Saving Water through Behavior Changing Technologies

Todd Levin, Argonne National Laboratory
Ralph Muehleisen, Argonne National Laboratory

ABSTRACT

The U.S. Environmental Protection Agency identifies two general categories for practices designed to increase water efficiency: engineering and behavioral. Engineering practices involve technologies designed to passively reduce water irrespective of the user's behavior (e.g., low-flow showerheads). Behavioral practices refer to changing users' habits irrespective of the technology being used (e.g. fewer showers). This binary focus overlooks the conceptual area where technology and behavior influence each other (e.g. showerheads that encourage shorter showers)—an area that has seen much less attention, and is ripe for development. We present findings and lessons learned from an inaugural workshop on "Saving Water Through Behavior Changing Technologies" that was hosted by Argonne National Laboratory. The workshop convened experts in water efficiency, behavioral sciences, design, engineering and other fields, along with commercial developers, and others who might significantly contribute to the design, development and dissemination of behavior-impacting technologies that reduce water consumption for buildings. An overview of trends in domestic water consumption is first provided and technological and institutional barriers to achieving greater efficiency are discussed. Next, we review characteristics of technologies that are desirable for affecting behavioral change. We then assess the current challenges and opportunities facing water utility efficiency programs, comparing and contrasting with the experiences of the electric sector. Finally, we propose several promising research pathways that may support the development of promising new technologies with potential to influence consumer behavior and reduce water consumption in the residential and commercial sectors.

Background

The United States is experiencing a number of key trends that have increased the imperative to develop and implement comprehensive water conservation efforts (USDOE 2014). While total domestic withdrawals of both fresh groundwater and fresh surface water have been roughly constant since 1980 (Maupin et al. 2014), populations are growing the fastest in arid regions that are more water constrained. At the same time, there has been an increase in the occurrence of extreme weather events and also the variability of precipitation patterns, resulting in less certain freshwater availability. The impact of these precipitation pattern changes is clearly illustrated by that fact that one-third of the U.S. was affected by severe drought in 2012 (USDOE 2014). The current water scarcity issues plaguing California have perhaps for the first time truly brought these concerns to the forefront of public attention. Additionally, new energy and water technologies are emerging that have the potential to augment and shift consumption patterns.

The U.S. Environmental Protection Agency (EPA) identifies two general categories for practices designed to increase water use efficiency and thereby reduce water consumption: engineering practice and behavioral practice (USEPA, n.d.). Engineering practices involve technologies designed to passively reduce water irrespective of the user's behavior. The EPA provides numerous examples of such technologies including low-flush toilets, low-flow showerheads, faucet aerators, and pressure reductions. Behavioral practices refer to changing users' habits irrespective of the technology being used. Examples include, running a dishwasher only when it is full, taking shorter showers, and turning off a faucet while brushing teeth or shaving. In addition to these two binary approaches to water conservation, there also exists a conceptual area where technology and behavior influence each other. This is an area that has seen much less attention, and is ripe for development.

With this in mind, The U.S. Department of Energy Building Technologies Office commissioned Argonne National Laboratory to conduct a scoping study of the market landscape for behavior-changing technologies in the water sector. To inform this scoping study, Argonne hosted a workshop that convened water experts and stakeholders from across the country. Discussions during the workshop were primarily focused on water consumption in and around residential and commercial buildings. Technologies to improve water consumption efficiency in industrial and agricultural applications, as well as those for cooling at thermal power generation units, were not explicitly considered due to the vastly different problem scope in those sectors. This paper report summarizes the findings developed through background research, stakeholder outreach, and stakeholder participation in a two-day workshop that was hosted at Argonne in April, 2015.

Methodology

The objective of this study is to identify concrete research pathways that can be implemented to increase the market penetration of technologies that influence water consumption behavior, and ultimately reduce water consumption in buildings. Findings were developed over four distinct stages.

