URBAN WATER MANAGEMENT: TRADITIONAL AND NON-TRADITIONAL MANAGEMENT METHODS AND THE EFFECTS OF ADVANCED METERS

A Thesis

by

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ABSTRACT

Urban water supplies have traditionally been managed through demand side management practices such as pricing, education, legislation, technology, maintenance, and more. These practices having varying effectiveness and should be combined for greater impact. Other factors that influence consumption, such as weather patterns, attitudes toward conservation, and socio-economic factors, determine how effective demand management is. A shift in management paradigms involving treating the various sources of urban water, drinking water, wastewater, and stormwater, as a single system and using water of a quality level that matches its use is occurring to help increase the amount of water that can be conserved through management. Another change in management practices is the implementation of advanced meters which have many benefits, including reduced water consumption and detection of water theft and leaks. The use of such Advanced Metering Infrastructure (AMI) is implemented in Arlington, Texas where having access to hourly consumption data has on the water usage of residents was observed to have slight reduction effects on the amount of water consumed by online data portal Users. These reductions varied depending on whether the consumption data was compared to the previous year or to the historical averages. This likely was influenced by vast differences in precipitation during these years. The demographic and socio-economic characteristics of the residents was examined along with the change in consumption data over of the residents who use the portal as compared with the change in consumption of those who do not. It was found that the in characteristics of the residents who used the portal were not largely different than from those that did not use the portal.

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1. INTRODUCTION

1.1 Motivation and objective of study

Adequate water supply is essential for all cities to provide for current needs as well as to plan for future populations. Population growth, climate change, pollution of water sources, and urban growth can create discrepancies between the amount of water available and the amount population demand (Gleick 2011 and Willis et al. 2010a, 2011b as cited in Makki et al. 2015, Jorgensen et al. 2009). These changing factors cause water to be a concern for governments and utility services, making water management strategies a necessity (Makki et al. 2015). Government and water providers have developed and introduced a variety of management strategies to help ensure the supplies are enough to meet future needs (Chen et al. 2005 and Marsden & Pickering 2006 as cited in Jorgensen et al. 2009, Kenney et al. 2008, Willis et al. 2010). These strategies manage either supply or demand. Supply strategies, such as pipeline extensions, creation of dams, alterations of reservoir storage capacities, are sought after by many water providers (Jorgensen et al. 2009), but these solutions are often costly as they require major infrastructural changes. If supply cannot be feasibly altered, water providers will turn to demand management. Demand management strategies include pricing policies, water restrictions, educational programs, maintenance programs, rebates for more water efficient devices, and more (Inman & Jeffrey 2006 as citied in Willis et al. 2010). When management strategies are developed the predicted or estimated water and monetary savings are often developed as well (Willis et al. 2010). These potential savings could be used to help determine the best or most effective management strategies. While demand management can seem like a simple choice is can come with its own costs and other issues, such as concern over fairness and equity of pricing (Jorgensen et al. 2009) or a lack of understanding and motivation. An example of government developing water management strategies is the Texas Water Development Board and the statewide surface water planning process it administers.

In Texas, the pursuit of statewide management of water was sparked by the drought of 1950s which lead to the creation of the Texas Water Development Board (TWDB) in 1957 and the first state water plan in 1961. This plan described to uses of ground and surface water, described to reservoirs development, estimated future water use, and sought to plan for the future needs. The TWDB continues to plan for future water supplies by creating new state water plans every five years. As the most recent state water plan estimates, by 2020 there will be 29.5 million people living in Texas and by 2070 there will be 51 million. This population increase will cause the municipal water demands to increase from an estimated 18.4 million to 21.6 million acre-feet per year, while the estimate water supplies will decline from 15.2 million to 13.6 million acre-feet per year. This disparity in water demand and supply are reason for the near 5,500 management strategies suggested in the plan (Texas Water Development Board 2017), and as many of these people will likely live in urban areas the management strategies used for urban supply will be of significant importance.

This thesis serves to explore urban water supply management in two ways. The first is to explore the ways in which water is currently managed in urban areas and the way in which management paradigms are shifting to include modern technology and address supply concerns through conservation. The water management is traditionally accomplished through the use of practices that help to control the demand of a population. The demand management practices to be discussed are pricing, education, legislation, infrastructure, and maintenance. However, water demand can also be affected by factors that cannot be controlled by management practices, such as weather, socio-economic characteristics, and attitudes and beliefs about water conservation. While current practices have their merits, a shift towards practices that consider all parts of the urban water supply system as potential sources of water and implementation of technology are being considered more often in order to more effectively manage water.

The second purpose of this thesis is to examine how Advanced Metering Infrastructure (AMI) affects the amount of water consumed by the residents of Arlington, Texas, an urban center near the Dallas Fort Worth area. Hourly water usage was logged using advanced meters which was transmitted to the utility service. The residents were then able to access to their hourly water consumption through a data portal. This thesis is an examination on how access to water usage information can affect the amount of water consumed and the characteristics of the residents who choose or do not choose to access their hourly data.

1.2 Organization of thesis sections

The current section has introduced the topics and analysis to be discussed in this thesis. Section 2 addresses the first topic through a review of literature concerning urban water management practices and the use technology in water management.

Section 3 and 4 address the topic of analysis for this particular project. The methodology used for analyzing the water consumption of the Arlington, Texas residents is described in Section 3. The subsections of Section 3 delineate the procedures used for data preparation and analysis of several different comparison scenarios. The results of each of these scenarios are in similarly named subsections of Section 4.

Section 5 summarizes the analysis results, possible sources of data shrinkage and concludes with the determined effects of AMI in water management practices.

2. LITERATURE REVIEW

2.1 Demand side management

The management of water utilities in the past has generally been to provide ample supply capacity that can meet the maximum peak demands with additional supply to deal with the uncertainty and account for unpredicted demand increases (Bahri & Vairavamoorthy 2016, Strbac 2008). However, since this is often a costly and inefficient way to manage consumption, demand side management (DSM) practices have been used to help lower the overall total demand in hopes of lowering the maximum capacity that would need to be made available. DSM strategies include water efficient devices, water restrictions, pricing, rebate programs, conservation or educational programs, and maintenance (Inman & Jeffrey 2006 and Gold Coast City Council 2005 as cited in Stewart et al. 2010). These strategies have varying effects on changing how the public views water consumption (Arbués et al. 2010 as cited in Beal et al. 2013, Olmstead & Stavins 2009, Nieswiadomy 1992).

2.1.1 Pricing

The traditional DSM practices to be discussed in this review includes five basic strategies, the first of which it the use of economics and pricing structure to help reduce consumption amounts is common. Price is often used as a management device because it is widely accepted that as water prices rise the amount of water used will fall (Olmstead & Stavins 2009). Pricing structures often takes one of two forms, increasing block rate (IBR) or decreasing block rate (DBR). IBRs increase the marginal price of water as the consumer enters higher tiers of use (Maas et al. 2017), while the opposite is true for DBR. Logically, IBR would be more effective in curbing extraneous use since water gets more expensive the more that is used. IBR is effective because the first tier of water use satisfies most use, while the higher tiers would restrain lavish consumption (Arbués & Barberán 2004, Chen & Yang 2009). This structure helps to reduce demand peaks and encourage conservation efforts (Kanakoudis 2002). Conversely DBR would promote overuse of water, though some argue that it is the more efficient choice as it is expected that price is less elastic in the first block (Ramsey 1927 as cited in Arbués et al. 2003). Either way, pricing can help to save water, and is a powerful awareness-raising tool for the consumers that combines environmental and economic benefits (Haruo et al. 2014).

