SUSTAINING WATER CONSERVATION: A SYNTHESIS OF RESEARCH ON MOTIVATORS, MESSAGE TAILORING, AND TACTICS

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Key Points:

- Synthesized 80 papers from behavior sciences, environmental psychology, resource management, and health communication fields.
- Identified intention, altruism, peer pressure, and ease or difficulty to adopt as factors that encourage and sustain conservation behaviors.
- Social comparison and public plea reduced water demand the most (8-54%).
- Include a public plea, social comparison, easy-to-adopt tips, and share additional resources to sustain conservation behavior beyond 1 year.

Abstract

We reviewed 80 studies from behavior sciences, environmental psychology, resource management, and health communication fields to learn why some voluntary message campaigns sustained conservation behaviors. We found past campaigns reduced residential water use by 0.6% to 54% and reductions lasted less than 1 year. The most effective campaigns included a public plea, social comparison information, easy-to-adopt conservation tips, and linked to additional resources. Effective campaigns also targeted different socio-psychological drivers, such as intention, altruism, peer pressure, and perception of ease or difficulty in adopting new conservation behaviors. To help users sustain water-saving behaviors for longer periods of time, we suggest managers (a) learn user's intentions and informational preferences, (b) launch feedback programs during critical periods such as a drought, (c) state what the water authority is doing to achieve the conservation goal, (d) customize message content based on a user's attitude and information preferences, (e) target one easy-to-implement conservation action at a time, (f) praise efficient behavior, (g) communicate through a variety of internet, paper, and other mediums, (h) regularly update message contents, (i) encourage users to publicly commit to conservation, (j) publicly recognize water savers, and (k) allow users to share their conservation experiences.

Plain Language Summary

Water managers launch messaging campaigns to reduce use during drought or other temporary natural or anthropogenic crises. We reviewed 80 studies from behavior sciences, environmental psychology, resource management, and health communication

fields to learn why some message campaigns were better at prompting conservation behaviors. We found past campaigns reduced residential water use by 0.6% to 54% and reductions lasted less than 1 year. The most effective campaigns included a public plea, social comparison information, easy-to-adopt conservation tips, and links to additional resources. We synthesized 11 recommendations for managers to help users sustain water-saving behaviors for longer periods of time. These recommendations range from segmenting users and customizing messages based on their conservation intent and information preferences to allowing users to share their conversation experiences with others.

1 Introduction

This paper's goal is to review and synthesize research from behavior sciences, environmental psychology, resource conservation, and health communication to identify how to prompt and sustain voluntary water conservation behavior beyond 1 year. The most common conservation prompts are water bills that show consumption information. Beyond consumption information, water managers can make public pleas to user's conscience (Brick et al., 2018; Katz et al., 2016), provide social and self-comparisons (Mitchell & Chesnutt, 2013), share easy-to-adopt conservation tips (Ferraro & Price, 2013), link to further conservation tips information (Ferraro & Price, 2013; Mitchell & Chesnutt, 2013; Schultz et al., 2019), encourage users to commit publicly to conservation actions (Dickerson et al., 1992), recognize water savers (Brick et al., 2018), and provide platforms for users to share their conservation experiences (Erickson et al., 2012). To motivate and sustain conservation behaviors, managers face ongoing challenges to learn user's intent and communication preferences, then strategically motivate, combine, and customize message contents at appropriate frequencies (Berkman, 2002; James & Rosenberg, 2022; Koop et al., 2019).

The efficacy of messaging campaigns to temporarily reduce use during supply shortages is well documented (Brick et al., 2018; Katz et al., 2016; Mitchell & Chesnutt, 2013; Schultz et al., 2019). Review articles detail the strengths and weaknesses of messages to encourage voluntary conservation (Inman & Jeffrey, 2006; Koop et al., 2019; Sønderlund et al., 2016; Syme et al., 2000). For example, Syme et al. (2000) pointed out that most voluntary informational campaigns achieved an approximate 10-25% reduction in water usage. They reported prior studies failed to provide enough evidence to justify the long-term effects and recommended incorporating psychological data such as user intention to conserve. Inman & Jeffrey (2006) reviewed different demand-side management tools such as price increments (block price increase), rebates to retrofit with more efficient appliances, and educational and informational campaigns. They posited that a combination of voluntary and mandatory tools can increase water savings. They also emphasized that consumer participation is the most crucial factor in the success of any demand-side management tactic, i.e., engage consumers in different water conservation activities to sustain conservation behavior.

More recent reviews, such as Sønderlund et al. (2016), investigated the effectiveness of sharing high-frequency data to lower water use. They examined 21 studies and reported how such data could be used to create consumption reports and social and self-comparison information to prompt conservation actions. Comparing a customer's use to neighbors or similar households is a popular strategic messaging technique. Many studies have reported the effectiveness of social comparisons in reducing water use. However, Schultz et al. (2016) stated that social comparison information alone may be inadequate to motivate all users. For example, Brick et al. (2018) reported a 0.6-2% decrease in consumption from social comparison interventions, while Ferraro & Price (2013) reported a decrease of almost 54% after employing similar approaches. These reductions may be due to a boomerang effect, where telling a customer their use is lower than neighbors may encourage the customer to increase use (Aitken et al., 1994; Schultz et al., 2016). To address these challenges, Koop et al. (2019) suggested mixing different messaging contents. There is still a need for more specific guidance on how managers can bring together an ensemble of strategic content to construct conservation messages and motivate users from different socio-psychologic groups. Beyond the selection of contents, there are also questions regarding the mode(s) of communication between the water authority and users (e.g., paper-based, internet-based, etc.), how often to notify users, and effect duration.

To help managers construct more potent conservation messages, we reviewed 80 articles from behavioral sciences, water conservation, energy conservation, environmental psychology, and health communication to identify factors that motivate and sustain conservation behaviors. The work answers three research questions:

1. What is the long-term effectiveness of feedback and strategic messaging campaigns?
2. How do communication channel and frequency influence water use behavior?
3. How to construct and tailor messages to reduce use and sustain conservation behaviors?

The next section describes the selection of articles. Subsequent sections synthesize lessons about psychological motivators, message construction, messaging components, feedback channels, communication platforms, message frequency, intervention duration, and sustaining conservation behaviors. A penultimate section recommends 11 ways water managers can better construct and deploy messages to reduce water use and sustain conservation behaviors over longer periods of time. A final section concludes.