Identify types of consumer change. We first created a working definition of consumer change, and sought to understand how such change could be motivated and evaluated through consumer actions. This resulted in the categorization of three different types of consumer change, and the decision to focus further research specifically on behavioral change.

Identify technology characteristics for motivating behavioral change. Through early outreach and research it was determined that the market for technologies that influence water consumption behavior is still relatively immature. Therefore, before discussing specific technological concepts for the water sector, it was important to first broadly identify desirable technology characteristics with the potential to motivate consumer behavioral change, and understand how these could be applied to reducing water consumption. We therefore sought to draw upon lessons learned and best practices from technologies that have successfully transformed behavior in other sectors.

Identify barriers to behavioral change and market Adoption. We next identified the barriers that have prevented these technology characteristics and the associated behavioral change from manifesting themselves in the water sector.

Identify R&D pathways to overcome barriers. Finally, we identified a number of research and development pathways that may be undertaken to overcome the barriers identified previously, increase the penetration of behavior-influencing technologies in the water sector, and ultimately reduce water consumption in buildings.

Types of Behavioral Change

Forced change. Forced change can be implemented through policies, regulations and standards. For example, EPA maintains national water use efficiency standards for residential and commercial fixtures and appliances (USEPA 2008). This can be an effective means of achieving prescribed efficiency gains, successful examples in other sectors include energy efficiency standards for refrigerators that were first introduced in the 1970s and the Corporate Average Fuel Economy (CAFE) standards that have been implemented for vehicle manufacturers. Similarly, in the water sector enhanced toilet efficiency standards that were implemented in the United States in 1994 are estimated to have save 18.2 trillion gallons of water; equal to the total water consumption of New York City, Chicago and Los Angeles over a 20 year period (American Standard 2014). However, forced change can also lead to consumer resistance and low product persistence as products will typically be designed only to meet these minimum standards. Therefore, standards must be updated regularly to encourage continual product advancement, a process which may not keep pace with the potential for innovation.

Voluntary change. Voluntary change can be implemented through educational programs that encourage consumers to use water more efficiently. The goal is to have consumers consciously change their consumption habits, for example, taking shorter showers, shutting off the faucet while brushing their teeth, or reducing water use for landscaping. The hope is that with time these behavioral changes will become the norm. This approach has had recent success in California, where consumers have become much more aware of water scarcity in the region and have started to adapt their behavior to consume water more efficiently. However, voluntary change may still encounter consumer resistance as it requires conscious actions that are disruptive to a consumer’s routine.

Transformative change. Transformative change is achieved when consumers take actions that result in decreased water consumption, not because they are consciously trying to reduce their consumption, but rather because those actions actually add convenience to their daily routine. For example, many consumers currently turn on their shower and then engage in other activities (teeth brushing etc.) while waiting for the shower to reach a desired temperature. As a result, consumers will naturally get distracted and may leave the shower running unoccupied well after the target temperature has been reached. A technology that can instantaneously heat water in the shower to a particular temperature would completely eliminate this behavior. Consumers will change their routines not out of a conscious desire to save water, but because they now save time by not having to wait for the shower to warm up.

Technology Characteristics for Motivating Behavioral Change

Workshop attendants were tasked with identifying technologies that have successfully transformed behavior in other sectors and industries, enumerating the specific characteristics of these technologies that empowered behavioral change, and then discussing how these characteristics could be integrated in new technologies to achieve the same transformation in the water sector.

Access to information on demand. There was a general consensus among workshop participants that providing users with access to more frequent, high resolution, and easily digestible information about their behavior is crucial for effecting behavioral change. In addition to being of primary direct importance, effective data collection and communication are also critical enabling components for many of the other characteristics that were discussed. The Nest Learning Thermostat provides an example of a product that has dramatically improved data access to consumers within the energy sector where such data has long been inaccessible. Improved data accessibility is specifically of importance in the water sector, where a lack of awareness is a major obstacle to influencing behavior. Improved data access will help consumers understand how and where they are using water so they can make informed decisions and then measure the impact of these decisions.

