia (an area that had recently experienced a prolonged severe drought), and measured the effect of giving consumers tailored information obtained through 5-second, utility-specific smart-meter data. Households were assigned to a control group or one of three experimental groups. The experimental groups were an education only group, a social comparison and education group, and a feedback group. The education only group received postcards with information on how to save water. The social comparison and education group received postcards with information about the percentage of comparable households involved in various water saving actions, as well as information on water conservation. Finally, the feedback group received information about total water use as well as that connected to different activities, as well as postcards with water conservation tips. Significant differences between the control group and the intervention groups emerged: the intervention groups consumed significantly less water than the control group (11.3 liters, approximately 7.9% reduction). There were, however, no differences between the intervention groups, and any treatment effects had decayed after a year. Thus, smart meter feedback might not be more effective than other more traditional (and lower cost) behavior change strategies (e.g. water saving information). However, because consumers were only given feedback from smart meters at a single rather than multiple time points, it is possible that continued access to smart meter data with regular feedback would prevent decay effects and prompt sustained conservation efforts.

Erickson et al. (2012) evaluated the efficacy of the Dubuque Water Portal (DWP) – a near real-time domestic water usage feedback system. During a 15-week period, smart-meters logged consumption data in 15-minute intervals, which was then made available to 303 participating households as well as to the water utility through an online portal. The data was refreshed every two or three hours and fed back to the consumer in hourly usage graphs, detailing not only total household usage, but also how the given household consumption compared to the neighborhood. Further, the portal included a team-based game centering on water conservation, as well as chat facilities enabling participants to communicate with one another anonymously. Results showed a 6.6% decrease in standard water use in the study's first nine weeks when only the intervention group could access the portal. However, it is important to note that most of the households were already saving water. As a result, the effects of the online portal may have been muted. Still, these results indicate that, at least in the short term, more frequent feedback can reduce consumption.

Petersen et al. (2007) fitted a high resolution consumption monitoring system in two college dormitories and supplied users with comprehensive feedback through an internet website in order to investigate the impact of water usage feedback combined with incentives and education. The website interface allowed users to view electricity and water data collected at any time, and order summary graphs for specific time-series, as well as information on the environmental and financial costs of consumption. A comparison group was provided with low-resolution, aggregate data readings once a week. Further, the study was framed as an energy and water saving competition between and within the two study groups (high- and low-resolution feedback). The group with the lowest consumption levels won a prize. Thus, participants received feedback about their own consumption relative to that of others.

Results revealed an average 3% (140 liters) decrease in water use per capita, with one dormitory logging an 11% reduction. Energy savings were considerably greater: although both low- and high-feedback conditions recorded an average 32% reduction, the high-resolution feedback group did conserve more than the low-resolution group (55% vs. 31%). In relation to water consumption, it should be noted that there was no high-resolution feedback for water consumption (due to technical errors), such that participants received only low-resolution water usage information. For this reason, it is likely that individuals would have been less able to strategize in order to reduce their water consumption. Additionally, because the study's primary focus was on energy conservation (e.g., the website name was "Dormitory Energy website") it is likely that individuals would have been more focused on saving energy than water. A final consideration relates to the fact that any conservation behavior took place in the context of a competition with incentives for recording the greatest reductions, meaning that the effectiveness of feedback might be tempered in the absence of such incentives.

Despite the lack of real-time consumption feedback for water, 55% of participants indicated that, given the opportunity, they would continue to view high resolution graphs and gauges of electricity *and* water consumption on a website even after the study was over. Another 45% stated that the online availability of high resolution consumption data would encourage them to conserve both water and electricity, suggesting an appetite for higher resolution information about one's water and energy use in order to assist conservation efforts.

Petersen et al. (2015) conducted a two-year study using the same experimental setting (i.e. an inter-dorm energy and water conservation competition) and similar population (Oberlin College dormitories) as Petersen et al. (2007). Two studies – one in 2010 and one in 2012 – were conducted to test the effects of the smart-meter based feedback that was made accessible to students through an online portal as described above. In contrast to the 2007 study real-time feedback for water consumption was available. Data recorded for the 2010 study was obtained from 107 dorms participating in the water competition (20 of which had access to real-time feedback technology as opposed to weekly updates) and 471 dorms in the electricity competition (160 of which had access to real-time feedback). The 2012 study was larger and based on 229 dorms participating in the water competition (17 with real-time feedback), and 1072 in the electricity competition (109 with real-time feedback). Results for the 2010 study indicated dorm average electricity and water consumption decreases of 3.7% and 5.2% (570 000 gallons), respectively. The 2012 study recorded a 3.2% decrease in electricity use and a 2.5% (660 000 gallons) decrease in water use. These reductions were statistically significant, and were, at least in terms of electricity usage, evident throughout the 20 day post-intervention period. It should be noted, however, that disentangling the water and electricity savings was not possible within the study design. As such, there is no gauge of how much water was conserved for its own sake as opposed to water saved as a byproduct of reducing energy consumption (full loads of laundry, shorter showers, etc. save energy *and* water) which was the primary focus of the study. Further, and as with the earlier study, these results occurred in the context of a race to conserve energy and water and as such might not reflect the pure effects of smart-meter feedback *per se*, but rather the impact of a saving competition. Indeed, the authors note that the central motivation for the observed reductions in consumption was related to the competition. Nonetheless, the study demonstrates the potential efficacy of smart-meter based feedback in reducing consumption.

Most recently, Liu et al. (2016) evaluated the effects of providing 28 households in New South Wales, Australia, with water consumption reports – *Home Water Updates* – based on smart-meter data. The reports were mailed out twice – once for the summer season, and once for the winter season. The information was of relatively high granularity, including a breakdown of water consumption in liters based on fixture (faucets, shower, washing machine, toilet, leaks, and outdoor) and length of use (shower) or number of times used (e.g., washing machine, toilet). The report also included information on the household's average total consumption (in liters and standard buckets of water) compared to that of the neighborhood, as well as three tips to save water.

Overall, the results for water consumption were inconclusive. In terms of average water consumption for the winter seasons, both the intervention group (N = 28) and the control group (N = 29) decreased from pre- to post-intervention. The intervention group used 20.3% less water than at baseline while the control group curbed their use by 12.7%. Between-group comparisons indicated that the control group used 8% more water than the intervention group post-intervention. Looking at consumption by fixture, the intervention group recorded reductions compared to the control. For the intervention group, outdoor water use was 25% lower than that of the control group, while relative savings by use of washing machine, shower, and toilet, comprised 24%, 15%, and 10%, respectively. However, these results were not statistically significant. For the summer seasons, the intervention group consumed more water on average than the control. Although water use increased for both groups post-intervention, the intervention group used 12% more water than pre-intervention while the control consumed only 3% more. Looking at consumption by fixture, however, the intervention group saved 21% in shower use and 17% in toilet use from pre- to post-intervention. However, as with the winter season data, the differences in summer season water use were not statistically significant. Strictly speaking, there was no difference in water use between intervention and control group across the duration of the study (Liu et al., 2016).