2 Selection of articles

This research included 80 studies from 1976 to 2019 on six conservation topics (Table 1). Seven water conservation review articles identified effects of recent voluntary conservation campaigns. Among these studies, we focused on the efficacy of different messaging contents, suggestions regarding messaging frequency, duration, and communication channel. We added 3 review articles on voluntary conservation in the energy sector because there are parallels between energy and water conservation. Next, we searched for the keywords “intrinsic motivation”, “extrinsic motivation”, “behavioral intention”, “behavioral nudges”, “behavioral sustenance”, “social comparison”, “feedback”, and “conservation message” in Google Scholar. We found 21 studied that focused on the motivational aspect of conservation behavior and user intentions, 32 individual water conservation studies, and 13 individual energy conservation studies. We did not find any studies on message tailoring in the water or energy sectors. However, within the health communication field, we found numerous studies on messaging and communication strategies and selected four studies on message framing and tailoring that used similar behavioral improvement approaches mentioned by the studies we reviewed from the behavioral sciences and environmental conservation fields. Table A in the Appendix identifies the communication medium, duration of pre- and post-intervention periods, sample size, year, and percent reduction in use for each paper we reviewed.

Table 1: Articles reviewed and synthesized

Topic	**Reviewed articles**
Water conservation review	7
Energy conservation review	3
Behavioral science	21
Water conservation	32
Energy conservation	13
Health communication	4
Total	**80**

3 Psychological motivators

Because users perceive information differently, understanding user's motivations can help managers construct more potent conservation messages. This section discusses different motivation types and some factors that affect user motivation.

3.1 Types of motivation

In general, there are two types of motivation: internal/intrinsic or external/extrinsic (Bénabou & Tirole, 2003). Internal motivators stimulate an individual to achieve something for the individual's own sake. Examples include a person who wants to do something because they find the act enjoyable, exciting, or because the individual wants to attain an abstract or spiritual satisfaction. Self-determination theory—a psychological theory concerning internal motivation—argues that three factors influence internal motivation (Ryan & Deci, 2000). The first is "autonomy" or the belief that the user owns and controls the behavior in question. Next is "competence" which is something the user achieves by repeating a behavior multiple time. "Relatedness" occurs when the user assumes a bond with their community. To prompt internal motivation, managers can provide water use information to help users improve end-use behaviors or urge consumers to reduce water use to increase flows for ecosystems or help the community manage through a drought.

On the other hand, external motivation is when a person commits an act to achieve an external goal, such as a reward. The theory of planned behavior (TPB), argues that intention is the best predictor of externally motivated behavior (Ajzen, 1991). Intention depends on three factors: attitude, subjective norm, and perceived behavioral control. "Attitude", as defined by TPB, is the rationale regarding the new behavior. In other words, the individual weighs the pros and cons of the new behavior and evaluates how the behavior may affect the individual. "Subjective norm" is how an individual evaluates their behavior in comparison to society or the individual's peers. And "perceived behavioral control" is the individual's perception of how easily the individual can incorporate the new behavior into their daily life. Examples of external motivations include comparative water use statements to prompt peer pressure with messages stating how an efficient household uses water (Mitchell & Chesnutt, 2013; Sønderlund et al., 2016) and public recognition for conserving water (Brick et al., 2018).

Past studies related to water conservation could not decisively state whether internal or external motivators are more effective to encourage users. Studies in other fields, such as environmental psychology, suggest that individuals with intrinsic/internal motivations sustain environmental behaviors for longer periods of time (Monroe, 2003). However, intrinsic motivation is often gained from life experience (De Young, 1993). Thus, managers may first use external goals to first motivate users to adopt conservation behaviors. Then hope that users develop internal motivation to sustain conservation behaviors over time (Bénabou & Tirole, 2003; Monroe, 2003). Some studies suggested that using different motivational agents simultaneously may increase the probability of encouraging and sustaining conservation behaviors (Delmas et al., 2013).

3.2 Additional factors that affect motivation

There are additional influencers of conservation behavior beyond autonomy, competence, relatedness, attitude, subjective norm, and perceived behavioral control (Aitken et al., 1994; Brick et al., 2018; Jorgensen et al., 2009; Lam, 2006; Schultz et al., 2016). For example:

- Cognitive dissonance is a psychological process where information tells the user they are behaving opposite to what the user thought they were doing (Festinger, 1957). The inconsistency between belief and behavior can trigger a behavioral change to conform to the belief. Aitken et al. (1994) reported a 4.3% drop in daily water use among users due to a messaging intervention that used cognitive dissonance. Such an approach can be effective because many people have incorrect perceptions regarding their water use practices (Beal et al., 2011).

- Personal norms are shaped by an individual's beliefs, experiences, and moral obligations (Cialdini et al., 1991; Schultz et al., 2016). The degree (high or low) of personal norm affects a person's susceptibility to social motivators, such as peer pressure (Chaudhary et al., 2017). Schultz et al. (2016) posited that someone with a high/strong personal norm is less likely to be encouraged or dissuaded by the activities of others. In their experiment, they found that users with low/week personal norms reduced their water use by 16-26% when they were informed that other users in the community were more efficient. On the other hand, users with high personal norms continued their pre-intervention behaviors, even though they received the same message.
- Trust refers to a user's faith in a water manager's sincerity to reduce water use (Jorgensen et al., 2009). Users adopt water conservation behaviors when they see the water provider is taking steps to reduce use, such as repair supply pipes that leak, launch feedback campaigns, update legislation, etc.
- Response efficacy refers to the user's belief in how their efforts help the community reach a collective conservation goal (Lam, 2006). Simply put, when a user believes that their contributions, i.e., water-saving measures, are helping the community to achieve a conservation target, the user will be more motivated to adopt and sustain conservation behaviors (Lam, 2006; Lowe et al., 2015; Warner et al., 2015).

Contextual factors such as the availability of efficient appliances, rebates, or incentives can also motivate water conservation behaviors (Russell & Fielding, 2010). The effect of contextual factors has not been fully studied in the water conservation field, whereas in environmental conservation studies, these factors are often considered as catalysts to internally and externally motivate conservation behavior (Monroe, 2003).

4 Messaging

This section identifies the important features of message campaigns that encourage and sustain water conservation behaviors. Features include message construction, content, frequency, intervention duration, and communication medium.

4.1 Message construction

Message construction includes message framing and norm activation. Framing makes messages more salient, while norm activation seeks to portray water-saving behaviors as socially desirable and praise-worthy.