Active feedback. Current water bills provide passive feedback that may reach a consumer once per month at most. Therefore a consumer may not be able to see the impact of any measures that they have taken until a significant amount of time has passed, and even then such impacts may be lost in the noise of other consumption. The Fitbit was discussed as one example of a technology with active feedback, as it can be programmed to sends user reminders to exercise when it detects periods of inactivity. In the water sector, active feedback could provide users with a daily summary of their water use or an instant email or phone notification when they exceed a predefined daily consumption budget. One study has found that consumers who receive regular home water reports reduce their water consumption by 4.4% to 6.6% more than those who do not (Mitchell and Chesnutt 2013).

Social interactions and peer accountability. Social interactions have increasingly become an effective tool for influencing behavior. Consumers can use social media to hold themselves accountable for actions that they commit to take, and to provide positive feedback when they achieve specific goals. Workshop participants discussed diet and exercise apps that will automatically share workout results over social media, or can make “shaming posts” when a user exceeds a daily calorie budget or fails to exercise for a given period of time. Such an approach could similarly be effective when applied to water consumption. This would similarly enable consumers to voluntarily share their water usage with friends and family, providing them encouragement to meet predefined usage goals.

Measurable goals and gamification. It is important for consumers to be able to define measureable goals for themselves and be able to measure their progress towards reaching their goals. Gamification can be introduced to make achieving these goals more enjoyable, which is an important component of getting people to make sacrifices or change to their routine in a way that requires effort and causes inconvenience or discomfort. Workshop participants discussed how dieting and exercising are not in themselves necessarily enjoyable activities for many people. However, many do find enjoyment in achieving concrete weight loss or exercise goals and participating in friendly competitions with peers.

Seamless integration. Finally, it is important that new technologies are seamlessly integrated into everyday life, so that they become standard components of modern appliances rather than luxury or novelty features. As an example, participants discussed the real-time ‘miles per gallon’ indicators that are now a standard component of many modern vehicles. These meters are now seamlessly integrated into car displays so as not to be overly distracting, and do not disrupt routines or require conscious action. However, they do provide drivers with constant feedback on how their actions are affecting vehicle efficiency in real-time. Drivers can instantly see the relative impact of accelerating or increasing their average speed. This constant feedback helps drivers understand how their driving habits affect gasoline consumption, even if on a subconscious level. Real-time digital water meters on faucets or other appliances can similarly provide constant, non-disruptive feedback to consumers.

It is also important that new technological features can be seamlessly integrated into existing infrastructure and consumer products. This is particularly true in the water sector where infrastructure is deeply integrated into existing cities and buildings, generally in inaccessible locations (underground, within floors and walls), and is therefore often very costly to replace.

Barriers to Behavioral Change

We now identify several key barriers that have inhibited the increased penetration of water-saving technologies and pose unique challenges toward influencing water consumption behavior. Potential pathways towards overcoming these issues will be discussed in later sections.

Water is too cheap. Participants at the workshop were in near uniform agreement that water is simply too cheap. Consumers are rarely motivated to reduce their water consumption for purely financial reasons, and similarly, institutional water conservation programs are rarely justifiable on the basis of economics alone. For a variety of reasons, many consumers also do not fully internalize the amount that they pay for their water consumption, but rather consider water to essentially be a free public good. This is partially explained by the fact that state and local water collection, sanitation, and distribution systems are funded through taxes and other mechanisms that are relatively opaque to most consumers. This issue is compounded by the fact that many consumers do not pay the water bill at their residence or place of business. Rather the bill may be paid directly by a building owner or landlord. In such cases, consumers receive no price signals to motivate change in their consumption behavior.