Although it is clearly tempting to use high resolution data obtained via smart meters to provide real-time feedback to consumers, it is important to consider consumers' feedback design preferences. However, there is limited research on this topic. Erickson et al. (2012) found that around 27% of participants reported interest and openness to the portal and accessed the portal at least once a week, and only 4% of the sample found the portal too difficult or confusing to use. Participants valued the hourly consumption usage graphs (88%) and social comparison graphs the most (66%). However, the online chat room was not widely used. In addition, although the graphs did not provide appliance-level data, participants were able to map their water use to their behavior and habits. Specifically, 77% of participants reported increased understanding of their water consumption as a result of using the portal, and 70% made valuable insights into how changes in their behavior affected consumption.

Petersen et al. (2015) also attempted to ascertain which feedback features participants used and valued the most in the online portal. Importantly, over half of the 2010 and 2012 cohorts (54% and 55%, respectively) never used the website, suggesting general disinterest in the feedback website. One fifth of participants, however, reported visiting the website more than once per week (19% in 2010 and 20% in 2012). The majority of these felt that the website was easy to use and navigate (71% in 2010 and 65.6% in 2012). They further valued three types of information in particular. Approximately 92% in 2010 and 89% in 2012 showed interest in competition-standing among dorms, 91% (2010) and 89% (2012) viewed graphs showing consumption patterns and changes for the given student’s dorm, and 81% (2010) and 80% (2012) valued the capacity for changing the unit of expression for resource use (kWh, gallons, CO_2, $) (Petersen et al., 2015).

Liu et al. (2016) found that 80-90% of their sample valued the feedback report features (average consumption pie chart, end-of-use metrics, and social comparisons) as interesting and useful, with 50-60% indicating that the feedback helped them save water.

Thus, extant research indicates a preference for feedback design that includes consumption pattern and changes over time as well as social comparison features (Erickson et al, 2012, Petersen et al., 2105, Liu et al., 2016). Thus, it may not be necessary to design more costly appliance-level monitoring systems to produce benefits of real-time data feedback.

What don’t we know about using smart meters and feedback to reduce water consumption?

At present, there is little evidence on whether smart meters and high resolution feedback are effective in reducing water consumption. Thus, the knowledge base is relatively limited, with a number of avenues for future research. First, gaps in the extant literature need to be addressed. For example, the participants in Fielding et al.’s (2013) study had just experienced a severe drought and may have been more aware of issues concerning water conservation and thus more receptive to demand management strategies than in other contexts. Thus, the effects of feedback in locations not prone to drought events or water scarcity need further scrutiny. It is also relevant to note that most participants in past research have been volunteers (Erickson et al., 2012; Petersen et al., 2007), with the result that they may have been more ‘water aware’ than the general population. In effect, past studies might have underrated the water conservation potential of various feedback interventions (as participants may already have been conserving). Further research, using a wider and more representative population of water consumers, is needed to clarify this matter.

In addition to any sampling issues, there are more noteworthy unknowns. First, a central concern relates to the "half-life" of feedback effects – that is, how long are such effects sustained? In the studies reviewed, water use often returns to baseline levels post-intervention, suggesting that the savings associated with smart meters may dissipate (Erickson et al., 2012; Fielding et al., 2013). However, Fielding et al. only provided one feedback once (at the start of the study), such that households were unable to use the smart meter technology to its full capacity (i.e. near real-time consumption updates), despite the fact that the meters were installed for 12 months. Similarly, Liu et al. (2016) only gave feedback twice post-intervention. In Erikson et al.'s study, participants *did* have free access to their consumption data, but the study only ran for 15 weeks. As a result, any long-term impact of the intervention could not be gauged completely. Petersen et al.'s (2015) study indicated a continued effect 20 days post-study, but this related only to energy, and not water consumption.

Other unanswered questions concern the kind of feedback that is most effective in changing behavior. In other words, is the provision of more frequent information about one's water consumption (i.e., daily updates versus quarterly updates via the utility bill) enough to change water use? Or, is there value in the provision of comparative feedback, either in the form of historical comparisons (i.e., is the individual using more or less water now than in the past) or social comparisons (i.e., is the individual using more or less water than others)? At present, there are no studies shedding any light on these questions as there is no research (known to the authors) that has looked at mere access to high resolution data versus access to high resolution *historical* data versus high resolution *social comparison* data. Fielding et al. (2013) found that providing social comparison feedback or high resolution data did not produce greater savings compared to providing water conservation information alone. However, as established earlier, households received such information only once. Erikson et al. (2012) provided households were free access to high resolution water consumption data, and to information on how their usage compared to others', but did not isolate the effects of the different types of feedback. In order for utilities to invest in the installation and maintenance of smart meter systems, and the development of consumer portals, it is crucial to show that providing consumers with more frequent access to information about their water use and how they might compare to others leads to greater water savings than standard water awareness campaigns. Research in the energy sector has shown decreases ranging from 5% to 20%, and emphasized the importance of high frequency, comprehensive and easily interpretable feedback tailored to the individual consumer and accompanied by conservation advice (Vine et al., 2013), but the literature in the water domain does not permit such conclusions to be drawn.

Finally, there is also a need for a systematic examination of consumer interest and engagement with consumption information disseminated through websites. As mentioned previously, Petersen et al. (2015) found that just over half of the study population used the study web portal once or more. This resonates with previous research on water consumption feedback where the authors found that in spite of the study population's enthusiastic participation in all aspects of their study, only 18% (26 of 141) visited the website once or more (Schultz et al., 2014).

Using In-Home Displays to provide consumption feedback to consumers

Another way to provide feedback from smart meters is via in-home consumption displays (IHDs). IHDs are smart-meter connected devices that can be installed anywhere in the home (Strengers, 2011) and can be used to present consumers with real-time (or near real-time) information on water use (e.g. by fixture and/or time of day), cost, and feedback about the user's consumption over time (i.e., historical comparisons) as well as comparisons with other's usage. The logic behind IHDs rests on the fact that most people lack knowledge about their own water use, and how much it costs both financially and in terms of the environment (Froehlich et al., 2010). As a result, more insight into how one's behavior relates to water consumption – such as that presented via IHDs – may motivate behavior change and conservation efforts.