4.1.1 Message framing

Framing is the process to construct a message to state why a conservation action is good or how over-use may harm the environment (Warner et al., 2015). A "gain-framed" statement tells users about an action's benefit or advantage. For instance, "Fixing your leaks will prevent damage to your house and save you $XXX in one year." Conversely, a "loss-framed" statement emphasizes the negative consequences or disadvantages if a user does not change their behavior. For example, "Fix your leak; otherwise, you will lose approximately $YYY in the upcoming year, and leaks will also damage your house's foundation."

There have been numerous studies on message framing in the health communication field, and most of these reported that gain-framed messages are better at helping users adopt preventative measures and sustain healthy behaviors for a prolonged period (O'Keefe & Jensen, 2007). Within the water field, we found only one article that reported that gain-framed personal messages improved users' water conservation outlook (Warner et al., 2015).

Conversely, Latimer et al. (2007) provided examples where loss-framed messages were better at helping users adopt healthy behaviors. Syme et al. (2000) was the first to note that water conservation messages that focused on what the user lost as an individual better helped users adopt conservation behaviors. Indeed, personal loss-framed messages might better motivate water conservation actions. For example, Britton et al. (2013) reported that 74% of the users in their study wanted to learn about leaks and the approximate cost associated with losses if leaks were not fixed.

Besides telling users the concurrent implications of wasteful water use, messages can also help warn users about a catastrophic future if they continue to use water inefficiently (loss-framed). Conversely, a gain-framed message may state what users can achieve as a community if they use water efficiently. Warner et al. (2015) assessed the effect of loss vs. gain-framed messages on this particular scenario and reported gain-framed message outperformed loss-framed messages.

4.1.2 Norm activation

Norm activating messages try to establish behaviors, such as conservation or water-saving habits, as praise-worthy or socially desirable behaviors. Norm-activating messages focus on a household's current water use behavior and tell users what to do to improve the behavior (Groot & Steg, 2009). Most studies used norm activating messages to compare water use with neighbors and provide tips to improve specific behaviors. These studies reported decreases in use during the intervention period (Ferraro & Price, 2013; Fielding et al., 2013; Liu et al., 2016). However, Schultz et al. (2007) noted that users who were already consuming less energy than their neighbors tended to increase their consumption once such comparative messages were delivered. Aitken et al. (1994) and Schultz et al. (2016) also reported a boomerang effect where energy and water consumers with low use gravitated towards larger consumption -- an average of 12% increase for water use -- after receiving information that they were using less than neighbors.

To negate or reduce the boomerang effect, Cialdini et al. (1991) proposed creating messages that notify users of what is expected from them instead of directly stating what to do. Katz et al. (2018) also reported that water users preferred messages constructed with suggestive and gentler tones over assertive language. Schultz et al. (2007) proposed to include visual aids such as smiling green- or frown red-faced emoticons to help users realize whether their behavior was efficient or wasteful. Later studies validated this finding. For example, Otaki et al. (2017) reported that high users from similar environmental, climatological, and socio-economic statuses reduced their water use while low users did not increase their water use. Recent conservation campaigns also used emoticons (Allcott, 2011; Mitchell & Chesnutt, 2013; Schultz et al., 2019).

4.2 Message contents

Figure 1 shows message contents from 32 studies in the water resources field and 13 studies in the energy conservation field that targeted different internal and external motivations and related factors. Prior water conservation campaigns sometimes used a single content, such as consumption information, whereas other studies combined multiple contents to improve the efficacy of the message.

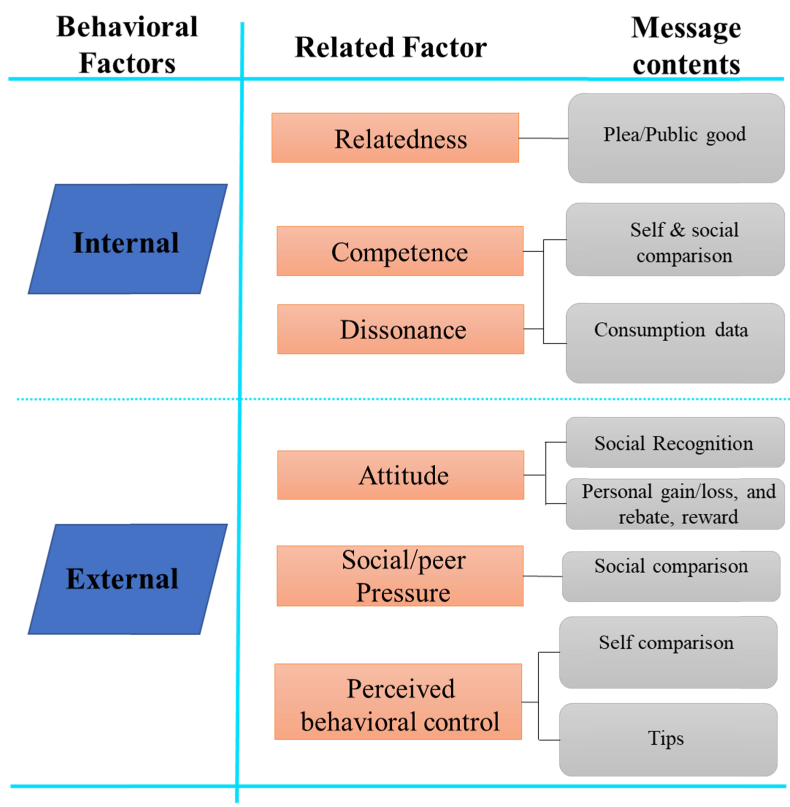

Figure 1: Activate psychological motivations with different message contents.

4.2.1 Consumption information

Consumption information shows volumetric (e.g., gallon or liter) use over a specific time (e.g., weeks or months) and is the most common form of feedback. A practical example is the water bill that shows usage and the associated billing information. Usage may be aggregated (cumulative), disaggregated (indoor vs outdoor, or by appliance), shown as a one-line statement (Ferraro & Price, 2013), or plotted (Liu et al., 2016; Mitchell & Chesnutt, 2013; Schultz et al., 2016). Consumption information functions as a self-motivating tool. Sometime such information may incite cognitive dissonance by confronting user with information that the user is consuming more water than he/she initially thought was using. This dissonance leads to inner disharmony or tension, and the user will eventually try to change their behavior to alleviate the tension (Aitken et al., 1994; Dickerson et al., 1992).