Water price and consumption data are not readily available. A typical residential or commercial water consumer receives data on their water consumption at most monthly, oftentimes less frequently, and in many cases never. Furthermore, water consumption may be reported in units that are obscure to a typical consumer, such as CCF (centum cubic feet - one hundred cubic feet - which is equal to 748 gallons). Even when a more standard unit like the gallon is used, monthly consumption data are often aggregated into thousand gallon blocks, due to the widespread use of analog meters. Additionally, fees and charges on residential and commercial water bills are split into several categories and it is not immediately clear to the consumer how much money would be saved by reducing their consumption.

Water utilities and regulators are highly fragmented. According to the EPA there are more than 50,000 community water systems serving almost 300 million people in the United States. More than half (55%) of these are very small, serving 500 people or less, while only a small fraction (8%) serve more than 10,000 people (USEPA 2013). In contrast, there are roughly 3,300 electricity providers in the United States (APPA 2015). These water utilities may also be overseen and regulated by local boards of elected officials, rather than through a single state public utility commission, as is more common in the power sector. This high level of fragmentation in the water sector results in a patchwork system of rules, regulations, and operational practices. It also makes it difficult to design and implement overarching policy that has the desired impact across all affected entities. The large fixed costs associated with developing and implementing water conservation programs may make such programs prohibitively expensive for smaller utilities with correspondingly small budgets.

At the federal level there are a number of agencies that have some level of interest in water conservation efforts (e.g. Environmental Protection Agency, Department of Energy, Department of Interior, Department of Agriculture, U.S Geological Survey and National Oceanic and Atmospheric Administration) however there is no single federal agency that is wholly tasked with addressing water-related issues and developing water policy on a national scale.

Water utilities revenues are tied to sales volume. In the water sector, utility revenues are generally tied to sales volume. As a result, conservation programs that reduce water consumption also reduce utility revenue streams. Therefore, these utilities have no incentive to encourage their customers to conserve water. As many utility costs are fixed regardless of the quantity of water delivered, these costs stay constant while revenue decreases with decreasing sales (Beecher 2010; Kenney 2014). As a result, utilities that do implement conservation programs face a compounding problem; they are increasing expenditures while decreasing revenue, and as such may need to increase water rates in their service territory. This outcome is counterintuitive and disagreeable for many consumers. Rather than being implemented directly by utilities, efficiency programs in the water sector are more typically funded by separate entities with a vested public interest in reducing water consumption such as the California Department of Water Resources.

Research and Development Opportunities

Several promising research pathways were identified to support the development of behavior-influencing technologies to reduce water consumption. These are segmented into three different categories, technology opportunities, enabling reforms, and behavioral opportunities.

Technology Opportunities

There was broad consensus among workshop participants that an affordable, next-generation water meter will be essential for enabling large-scale behavioral change. Such a meter would facilitate improved access to consumption and cost data for both utility providers and consumers themselves. This will enable utilities to more efficiently design conservation programs and evaluate their impacts, and empower consumers to better understand their own consumption habits. Collecting high-resolution consumption and cost data is a vital first step towards facilitating behavioral change, but such data are only valuable if they can be analyzed and communicated to stakeholders in a timely, straightforward and meaningful way. New software and data standards will be needed to facilitate this process.

The following four key characteristics for this meter were also specifically identified. While a number of meters are currently available which have one or several of these characteristics, workshop participants were in agreement that there is no one single technology that adequately incorporates all of these attributes.

- **Plug-and-play.** It is important that such meters could be quickly and easily installed by consumers themselves, as the need for professional installation would likely be a significant barrier to mass-market adoption.

- **Real-time.** Currently most water consumption data are recorded and aggregated over periods of a month or more. Access to high resolution, real-time data would enable consumers to visualize the water usage of individual appliances as it occurs. In addition to providing and greater insights into water consumption habits, real-time data would help both consumers and water providers detect leaks and other accidental water releases more quickly and efficiently.

- **Wireless.** The meter would ideally be able to transmit any data it records wirelessly to a centralized data hub where it can be stored and integrated with software for filtering, analysis and communication to consumers.