Over the years, there have been many studies to determine the price elasticity of water. Many studies have found that water demand is best estimated to be inelastic (Arbués et al. 2003, Olmstead & Stavins 2009, Harou et al. 2014) because the price elasticity of water has an absolute value of less than one (Arbués et al. 2004). This inelasticity indicated that as the price of water increase, less water will be consumed by customers. Schleich & Hillenbrand's 2009 study of 600 water supply areas in Germany found price elasticities between -0.230 and -0.252, Arbués et al.'s 2004 study of 1,596 random domestic water users in Zaragoza, Spain was more inelastic, resulting in price elasticities between -0.029 and -0.058, and Ruijs et al.'s (2008) study of Sao Paulo, Brazil resulted in elasticities between -0.45 and -0.50. Kenney et al. (2008) found price elasticity to be less inelastic with an average value of -0.60 in a study of 10,000 households in Aurora Colorado. This same study also showed the consumers who often used more water were more responsive to price, with an elasticity of -0.75, while those who typically used less water were less responsive, with an elasticity of -0.34. This is not surprising, as an increase in price could easily be more noticeable if lots of water is typically consumed. Yet another inelastic value was found, an elasticity of -0.33, in a study of 119 Californian households (Renwick & Archibald 1998). The 1997 meta-analysis of 124 US residential elasticity estimates yielded an average of -0.51, with long- and short-term elasticities of -0.64 and -0.38 respectively (Espey et al. 1997). This meta-study was continued six years later by Dalhuisen et al. (2003) in which 190 additional estimated were used to produce an average price elasticity of -0.41. Based on these studies and meta-studies it could be suggested that water prices are inelastic in many regions.

This inelasticity is possibly due a lack of understanding of how water pricing works (Arbués et al. 2003). Additionally, the water bill usually represents a small portion of the household budget causing the understanding of water prices to be less important (Arbués et al. 2003, Renwick & Archibald 1998). It is also suggested that a lack of understanding of the rate structure could contribute to the inelasticity of price (Arbués et al. 2003). Likewise, Cominola et al. (2015) noted that because of the limits on the consumers' price elasticity, increasing the price of water will reduce water demand significantly in the short term but have very limited long-term effectiveness.

The effectiveness of pricing as a conservation tactic can be influenced by factors such as region, income, and family size. A study of 430 US water utilities in 1984 to estimate the urban water demand of the U.S. found that water price is more elastic in the

West and South, possibly because residents in these areas are more aware of water scarcity and are thus more flexible in the amount they will pay for water (Nieswiadomy 1992). Though elasticities vary across the US, a 10% increase in water prices can be expected to decrease short term use by an average of 3-4% (Olmstead & Stavins 2009).

Several studies found that there was a variance in how consumers of differing income levels reacted to price changes. If price is used as the main DSM practice, the lower income customers will bear more of the conservation burden than their higher income counterparts. Lower income households were found to be up to 5 times as responsive to change in water price (Renwick & Archibald 1998) because the water bill makes up a larger portion of their budget (Renwick & Green 1999, Ruijs et al. 2008, Olmstead & Stavins 2009). This may lead to greater reductions in low income communities than in higher income communities (Renwick & Green 1999, Ruijs et al. 2008, Olmstead & Stavins 2009). Higher income households tend to be significantly less responsive to water prices than lower income (Olmstead & Stavins 2009) and have a lower level of awareness of their rate structures because it is a smaller portion of their budget (Arbués et al. 2003). Price increases can also affect households based on the number of people in the family. Larger families are more greatly affected by price increases as more water must be consumed to meet their basic needs (Arbués & Barberán 2004) and they will pay higher average prices if their rates are not corrected for family size (Ruijs et al. 2008). As mentioned in the introduction, these differences in how price affects different demographics is cause for some concern regarding policy fairness.

Overall, if policy makers use price as a tool for managing demand, it can be expected that an increase in price will lower the amount of water consumed (Arbués et al. 2000, Arbués & Barberán 2004, Olmstead & Stavins 2009). Prices can convey messages to users, causing them to have an increased awareness of the amount of water that they are consuming (Arbués & Barberán 2004). However, use of price exclusively would have limited results (Arbués et al. 2000, Ruijs et al. 2008). Therefore, pricing policies should be combined with other methods which promote conservation through efficiency and behavior (Ruijs et al. 2008).

2.1.2 Education

The second basic DSM practice is the use of education. Educational campaigns are commonly used among utilities, and there is reason to believe that they are effective tools. However, it is unclear if the effectiveness stems from the appeal of reducing cost the customer or if the customer simply feels good about conserving (Maas et al. 2017). The use of education and public awareness campaigns has varying effects (Cominola et al. 2015). In California, from 1989-1996, public information campaigns were used to alert the residents of shortages and provide information on usage reductions to encourage water-efficient behavior. This produced a reduction in use of 8%. However, since this study occurred during a period of drought, it could be expected that these same results would not be achieved during a period of more normal precipitation (Renwick & Green 1999). The effects of educational programs can also vary based on the area in which they are implemented. Nieswiadomy (1992) found that the use of education led to reduced water use in the western U. S., most likely due to a heightened awareness of water scarcity. Education measures are consistently effective across different regions. However legislative DSM practices such as mandatory restrictions could possibly reduce water demands more reliably (Beal et al. 2013).

2.1.3 Legislation

The third traditional DSM practice is legislation. This legislation takes the form of rationing, allocation, or restrictions. While fewer studies were found concerning this area, it is worth noting that the information found is significant. Renwick and Green (1999) studied the use of these programs in the previously mentioned 1989-1996 California study. It was found that rationing and allocation programs reduced the average household water demand by 19%, and the use of watering restrictions reduced the demand by as much as 29%. Similarly, it was observed by Cominola et al. (2015) that restrictions applied to activities like car washing and irrigation could reduce water use by as much as 30%. Literature consistently shows noteworthy water savings (up to 30%) produced by the mandatory restrictions, while voluntary restrictions understandably produce more variable results that commonly lag behind the mandatory restrictions (Lee 1981, Lee & Warren 1981, Shaw & Maidment 1987, 1988, Renwick and Green 2000, Kenney et al. 2004 as cited in Kenney et al. 2008). Unfortunately, the implementation of these regulatory measures can come late as it is often reactionary rather than proactive (Farrelly & Brown 2011, Kennedy 2010; Renwick & Archibald 1998, Beal et al. 2013).

2.1.4 Infrastructure

Another way to manage demand is to encourage the use of more conservative infrastructure, such as automatic sprinklers, low flow toilets and water efficient showerheads or washing machines (Cominola et al. 2015, Haruo et al. 2014, Renwick & Green 1999, Willis et al. 2010, Kenney et al.2008), and to maintain the existing infrastructure. Increasing efficiency through engineering and development of technology has created reductions in water consumption (Willis et al. 2013). The study done in California by Renwick & Green (1999) found that the distribution of free retrofit kits, which typically include a low-flow showerhead, tank displacement devices, and dye tablets for leak detection, resulted in the average residential demand reducing by 9%. A later study in Tampa, Florida of 26 single family homes retrofitted faucets, showerhead, toilets, and clothes washers. It was determined that retrofitting the households' infrastructure resulted in a 49.7% reduction of water use because of increased efficiency (Mayer et al. 2004). Comparable results were produced by a different study, with reductions between 25 and 50% (Inman & Jeffrey 2006 as cited in Willis et al. 2013). A study of 151 in Gold Coast City, Australia replaced low efficiency showerhead and clothes washers with high efficiency models, resulting in an annual water savings of 11.3 kL and 14 kL, respectively, per person (Willis et al. 2013). The use of water efficient appliances offers enormous potential in the reduction of water use; however, the actual benefits are often found to be inconsistent (Cominola et al. 2015). This could be due to the amount of potentially conserved water being lessened because of a consumer's behavioral changes (Olmstead & Stavins 2009). Consumers may start to take longer showers because they believe having a more efficient showerhead guarantees that less water will be used. The same could be said about clothes washers, customers may not try as hard to fill the machine before running, counting on the increased efficiency to save water rather than trying to actively conserve. The installation of water saving devices can even cause an increase use due to these misguided beliefs (Inman & Jeffrey 2006 as cited in Willis et al. 2010). Additionally, consumers may not attempt to conserve water when using less efficient devices if they have water saving appliances elsewhere in their home (Syme et al.2000 as cited in (Beal et al. 2013)

2.1.5 Maintenance

The final DSM practice to be discussed is maintenance. This normally consists of the reduction and elimination of leaks in the supply network. Though leaks may not immediately seem concerning, over extended periods of time they make up for a major portion of loss in a distribution system. With the average daily per capita leakage rate being 7.9 gallons in the U.S. (Water Resources Foundation 2016), these leaks account for a sizable portion of water use. Loss rates vary based on the type and severity of the leaks, but in general leaky taps lose 3-30 liters per day and toilets lose 10-340 liters or more (Britton et al. 2008), and Roberts (2004 as cited in Britton et al. 2008) found that leaks make up 7.5% of all indoor use. The identification and repair of these leaks can substantially increase the efficiency of a supply network at relatively low costs when compared with the cost of augmenting the water supply capacity of the network (Cominola et al. 2015). Because the purpose of demand management is conservation, it is important to reduce water use as well as water loss.