What do we know about using IHDs to reduce water consumption?

In an extensive test of IHDs, Kenney et al. (2008) installed IHD devices in 10 000 households and tracked consumption behavior over an eight year period. The IHDs gave users access to near real-time consumption data so that users could regulate consumption behavior to fit their monthly water budget. Results revealed that participants used significantly *more* water (16%) after the IHDs were installed. However, this increase was due to the fact that consumers seemed to modify *when* they used water rather than *how much* water they used to fit with variable price tariffs. Indeed, during the study period, new pricing tariffs were introduced, and further analysis revealed that households decreased their water consumption, but only during high peak hours. That is, the detailed consumption data provided by the IHD enabled consumers to change their water use to low peak hours, thereby saving money, but not water. This result might suggest that conservation efforts are driven by financial rather than environmental concerns, but Kenney et al.'s research shows that, given the opportunity, consumers can and do use IHDs to change consumption practices.

The findings from Kenny et al.'s (2008) study are complemented in a Swiss study, where researchers installed IHDs in 91 household showers. The IHDs – fixed to the shower wall – displayed the amount of water used in liters in real time. This intervention reduced the amount of water consumed during showers with an average 18 liters per shower (22.2% reduction compared to pre-intervention) over the three-month trial period. Both low and high consumers at baseline reduced consumption post-intervention. The former group saved 4.9%

in overall water use after an initial slight increase in consumption, and the latter group saved 20.9% (Tasic et al., 2012). Further, in a follow-up assessment, Tasic et al. (2015) found that this effect remained 12 months after the conclusion of the original study. This research thus demonstrates that, in their own right, real-time IHDs have high potential in reducing water consumption. However, the way that the provision of IHDs fits with other demand management strategies, such as variable price tariffs (Kenney et al., 2008) and baseline consumption levels (Tasic et al., 2012) to shape consumers' motivations for water conservation needs to be understood.

Next, Froehlich et al. (2012) investigated display preferences in relation to IHDs, rather than testing the impact of IHDs on water consumption. Consumers preferred appliance-specific consumption information over overall consumption information (56% vs. 27%), and preferred to receive detailed breakdowns of hot and cold water use rather than overall use (48% vs. 8%). Individuals also expressed a clear preference to be able to see consumption levels at multiple levels (i.e., days, weeks, *and* months) as opposed to only a single level (i.e., days or weeks or months; 65% vs. 35%). Further, consumers wanted to receive information about both volume and cost of consumption, rather than either metric alone (71% vs. 29%). Finally, although consumers evaluated all forms of feedback positively, historical self-comparison feedback was rated highest, followed by comparison with a goal and comparison with demographically similar others. Overall, consumers wanted IHDs to provide detailed feedback about their water use.

In a slight variation on more 'traditional' IHDs, Willis et al. (2010) installed a smart-meter connected alarming visual display – *the WaiTEK Shower Monitor* – in bathroom showers of 44 households for three months. The devices worked by sounding an alarm once water usage exceeded 40 liters. Two weeks post-installation, the average reduction in shower water consumption was 15.4 liters (27%) per household. This was because individuals –

including those who were already conserving water – spent less time in the shower. For example, the frequency of shower events greater than ten minutes decreased from 14% to 6.4%, and the shower head flow-rate also decreased by 10.2%. Further, Willis et al. estimated that the payback period for installing the device would be 1.65 years and 3% of total city consumption would be saved if the devices were installed in all homes in the region.

In a follow-up, Stewart et al. (2013) examined the impact of the *WaiTEK* system by adding a three-month post-intervention consumption check and user evaluation to the original research design. Most users reported favorable attitudes to the shower monitor. In particular, 88.2% indicated overall satisfaction with the technology, rating it highly in terms of facilitating greater understanding of water use and increasing intentions to change behavior. However, Stewart et al. found that any decreases in water consumption immediately following the installation of the *WaiTEK* system had disappeared completely three months later, with water use either returning to or exceeding the pre-intervention baseline. Specifically, after an initial increase in shower events shorter than seven minutes (from 61% to 75.6%) and a decrease in mean shower duration of 18.5%, shower duration gradually increased over the next three months and was only 3.9% lower than baseline at the end of the three month post-intervention period. Similarly, decreases in shower event volume and flow rates (26.8% and 10% reductions, respectively) recorded shortly after installation, not only rebounded to their original level, but surpassed it by 1.1% and 4.1%, respectively. Thus, the *WaiTEK* system may be highly efficient in the short-term only, with most effects decaying over time.

Other alarm-based approaches include ambient light displays, typically installed in showers and at faucets. These devices are connected to simple flow-rate sensors and alert the user to their level of consumption with, for example, traffic light displays (Kuznetsov and Paulos, 2010) and gradually illuminating vertical LED rods that represent real-time water consumption (Kappel and Grechenig, 2009). Some success has been achieved with these devices, with the low installation cost, simplicity and high interpretability of the alarm displays particularly valued by users (Kappel and Grechenig, 2009; Kuznetsov and Paulos, 2010). Overall, alarm-based devices may be useful in encouraging conservation, and benefit the user in terms of immediate financial savings. This effect, however, may be short-lived and decay over time, with only a single study establishing a lasting effect (Tasic et al., 2015).

What don’t we know about using IHDs to reduce water consumption?

There are a number of gaps in the research base for IHDs. For example, Kenney et al. (2008) and Froelich et al. (2012) note that more environmentally conscious and pro-conservation individuals may volunteer for evaluation studies, so the size of the effects in the broader population is unknown. In addition, given that many IHDs present information about cost, as well as volume, of consumption, it is not clear which element is the key driver of conservation efforts. This is particularly relevant because IHDs can be used to present different types of feedback to the consumer and, indeed, this is precisely what consumers want (Froehlich et al., 2012). In addition, and as noted above, potential backlash effects need to be considered, because IHDs may actually increase consumption when combined with variable price tariffs (Kenney et al., 2008). On this note, Tasic et al. (2012) similarly showed that IHD feedback affected consumers differently depending on their baseline water usage. Specifically, low consumers initially increased their water use before declining relatively slightly, and high consumers reduced their water use instantly and dramatically. Finally, it is important to explore how long any decreases in consumption might last. For example, Stewart et al. (2013) reported that the decreases in shower use with the *WaiTEK* had disappeared at a 3-month follow up but Tasic et al. (2015) found no effect decay after 12 months. It is apparent that longer term follow-up of effects of feedback need to be undertaken more systematically.