- **Affordable**. The meter should be cheap enough that it can be ubiquitously applied to a range of different appliances throughout a household: showers, faucets, toilets, washing machines, dishwashers etc. A target of $10 per meter was discussed as a price point that could enable wide-spread usage across a variety of applications, as opposed to limited penetration as a niche or novelty product.

Next-generation Appliances

While water consumption data can be collected through external, third-party water meters, it will also be important to develop smart appliances that can engage in two-way communication with the data platform and therefore consume water more intelligently. In addition to the general technological characteristics outlined earlier, several specific ideas for smart water technologies were discussed.

Programmable showerheads and faucets. Programmable showerheads and faucets would be able to instantly provide water at a target temperature and flow rate that could be customized for each user. This would reduce water waste that occurs while users are fine tuning temperature settings and could also reduce consumption by allowing consumers to regulate flow rates according to their preference. A similar system could be implemented for kitchen faucets, with varying temperature and pressure presets for different uses such as hand washing, dish washing, drinking water etc.

Instantaneous water heaters. Instantaneous water heaters would also be an important component of the programmable showerheads described above. They would enable rapid delivery of water at a prescribed temperature, reducing losses associated with waiting for showers to heat up. They also have the advantage of consuming less energy than traditional centralized hot water heating systems.

Smart landscaping. Over 50% of residential water consumption is used for outdoor applications, primarily landscaping (Mayer et al. 1999). Smart landscaping systems could be linked to weather forecast data that enable a more intelligent allocation of water based on anticipated shortages or surpluses due to precipitation. Sensors in the ground could detect moisture content in the soil and adjust the output of sprinklers and other irrigation accordingly.

Leak and defect detection. Losses during water distribution may account for up to 15% of total water consumption in the United States and leaks in homes alone waste over one trillion gallons of water each year (USEPA, n.d.). Leaks can go undetected for days or months, wasting tremendous amounts of water. Most seals within faucets are made of rubber washers, which naturally shrink and crack over time during wetting and drying cycles, will eventually defect and causing leaks. Such leaks result in gradual consumption increases that typically go undetected or untreated by many consumers. More significant leaks also occur at all levels throughout a utility-scale water distribution infrastructure. Most water distribution systems are not capable of automatically sensing leaks, instead relying on manual identification of usage spikes that often are not apparent due to infrequent consumption data reporting.

Enabling Reforms

While the workshop was focused on identifying novel technologies and technological characteristics with the potential to influence water consumption behavior, it also became clear that such technological progress does not exist in a vacuum. Participants also discussed a number of policy, institutional, and regulatory reforms that could be instituted to help create an environment that supports the development and deployment of advanced technologies in the water sector.

Higher rates. Workshop attendants were generally in agreement that the water prices paid by consumers need to be increased in order for significant behavioral change to be realized. The low price of water compounds many of the issues created by the poor availability of water consumption data. For example, there are minimal incentives for consumers to invest time and energy into understanding their imprecise and confusing water bills, as water consumption does not represent a significant expense in a typical household. Similarly, low prices make it difficult for consumers to justify personal investments in water efficiency measures on a purely economic basis. Low prices also result in reduced revenue for water utilities compounding their internal problems of maintaining and improving their infrastructure.

Increasing block pricing. It is politically challenging to raise water rates due to the complex competing interests involved. Chief among these is the general belief that water consumption up to a certain level should be considered a basic human right in modern societies, whereas consumption beyond that level can be classified as a more standard consumer product. Increasing block pricing would align economic incentives with this social objective. It was also suggested that customers could be charged different rates for indoor and outdoor water use, reflecting the concept that outdoor water consumption is typically more of a luxury good than indoor use. However, the challenges inherent in implementing and enforcing such an approach make it highly unlikely to be implemented anytime in the near future. Other revenue stabilizing mechanisms that appropriately value water based on its short term availability, such as drought or shortage surcharges, could also be considered.