Users generally prefer volumetric (gallon/liter) and financial information ($/gallon or $/liter) as opposed to figurative values, such as buckets of water (Liu, 2016). Some studies suggested adding block prices to encourage conservation (Brick et al., 2018). However, if aggregated data was shared, other studies posited that it was better to use visual aids instead of statements to attract users' to their water use information (Fischer, 2008). Suggested visual aids to help users understand their use are time-series data (Barnett et al., 2020), color-coded emoticons (Mitchell & Chesnutt, 2013; Otaki et al., 2017), and color-coded scales (Pereira et al., 2013).

Over 80% of reviewed studies used consumption information to improve users' water use behavior. Studies reported two specific reasons why such an information-centric approach might not improve water use habits. First, the water price is relatively inelastic in the residential sector, meaning the price of water is too low to make any noticeable impact on a household's finances (Cahn et al., 2020; Geller et al., 1983; Inman & Jeffrey, 2006; Liu & Mukheibir, 2018). Second, users often receive the billing information or water use feedback after a significant time has passed—making it difficult for users to relate the information to their behavior (Levin & Muehleisen, 2016). Studies that only used consumption information for conservation purposes yielded between 0.6-4.3% reduction in water use (Aitken et al., 1994; Brick et al., 2018; Petersen et al., 2007). Some studies hypothesize that circulation of high-frequency water data may have significant impact on user behavior. Liu et al. (2016), and WaterSmart (2014) provided evidence that high-frequency and appliance-specific water data led up to 8% reduction in water use among the treatment group compared to the control group. But a one year-long study in the energy field reported instantaneous electricity use information did not have any effect on users' energy consumption (Pereira et al., 2013).

Studies reported a much higher reduction up to 26% when consumption information was used in combination with other strategic messaging contents, such as comparative statements (Ferraro & Price, 2013; Mitchell & Chesnutt, 2013), authority's appeals to cut back water use to respond to droughts (Brick et al., 2018; Katz et al., 2016), and information on how an efficient households use their water (Schultz et al., 2016, 2019).

4.2.2 Conservation tips

Water-saving tips are distributed during conservation campaigns and almost 70% of the reviewed studies provided some types of water saving tips with their circulated message. Tips help users see how to incorporate water saving behaviors into their day-to-day lives. A user's intention to adopt a conservation behavior increases when the users believes they can easily perform the behavior (Ajzen, 1991).

In most studies, circulated tips were generic, i.e., the same tips were to provided to every household. Tips mentioned different end uses and a list of measures that households could take to reduce the water loss. The most circulated tips were how to detect toilet leaks, recommendations on plant selection for landscaping, irrigation system tune-up, and requests to save water by cutting back shower time (Brick et al., 2018; Ferraro & Price, 2013; Fielding et al., 2013; Liu et al., 2016; Mitchell & Chesnutt, 2013; Schultz et al., 2019; Tiefenbeck et al., 2013). In addition, recent studies reported sharing tips such as leak detection techniques, benefits of retrofitting with efficient appliances, timing lawn watering, covering swimming pools, taking smaller (lower volume) baths, and reducing faucet run times (Brick et al., 2018; Britton et al., 2013; Ferraro & Price, 2013; Mitchell & Chesnutt, 2013; Schultz et al., 2019). Contrary to generic tips, customized tips target each household with one or more end-use behaviors that the household is performing inefficiently and provide guidance on how to improve those behavior(s) (Fielding et al., 2013).

The effect of tips on water demand reduction is difficult to determine because in most cases, tips were used in combination with other strategic messaging contents. Only a few studies assessed the standalone effect of tips. Schultz et al. (2016) found that treatment groups that received only water-saving tips did not reduce their water use significantly. Brick et al. (2018) also reported that a "tips only" treatment group reduced their water use by 0.6%–the least of any other treatment group. One probable reason why tips alone cannot improve the end-use behavior is that adults are less responsive to educational approaches than school-aged children (Thompson et al., 2011). Also, users are less likely to try recommendations when the suggested steps/actions to save water are perceived as too difficult to employ or cost more than users can afford (Geller et al., 1983; Hayden et al., 2015). Finally, some studies argue that conservation tips must be specific to help users focus on a particular end-use behavior (Sønderlund et al., 2016;

Syme et al., 2000). One study provided customized tips to its treatment group and reported a water use reduction between 8-15% (Fielding et al., 2013). However, the same study also mentioned that their "tips only" treatment group had prior water-saving experiences during an extreme drought period.

Larger water savings were reported when the tips were used in combination with other strategic components. For example, providing tips while comparing a household's water use to an efficient neighbor reduced use by 5-54%. And in some cases, households retained their efficient behaviors for a prolonged time (Ferraro & Price, 2013; Mitchell & Chesnutt, 2013; Schultz et al., 2019). Our review of energy-related conservation studies also revealed that tips were most effective when circulated with social comparison information (Allcott, 2011; Andor & Fels, 2018). For instance, Dolan and Metcalfe (2015) found that tips with comparison information resulted in an 11% decrease in energy usage on average as compared to only comparison information that resulted in a 4% decrease.

4.2.3 Social comparison

These messages compare a household's water use to use by neighbors (Brick et al., 2018; Ferraro & Price, 2013) or an efficient household from the same community (Mitchell & Chesnutt, 2013). This tactic effectively reduces water use because it utilizes peer pressure and implicitly says that the user is not using water efficiently. As users are informed about how inefficient they are compared to others in the community, they try to improve their behaviors to fit in with the community (Mesoudi, 2016).

Past studies used statements and bar charts (Brick et al., 2018; Ferraro & Price, 2013; Mitchell & Chesnutt, 2013; Schultz et al., 2019; WaterSmart, 2014) and sometimes ranks (Otaki et al., 2017) to provide comparisons. The statements usually covered the volume of water the household was using, the average volume of water used by the household's neighbors, and generic tips for the household to save water. In addition, some studies used emoticons to emphasize the efficiency status of households (Mitchell & Chesnutt, 2013).