2.2 Other factors

User demand can be influenced by things other than DSM practices, such as the weather, attitudes and behavior, and socio-economic factors. Weather patterns such as rising temperatures and rainfall affect the amount of water consumed by impacting short term water use decisions. Water use can increase significantly when temperatures rise, or rain becomes scarcer (Brown et al. 2013 as cited in Garcia-Cuerva et al. 2016) and Kenney et al.'s (2008) study found that for every degree the average daily temperature rose water consumption increased 2%. Conversely, it would not be unreasonable to assume that consumers would use less water during periods with a large amount of rainfall. The same study also showed that water consumption would decrease 4% with every inch of precipitation. However, the amount of rain may not be the only contributing factor to decreased use. Arbués et al. (2003) found in a review of other studies that water users would appear to respond more the occurrence of rain than the amount of actual rainfall, suggesting a psychological correlation. People may recall the number rain events, even small ones, more than the actual amount of precipitation that their area had received and decrease their usage in response. This would mean that the number of rainy days could be better explanation for usage reduction than the amount of rain during a period.

Changes in attitudes towards conservation measure, as well as conservative behaviors, will become more necessary as population demands grow, even with efficiency gained through technology (Midden et al. 2007 as cited in Steg & Vlek 2009). Fortunately, a national survey of 2,800 respondents showed that the majority of the population already conserves water (Garcia-Cuerva et al. 2016). People who consider themselves to be conscious of conservation matters would certainly be expected to use less water. Consumers who choose to conserve out of ecological concerns may even use less water than those concerned mainly about cost, and certainly use less than those who are merely reducing use because they are forced to by restrictions, since the conservation effort would be a personal choice. This was confirmed in a telephone study in Colorado, where consumers who identified as eco and socially motivated used significantly less water (conditional on household characteristics) than consumers who were motivated by cost (Maas et al. 2017).

Though people concerned about water conservation may have good intentions, they might not always act in a way that achieves their goals. Positive attitudes towards conservation, and resulting behavioral changes, have become more common (Beal et al. 2011, 2013, Millock & Nauges 2010, Willis et al. 2010, 2011), perceptions of consumption and actual consumption are often mismatched due to lack of correspondence between conservative attitudes and behaviors (Kraus 1995 and Dolnicar & Hurlimann 2010 as cited in Beal et al.2013). The difference in perceived and actual water use is also affected by socio-economic factors. Beal et al.'s (2013) study showed that households with lower incomes, lower levels of education, fewer water saving devices, and fewer occupants tend to overestimate the amount of water that is actually used. These same households had greater intentions of saving water, and saw themselves as water conscious. Conversely, the households that underestimated their water use had higher incomes, more occupants (particularly children), and more water saving devices. These households did not generally see themselves as water conscious, nor did they have much intention of lowering their consumption. This underestimation could be caused by the fact that, as mentioned before, their water bill is not a sizable portion of their budgets or that they wrongly assume that efficient appliances guaranteed water was being saved. Because consumption is tied to community attitudes and behaviors, as well as other socio-economic factors, the effectiveness of DSM practices can be influenced. This should be taken into consideration when water providers are deciding what management strategies should be put into place.

Overall, traditional DSM practices have seen a fair amount of success. Price increases in conjunction with voluntary DSM policies can produce moderate water reductions (5-15%), and larger price changes used with mandatory DSM policies can produce even greater reductions (>15%) (Renwick & Green 1999). Despite the results, these strategies may not always be enough, and innovative ways to manage water must be explored.

2.3 Shift towards integrated urban water management

Water supplies are facing the pressure of growing populations and household consumption. Because of this, a different approach to addressing the problem of water scarcity has seen a rise in popularity amongst governments and other water providers, Integrated Urban Water Management (IUWM). This shift is being made in an effort to guarantee water security (Beal & Stewart 2011 and Correljé et al. 2007 as cited in Makki et al. 2015, Stewart et al., 2010) and cope with population growth and climate change (van de Meene et al. 2011). IUWM is the "strategic long-term planning approach to urban water management which considers water services, sources, stakeholders, and impacts in order to create the best possible community outcomes" (Furlong et al. 2016). This method integrates the water sources of urban planning (Furlong et al. 2016), whereas the traditional urban water cycle is separated into three different systems: drinking water, wastewater, and stormwater (Díaz et al. 2016). This approach requires the water systems to be thought of as one complete system. This system seeks to reduce the amount of pollution generated, use and reuse water as close to its source as possible, and to match water quality to the water's intended use (Díaz et al. 2016). Matching appropriate quality to the water's intended use is important as it reduces the amount of wasted potable water. Using reclaimed, grey or storm water for toilet flushing, irrigation and industrial use decreases the amount of water that is withdrawn from fresh water systems and that has to be treated. Unfortunately, there is some resistance to water reuse as it tends to produce a "yuck factor" with the public, though this is likely caused by a lack of understanding of reclaimed water (Garcia-Cuerva et al. 2016).

The use of IUWM is has the great opportunities for results in areas that are facing climate change as well as small- to mid-sized cities as these areas are likely to face rapid urban growth (Bahri & Vairavamoorthy 2016) as well as areas where water supply is already a concern. In Southeast Queensland, Australia implementation of IUWM strategies produced large reductions in water use and greater community awareness of water (Makki et al. 2015). The following table illustrates the some of the key differences between conventional and integrated approaches to urban water management.

Table 1: Several Differences in Urban Water Management Paradigm Approaches

Conventional Approach	Integrated Approach
Sources of Water: surface and groundwater	Alternative water sources: surface water, groundwater, rainwater, wastewater, desalinated water
Same quality for all uses	Matching quality with intended use
Demand equals quantity	Demand is multifaceted. Infrastructure matches the characteristics of water required or produced for end-users in sufficient quantity, quality, and level of reliability.
Linear approach to collection, treatment, use and discharge	Circular approach offering integrated systems to provide water, energy, and resource recovery
Fragmented institutions	One urban water cycle. Physical and institutional integration sustained through coordinated management efforts
Top down planning	Involvement of stakeholders

Adapted from Bahri & Vairavamoorthy (2016)

Despite the benefits, IUWM could pose some difficulty in implementation. There are many barriers, such as institutional fragmentation, limited long term planning, inadequate community participation (van de Meene et al. 2011), and well as requiring many changes from the conventional and currently uses approaches. Clarification of the roles and responsibilities of various actors, coordination and communication with the community, education of the public, and harmonization of policies and laws are just a few of the steps identified by Bahri & Vairavamoorthy (2016) that must be taken in order for IUWM to be implemented. Shifting from traditional paradigms would be difficult, but necessary, for sustainable water management (van de Meene et al. 2011) and the potential benefits would provide balance and security to the management of urban water. Another prominent issue with IUWM is that understanding water demand,

and the factors that affect demand, at multiple spatial and temporal scales would be key to its application (Rathnayaka et al. 2017) and investments in infrastructure (Díaz et al. 2016) that can provide that information.

