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Measuring water use, conservation, and differences by gender using an inexpensive, high frequency metering system

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ABSTRACT

We present an inexpensive, open source, water metering system for measuring water use quantity and behavior at high temporal frequency. We demonstrate this technology in two high-traffic, public restrooms at Utah State University before and after installing high efficiency, automatic faucets and toilet flush valves. We also integrated an inexpensive sensor to count user traffic. Sensing restroom visits and water use events allowed us to identify fixture malfunctions, average water use per person, variability in use by fixtures (faucets versus urinals and toilets), variability in use by fixtures compared to manufacturer specifications, gender differences in use, and the difference in use after retrofit of the restrooms with high efficiency fixtures. The inexpensive metering system can help institutions remotely measure and record water use trends and behavior, identify leaks and fixture malfunctions, and schedule fixture maintenance or upgrades, all of which can ultimately help them meet goals for sustainable water use.

1. Introduction

Over the past several years, the market for smart meters capable of providing high temporal resolution data for advanced data collection and analytics has been led by natural gas and electric utility companies. New innovations in smart monitoring and analysis of water use are being driven by needs to evaluate water demands for individual end users and end uses (Nguyen et al., 2013). Water shortages like those experienced in recent years in the state of California have forced water managers to look for new ways to closely measure and monitor scarce water resources (MacDonald, 2007; Office of the Legislative Auditor General, 2015). Additionally, managers seek ways to decrease operational costs, and smart water meters can, in some cases, reduce personnel costs through automated data collection and billing. Thus, there is increasing interest in high resolution, smart metering technology as a means for better measuring and managing water end-uses (Boyle et al., 2013).

With the increasing interest in water conservation programs, measuring and managing indoor water use has become an important research topic (Vickers, 2001; USEPA, 2005; Inman and Jeffrey, 2006; Rosenberg and Lund, 2009; Boyle et al., 2013; Cominola et al., 2015). However, many limitations exist in current water use data collection and water management programs. There may be no ongoing monitoring. Or, where monitoring is ongoing, it is often conducted at too aggregate a level (e.g., a single meter for an entire building) or too coarse of a temporal or spatial scale to reveal water use behaviors. Measuring and recording water use with fine temporal and spatial resolution can help managers isolate end uses, better understand the quantity and timing of water use, and identify opportunities for savings (DeOreo et al., 1996; Nguyen et al., 2013, 2014). In residential applications, it has also permitted appropriate water saving goals to be established and has served as a benchmark from which water savings can be quantified (USEPA, 2005; DeOreo et al., 2016). In practice, high frequency measurements of water use can also provide important insights into water use behaviors, which conservation programs/measures work, which do not, and which efficiency solutions are most worthwhile – especially for large institutions where there is potential for significant budgetary savings through more efficient water use (Koeller, 2011). Because of this, smart metering technology can play an important role in providing the data necessary for improving water management.

There has been a wide range of definitions of what is meant by "smart metering systems" (Cominola et al., 2015). Many water

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meter manufacturers sell advanced, or smart, meters capable of storing and/or transmitting measurements at high temporal frequencies (Willis et al., 2011), which is an advance over older, analog systems that require labor-intensive, manual reading (typically monthly). However, according to Boyle et al. (2013), enhanced water management using smart metering technology requires four key concepts: first, the ability to make measurements with high frequency; second, the ability to transfer the data; third, capabilities for automated data processing and analysis; and lastly, capability to provide feedback to water managers and users based on results. Challenges in working with data from smart meters include: 1) the high cost of replacing existing meters with smart meters; 2) limited data storage and battery life, 3) limitations in communication bandwidth for transferring the high volume of data produced; and 4) difficulty in implementing post-processing algorithms for extracting meaningful information from the data collected (Stewart et al., 2013; Beal and Flynn, 2014; Mutchek and Williams, 2014). Despite these challenges, the ability to increase the frequency of data collection and the creation of rapid and accurate analysis of high-resolution data open up the ability to answer many research questions that will contribute to better understanding of end-use water demands. Such high frequency data collection can assist water managers in management of water demands and implementation of water conservation programs at a more precise scale than was previously possible (e.g., at an individual end use level rather than at the aggregate level of an entire building or residence).