Social comparison was used in over 50% of the reviewed articles of residential water use. Social comparison is also one of the most effective message contents to improve water use behavior. Schultz et al. (2019) reported that a social comparison intervention resulted in an average of 8% water use decrease by the treatment group (8,362 households) than the control group (10,349 households). Schultz et al. (2016) also reported a 16-26% decrease in water use among the users in the treatment group when these users were also provided statements that compared the household's current and past use. Ferraro and Price (2013) also observed a 54% decrease in Atlanta, Georgia water use by households that received a comparative statement, water-saving actions adopted by efficient households, and a plea from the water authority relative to the control group. Their results imply that the effectiveness of social-comparison information can be vastly increased when combined with other strategic contents. Our investigation into energy field revealed similar outcomes (Allcott, 2011; Andor & Fels, 2018). We found only one study that reported that social comparisons were ineffective (Myers & Souza, 2019). Other studies reported that social comparison reduced energy consumption behavior by 0.3% (low energy consumers) to 30% (high energy consumers). In more than 90% of studies, social comparison was an effective tactic (Allcott, 2011; Andor & Fels, 2018).

4.2.4 Plea from the authority

Some studies distributed messages to reduce water use to protect the environment or achieve another public benefit. Brick et al. (2018) termed such messaging contents as "public good" requests, and Schultz (2010) referred to such messages as "pleas". Usually, depletion of local reservoirs or other water sources (Ferraro & Price, 2013) and drought information (Brick et al., 2018; Katz et al., 2016; Schultz et al., 2019) were used to construct pleas to help users grasp the importance of reducing use. These messages used local infrastructure or depletion scenarios to help users connect to something they knew well and could easily relate to. The motivational driver utilized for such messages is called "relatedness". Relatedness helps users connect their altruistic beliefs to pleas from authorities (Ryan & Deci, 2000). Pleas from authorities have other benefits as well. By mentioning the water shortage situation and the water manager's measures to address it, users are assured of the authority's sincerity regarding conservation. This sincerity reinforces users' trust in authorities—another motivational driver (Jorgensen et al., 2009).

When constructing plea requests, studies used the name of a known place (e.g., city, or reservoir) with a current depletion situation, conservation, or water reduction target (Brick et al., 2018; Schultz et al., 2019). Messages also identified the impact of water shortage on wildlife or human health (Ferraro & Price, 2013). In addition, authorities attached their logo to messages to ensure its authenticity.

Our investigation revealed that public plea is one of the most effective messaging contents. In their study of 400,000 users in Cape Town, South Africa, Brick et al. (2018) found that plea was more effective among wealthy user groups who reduced their consumption by 1.9%. Ferraro and Price (2013) included social comparison messages and pleas in one treatment group and reported a 54% reduction compared to the control group. The treatment group also retained their efficient behaviors after two years.

4.2.5 Self-comparison

These messages compare a household's water use from two separate but consecutive/successive time periods (e.g., two or three successive months in summer, successive weeks in a month, etc.). These comparisons help the user understand how the household improved their behavior over time or vice versa. From a psychological perspective, self-comparisons improve users' perception that they are in control over their consumption behavior. These comparisons build competence that leads to efficient use, especially when users see improvement over time. In cases where users see an increase in usage, the information can trigger cognitive dissonance and help users rein in their unthrifty behavior. Self-comparisons are also effective when users are skeptical that a social-comparison is to a similar household.

Self-comparisons are often shown as bar graphs where each bar represents the total or average water use in a unit time, e.g., month, billing cycle, or monitoring cycle (Barnett et al., 2020; Mitchell & Chesnutt, 2013; WaterSmart, 2014). In other cases, a one line statement was provided to tell user about their use in consecutive time periods (Becker, 1978).

The stand-alone effect of self-comparison information has not been documented by water conservation studies. More than 22% of our reviewed articles reported using self-comparison information in combination with other strategic messaging contents. Water savings ranged between 4-6% (Mitchell & Chesnutt, 2013; Tiefenbeck et al., 2013;

WaterSmart, 2014). Some studies in the energy field reported the individual efficacy of a self-comparison. Becker (1978) reported that households in New Jersey, United States were asked to reduce their energy consumption by 20% during the summer. The treatment group received self-comparison information three times per week and successfully reduced their energy consumption by 13% compared to the control group. Petkov et al. (2011) reported that the efficacy of self-comparison report can be increased if only one end-use is targeted instead of cumulative consumption.

4.2.6 Rebate, reward, and additional resource information

Contextual factors include rebate notifications (Mitchell & Chesnutt, 2013; Schultz et al., 2019), availability of mobile phone applications (Schultz et al., 2019), customer helplines (Allcott, 2011; Brick et al., 2018; Mitchell & Chesnutt, 2013), websites with water-saving tips (Ferraro & Price, 2013), and information focusing on efficient appliances (Brent et al., 2016). Individually, contextual factors do not motive conservation behavior. However, contextual factors increase message potency when coupled with social comparisons, self-comparisons, and pleas from authority (Monroe, 2003; Russell & Fielding, 2010). Behavior improvement tactics, such as community-based social marketing, use contextual factors to nudge users towards adopting conservation actions (Mckenzie-Mohr, 2000).

4.2.7 Leak information

Metering technology can identify leaks by tracking flows that continue for a prolonged period. With smart meters and data loggers, researchers can identify minimum night flow (MNF) and then detect leaks by analyzing high-frequency data (Farah &

Shahrour, 2017). Many recent studies incorporated leak information in their messages to tell users about potential damage to their houses (Britton et al., 2013). Furthermore, leak identification was the most sought-after information by users who used or intended to use smart-meters (Cahn et al., 2020; Liu et al., 2017; Liu & Mukheibir, 2018). Liu et al. (2017) reported that almost 80% of users are interested in seeing leakage information in internet portal-based feedback systems. Some commercial smart-meter companies already offer leakage detection features (Flume, 2021). From a psychological perspective, leak information targets users' attitude—the factor that helps users decide whether an action is beneficial or detrimental to them. For example, users will fix a leak if a user thinks that fixing leaks will reduce long-term damage to his/her home.

Most studies that used high-frequency water data used leak information as a strategic component. The preferred visual aid was time-series charts that showed the timing and volume of leaks (Britton et al., 2013). Britton et al. (2013) also reported that users wanted to view total water loss volume, price of the leaked water, leak types (if possible), where leaks were located, and a lump-sum estimate of the repair cost. Beyond internet portals, some studies suggested a more instantaneous system to notify users of leaks, such as text alerts or mobile phone applications (Cahn et al., 2020).

Including leak information in messages is new; we found only two studies used leakage information to promote water conservation behavior and reduce water use. Leak information was most effective when the report mentioned the monetary loss if leaks were not repaired (Britton et al., 2013). Britton et al. (2013) also offered a rebate of almost $70 (AUD$100) if users repaired leaks. Because of these additional interventions, the reported savings were exceptionally high (approximately 89%). The study also conducted a post-intervention survey where it was revealed that 93% of the users who were contacted, fixed the leaks to prevent further damage to their home, while 72% mentioned money-savings as an added motivation.