2.4 Advanced metering infrastructure

Advanced meters are digital devices that record the amount a utility is used and send the usage data securely to the utility. There are several types of advanced metering, automatic meter reading, automatic or advanced meter infrastructure, end-use, and source. Automatic meter reading (AMR) and automatic or advanced meter infrastructure (AMI) are very similar, though they have a couple key differences. AMR, or touch meters, typically record and store usage data at high resolutions, allowing for continuous consumption recording, but the data must be collected at a close range. AMI generally collects data at a lower resolution, though it does have high resolution capabilities, and actually transmits the usage data directly to utilities without the need of manual or close proximity collection. End-use metering involves measuring the amount of water used by each individual water using appliance in a home. This method is very costly and generally not accepted by residents because it is seen as intrusive, though it provides higher resolution of water use. Source metering is done with a single meter that measure the total flow for the household. This method is more accepted by the residents and is easier to implement, but has lower accuracy (Cominola et al. 2015). End-use and source metering may use either AMR or AMI meters.

Advanced meters have many benefits both to the consumer and to the utility. These meters are more efficient for collecting data because they may be read remotely and they are able to provide consumption information, at spatial and temporal resolution that had not been possible in the past. This information could be used to evaluate DSM strategies and consumption patterns for different demographic groups (Beal et al. 2013; Stewart et al. 2010, Willis et al. 2013) and is essential to understanding and modeling individual behavior allowing for personalized water demand management strategies. A study was performed to see if the advanced meter data collected from nine properties in Greece could be used to predict water consumption with some success, though the models lacked some accuracy (Walker et al. 2015). The advanced metering also serves to promote beneficial changes in the behavior and attitudes consumers have regarding saving water. Conservation efforts are more perceptively rewarded because the meters transmit usage in real time (or near real time), allowing for more accurately billing of the consumer. This is better than the current method utilities use in which the end of the month usage is estimated and charged to the customers. These readings could also be used to apply a more dynamic price structure accurately.

Another benefit is that as the data is recorded over time, it builds a database of individualized usage. This data could then be used to detect anomalies in the data, which could lead to the identification of leaks or theft of utilities. A study in Point Vernon, Australia used of 2,359 residential AMR meters to find leaks in the distribution system (Britton et al. 2008). This was done by identifying meters which had not a single reading of zero flow within a 48-hour period. From the time that the 47 meters with leaks were identified to the time when the leaks had been repairs (156 days on average), a total of 4.2 million liters of water had been lost.

The historic data could also be used to provide personalized feedback to consumers on how their recent use has differed from the norm, and how they could improve conservation efforts. There is often a significant difference in the amount of water the customers perceived they were using, and the amount that they were actually using caused by a lack of consumption feedback (Beal et al. 2013). However, when feedback is provided the perceived water use and actual use converge, allowing customers to better estimate how much they are using, if they are conserving or if the need to cut back of their use. A study of 221 households in Australia observed that giving consumers feedback to their usage data was found to reduce water consumption by 7.9% (Fielding et al. 2013). Feedback can be provided in the form of an online portal like the following study in Dubuque, Iowa. This study found that when 303 consumer households were given access to an online portal to view water use, their normalized consumption dropped 6.6% over nine weeks (Erickson et al. 2012). Online access to data also enables consumers to act more conservatively if they notice that their water use is higher than they want it to be. Other studies suggest that consumption feedback can reduce usage from 3 (Petersen et al. 2007 as cited in Sønderlund et al. 2014) to 53.4% (Willis et al. 2010). Sønderlund et al. (2014) observed that when feedback is given with time-series data, historical and social comparisons, and water saving advice, it reduces water use more effectively.

The following table provides a summary of sources that cited the previously mentioned benefits of advanced metering.

Table 2: The Benefits of Advanced Meters

Benefits **Source**	**Remote Data Collection**	**Spatial & Temporal Resolution**	**Consumer Behavior**	**Historical Data**	**Customized Feedback**	**Real Time Data**	**Dynamic Pricing**	**Anomaly/Leak Detection**	**Efficiency & Sustainability**	**Utility/Consumer Relationship**
Chou & Yutami 2014	X			X	X	X	X	X	X	X
Cominola et al. 2015		X	X		X					
Díaz et al. 2016	X			X		X		X		
Harou et al. 2014				X		X	X	X		
Lloret et al. 2016						X		X	X	
Makki et al. 2015	X	X		X						
Sønderlund et al. 2014		X	X	X	X	X		X		
Stewart et al. 2010	X	X	X		X	X		X		
Walker et al. 2015		X						X		
Willis et al. 2010	X	X								

There is the potential that having so much access to water usage data and feedback could have negative effects as well. If a consumer who typically tries to be more conservative because they are not sure of how much they have used suddenly has access to exact consumption data they might stop acting as conservatively. The knowledge that they have not used as much as they had though may cause them to relax and use more water than they would have before. This effect was shown in a survey of 28 Australian households (Strengers 2011) in which an in-home display presented the level of water used in stoplight form, that is to say that low, medium, and high usages were displayed with green, orange, and red lights, respectively. It was found that that when presented with an orange light consumption was legitimized since a high usage level had not yet been reached. Even if having ready access to usage data does not cause an increase in total consumption, the novelty of being checking water usage could wear off causing any positive effects of the feedback to be lessened.

Though consumers having so much access to their data may help the legitimize extra use, the benefits of advanced metering are still numerous and will help to provide the insight that will be required for better water management strategies, like IUWM, in the future. The effects of the advanced meters are explored in the following section through the study of the advanced metering and data portal used by the water utilities of Arlington, TX.

3. METHODOLOGY

This study explores how allowing consumers regular access to their usage data affects the amount of water they consume. This was done by comparing usage data in several different scenarios. Water usage data used in this study was obtained from City of Arlington Water Utilities Department using primarily Sensus SRII meters. These meters are used to collect usage data in one-hour intervals though they have the ability to collect data in 15-minute intervals. The usage data is stored at the radio on the meter and transmitted to data collectors every four hours. If for some reason the meter is unable to transmit, due to radio signals being blocked by a parked car or other obstacle, the data will continue to be stored until it is successfully transmitted. However, if the data goes without being transmitted for too long the data packages will be deleted to make room for new usage measurements. The original Arlington pilot area of AMI deployment included approximately 17,000 meters and as of August 2017, nearly 50,000 of the meters had been installed. The water utilities consumers that have an advanced meter installed were given the opportunity to sign up for an online portal. Through this portal, the residents were able to access charts and graphs showing how much water they had used over different time intervals, such as daily or hourly, as well as how much that usage cost them.

It was hypothesized that having access to high resolution usage data would reduce the amount of water a customer consumes. Access to this data would allow customers to monitor their consumption, check for unexplained usage, and view how much their usage had cost them. Seeing the usage with its associated cost could make the customers more aware of their use and encourage them to be more careful about their consumption. This hypothesis was tested in multiple comparison scenarios. The first scenario compared the winter water usage of portal Users to Non-Users during the year of 2015 and annual water usage of portal Users to Non-Users during the year of 2015. The second and third compared the water used by more established portal Users and Non-Users between the years of 2014 and 2015 and calculated to the cost of that consumption. The next comparisons were of the established portal Users and the newer Users and how water and cost was reduced from 2014 to 2015. The final scenarios compared the difference in water used and the associated costs by portal Users and Non-Users between the year of 2015 and their historical average consumption. In all scenarios, the Non-Users act as the control since they do not have access to, and are therefore not influenced by, the hourly data available through the portal. Additionally, the issue of data pool shrinkage when comparing the historical and 2015 data is addressed, and likely causes identified. Finally, the characteristics of the portal Users and on-Users are examined through survey results.

Through these comparisons the following research questions could be answered:

1. Do the AMI portal Users have different indoor consumptions than then Non-Users?
2. Did the AMI portal Users have different water consumptions during 2015 than the Non-Users?
3. Does the AMI portal lead to significant year to year water reductions?