Revenue decoupling. Water utilities also have minimal incentives to promote more efficient water usage, as their revenues are tied to the consumption levels of the customers. A similar problem was identified in the electric sector and has been approached in many jurisdictions through revenue decoupling (RAP 2011). Through this mechanism, a utility's revenue is tied to their ability to serve the needs of their customers as opposed to the amount of energy that they provide. This distinction empowers electric utilities to invest in efficiency and demand side management programs that are often cheaper alternatives to further increasing supply through investments in new generation units and transmission and distribution infrastructure. These programs typically offer incentives to consumers who take well-defined measures to reduce their energy consumption. The resultant reduction in electricity demand negates the need for investments in new infrastructure. Revenue decoupling for water utilities began for some customers in California in 2008, but this is still not a widespread practice across the country.

Regulatory and institutional aggregation. Due to the high level of disaggregation among service providers and regulators in the water sector, individual water conservation programs are typically limited in their scope and geographic reach. This results in high costs and barriers to entry for each new program. The aggregation of small municipal water providers and utilities through regional consortia could help to address this issue by helping coordinate uniform conservation programs and reduce the associated implementation costs. The disaggregated institutional landscape is also impacted by the dispersed nature of freshwater as a natural resource. Groundwater aquifers may span multiple different municipalities, regions, and regulatory landscapes. Therefore, the water withdrawals made by one municipality may influence water availability in the entire neighboring region. This "tragedy of the commons" provides an incentive for each agent to increase their water consumption in the short term for fear of losing available supply to their neighbors over the long term.

Integrated water and energy efficiency programs. In 2012 nearly $6 billion dollars were invested in rate-payer funded energy efficiency programs in the electric sector, which saved over 126 terawatt-hours of electricity (Cooper and Wood 2014). This level of support is simply not available for similar programs in the water sector. However, as energy is required to treat water, deliver it to consumers and, and collect wastewater after it has been consumed an integrated efficiency program framework could be implemented to recognize this relationship. Such programs could draw upon rate-payer funds from the energy sector – where a stronger efficiency program infrastructure already exits – to finance water efficiency programs that also save energy. An example of this framework can be found in Southern California where in 2012 the Los Angeles Department of Water and Power and Southern California Gas Company entered a partnership that allows them to jointly offer efficiency programs to customers in their shared territories (Drake et al. 2014).

Behavioral Opportunities

Consumer education and communication. A typical residential consumer has little to no concept of how much water he or she consumes in a day or a month. Part of this is due to poor data availability, as has been discussed previously. However, this is also partially due to the fact that consumer awareness and interest in water conservation is low. As an increasing number of consumers begin to recognize the social imperative to reduce their water consumption, stakeholders now have an important window of opportunity to provide consumers with the tools they need to make informed decisions on how to reduce their consumption. For example, the 'miles per gallon' (MPG) metric for vehicles has become a pervasive part of our culture. Car manufacturers advertise MPG ratings on their commercials and many consumers factor MPG strongly into their choice of purchase. The gallon per minute (GPM) metric similarly exists for water products, but it has not reached the same level of public awareness. Manufacturers typically design their products to meet minimum standards, and offering a product with a lower GPM rating does not provide a competitive advantage as high MPG does in the vehicle market.

Research is needed to inform the design and implementation of any such education efforts. Such research would improve stakeholder understanding which approaches to marketing and consumer education can effectively capture consumer attention and motivate behavioral change. For example, many consumers don't respond well to simple messages telling them to "reduce your water use". Such a message is too broad, does not include actionable information, and implies that some sort of sacrifice is necessary. Research could focus on identifying forms of water conservation messaging that register more strongly with consumers.

Consumer perception and human psychology. Providing consumers with additional information tends to increase their knowledge and understanding of an issue but all else equal, does not generally lead to changes in behavior (WaterSmart 2014). It is human nature to resist change and maintain the status quo, and it is well known that there is a large gap between what consumers claim to care about and the actions they are actually willing to take. Additional research is needed to better understand how increased education, communication, and information availability interact with human psychology, behavioral economics, and behavioral science to influence actual changes in water consumption behavior. This will provide policy makers with the tools they need to motivate consumers to make intelligent and efficient water consumption their default action so that conscious behavioral change is no longer necessary.