Mail-based Consumption Feedback

Advances in technology, such as smart meters, can be harnessed to change water usage by providing higher resolution, more frequent feedback about individuals' water consumption. However, other research has tested the effect of low technology feedback methods, such as mail-based feedback (Ferraro et al., 2011; Geller et al., 1983; Kurz et al., 2005). Given the small evidence base on the use of smart meters, it may be informative to review the insights gained from research using more traditional feedback methods.

What do we know about using mail-based feedback to reduce water consumption?

Geller et al. (1983) conducted a ten week longitudinal study of 129 households in the USA to investigate the combined effect of educational instruction, consumption feedback, and engineering strategies for reducing water and energy consumption. The educational instruction consisted of a handbook given to participants, detailing the problems inherent in wasteful water consumption, the relationship between water and energy use, and methods for curbing water use in the home. The feedback component involved weekly consumption graphs and daily consumption feedback cards mailed out to participants, informing them of the amount of water used the preceding day, and the percentage of increase or decrease from median baseline and average consumption. The engineering approach involved installing water-saving devices in the household (aerators, toilet dams, etc.). Significant water savings occurred only with the water saving devices, although the savings were much less than expected, suggesting that people may have used *more* water post-installation. There were, however, no effects of the educational or the feedback components. This failure was attributed mainly to the low cost of water in general, as well as a water rating structure that decreased as consumption increased. As a result, interest in saving water was limited due to a lack of financial benefit.

Aitken et al. (1994) found more promising results for the effect of feedback on residential water consumption in 321 households in Melbourne, Australia. Participants were divided into three treatment groups: a *dissonance and feedback group*, which received feedback cards highlighting their previously stated status as environmentally responsible citizens (so that using lots of water would be inconsistent – or dissonant – with their self-concept), as well as information comparing the household's consumption with an artificially low city-wide baseline; a *feedback group* that received a card detailing the household's consumption and what would be expected for a similar household; and a *control group*. Results demonstrated significant decreases in water consumption for both treatment groups. The *dissonance and feedback group* registered the largest decrease over time with a 4.3% (326 liters) reduction in weekly water use. However, it should be noted that when households were divided into high- and low-consumers (based on pre-intervention consumption), a 12% (163 liters) *increase* in water consumption was recorded for low-consuming households. This was thought to reflect a relaxation of conservation efforts in these households once they became aware of their favorable comparison to similar others, suggesting a need to tailor feedback to households. Such tendencies have also been found for energy consumption (Schultz et al., 2007). Overall, Aitken et al. conclude that simply reminding people of their previous pro-environmental stance (such that using water induces dissonance) along with feedback about their consumption can effectively reduce domestic water consumption.

Kurz et al. (2005) tested the impact of information leaflets, attunement labels, and socially comparative feedback on water and energy consumption in 166 households in Perth, Australia over a six month period. The attunement labels comprised notes designed to be attached to various appliances, each indicating the extent to which the given appliance impacted on the environment. The same information was included in information leaflets mailed out to the relevant households. Finally, socially comparative feedback sheets were mailed out to participants as well on a biweekly basis, and contained information on households’ water and energy consumption in comparison to other demographically similar participating households.

No effects were found on energy consumption, but there were differences among the treatment conditions on water consumption. Specifically, the use of attunement labels, but not information or social comparison feedback, was associated with a 23% decrease (>1,000,000 liters) in consumption from baseline levels. Thus, although the attunement labels contained identical information to the information leaflets, water conservation information needs to be salient at the point at which individuals make decisions about water use to be effective. This resonates with research on the effectiveness of ambient light displays and alarms, which also make water use salient at the point of interaction with the device (Kappel and Grechenig, 2009; Willis et al., 2010). However, it should be noted that, unlike Aitken et al. (1994) there was no evidence to suggest that socially comparative feedback was effective in changing consumption levels.

In a more recent test, Ferraro and Price (2013) allocated residents of a county in Atlanta USA (n = approx. 170000) to one of three experimental conditions: an *information only* condition, a *weak social norms* condition, and a *strong social norms* condition. The *information only* received “facts and tips” sheets on how best to reduce water consumption, while the *weak social norms* condition received a letter detailing the current water crisis and the importance of conserving. The *strong social norms* condition received social comparisons as well as information detailing water use from the previous year. Results indicated significant declines in water consumption across the three experimental groups relative to a control group: Compared to the previous year, consumption declined by 8.41% in the information only condition, 10.08% in the weak social norms condition, and 12.01% in the strong social norms condition. This was significantly different to the reductions seen in the control group (7.83%). Compared to the control condition, the declines observed in the treatment groups were greater by between 7.41% and 53.38%. Further analysis revealed that the effects of social norms were most pronounced for high-use households. However, decreases in water consumption were greatest in the month following the intervention, after which the effect decayed, particularly among high-use households. In a follow-up study conducted two years later, Ferraro et al., (2011) (the original study was conducted in 2009, but published in 2013) looked at consumption levels for each of the treatment groups to assess any lasting impact. Results revealed a lasting effect only in the strong social norms condition, with a complete decay in the weak social norms and the technical advice conditions.

In a similar study, Tiefenbeck et al. (2013) assessed the impact of norm-based consumption feedback on water use in a 154 household apartment building. The feedback in this research consisted of a weekly water consumption hardcopy report, detailing the household's water use in gallons per person compared to the average for the building. The report also included information about the amount of water needed for everyday activities (e.g. a bath requires 70 gallons of water, a five minute shower takes 10 gallons), and was framed as an environmental and moral initiative. The feedback group and the control group both comprised 77 households. While both groups displayed similar levels of water consumption in the initial two-week baseline period, households that received the intervention reduced their water consumption by 6% while there was no change in the control group. Thus, similar to Ferraro et al. (2011, 2013), Tiefenbeck et al. (2013) highlight the potential of using social norms to curb water consumption.

Similar findings were reported by Schultz et al. (2014) who conducted a study on the effects of personalized normative feedback in reducing water consumption. Here, the authors supplied 301 participants with either hardcopy or web-based tailored feedback. Depending on condition, participants received a mix of information on consumption combined with tips to save water, norm comparisons based on others in his or her neighborhood, and an indication of social approval or disapproval of the norm comparison. Results indicated that norm-based information alone as well as combined with social approval was related to statistically significant decreases in water consumption (by 26.5% and 16.2%, respectively) relative to the control group. Water saving tips, however, had no discernible effect. Similar to Tasic et al. (2012), baseline consumption moderated the effects of norm-based information such that high consumers were affected by the intervention more than low consumers. This moderation effect disappeared, however, when the norm-based information was combined with an indication of social approval (essentially replicating Schultz et al.'s 2007 findings on energy consumption). Participants with strong personal norms were also less influenced by social approval than those with less defined personal norms. Finally, and as stated earlier, the results showed that hardcopy information was more effective than web-based information with only 18% of participants engaging with the web-portal over the course of the study. The authors suggest that this may be due to the relatively low-tech version of their website, which lacked in various interactive features, such as, for instance, "push" functions and alerts, prompting users to action via smart phones and tablets. All in all, the findings by Schultz et al. (2014) resonate with Tiefenbeck et al. (2013), Ferraro and Price (2011), and Ferraro et al. (2013) in terms of the effectiveness of social norms based feedback. The results also fit well with previous indications that baseline feedback effectiveness is dependent on baseline consumption, with high consumers the most likely to be influenced by intervention (Tasic et al., 2012).