4. Do the reductions in caused by the AMI portal change with time after account holders have joined the portal?

For this study, the total monthly water usage data records were obtained for the advanced meters. These data records contained the meter ID and types (residential, commercial, sprinkler, etc.), the physical address of the meter, the account ID associated with the meter, the customer's user ID if they had elected to sign up for the data portal and the total monthly usage.

3.1 Comparison of 2015 usage between Users and Non-Users

The first data comparison scenario was the water usage of the portal Users and the portal Non-Users for the year of 2015. After the monthly usage data records were gathered for the water meters of Arlington, Texas, the residential meters were separated from the other meter types. This was done so the consumption comparison results would be only for residential meters and not be distorted by the other types, such as commercial, fire line and sprinklers. The data records each contained a single month's usage for an account, therefore the records had to be combined so that an account's consumption for multiple months could be viewed on a single record. Some records were not used in analysis because the monthly consumption was unreasonably low or even negative due to records manipulation by the utility. It was assumed that a single person would use at least 20 gallons per day. Therefore, if an account showed a monthly consumption lower than 20 gallons per day it was not considered for the comparison and removed. Once the low use records were removed, the accounts were separated into portal Users and Non-Users. The necessary data manipulations were done using Microsoft Access.

3.1.1 2015 Winter comparison

The comparison of the portal Users and portal Non-Users during the winter months of 2015 is important because it will show if the average user consumes more or less water than the Non-Users. If the portal Users are consuming less water than the Non-Users, this could mean that the portal will not have a substantial impact on the amount water reduction possible since the Users are already using a smaller amount. This could also mean that the portal Users are more water conscious than the Non-Users meaning that the Non-Users are not likely to reduce their consumption anyway. Conversely, if the portal Users are consuming more water on average, the portal could have a larger impact on the total amount of water used by Arlington residents as it would reduce the amount of water consumed by high usage customers. The examination of the winter months likely gives a better representation of the typical indoor usage of a household as the demand for water outdoors will be smaller since sprinkler systems and pools are less likely to be used.

The comparison of winter usage included data from December 2015 and January and February 2016. Usage outliers were determined for each of the account categories in two ways, by monthly usage and by total winter usage. A monthly usage record was considered an outlier if the usage of a month was outside two standard deviations of the average usage for that month. The range of two standard deviations was chosen as it kept 95% of the accounts, removing only the extremely low and extremely high usage amounts. These records would not have adequately represented the different account categories. If an account was identified as an outlier for any one of the winter months it was not used during the comparison. The total winter usage outliers were flagged if the total winter usage of an account was outside two standard deviation of the average total winter use. Like before, if an account was identified as an outlier it was not used in the comparison. The two methods of outlier determination were done to ensure that (1) the total winter consumption was not skewed by a single month's data with questionable accuracy and that (2) this analysis focused on "typical" Users without the bias of extreme low or high consumptions.

For both types of outlier removal, the comparison results were found by totaling the usage and number of accounts for both portal Users and Non-Users. These totals were used to calculate the average total winter use for the portal Users and Non-Users. The percent difference in usage between the portal Users and Non-Users was calculated using the following equation:

$$\text{\% Difference} = \frac{\left| AverageUse_{User} - AverageUse_{Non-User} \right|}{\frac{1}{2}\left(AverageUse_{User} - AverageUse_{Non-User} \right)} * 100 \tag{1}$$

From this equation, a negative value indicates that the portal Users have use less water on average than the Non-Users. The results from this section are shown in Section 4.1.1.

3.1.2 2015 Annual comparison

Like the winter comparison, the annual comparison illustrates the likely impact of portal access based on which customer group uses more water. The annual comparison however will illustrate the effect the portal could have over the entire calendar year, including summer and fall which are typically high water usage months in Texas due to higher temperatures.

The comparison of annual usage between portal Users and Non-Users included data from each month for the year of 2015. Usage outliers were taken out in the same two ways as described in the previous subsection, where if an account's usage for any month was outside two standard deviations of the average monthly usage of all the accounts, that month's data was not used in the analysis. Additionally, the comparison results, shown in Section 4.1.2, were found in same way as described as above.

3.2. Comparison of 2014 and 2015 usage of Users and Non-Users

When comparing the data records between 2014 and 2015 data, it was found that some account numbers had multiple meter IDs associated with them. Because of this, the 2014 and 2015 data records were given a unique identifier that combined the account number and meter number. This allowed for duplicate data to be removed and for the 2014 records to be easily and accurately matched to the 2015 records. The comparison of the 2014 and 2015 records was based on if an account owner signed up for the portal and when they signed up. The accounts were put into one of the two following categories: Users or Non-Users. These categories were chosen to help illustrate the effect that the portal has on water consumption. The Users would have been able to see their consumption data during both years, possibly causing them to use less water, whereas the Non-Users would have to rely on their memory, recalling how much water they thought they had used, rather than having an accurate measure of consumption.

The User category consists of the accounts that signed up to view the portal at any time during 2014 or 2015. The next category, Non-User, is made of the accounts that chose not to sign up for the portal at all and those who signed up in 2016. Both groups are treated as Non-Users since the 2015 data for accounts that signed up in 2016 would not have been seen by the account owner and therefore not affected by portal use.

Before analysis was performed, the data was prepared by removing low usage values. If a record showed negative consumption or that less than 20 gallons per day was used in a single month that month’s data was not used since it would be unreasonable for even a single person the use less than this amount. Outliers were found in the same manner as in the previous comparison in which data outside two standard deviation of the mean was considered an outlier. If an account contained an outlier for a given month during one or both years, the account was not used in the analysis of that month. The remaining record data was used to find the percent reduction of water usage for each month using the following equation. From this equation, a negative percent reduction indicates that consumption during that month in 2015 was greater than in historical averages.

$$\text{\% Reduction of Water Use} = \left(1 - \frac{Usage_{2015}}{Usage_{2014}}\right) * 100 \qquad (2)$$

A second round of outlier removal was done in which percent reduction outliers were found. This second round of removal ensured that unreasonable increases or decreases in water use were not included in the analysis. For example, an account that had used 795 gallons in August 2014 was found to have used 30,010 gallons in August of the next year, resulting in a -3,675% reduction. While these monthly totals were acceptable individually, the drastic increase from one year to the next was implausible. These results are displayed in Section 4.2.1.

After both types of outliers had been identified, the data could be compared in order to analyze the effects that portal access had and how much water was saved. The resulting comparison between portal Users and Non-Users, is shown in Section 4.2.

3.3 Comparison of 2014 and 2015 portal Users and Non-Users

The reduction of water is not only important because it reduces the amount of resources used and possibly wasted, but also because it saves the consumers money as well as the utility service since they have to treat and provide less water.

The data from the previous comparison is used to calculate the water savings in terms of dollars. This was done by applying the 2015 City of Arlington Water Utilities Department price structure to both the 2014 and 2015 usages. This rate structure is shown in Table 13. The percent reduction of money spent on water was calculated for the User and Non-User categories and compared. These results are shown in Section 4.3

3.4 Comparison of 2014 and 2015 usage by 1st and 2nd year portal Users

This comparison separates the Users category and separates it into two groups for comparison: portal Users who are still in their first years of using the portal and portal Users who have enters their second year of portal user. It is important to differentiate between 1st and 2nd year portal Users so that the effectiveness of the portal can be examined over time. If the Users in their first year of joining the portal are shown to have reduced their consumption more than the Users in their second year of joining the portals it could indicate that the portal's reduction effects are not permanent or that customers cannot be expected to continually greatly reduce their consumption from year to year.