Gamification. Natural competitive tendencies can be leveraged to motivate consumers to use water more efficiently. For example, utilities could pool neighboring homes with similar consumption profiles and offer a small financial incentive for the one that consumes the least water each month. This might be coupled with a user-friendly data reporting interface where each household could monitor how their usage compares with their neighbors'. Similarly, contests could be introduced within a single home if each household member were provided a simple means of logging their water use, i.e. swiping a personalized card before taking a shower or using the clothes washer. Alternatively, a similar approach could be used to establish and enforce monthly water budgets for a single household. Homes might be offered lower rates for committing to stay below a certain consumption threshold, but would face a steep rate increase if they cross it.

Limiting choices. Consumers can be overwhelmed when presented with too many choices, which oftentimes leads to inaction over to the fear of making a sub-optimal decision. This problem may be exacerbated in the water sector where initial consumer awareness is already low. Consumers presented with a number of different potential new water-saving showerheads may ultimately decline to purchase any of them, preferring instead to maintain the status quo. Alternatively, if a single option is presented with a simple actionable message i.e. "install this to save water", consumers may be more willing to act. Research could be conducted to analyze how presenting consumers with limited, clear and concise water conservation options impacts the adoption of these technologies and actions.

Emotional connections. Workshop participants also discussed the possibility of increasing the public's emotional connection to water conservation issues. Similar efforts with climate change and other environmental issues have had more success making the potential impacts tangible and connecting with consumers. There is a sense that while water conservation has started to enter the public consciousness, it still lacks this emotional connection. For example, even during the drought conditions currently being experienced in California most people have never directly suffered from a lack of water availability. This makes it difficult for an average consumer to internalize the long-term externalities associated with inefficient water usage. Research is needed to understand how to establish this connection with consumers, drive home the potential long-term impacts of water scarcity, and ultimately effect behavioral change.

Conclusions

This report summarizes the key findings of a workshop that convened experts from a wide range of water-related disciplines with the goal of identifying technologies that can be developed and deployed to change water consumption behavior. While efforts to reduce water consumption have gained momentum in recent years, there are a number of key barriers that have limited the effectiveness of such efforts. Chief among these is the fact that many consumers have limited awareness of their water consumption patterns due to poor data availability, and/or are unmotivated to reduce their consumption due to low costs and split incentives. Without improved data availability and stronger price signals, it will be difficult to effect true transformative behavioral change.

This report also reviews a number of technology characteristics that have successfully motivated behavioral change in other sectors, as well as several technologies that could be developed specifically for the water sector. Workshop participants discussed how technologies that provide active feedback, and promote measurable goals and social accountability have successfully influenced changes in other types of behavior. A range of regulatory and policy actions that could be implemented to support such efforts are also presented. These include institutional aggregation, revenue decoupling, and price structure reforms. Finally, several R&D pathways were proposed, including efforts to identify optimal communication strategies and to better understand consumer perceptions and psychology as they relate to human behavior regarding water consumption.

The findings presented here can help to inform policy makers and they develop new policies and seek to support new research to help consumers use water more efficiently. It is our hope that these findings will also be utilized to prioritize topics for additional follow-up workshops to address individual issues and barriers more directly and in more detail. The goal of such future workshops will be to develop specific solutions, research plans, and technology development pathways that can be undertaken to increase the market penetration of technologies that effect behavioral change and reduce water consumption.

References

American Standard. 2014. “18 Trillion Gallons of Water Saved during 20 Years of Low-Flow Toilet Regulations.” March 20. http://www.americanstandard-us.com/pressroom/18-trillion-gallons-of-water-saved-during-20-years-of-low-flow-toilet-regulations/.