Finally, Jeong et al. (2014) examined the effects of mail-based water and energy consumption feedback in 18 residential dormitories (N = 4700) at Virginia Tech, USA over a six week period. Three groups were formed: a *control group*; a *water-only feedback group* that received a weekly water report, indicating level and per capita daily and overall water consumption in gallons, as well as training in water conservation and general environmental awareness information; and a *water and energy feedback group* that received this information *as well as* information on energy consumption related to such water use. Results indicated that the water-only feedback group used 3.69% less water compared to the control group, a difference that was not statistically significant. In contrast, the water-and-energy feedback group used significantly less water (7.27%) than the control group, suggesting that tapping into consumers' desire to save energy might contribute to greater water savings.

What don't we know about using mail-based consumption feedback to reduce water consumption?

Overall, the evidence base for the effectiveness of mail-based feedback on water conservation shows relatively strong themes. Although both Geller et al. (1983) and Kurz et al. (2005) found no effects of social comparison feedback on water consumption, the bulk of the remaining research *did* find that feedback that incorporated social comparisons reduced water consumption significantly (Aitken et al., 1994; Ferraro and Price, 2013; Tiefenbeck et al., 2013; Schultz et al., 2014). Moreover, Ferraro et al. (2011) established that only the social comparison condition was associated with reduced water consumption two years later. Finally, Jeong et al. (2014) found that feedback about the *total cost* of water consumption (i.e. water use and the associated energy use) might be most effective in reducing water consumption.

Before considering the knowledge gaps for mail-based feedback, it is important to consider how certain aspects of past research might impact on our interpretation of whether feedback is effective or not. It is perhaps not surprising that most studies have been conducted in areas that have recently experienced or are currently experiencing water scarcity (Aitken et al., 1994; Ferraro et al., 2011; Fielding et al., 2013; Kenney et al., 2008; Kurz et al., 2005; Schultz et al., 2014; Willis et al., 2010). As a result, the population may have been primed to conserve, making them more responsive to the intervention strategies, and lessening the significance of the drops in consumption. Alternatively, increased awareness of the need to save water could mean that the population was already trying to conserve, making the decreases in water use all the more significant. A preponderance of studies conducted in water-stressed areas could over-estimate *or* under-estimate the true impact of feedback. One clear unknown is whether feedback strategies are effective in locations that are not water stressed, and a priority for future research would be to provide these tests.

Another unknown is how feedback strategies interact with other demand management strategies, such as water pricing. Geller et al. (1983) suggested that the reason feedback was not effective in reducing water consumption was because consumers had no financial motivation to reduce their consumption. Similarly, Kenney et al. (2008) found that, when combined with variable tariffs, consumers used consumption feedback to shift *when* water was used rather than to reduce overall consumption. Thus, more research linking water pricing with the impact of feedback is needed.

The optimal frequency of feedback and type of feedback is also unknown. In the energy domain, it is generally true that feedback effectiveness increases with feedback frequency (Abrahamse et al. 2005). However, whether this is true for water use is unknown. Kurz et al. (2005) found that biweekly feedback did not reduce consumption but Ferraro and Price (2013) found that a single dose of comparative feedback was effective in reducing consumption (see also Aitken et al., 1994), and that these effects persisted two years later (Ferraro et al., 2011). One possibility is that feedback is most effective when consumers can set their own level of feedback, by choosing how often to access their own consumption data through web-based portals (e.g., Erickson et al., 2012). In relation to the most effective type of feedback, it is important to differentiate intra-individual comparison feedback (i.e. “how much do I consume now compared to last year?”) from inter-individual comparison feedback (i.e. “how much do I consume compared to my neighbors/similar others/efficient others?”). Many of the studies reviewed involve multiple types of feedback and the effects of each type needs to be tested separately to be able to make recommendations regarding which type to use for which consumer/household. Table 1 presents a summary of all case studies considered in this review, including the study location, design, sample size, type of feedback provided, the effects on water consumption, as well as participants’ views on feedback if relevant, for ease of perusal and review.

[INSERT TABLE 1 ABOUT HERE]

Discussion

The evidence base on using smart meters to provide domestic water consumption feedback – or the use of feedback on water consumption more generally – is not extensive, but several themes and variations do emerge. A direct and comprehensive comparison of the efficacy of the different feedback methods – or indeed a synthesis of study results – is difficult as the research reviewed here differs in terms of outcomes assessed and measurement metrics used, sample sizes, and study methods (quantitative and qualitative; see Table 1). At face value, the results are somewhat mixed. In terms of effectiveness in managing water use, the available evidence suggests that feedback can reduce water consumption by between 2.5% (Petersen et al., 2015) and 28.6% (Stewart et al., 2011). Across all studies that found that feedback decreased water use, and reported a volumetric indication of this decrease (14 out of 21 studies, not counting studies that report e.g. shower time; see Table 1), the average reduction in consumption was 12.15% (SD = 8.75) (all reported consumption decreases weighed equally), with the largest decrease recorded by Stewart et al (2011).

Effective feedback: Themes and variations

Most of the 21 studies reviewed found that feedback was effective in managing consumption, but three studies (Geller et al., 1983; Kurz et al., 2005; Liu et al., 2016) found that feedback had no effect on water consumption, and one study reported a 16% increase in consumption as a result of feedback (Kenney et al., 2008). Thus, nearly one fifth of the studies reviewed (n = 4) do not appear to support the effectiveness of feedback. Liu et al. (2016) used a considerably small sample of 68 households, which may account for the lack of statistical significance in their findings. Geller et al. (1983), Kenney et al. (2008) and Kurz et al. (2005) used large sample sizes and looked specifically at the impact of feedback on consumption, but the lack of effects might reflect the low salience delivery method of the feedback (Kurz et al., 2005), a moderating effect of low water prices and billing structures conducive to overuse (Geller et al., 1983; Kenney et al., 2008), or the absence of *total consumption* information; that is, the energy use associated with water use (Jeong et al., 2014). Although these studies seem to undermine the value of feedback in reducing water consumption, such results may not reflect the effectiveness of the feedback in and of itself, but rather the influence of other variables (see Figure 1).