The 1st year User category is made of the 2014 and 2015 portal user types. 2014 Users are portal Users who signed up sometime in 2014. When comparing the 2015 data, if a specific month was less than one year from the sign-up date then for that month the account was categorized as a 1st year User. For example, if an account signs up June 2014 during the period of January to May 2015 the account is a new user. 2015 Users are portal Users who signed up sometime in 2015. When comparing the data from these accounts, only the months where the account was considered a user were included in the analysis. For example, if an account signs up June 2015 during the period of January to May 2015 the account is a not a portal user and is not included in the data analysis. However, from June to December 2015, the account is considered a 1st User and is included in the analysis.

The 2nd year User category is made of only the 2014 portal user type. When comparing the 2015 data, if a specific month was one year or more from the sign-up date the for that month the account was categorized as a 2nd year user. Similar to the example before, if an account signs up June 2014 it would be an 2nd year user from June to December 2015. The 2nd year User subcategory is important for determining if the portal continues to have an impact on the conservation of water or if the conservation effort decreases over time.

The Users in their second year of joining the portals and the Users in their first year of joining the portal were compared using the Non-User group's reductions as a baseline. The difference in percent reduction between the Users in their second year of joining the portals and the Non-Users and between the Users in their first year of joining the portal and the Non-Users were calculated and compared. This baseline allows for the potential reductions caused by the portal to be illustrated in terms of immediate and long-term results by the 1st and 2nr year Users, respectively.

3.5 Comparison of 2014 and 2015 usage cost by 1st and 2nd year portal Users

Similarly, to the previous cost comparison, the usage data from the previous subsection was also used to calculate the water savings in terms of dollars. This was done by applying the 2015 City of Arlington Water Utilities Department price structure to both the 2014 and 2015 usages. This rate structure is shown in Table 11. The percent reduction of money spent on water was calculated for the 1st and 2nd year portal User categories and compared. These results are shown in Section 4.5.

3.6 Comparison of historic and 2015 usage of Users and Non-Users

A comparison of historic and current usage was desired as historical averages would comprise of more established usage patterns. This would allow for the reductions to be calculated when compared to data with more average precipitations and therefore more average water demands. Before the historical data could be used for analysis, it had to be sorted through so that comparisons could easily be made. The historical data comprised of usage data from 2009 to 2013. Data from this time period was chosen as it was outside the time during which the portal was online. Therefore, none of the account holders would have had access to, or been influenced by, the portal. This data set included numerous account numbers that had multiple meter IDs associated with them over this time period. This indicated that the meters could have been replaced over the years with newer models. Simply excluding these instances would have removed a substantial portion of the data pool. The accounted needed to be kept but the issue of meters being changed over the years still needed to be addressed. Thus, the records needed to be combined. This had to be done in a way that eliminated old meter IDs, but kept the usages data they had collected. The data records in which a single account had many associated meters were "collapsed" such that all usage data for the account was kept along with the most recent meter ID. However, if an account had multiple meter IDs and the usage for these meters overlapped the account was separated from the other records for further inspection. This was done by applying macro script the from Appendix A. An example of record collapsing and of records that would be separated for further inspection is shown below:

Table 3: Record Collapsing Process Illustration

Records before "collapsing"				
AccountID	MeterID	January 2009	January 2010	January 2011
10001000	1111	3500		
10001000	2222		4000	
10001000	3333			4500
Record after "collapsing"				
AccountID	MeterID	January 2009	January 2010	January 2011
10001000	3333	3500	4000	4500

Table 4: Records Separated For Inspection Illustration

AccountID	MeterID	January 2009	January 2010	January 2011
10002000	1111	3500	35000	
10002000	2222		4000	4000
10002000	3333			4500

This round of analysis was performed in the same manner as in the previous scenarios, using the same outlier removal techniques, however this time the 2015 account use was compared to historical (2009 – 2013) averages and the User category was not separated into Old and Users in their first year of joining the portal. This separation was not necessary as none of the account holders would have been portal Users during the historical data period. These results are displayed in Section 4.3.1.

The initial results of this section showed that the Non-Users exhibited much higher levels of reduction than the Users. This led to an investigation of what could have caused this outcome and why it was so different from the 2014/2015 comparison. Two things were explored: the average number of gallons used per account per day (GPAD) and the amount of precipitation received. Examination of the GPAD for the User and Non-User groups would provide insight of why the difference in usage reduction was so great, as well as which account type was using more water on average. The GPAD of each month was calculated for each of the account categories using the following equation:

$$\text{GPAD} = \frac{\text{Total Monthly Usage}}{\text{\# of Accounts Used in Comparison} * \text{\# of Days in the Month}} \tag{3}$$

As noted in the literature review, the amount of rain that a region received has an impact on the amount of water consumed. Because precipitation amount in 2014 and 2015 had been so different, it is possible that this impacted the amount of water used, causing the results from the comparison of the two years to show abnormal reductions. The weather data from 2009 to 2015 was gathered from NOAA's National Climatic Data Center (NCDC) at three airports near Arlington, Texas: Love Field, Dallas/Fort Worth, and Arlington. The daily precipitation amounts were converted into cumulative precipitation at each of the airports for 2014 and 2015. The normal cumulative precipitation was found similarly. The GPAD comparison and this precipitation data is shown in section 4.6.

3.7 Comparison of usage cost

The water usage from historical and 2015 records was also used to calculate a difference in water costs. This was done, as in the previous analysis scenarios, by applying the 2015 water rates to the monthly usages. These results are displayed in Section 4.7.

3.8 Data pool shrinkage

During the historical analysis scenario, it was observed that there were far fewer matches between 2015 accounts and the historical accounts than between the 2015 and 2014 accounts. Of the approximately 21,000 steady accounts in 2015, an average of 3,842 historical matches passed both outlier tests whereas the average number of matches that passed the outliers between 2014 and 2015 was greater than 13,000. A portion of this can be attributed to the fact that many historical accounts had missing data, but the difference was still large enough that further investigation was required.

It was speculated that the lack of historical record matches was related to the movement of residents in and out of Arlington. As resident moved, they would be given a new account with a new account ID. This would lead to lots of newer account IDs that would not be present in the historical data. The average moving, or turnover, rate of housing was assumed to be the inverse of the average length of time a resident would stay in a particular home. This information was obtained from the United State Census Bureau. Once the length of stay was calculated, turnover rate could be applied over the six-year data period (2009-2015) to estimate the number of steady 2015 accounts that would be expected to have historical matches. The results of the data shrinkage are shown in Section 4.3.3.

3.9 Analysis of User and Non-User characteristics

The results of a previously administered survey were used to characterize the portal Users and to determine if Users and Non-Users tended to have similar attributes. If the Users and Non-User attributes were similar it would indicate that these characteristics do not affect the likelihood of becoming a portal user. This could mean that if portal Users were to reduce consumption more than Non-Users it could be caused by their access to the data portal.

The survey included questions from multiple categories about conservation and consumption as well as questions about socio-economic characteristics. The survey categories used in this analysis were Personal Capabilities, Efficient Infrastructure, Habits, Attitudes, Perceived Barriers, Household Culture, and Procedural Knowledge. The survey questions for each of these categories are shown in Appendix A. The answers to the survey questions were given a numerical value (shown in the parentheses next to the answer choices in Appendix A) so that they could be easily quantitatively analyzed. The values of the answers in each section were totaled for each of the survey takers. Next the average sum of each section was found and compared for the Users and Non-Users.

The socio-economic characteristics used for analysis were Ethnicity, Age Range, Education, and Income. These questions are also shown in Appendix A. The number of each response for these characteristics was tallied for the Users and Non-Users, allowing for the percentages of each characteristic to be calculated and compared.

4. RESULTS

4.1 Comparison of 2015 usage between Users and Non-Users

This first scenario compares the winter and annual water consumptions of the Users to the Non-Users during 2015. Outliers were removed from the data in two ways, by monthly total or by annual total. The average monthly usage for Users and Non-Users was calculated after removing outliers. The results of both comparisons are shown in the following two subsections.