4.2.8 Social recognition

Social recognition or commendation is a form of reward in which users are praised publicly for exhibiting environmentally friendly behaviors. This external motivator can also help users sustain their environmentally friendly behaviors because once users are publicly praised, they feel obligated to continue the behaviors (Lockton, 2012).

To commend users with efficient behavior, water managers used decals that praised users' conservation behavior (Seaver & Patterson, 1976), or uploaded photos of efficient users to the city website to recognized these users as exemplary citizens (Brick et al., 2018).

Only two reviewed studies used social recognition to promote conservation behaviors. Seaver and Patterson (1976) was one of the earliest studies reporting the effectiveness of social recognition in the energy field. The research assessed the effect of fuel savings after the authority declared a fuel crisis in 1973 and reported that the treatment group that received a decal saying "we are saving oil" along with consumption feedback reduced their usage compared to the control and other treatment groups. In a water conservation study involving 400,000 households in Cape Town, South Africa, Brick et al. (2018) observed a 2.3% decrease in water use among financially prosperous high-water users after the city offered to post photos of any citizen who conserved 10% every month on the city website as a form of recognition. This study also employed other interventions, such as social comparison, tips, and consumption information, and reported that social recognition was the most influential motivator among the wealthy consumer group.

4.3 Communication medium

Historically, most messaging campaigns have used paper-based reports to show users their consumption. More recently, paper-less communication through emails, in-home-displays, and web portals are also used. We found six distinct methods of communication:

1. Paper-based feedback (Brick et al., 2018; Britton et al., 2013; Ferraro & Price, 2013; Katz et al., 2016; Liu et al., 2016; Mitchell & Chesnutt, 2013; Schultz et al., 2016, 2019; Tiefenbeck et al., 2013),
2. Electronic reports through emails (Schultz et al., 2016),
3. Feedback through fax (Otaki et al., 2017),
4. Web portals (Erickson et al., 2012; Mitchell & Chesnutt, 2013; Petersen et al., 2007),
5. In-home displays (Froehlich et al., 2012; Willis et al., 2010), and
6. Mobile phone applications (Schultz et al., 2019).

Some studies used both paper and electronic-based feedback simultaneously and reported the effectiveness of both mediums (Mitchell & Chesnutt, 2013; Schultz et al., 2019). Schultz et al. (2019) only provided high-frequency water use information through a mobile application, while feedback reports were mainly delivered through postal mailings.

The selection of communication platform (i.e., paper, or electronic) was mostly determined based on the type of data that the researchers (or managers) wanted to relay to their water users and frequency of message circulation. For instance, if the goal was to use 5 to 10 second water use data to send appliance-specific conservation tips, then mostly internet portals and in-home displays were used (Froehlich et al., 2012; Willis et al., 2010). Message contents such as consumption, social comparison, self-comparison, and generic tips can be shared by any communication medium using 5-10 second data (Fielding et al., 2013; Schultz et al., 2019) on up to bi-annual water use information (Liu et al., 2016).

The communication medium affects customer engagement. Electronic communication platforms, such as web portals and in-home displays can supply instantaneous and appliance-specific data. The graphic interfaces are often customizable, which helps users better engage with the data. Prior studies posited that the specificity and user engagement may play a key role in improving conservation behavior (Inman & Jeffrey, 2006; Sønderlund et al., 2016; Syme et al., 2000). Our review found that, in the energy sector, interactive systems were more effective at reducing energy usage and better at engaging users in conservation actions (Karlin et al., 2015; Petkov et al., 2011). However, in the water sector, our investigation reveals that web-based and in-home displays were not as successful at reducing water demand as conventional paper-based communication systems. Several studies reported users' general disinterest in accessing websites. For instance, Schultz et al. (2016) reported that only 18% of eligible participants accessed websites to check their water use information during the study. Furthermore, the reduction in usage reported by paper-based feedback ranged from over

5% (Mitchell & Chesnutt, 2013) to almost 54% (Ferraro & Price, 2013), and when leak detection information was conveyed, users saved almost 90% water in some cases (Britton et al., 2013). Conversely, the reduction reported by web portals ranged from 3% (Petersen et al., 2007) to slightly more than 6% (Erickson et al., 2012). Willis et al. (2010) used alarming in-home visual displays to notify users when their shower duration exceeded 5-minutes or 10.5 gallons (40 L); they reported an average 27% reduction in water usage. However, the average volumetric reduction was only 4 gallons per shower, whereas Mitchell and Chesnutt (2013) saw an average 5% reduction in daily water use or a decrease of more than 14 gallons/day.

Liu and Mukheibir (2018) posited that paper-based feedback and systems where information was pushed to consumers (e.g., through text messages) better engaged users because users readily noticed the feedback and took action. Conversely, users had to pull information from web portals or in-home displays and, in most cases, users were not motivated to do so. This was also the case in the Erickson et al. (2012) study where 49% of the users who did not access the portal reported that they "kept forgetting" about the portal, whereas some of the other participants responded that it did not give them any goal or motivation to work on. However, the small percentage of users who used the portals regularly engaged themselves in other activities offered by the portals, such as chats and friendly games. This type of engagement was also reported by Liu et al. (2017) and many other energy-feedback studies that used web portals (Karlin et al., 2015; Petkov et al., 2011). Past review studies of water conservation and studies from behavioral science have pointed out that engaging users in different conservation activities is a pre-requisite to sustain conservation behaviors (Pope et al., 2018; Sofoulis, 2005). Hence, although paper-based systems have proved to be more effective for reducing water use, the application of web portals and in-home displays should not be disregarded as they have the potential to sustain the improved behavior.

4.4 Messaging frequency

Feedback frequency or intensity refers to the amount of feedback users receive in a given timeframe. The gap between action, i.e., water use and feedback determines the effect of feedback (Levin & Muehleisen, 2016). Hence, it is assumed that the higher the feedback intensity, the better the probability of reducing consumption (Fischer, 2008). Unfortunately, while studies from the medical field indicate that real-time feedback can improve behavior (Lee & Dey, 2014), there has not been any study in either the water resources or energy fields that has evaluated the effects of feedback frequency.