APPA. 2015. “2015-2016 Annual Directory and Statistical Report: U.S. Electric Utility Industry Statistics.” Arlington, VA: America Public Power Association. http://www.publicpower.org/files/PDFs/USElectricUtilityIndustryStatistics.pdf.

Beecher, Janice A. 2010. “The Conservation Conundrum: How Declining Demand Affects Water Utilities.” *Journal AWWA* 102 (2): 78–80.

Cooper, Adam, and Lisa Wood. 2014. "Summary of Electric Utility Customer-Funded Energy Efficiency Savings, Expenditures, and Budgets." Washington, DC: The Edison Foundation Institute for Electric Innovation. http://www.edisonfoundation.net/iei/Documents/InstElectricInnovation_USEESummary_2014.pdf.

Drake, Mark, Mugimin Lukito, Gillian Wright, David Jacot, and Gretchen Hardinson. 2014. "Creating a One-Stop-Shop for Resource Efficiency: A Public-Private Partnership in the Delivery of Energy and Water Efficiency Programs." In , 5–117 – 5–128. Pacific Grove, CA: ACEEE. http://aceee.org/files/proceedings/2014/data/papers/5-451.pdf.

Kenney, Douglas S. 2014. "Understanding Utility Disincentives to Water Conservation as a Means of Adapting to Climate Change Pressures." *Journal AWWA* 106 (1): 36–46.

Maupin, Molly A., Joan F. Kenny, Susan S. Hutson, John K. Lovelace, Nancy L. Barber, and Kristin Linsey. 2014. "Estimated Use of Water in the United States 2010." U.S. Geological Survey Circular 1405. U.S. Geological Survey. http://dx.doi.org/10.3133/cir1405.

Mayer, Peter W., William B. DeOreo, Eva M. Optiz, Jack C. Kiefer, William Y. Davis, Benedykt Dziegielewski, and John Olaf Nelson. 1999. "Residential End Uses of Water Study (1999)." Denver, CO: America Water Works Association. http://www.waterrf.org/publicreportlibrary/rfr90781_1999_241a.pdf.

Mitchell, David L., and Thomas W. Chesnutt. 2013. "Evaluation of East Bay Municipal Utility District's Pilot of WaterSmart Home Water Reports." M.Cubed and A&N Technical Services, Inc. http://californiawaterfoundation.org/uploads/1389391749-Watersmart_evaluation_report_FINAL_12-12-13%2800238356%29.pdf.

RAP. 2011. "Revenue Regulation and Decoupling: A Guide to Theory and Application." Montpelier, VT: The Regulatory Assistance Project. http://www.raponline.org/document/download/id/861.

USDOE. 2014. "The Water-Energy Nexus: Challenges and Opportunities." Washington, DC: U.S. Department of Energy. http://www.energy.gov/downloads/water-energy-nexus-challenges-and-opportunities.

USEPA. 2008. "National Efficiency Standards and Specifications for Residential and Commercial Water-Using Fixtures and Appliances." Washington, DC: Environmental Protection Agency. http://www3.epa.gov/watersense/docs/matrix508.pdf.

———. 2013. "Fiscal Year 2011 Drinking Water and Ground Water Statistics." EPA 816 - R - 13 - 003. Washington, DC: U.S. Environmental Protection Agency. http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/upload/epa816r13003.pdf.

———. n.d. "Fix a Leak Week Fact Sheet." Washington, DC: Environmental Protection Agency. http://www3.epa.gov/watersense/docs/ws_fixaleakfactsheet508.pdf.

———. n.d. "How to Conserve Water and Use It Effectively." Washington, DC: U.S. Environmental Protection Agency. http://water.epa.gov/polwaste/nps/chap3.cfm.

WaterSmart. 2014. "Tapping into the Power of Behavioral Science: Insights & Opportunities for Water-Use Efficiency." San Francisco, CA: WaterSmart Software. http://www.watersmart.com/wp-content/uploads/2014/11/WSS_TappingintoBehaviorScience.pdf.