4.1.1 2015 Winter comparison

The comparison of the portal Users to the Non-Users was done to find which group used less water on average during a given time period. This is important because if the Users were to consume less water it might mean that the portal was being used by those who were already water conscious, and the portal might not reduce the total amount of water consumed. However, if the Users were to consume more water than the Non-Users the opposite might be true, this would allow the portal to reduce User consumption by giving access to usage data and consumption patterns.

Table 5: Winter 2015 with Outliers Removed by Month

Account Category	Number of Accounts	Total Usage (gal)	Average Usage
Users	948	14,515,120	15,311.1
Non-Users	25,739	396,274,104	15,395.9
		Percent Difference:	-0.55%

Table 6: Winter 2015 with Outliers Removed by Total

Account Category	Number of Accounts	Total Usage (gal)	Average Usage
Users	973	15530566	15961.5
Non-Users	26527	435173036	16404.9
		Percent Difference:	-2.74%

As shown in Table 5 and Table 6 above, the Users consumed less water on average than the Non-Users for both methods of removing outliers. Though the difference was small, suggesting that the indoor consumption of the Users and Non-Users are similar, these initial results indicate that the portal Users may consume less water than Non-Users. The same analysis was done for the entire year of 2015 to see if these results would continue over the calendar year of 2015.

4.1.2 2015 Annual comparison

The comparison of the entire year of 2015 shows whether or not the small difference in consumption between the Users and Non-Users would continue throughout the entire year. This is important because if the Users consume more water on average, the portal could potentially have a larger impact on the total amount of water consumed by the Arlington population. Additionally, because the indoor consumptions were found to be similar by the previous scenario, it would suggest that the outdoor water consumptions of the two groups are different.

Table 7: Annual 2015 with Outliers Removed by Month

Account Category	Number of Accounts	Total Usage	Average Usage
Users	704	64,306,479	91,344.43
Non-Users	16,114	1,203,994,024	74,717.27
		Percent Difference:	20.03%

Table 8: Annual 2015 with Outliers Removed by Total

Account Category	Number of Accounts	Total Usage	Average Usage
Users	838	90,530,832	108,032
Non-Users	18,668	1,596,305,743	85,510
		Percent Difference:	23.27%

The annual results in the above tables showed that the Users were consuming a large amount more water on average than the Non-Users, with differences of close to 20%. However, the greater annual usage by the Users does not definitively mean that the portal was not effective. As stated earlier, this difference in annual consumption suggests that the outdoor water demand of the portal Users and Non-Users is different. Thought the Users are shown as having higher consumption, the portal is meant to reduce water consumption over time. Thus, the next comparison of how the Users and Non-Users changed their usage habits from one year to the next is beneficial.

4.2. Comparison of 2014 and 2015 usage of Users and Non-Users

The second comparison scenario analyzed the amount that the Users in their second year of joining the portals and Non-Users consumption was reduced from 2014 to 2015. As described in Section 3.2, this required low usage values and two rounds of outliers to be removed, by monthly total and then by percent reduction, before analysis.

The pricing structure in Table 11 was then applied to the usage data in order to calculate the amount of savings generated in 2015 through the reduction of consumption.

The comparison of 2015 data and 2014 data after both rounds of outliers were removed is shown in the tables below. Table 9 and Table 10 contain the number of accounts for a month, their contributing monthly usage totals, usage reduction, and percent reduction for the Non-User and Users in their second year of joining the portal groups respectively.

Table 9: The Total Monthly Usage And % Reduction for Non-Users

Non-Users						
Data Month	Number of Accounts	2014 Usage (gal)	2015 Usage (gal)	Reduction	% Reduction of Total Usage	Average Reduction Per Account
JAN	9,784	50,436,147	53,015,456	-2,579,309	-5%	-264
FEB	10,086	48,484,001	55,823,561	-7,339,560	-15%	-728
MAR	10,199	59,020,634	44,593,567	14,427,067	24%	1,415
APR	11,216	69,985,371	54,189,515	15,795,856	23%	1,408
MAY	12,333	107,285,712	60,282,903	47,002,809	44%	3,811
JUN	12,554	96,741,457	88,199,725	8,541,732	9%	680
JUL	13,091	114,387,991	115,287,955	-899,964	-1%	-69
AUG	13,956	136,119,064	174,752,241	-38,633,177	-28%	-2,768
SEP	14,332	118,353,981	138,253,609	-19,899,628	-17%	-1,388
OCT	15,281	117,509,159	122,974,425	-5,465,266	-5%	-358
NOV	15,114	80,259,552	69,662,568	10,596,984	13%	701
DEC	15,934	72,430,303	77,141,708	-4,711,405	-7%	-296
Total Gallons Saved				16,836,139		2,145

Table 10: Total Monthly Usage And % Reduction for Users

Users						
Data Month	Number of Accounts	2014 Usage (gal)	2015 Usage (gal)	Reduction	% Reduction of Total Usage	Average Reduction Per Account
JAN	416	2,083,195	1,981,601	101,594	5%	244
FEB	436	2,083,599	2,203,802	-120,203	-6%	-276
MAR	446	2,779,356	1,864,334	915,022	33%	2,052
APR	512	3,908,263	2,499,901	1,408,362	36%	2,751
MAY	578	6,113,915	2,713,461	3,400,454	56%	5,883
JUN	575	5,449,453	4,319,851	1,129,602	21%	1,965
JUL	631	7,505,220	7,321,479	183,741	2%	291
AUG	660	9,130,342	11,354,423	-2,224,081	-24%	-3,370
SEP	692	8,128,242	9,271,339	-1,143,097	-14%	-1,652
OCT	716	6,940,706	7,184,211	-243,505	-4%	-340
NOV	739	4,690,876	3,143,435	1,547,441	33%	2,094
DEC	739	3,743,009	3,268,975	474,034	13%	641
Total Gallons Saved				5,429,364		10,283