In this paper, we present an inexpensive, open source, water metering system that uses off-the-shelf electronic components and analog, positive displacement water meters to measure water use quantity and behavior with high frequency. We used this system to conduct a study of water use in two high-traffic, public restrooms within an educational building on Utah State University's (USU) campus in Logan, Utah, USA. Using meters installed on the water supply lines for the restrooms, we collected data to disaggregate water end uses before and after retrofit of the restrooms with high efficiency water fixtures. We also integrated people counter sensors to pair measurement of water use with measurement of the number and timing of restroom users, allowing us to identify temporal patterns and per capita water use within the restrooms with high resolution. We designed the data collection to answer three primary research questions: 1) How can we quantify water use and behavior in high-traffic university facilities and identify potential water savings after installing high efficiency water fixtures?; 2) How can we estimate individual water use and potential gender differences?; and 3) How can we verify manufacturer specifications of expected fixture performance by metering water usage? These questions were formulated in collaboration with USU's Facilities department to address their information needs and to provide data that could be used to evaluate changes in water use associated with infrastructure investments.

2. Background

Positive displacement water meters with analog, mechanical data registers are used extensively in residential and industrial applications for measuring water use given their low cost and high accuracy at low to moderate flow rates (typically measurements are within 0.25–0.50% of the actual flow) (Boyle et al., 2013). These meters measure cumulative, volume-based water use and are typically read manually on the order of once per month. Monthly data do not capture the timing of water use events or the underlying behavior of water users, which can be important in informing better water supply design and management (Cole and Stewart, 2013; Gurung et al., 2015). Additionally, low frequency data do not facilitate easy identification of leaks or testing of appliances or fixtures to see if they are performing according to standards. These limitations can potentially be overcome using high frequency data collection that can characterize the timing and magnitude of individual water use events.

There are commercially available smart meters that provide high frequency water use data (Table 1). However, these smart meters have not yet seen widespread adoption in the U.S. due to the four major challenges of cost, data storage and battery life, data transfer, and data processing. Like any technology development and application, challenges such as these arise and need to be overcome. For example, to date, smart water meters can cost hundreds or even thousands of dollars each, which can mean tens of thousands to millions of dollars in retrofit or replacement costs for water utilities, depending on the scope of the project and the existing status of their system's meters (Beal and Flynn, 2015). Cost can even be an issue for smaller scale scientific studies requiring detailed data collection efforts. Each adoption issue is still subject to ongoing investigation and development. However, these are the key aspects that, when fully developed, will make smart metering a viable mechanism for quantifying end water use demand and determining accurate management strategies (Cominola et al., 2015). Table 1 summarizes some of the current smart metering technology available and their main characteristics as described in Froehlich et al. (2009), DeOreo et al. (1996), and Nguyen et al. (2013). Current technologies are making efforts to fulfil the need for smart metering, but some still lack functionality in one or more of the aspects mentioned above to be considered complete.

In this study, we specifically worked to address components of the four smart metering challenges listed above. We did this in the context of measuring water use behavior in two high-traffic, public restrooms on USU's campus. We studied these restrooms mainly because reducing the amount of water used within public restrooms can result in significant reduction of the water budget for institutional water managers. On average, more than 500 users per day walk in and out of the restrooms we studied, and there are many other public restrooms on USU's campus. Finding ways to improve water use efficiency and implement plans to decrease water demand, especially in high traffic areas, is an attractive strategy for institutional water managers to save water and reduce overall costs to the university through demand management.

Institutional water managers have two options for decreasing water demand: 1) create water conservation campaigns to educate users in efforts to change their behaviors; and 2) change or modify the setup of water fixtures using technology that claims high efficiency. Conducting water conservation campaigns can be an effective means to achieve water use behavior improvements, especially when quantifiable data can be provided to water users to empower social marketing efforts (Silva et al., 2010). Alternatively, installing higher efficiency water fixtures may be a permanent solution for reducing water demand while still meeting user's needs as long as the water savings are significant and justify the cost of the retrofit, facts that can be verified when substantiated via data collection.

However, questions remain about how well high efficiency water fixtures perform, the extent to which they are effective in changing water use behavior and ultimately total water use, and how knowledge of water use behaviors can be applied to maximize water savings with minimal investment in conservation campaigns and fixture retrofits. In the study we present here, collection and post processing of high frequency flow data helped us answer these questions. We designed and prototyped a data collection system that allowed us to collect high frequency water use data within each restroom along with timing and counts of water users. We monitored the restrooms before and after retrofit with high