Fischer (2008) posited that users could conserve energy if users received feedback right after an action. In the Willis et al. (2010) study, an alarming in-home visual display reduced users' shower times from 7.2 minutes to 5.9 minutes (average 27% reduction) through instantaneous feedback. In the energy field, (Tiefenbeck et al., 2016) also reported that instantaneous feedback while taking a shower could reduce energy use by 22%. However, after reviewing contemporary feedback studies in the energy field, Karlin et al., (2015) contradicted these findings by stating that while a single end-use can be improved through such feedback, the effectiveness diminishes when multiple end-uses come into play. They argued that users do not usually pay attention to instantaneous feedback because they have to perform multiple end-uses throughout the day, and it is not practical for them to pay attention to feedback continuously. Furthermore, Karlin et al., (2015) also reported that a direct connection did not exist between increased energy feedback and consumption efficiency. Pereira et al. (2013) also did not see changes in energy use after providing instantaneous feedback on energy consumption to 12 participants for a year.

The number of feedbacks per period varied considerably. In the case of paper-based feedback studies, users received as few as one feedback (Schultz et al., 2016) or up to 6 feedbacks (Schultz et al., 2019) during the entire intervention period, which spanned a couple of months. When online portals were used, feedback intensity varied from 2 to 3 hours (Erickson et al., 2012) to 1 week (Petersen et al., 2007). We did not find a clear relationship between the frequency of conservation message and the decrease in water use. For example, Erickson et al. (2012) reported a 6.6% decrease in water use from 2 to 3 hour feedback intensity, Tiefenbeck et al. (2013) reported a 6% decrease from weekly feedback intensity, and Mitchell and Chesnutt (2013) reported a 5% decrease from bi-monthly feedback. Liu et al. (2016) reported an 8% decrease in water use from biannual feedback. Thus, the effect of feedback frequency on water use remains unclear.

4.5 Intervention Duration

Intervention duration is the timeframe between the first and the last message/feedback that users receive. Post-intervention refers to the period after feedback or messages are sent and are used to assess the effects of interventions. The duration of interventions ranged from 1 week (Schultz et al., 2016) to 52 weeks (Mitchell & Chesnutt, 2013). Most studies initiated their intervention just before or during summer and ended just before fall (Brick et al., 2018; Fielding et al., 2013; Katz et al., 2016). These studies reported that a significant reduction in consumption resulted, ranging from 0.6% (Brick et al., 2018) to almost 54% (Ferraro & Price, 2013) during the intervention period. However, there have been only a few post-intervention studies, and all reported users returning to their pre-intervention use levels when the intervention ended (Ferraro & Price, 2013; Fielding et al., 2013; Schultz et al., 2019). Ferraro and Price (2013) reported that although the effect of intervention dissipated, the treatment group that received social comparison information was still using less water than other experimental groups, suggesting that some content may have a prolonged temporal effect than others.

Past review studies from the energy field indicate that any intervention lasting three months or more reduced energy consumption (Fischer, 2008). However, Karlin et al., (2015) indicated that 3 to 6 month long interventions achieved the highest savings, and posited that prolonged intervention might be counterproductive since studies that ran more than six months saw savings decline over time. This finding was based on empirical data that used only information and tips for feedback purposes; it was not clear whether other behavior influencing techniques were involved. Studies have shown that continued messages can help users retain efficient behavior for a prolonged time. For instance, in their year-long experiment involving smart water monitoring techniques, Mitchell and Chesnutt (2013) reported that users retained their conservation behaviors and attained a reduction in use of approximately 5% throughout the intervention period. The experiment used social comparison as one of its primary motivators. Similar results were reported by Allcott (2011) as he investigated the effect of strategic feedback messaging that used social comparison, tips, and consumption information for improving energy behavior over two years and reported that all users retained their energy-efficient behaviors and high users managed to save more than 6% of energy use.

5 Sustain conservation behaviors

Sustaining conservation behavior means users adopt and continue to use water efficiently without relapsing back to prior unthrifty behavior. User-to-manager connectivity (Britton et al., 2013) and user engagement (Inman & Jeffrey, 2006; Sønderlund et al., 2016; Syme et al., 2000) are two important factors to help users adopt and sustain efficient behaviors. There are commercial companies that provide internet and mobile phone-based applications for monitoring water use, and in many areas, the utilities are working with those companies (Flume, 2021; Mitchell & Chesnutt, 2013). Hence, managers can connect with users via these electronic platforms. However, engaging users in water saving activities beyond 1 year remains a challenge. We found one water conservation study where users engaged in water-saving activities and retained their efficient behavior. The Project Hydro first identified users' information preferences through surveys (Lowe et al., 2015). Next, posters, billboards, and road signs were created with these information pieces. Project Hydro was able to reduce demand by 25%, and a 2-year post-intervention study revealed that the users retained their efficient behavior.

Project hydro used community-based social marketing (CBSM) to construct and deploy conservation messages. This tactic has also seen use in health and environmental field since early 1990s (Mckenzie-Mohr, 2000; Monroe, 2003). Stead et al. (2007) provided evidence of using CBSM for reducing alcohol and tobacco use; Gordon et al. (2006) mentioned application for promoting physical activity, and Drury (2009) reported use in species conservation. In addition, some of our reviewed studies posited that the

CBSM approach can improve users' perception of their water use and eventually improve user behavior (Beal et al., 2011, 2013). CBSM approach has five distinct steps (Mckenzie-Mohr, 2000).

1. Understand the reasons behind users' behaviors.
2. Select a single behavior to target.
3. Divide users into groups based on their psychological (step 1) and behavioral (step 2) profiles.
4. Customize interventions to help individual users change specific behaviors.
5. Create a pilot project for a few users then apply lessons to a full-scale application.

A similar strategy can be used to create conservation messages that combine users' informational preferences with water use behavior data to provide customized messages to reduce specific behavioral or technology end-uses of water.

6 Suggestions to sustain conservation behaviors

Here, we synthesize suggestions for managers to improve conservation message efficacy and sustain behavior beyond 1 year. Successful feedback programs construct messages that address users about the problem and share what the water authority is doing to reach the conservation goal. Feedback programs also provide consumption and comparison information to internally and externally motivate users, offer customized, easy-to-adopt conservation tips, and share additional resources such as rebates, links to where to purchase efficient appliances, the water authority's web page, and help lines

(Figure 2). Including all this information may overwhelm users, so blue filled boxes in Figure 2 highlight the most important messages.

Figure 2: Recommended feedback content and information. Blue fill marks the most important information.