Other factors that might determine the effectiveness of feedback include how the intervention is framed and the willingness of consumers to engage with the demand management strategy. Although the use of an engaged and motivated population could be considered a threat to the broader generalizability of feedback-based interventions, this might also flag the need to prepare and motivate any population to use and engage with intervention measures and technology for maximum effectiveness. Moreover, given the fact that the majority of past research has been conducted in contexts facing water scarcity or drought, the positive effects of feedback identified are over and above any measures taken by governments or water authorities to manage demand during periods of water stress (e.g. water restrictions, awareness campaigns). Thus, feedback does seem to add value to more established methods of promoting conservation.

The nature and delivery of the feedback as well as the attributes of the audience are also crucial. Social and historical comparisons were used effectively in mail-based (Aitken et al., 1994; Ferraro et al., 2011; Schultz et al., 2014; Petersen et al., 2015), smart-meter (Erickson et al., 2012) and IHD feedback studies (Froehlich et al., 2012). High-granular and frequent (near real-time) data feedback, as well as easy-to-read consumption graphs and statistics on both volume and price featured as valuable consumer information sources, as did appliance-level feedback (Erickson et al., 2012; Froehlich et al., 2012; Geller et al., 1983; Kenney et al., 2008; Petersen et al., 2007, 2015). Finally, information on how to use the feedback to cut down on consumption was also a valued and effective measure (Erickson et al., 2012; Ferraro et al., 2011; Fielding et al., 2013; Froehlich et al., 2012). Thus, most of the evidence on consumer preference in terms of the format of consumption feedback indicated detailed time-series data about cost and consumption, social and historical (self) consumption comparisons, appliance-level feedback, and guidance on how to use that feedback to manage water use. Given the potential cost of collecting, processing and feeding back information in several different ways, selecting a few feedback designs may be prudent to balance cost and benefit. As indicated in the work of Ferraro and Price (2013), Ferraro et al. (2011), Erickson et al. (2012), Tiefenbeck et al. (2013), Schultz et al. (2014), and Petersen et al. (2015), social and historical comparison graphs and data are perhaps most valued and effective in curbing consumption, highlighting these functions as potential core feedback methods in both mail-based and high-tech feedback formats.

In terms of delivery methods, the immediacy of feedback appears to be related to its effectiveness. That is, engaging the consumer at the point of use (e.g., at the fixture) yielded some of the most promising effects overall with large effect sizes recorded in studies on consumption alarms (e.g. 27% reduction in water use; Willis et al., 2010; 22% in Tasic et al., 2012 and Tasic et al., 2015) and attunement labels (23% reduction in water use; Kurz et al., 2005), although the persistence of such effects is yet to be determined (Stewart et al., 2013). In the context of the increasing pervasiveness of online technology in everyday life, it is also important to note the studies that indicated a relatively low level of participant engagement with web-portals and other online systems of feedback (Schultz et al., 2014; Petersen et al., 2015).

The way in which consumers respond to feedback appears to be dependent on current consumption levels: high-users react more positively to feedback than low-users, who either increase consumption, or remain at the same level of use (Aitken et al., 1994; Ferraro et al., 2011; Tasic et al., 2013; Schultz et al., 2014). There is also evidence that presenting *total costs* of water consumption by, for example, including related energy use, maximizes feedback effectiveness (Jeong et al., 2014). Thus, feedback information that is comprehensive and tailored to specific populations or even individuals is needed. Online portals could be adapted to include information about the total cost of consumption and to change as a function of specific user consumption levels and other relevant information (e.g. socio-demographics, geographical region, city vs. country, etc.). Figure 1 outlines the way in which feedback method (i.e., web portal, IHD, mail) and feedback type (i.e., real-time consumption, self or historical comparison, social comparison) fit together to influence water use, as well as factors that might enhance or attenuate the impact of feedback on consumption.

INSERT FIGURE 1 ABOUT HERE

Recommendations for Future Research

In the context of any synthesis of results, it should be noted that the current review is based on relatively few studies, and that there are a number of gaps in the knowledge base that should be considered in future research. In light of the research reviewed, these gaps include, but are not limited to the following questions:

For whom does feedback work?

Most studies draw upon volunteer samples. However, it is unclear whether these samples are representative of the wider population, or consist primarily of people who are particularly environmentally minded, and thus more responsive to feedback. Research to date has also been conducted in only a few countries (e.g., the USA, Australia, Austria, and Switzerland) and research in other locations is needed to check the generalizability of any effects. Moreover, even within studies, there is evidence that the feedback is differentially effective for different types of consumers (i.e., low and high consuming households).

How does feedback work?

It is also unclear as to the exact mechanisms and channels through which feedback changes behavior. For example, is there a minimum or maximum amount of data/information that needs to be presented to the consumer to change behavior? What type of feedback is most effective (e.g. absolute consumption or consumption relative to other consumer)? What is the best means/media (e.g. smart phone, TV, specialized water company display) and format (tables, charts, other) for delivering water consumption information to the consumer? More qualitative research is required to understand these issues fully.

When does feedback work?

The way in which the price of water moderates the effect of feedback needs to be investigated (see Kenney et al., 2008). Also, given that many uses of water also involve the consumption of energy (e.g., showering, laundry, dish washing), it is important to investigate further whether water consumption feedback is more effective when it also provides information on energy consumption (Jeong et al., 2014; Petersen et al., 2015).

How long do feedback effects last?

Most studies are conducted over relatively short time-frames, with evidence of both post-intervention decay effects (Ferraro et al., 2011; Keppel & Grechenig, 2009; Stewart et al., 2013), and lasting effects (Geller, 1983; Kurz et al., 2005; Tasic et al., 2015). However, over half of the reviewed studies (N = 12) report no post-study evaluations Thus, the long-term effects are largely unknown. To this end, longitudinal research could be valuable in establishing the long-term effect of feedback.

How does feedback compare with other demand management strategies?

It is also important to consider how different feedback methods compare in terms of cost and benefit and ease of use. That is, are the water savings associated with smart-meter related feedback greater than the water savings associated with more traditional demand management strategies such as awareness campaigns or the provision of water-saving devices? And are the water savings large enough to justify the additional investment needed to install, maintain, and monitor the devices, as well as the investment in developing web-based portals or applications that allow consumers easy access to their consumption data? To date, no research has investigated these questions, highlighting the need for carefully designed research experiments to robustly establish the relationship between a multitude of potential factors affecting feedback design and reductions in water use.

Recommendations for Implementation

On the basis of our review, consumption feedback can be used effectively to reduce water consumption, but is most efficient in curbing water use when it:

(i) is delivered at the point of use, such as in the form of attunement labels or ambient light displays.

(ii) includes high-granular time-series data of cost and consumption, social and historical (self) consumption comparisons, as well as appliance-level feedback.

(iii) is tailored to the household, particularly in terms of high- vs. low-users.

(iv) is delivered with water saving advice, detailing how to use the feedback to manage consumption.

Considerations for the water industry

The potential advantages of developing and investing in smart meter technology center on better overall management of water consumption, more environmentally responsible consumption, more effectively managed water systems (with reduced leakage, energy use and carbon footprint and other benefits), lower cost for both provider and user, and more sustainable charging systems (Oracle, 2009; Wessex Water, 2013). While the evidence generally supports the potential of providing feedback to consumers via smart meters, implementing the recommendations of the review is not without challenges for the water industry. A mass roll-out of smart meter technology is a potentially costly affair in the short term in terms of equipment development, the difficulties associated with installation and measurement, the need for enhanced training of personnel, as well as infrastructure design and data management and data privacy issues (Boyle et al., 2013; Giurco et al., 2010; Ockenden, 2014; Oracle, 2009). In addition, the potential disadvantages of reduced demand for water need to be considered, such as negative impacts on water quality associated with reduced flow velocities through the water distribution network. Further, as indicated above, there are several gaps in knowledge on the specific mechanisms and implementation methods that facilitate the most effective smart meter technology and its use by consumers (see also Boyle et al., 2013). More research is needed to map out the most effective types of technology, the best way to implement it, and the most efficient user training methods for both consumer and industry.

Although the main advantage of smart meter technology appears to relate to facilitating lower consumption on the household side, wider scale implementation can also provide benefits for water utilities on the water supply system side. Such benefits include the potential for more accurate water rates, greater ease of identifying and dealing with leaks in the water distribution network and inside customers' premises, and better adaptability of water and information systems to keep up with population growth and demand management (Boyle et al., 2013; Oracle, 2009; Cardell-Oliver et al., 2016). Further benefits of smart metering for water utilities include: energy savings, reductions in carbon footprints (due to less water being pumped into water systems), reductions in the consumption of treatment chemicals (due to reduced water consumption and leakage), the reduction of environmental impacts due to lower pressure on natural resources, an increase in capacity of water utilities to maintain the performance standards, and the deferral of capital costs for infrastructure expansions (Ockenden, 2014; Oracle, 2009). The reductions in maintenance, service and operations costs associated with smart meter water management also comprise a considerable advantage over the water industry status quo. Further, when acknowledging those benefits that cannot be quantified in straightforward economic terms – such as environmental responsibility and mitigation of a global decreasing water supply – the advantages of such technology mitigate the short-term expense shouldered by government and water industry.

Finally, deploying smart water metering also has the potential to provide for significantly improved customer experience (Boyle et al., 2013). This has become increasingly important as regulators provide financial rewards for water utilities delivering high customer service quality. Information provided by smart metering technology could improve the quality of customer service by allowing customers to understand their actual consumption in real time, by providing high consumption and leak alerts, and by allowing customers to actively control their consumption.

Conclusion

This paper has surveyed and reviewed the current evidence base as to the effectiveness of consumption feedback in managing water use, with a particular focus on recent technologies, such as smart-meters and IHDs. Overall, there is promise in the use of such technologies to inform and educate consumers to reduce consumption. This has been achieved in most of the reviewed studies through the provision of more detailed, frequent and immediate consumption information delivery. Specifically, the included studies that report a positive effect on water consumption (i.e. 17 of 21 studies) indicate reductions between 2.5% and 28.6%, with an average of 12.15% (SD = 8.75). Thus, the overall potential of smart-meter technology to curb domestic water use is clear. However, more research is needed to determine the most effective type of feedback in terms of information content and granularity, delivery frequency and medium. Further, the effect of extraneous factors, such as water pricing and user demographics upon consumer responses to water use feedback requires further exploration. To this end, the review has identified several limitations and gaps in knowledge, all of which represent important avenues for future investigation, and has considered the implications of the findings of the review for the water industry.

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Table 1
Empirical studies assessing water consumption feedback type, value and behavioural impact

	Author (year)	Country	Research design & length	*N*	Feedback type (technology)	Participant rated value of feedback type	Effect on water consumption	Length of effect
1.	Aitken et al. (1994)	Australia	Pre/post (3 mths)	490	Social comparison & cognitive dissonance (mail-based)	--	Decrease in high consumption households (4.3%)	No data available
2.	Erickson et al. (2012)	USA	Pre/post (15 wks)	303 (households)	Social comparison, consumption feedback (smart-meter/web portal)	Hourly consumption graph & social comparison most valued.	Decrease (6.6%)	No data available
3.	Ferraro & Price (2013)	USA	Pre/post (4 mths)	Approx. 170000	Information, social comparison, historical comparison (mail-based)	--	Decrease (8.41%-12%; m = 10.21).	See row below
4.	Ferraro et al. (2011)	USA	Post (2 yrs)	106872	Information, social comparison, historical comparison (mail-based)	--	--	Total decay in all conditions but one (social comparison)
5.	Fielding et al. (2013)	Australia	Pre/post (18 mths)	221 (households)	Conservation education, social comparison and/or tailored end-use consumption feedback (smart-meter)	--	Decrease (7.9%)	Total decay < 12 months post study
6.	Froelich et al. (2012)	USA	Survey (NA)	671	Consumption feedback by individual fixture, goal, historical and social comparison (smart-meter/IHD)	Individual fixture feedback and high granularity data most valued.	--	No data available
7.	Geller et al. (1983)	USA	Pre/post (3 mths, 2wks)	129 (households)	Educational instruction, installation of water saving devices, consumption feedback, (mail-based)	--	Decrease with water saving devices only (exact value not supplied); no effects of education or feedback	37% had installed device two months post study.
8.	Jeong et al. (2014)	USA	Pre/post (5 wks)	18 residential halls	Water and energy consumption feedback (mail-based)	--	Decrease (7.27%)	No data available
9.	Kappel & Grechenig (2009)	Austria	Pre/post (3 wks)	4 (households)	Visual consumption feedback (IHD)	LED-rod valued and intuitive	Decrease in shower water consumption of 10 liters/day/household	Total decay post study
10.	Kenney et al. (2008)	USA	Pre/post (8 yrs)	10000 (households)	Consumption feedback (smart-meter/IHD)	--	Increase (16%)	No data available
11.	Kurz et al. (2005)	Australia	Pre/post (5 mths)	166 (households)	Information, attunement labels, social comparison (mail-based)	--	Decrease for attunement labels only (23%)	Decrease sustained six weeks post study.
12.	Kuznetsov & Paulos (2010)	USA	Pre/post (3 wks)	11	Ambient ‘traffic-light’ faucet display, LED consumption graph shower display	Light displays valued, but suggestions for intuitive design	Decrease in average shower time (30%)	No data available