To sustain conservation actions past intervention periods:

1. Conduct a survey and group users based on their intent and communication preferences. Use the survey to: a) start a conversation with consumers to understand their intentions regarding water conservation, and b) Identify their information preferences because not all users will respond to the same type of content. Grouping users helps managers create group-specific content. Examples of groupings can be: degree of conscience regarding the environment, sensitivity to peer pressure, heightened personal norms, past conservation behavior, financial capability, and responsiveness to rewards or monetary incentives.
2. Launch feedback programs during critical periods such as a drought. These conditions get users' attention and can internally motive users to conserve.
3. State what the water authority is doing to achieve the conservation goal,
4. Customize message content—consumption information, peer- or self-comparisons, tips, and further information—based on a user's attitude and information preferences.
5. Set the correct feedback frequency. When disaggregated data is available, focus to change one behavior at a time.
6. Praise water efficient behavior to positively reinforce desired actions.
7. Use both paper-based and internet-based communication mediums because paper-based feedback is still a popular form of communication. However, digital platforms are becoming more available and popular. Help users acclimatize to mobile and web-based applications to engage them in water-related activities,

such as checking for leaks, engaging in group chats, and friendly games, where users save water as a group.

8. Update the feedback message to maintain user attention. For example, change water-saving tips every three months or more frequently.
9. Encourage users to make a public commitment to conserve because users who made a public commitment to conserve water were more likely to sustain their behavior over time.
10. Recognize water savers via a website or other means because recognition is popular among wealthy users who are also, in many cases, the largest water users.
11. Allow users to share their conservation experiences with neighbors because sharing experiences can improve a household's trust in their neighbors and boost their motivation to conserve (James & Rosenberg, 2022; Jorgensen et al., 2009; Syme et al., 2000).

7 Conclusions

This paper reviewed 80 research studies from behavioral sciences, water conservation, energy conservation, environmental psychology, and health communication to learn how prior studies used strategic messages to encourage and sustain water conservation behaviors beyond 1 year. Message contents such as usage information, social- and self-comparisons, tips, and further information reduced use by up to 54%. Individual effects were often difficult to identify because studies often combined message contents. Feedback duration, frequency, and communication medium also affected water savings. Sustaining voluntary water conservation behaviors beyond the longest study period of 1 year remains a challenge.

We synthesized 11 suggestions to better sustain conservation behavior over time. These suggestions include learn user's intentions and informational preferences, launch feedback programs during critical periods such as a drought, and state what the water authority is doing to achieve the conservation goal. Further, customize message content based on a user's attitude and information preferences, target one easy-to-implement conservation action at a time, praise efficient behavior, and communicate through a variety of internet, paper, and other mediums. Additionally, regularly update message contents, encourage users to publicly commit to conservation, recognize water savers, and allow users to share their conservation experiences.

Future work can apply community-based social marketing to design messages to meet users intentions and information preferences. Each suggestion to sustain conservation behaviors will benefit from longer-term efforts to document individual and combined effects after interventions.

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Data availability

No data was generated for this study.

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Appendix

Tables

Table A: List of reviewed studies that used feedback and strategic message for conservation.

Field	Communication medium	Study	Intervention duration	Post-intervention	Sample Size (number of households)	Year	Percent (%) reduction in usage
Energy	In home display	Seligman et al. 1978	4-weeks	ns	20	1976	16%
Energy	Electronic/computer-based	Dobson & Griffin, 1992	8-weeks	ns	25	1991	13%
Energy	Electronic/computer-based	Benders et al., 2005	21-weeks	ns	190	2002-2003	8.50%
Energy	Electronic/computer-based	Ueno, Inada, Saeki, & Tsuji, 2006	40-weeks	ns	19	2003	9%
Energy	Paper-based	Allcott, 2011	102-weeks	ns	600,000	2009-2010	0.3-6.3%
Energy	In home display and computer-based	Tiefenbeck et al., 2016	8-weeks	2-weeks	697	ns	22%
Energy	Electronic/computer-based	Alberts et al., 2016	6-weeks	2-weeks	466 post-graduate students	2013	22%
Energy	In home display	Tifenbeck er al., 2018	8-weeks	ns	636	ns	22%
Water	Paper-based	S. C. Thompson & Stoutemyer, 1991	8-weeks	8-weeks	171	1991	6-18%
Water	Paper-based	Aitken et al., 1994	12-weeks	ns	226	1991	4.30%

Field	Communication medium	Study	Intervention duration	Post-intervention	Sample Size (number of households)	Year	Percent (%) reduction in usage
Water and energy	Electronic	Petersen et al., 2007	2-weeks	ns	1,612	2005-06	32% decrease in energy use 3% decrease in water use
Water	Electronic	Willis et al., 2010	2-weeks	2-weeks	151	2008	
Water	Electronic	Erickson et al., 2012	15-weeks	ns	303	ns	
Water	Paper & electric	Mitchell & Chesnutt, 2013	52-weeks	ns	10,000	2012	4.4-6.6%
Water	Paper-based	Fielding et al., 2013	21-weeks	52-weeks	221	2010-11	8-15%
Water	Paper-based	Ferraro & Price, 2013	16-weeks	ns	100,000	2007	7.41-53.38%
Water	Paper-based	Tiefenbeck et al., 2013	12-weeks	2-weeks	154	2011	6%
Water	Electronic and Paper-based	WaterSmart, 2014	ns	ns	ns	2014	5%
Water	Electronic, Paper, Billboard, Road Signs	Lowe, Lynch, & Lowe (2015)	104-weeks	ns	535	2007	25%
Water	Paper & electric	Schultz et al., 2016	1-week	1-week	296	ns	16-26%

Field	**Communication medium**	**Study**	**Intervention duration**	**Post-intervention**	**Sample Size (number of households)**	**Year**	**Percent (%) reduction in usage**
Water	Paper-based (post card)	Katz et al., 2016	26-weeks	5-weeks	934	ns	7.60%
Water	Paper-based (post card)	Liu et al., 2016	20-weeks	4-weeks	57	2012-14	20.30%
Water	Paper-based	Brick et al., 2017	20-weeks	ns	400,000	2015	0.6-1.3%
Water	Electronic	Otaki, Ueda, & Sakura, 2017	24-weeks	ns	246	ns	reduction reported through Mann-Whitney and Kruskal-Wallis test, and no actual values were used
Water	Paper-based	Nayar & Kanaka, 2017	4-weeks	ns	74	ns	5.02-10.6%
Water	Paper-based	Schultz et al., (2019)	26-weeks	60-weeks	18,711	2015-17	8.35%