					improvements		
13. Liu et al. (2016)	Australia	Pre/post (10 mths)	68 (households)	Consumption feedback by fixture, social & self comparison (mail-based)	80-90% of participants valued feedback and perceived it as relevant/motivating	No significant decrease	N/A
14. Petersen et al. (2007)	USA	Pre/post (7 wks)	Oberlin college dormitories	Consumption feedback, education (smart-meter/web portal)	Real-time consumption data most valued	Decrease (3%)	No data available
15. Petersen et al. (2015)	USA	Pre/post (7 wks)	Oberlin college dormitories	Consumption feedback, education (smart-meter/web portal)	--	Decrease (2010: 5.2%; 2012: 2.5%)	No data available
16. Schultz et al. (2014)	USA	Pre/post (6 wks)	301 (households)	Social comparison, social approval, water saving tips (mail- and web-based)	--	Decrease (16.2-26.5%; m = 21.35%)	No data available
17. Stewart et al. (2013)	Australia	Longitudinal (7mths)	44 (households)	Consumption feedback (smart-meter/IHD)	97.1% of participants valued the technology and would continue to use it	Decrease (28.6%)	Total decay three months post study
18. Tasic et al. (2012)	Switzerland	Pre/post (3 mths)	91 (households)	Consumption feedback (smart-meter/IHD)	--	Decrease (22.2%)	N/A
19. Tasic et al. (2015)	Switzerland	Post (12 mths)	50 (households)	Consumption feedback (smart-meter/IHD)	--	Decrease (22%)	Decrease sustained at 12 months
20. Tiefenbeck et al. (2013)	USA	Pre/post (10 wks)	154 (households)	Social comparison (mail-based)	--	Decrease (6%)	No data available
21. Willis et al. (2010)	Australia	Pre/post (5 mths)	151 (households)	Consumption feedback (smart-meter/IHD)	--	Decrease in 10-minute shower events (7.6%); increase in <40ltr shower events (19.4%); decrease in shower flow rates (10.2%)	Total decay three months post study (Stewart et al., 2013)

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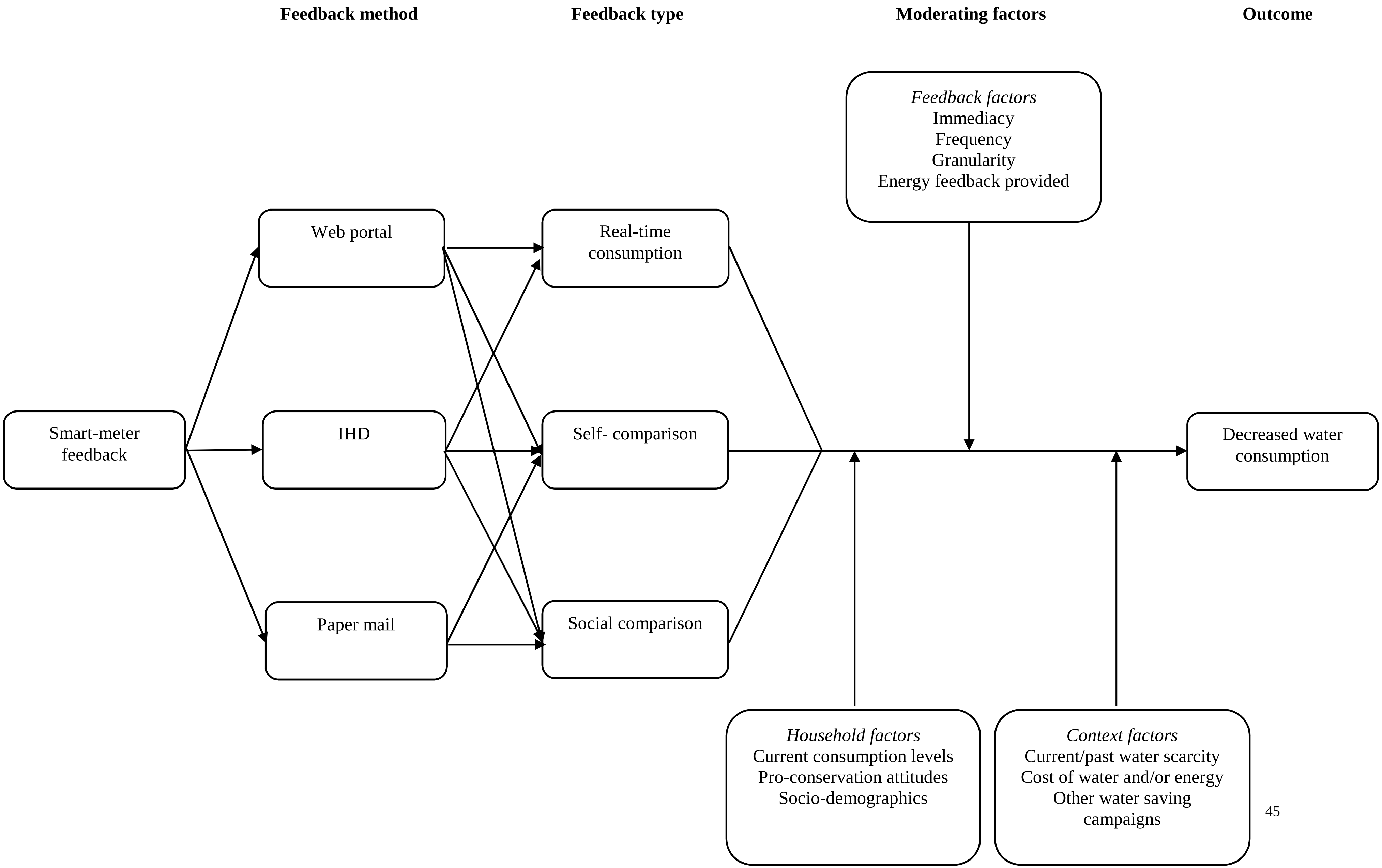
Feedback method
Feedback type
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