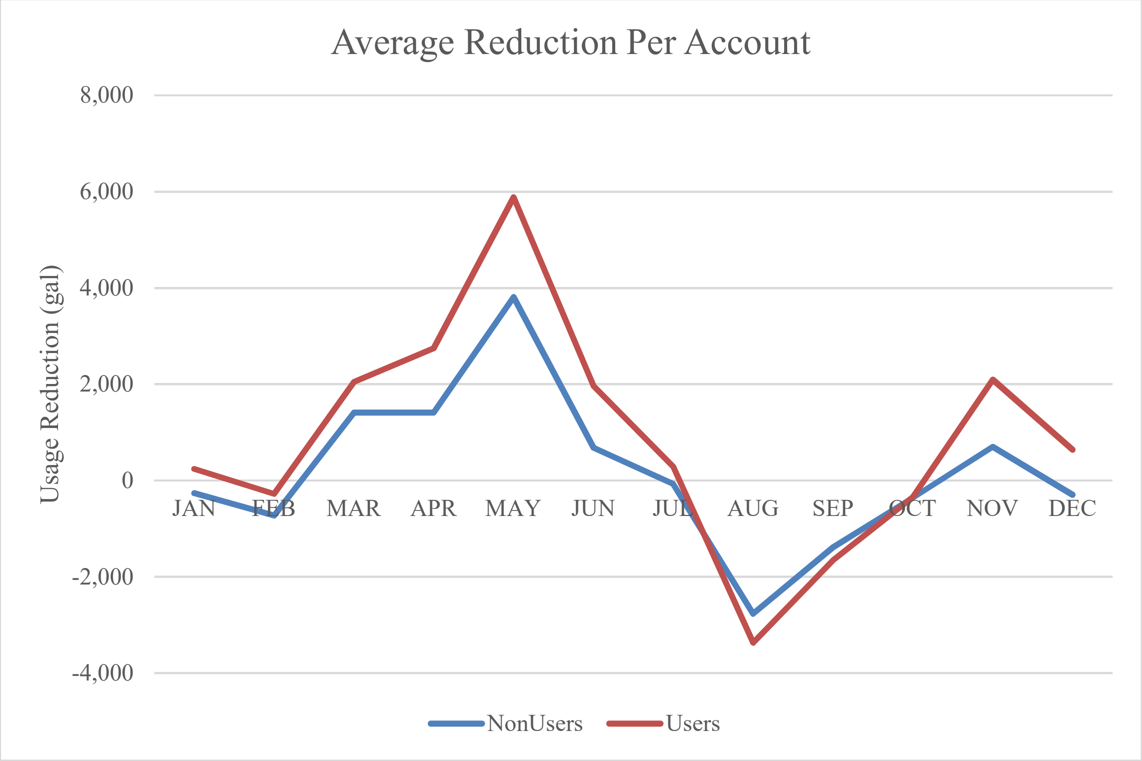

Figure 1: Average Reduction in Usage from 2014 to 2015 by Users and Non-Users

From the above tables is can be seen that there were months during which usage had increased from 2014 to 2015, indicated by the negative percent reduction. While the Non-Users increased their total consumption dramatically compared to the Users in their second year of joining the portals, the average account holders for each group increased their usage by close to 600 gallons per month. However, the Non-Users increased their usage slightly less than the Users in their second year of joining the portals. It is important to note however, that during most months, the portal Users had better percent reductions than the Non-Users. This could indicate that the portal is effectively reducing consumption, or at least curbing increases, even if the total gallons saved per account show otherwise.

4.3 Comparison of 2014 and 2015 usage cost of Users and Non-Users

The data from the previous usage comparison was used to calculate to monetary savings for the Users in their second year of joining the portals and the Non-Users during the months of June through December. In order to accurately compare the cost of the water used in 2014 and 2015 the same price structure was applied to both years. The price structure found below in Table 11 was used to calculate the costs of the water usage from the above section.

Table 11 : 2015 City Of Arlington Water Utilities Department Price Structure

Usage (1,000 gallons)	Rate
0 - 2	$1.78
3 - 10	$2.46
11 - 15	$3.55
16 - 29	$4.22
> 30	$5.24

Table 12: The Total Monthly Cost And % Reduction for Non-Users

Non-Users						
Data Month	Number of Accounts	2014 Cost	2015 Cost	Reduction	% Reduction of Total Usage	Average Reduction Per Account
JAN	9,784	$112,406	$120,297	$(7,891)	-7%	$(0.81)
FEB	10,086	$106,761	$128,857	$(22,096)	-21%	$(2.19)
MAR	10,199	$135,548	$96,352	$39,196	29%	$3.84
APR	11,216	$164,693	$122,265	$42,428	26%	$3.78
MAY	12,333	$288,337	$132,894	$155,444	54%	$12.60
JUN	12,554	$243,107	$218,781	$24,326	10%	$1.94
JUL	13,091	$300,387	$306,607	$(6,220)	-2%	$(0.48)
AUG	13,956	$371,712	$519,698	$(147,986)	-40%	$(10.60)
SEP	14,332	$304,269	$375,452	$(71,183)	-23%	$(4.97)
OCT	15,281	$304,658	$313,534	$(8,876)	-3%	$(0.58)
NOV	15,114	$180,635	$152,466	$28,169	16%	$1.86
DEC	15,934	$158,042	$170,021	$(11,979)	-8%	$(0.75)
Total Saved:				$13,334		$3.66

Table 13: Total Monthly Cost And % Reduction for Users

Users						
Data Month	Number of Accounts	2014 Cost	2015 Cost	Reduction	% Reduction of Total Usage	Average Reduction Per Account
JAN	412	$4,580	$4,310	$270	6%	$0.65
FEB	429	$4,507	$4,819	$(312)	-7%	$(0.73)
MAR	445	$6,535	$3,986	$2,549	39%	$5.73
APR	510	$9,783	$5,552	$4,231	43%	$8.30
MAY	576	$17,031	$5,912	$11,118	65%	$19.30
JUN	572	$14,491	$10,537	$3,953	27%	$6.91
JUL	629	$21,739	$21,089	$650	3%	$1.03
AUG	652	$27,446	$36,796	$(9,350)	-34%	$(14.34)
SEP	660	$21,870	$26,291	$(4,421)	-20%	$(6.70)
OCT	697	$18,069	$18,883	$(814)	-5%	$(1.17)
NOV	730	$11,042	$6,628	$4,413	40%	$6.05
DEC	735	$8,469	$7,034	$1,436	17%	$1.95
Total Saved:				$13,724		$26.99

Not surprisingly, the months that showed an increase in usage in Table 9 and Table 10 also showed an increase in cost. Because the total gallons of water used by each of the groups increased, the total amount of money increased as well, however the average increase in cost per account for both groups is essentially negligible.

4.4 Comparison of 2014 and 2015 usage of 1st and 2nd year portal Users

As stated in Section 3.4, this comparison evaluates the effectiveness of the portal over time by comparing the reductions of the 1st and 2nd year portal Users. If the Users in their first year of joining the portal have reduced their consumption more than the Users in their second year of joining the portals it might indicate that the portal does not having lasting effects on the amount of water used or that customers cannot be expected to repeatedly produce large reductions in their consumption every year.

Table 14 and Table 15 are similar to Tables 9 and 10, showing the number of accounts, the monthly usage, reduction, percent reduction, and average reduction per account of the Users in their first year of joining the portal. However, these tables show data for the 1st and 2nd year Users. Table 16 contains the difference in percent reduction between the Non-Users and the two types of Users. This data is also shown graphically in Figure 2. The first half of Table 15, Table 16, and Figure 2 have no data for the 2nd year Users as there are no portal Users who are in their second year of portal use during these months. This is because the portal had not gone online until June of 2014.

Table 14: Total Monthly Usage And % Reduction for 1st year Users

1st Year Users						
Month	Number of Accounts	2014 Usage (gal)	2015 Usage (gal)	Reduction in Usage (gal)	% Reduction of Total Usage	Average Reduction Per Account
	416	2,083,195	1,981,601	101,594	5%	244
	436	2,083,599	2,203,802	-120,203	-6%	-276
	446	2,779,356	1,864,334	915,022	33%	2,052
	512	3,908,263	2,499,901	1,408,362	36%	2,751
	578	6,113,915	2,713,461	3,400,454	56%	5,883
	424	4,143,931	3,302,080	841,851	20%	1,985
	207	2,586,946	2,400,174	186,772	7%	902
	95	1,476,011	1,736,169	-260,158	-18%	-2,739
	108	1,549,873	1,526,900	22,973	1%	213
	128	1,590,796	1,363,181	227,615	14%	1,778
	131	1,162,735	631,586	531,149	46%	4,055
	135	897500	648898	248,602	28%	1,841
Total Gallons Saved:				7,504,033		18,690

Table 15: Total Monthly Usage and % Reduction for 2nd year Users

2nd Year User						
Data Month	Number of Accounts	2014 Usage (gal)	2015 Usage (gal)	Reduction	% Reduction of Total Usage	Average Reduction Per Account
JAN	-	-	-	-	-	-
FEB	-	-	-	-	-	-
MAR	-	-	-	-	-	-
APR	-	-	-	-	-	-
MAY	-	-	-	-	-	-
JUN	151	1,305,522	1,017,771	287,751	22%	1,906
JUL	424	4,918,274	4,921,305	-3,031	0%	-7
AUG	565	7,654,331	9,618,254	-1,963,923	-26%	-3,476
SEP	584	6,578,369	7,744,439	-1,166,070	-18%	-1,997
OCT	588	5,349,910	5,821,030	-471,120	-9%	-801
NOV	608	3,528,141	2,511,849	1,016,292	29%	1,672
DEC	604	2,845,509	2,620,077	225,432	8%	373
Total Saved:				-2,074,669		-2,330

Table 16: Difference In % Reduction Of Usage Between Non-Users And Users

User Category	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st Year	10%	9%	8%	13%	12%	11%	8%	11%	18%	19%	32%	34%
2nd Year	-	-	-	-	-	13%	1%	3%	-1%	-4%	16%	14%

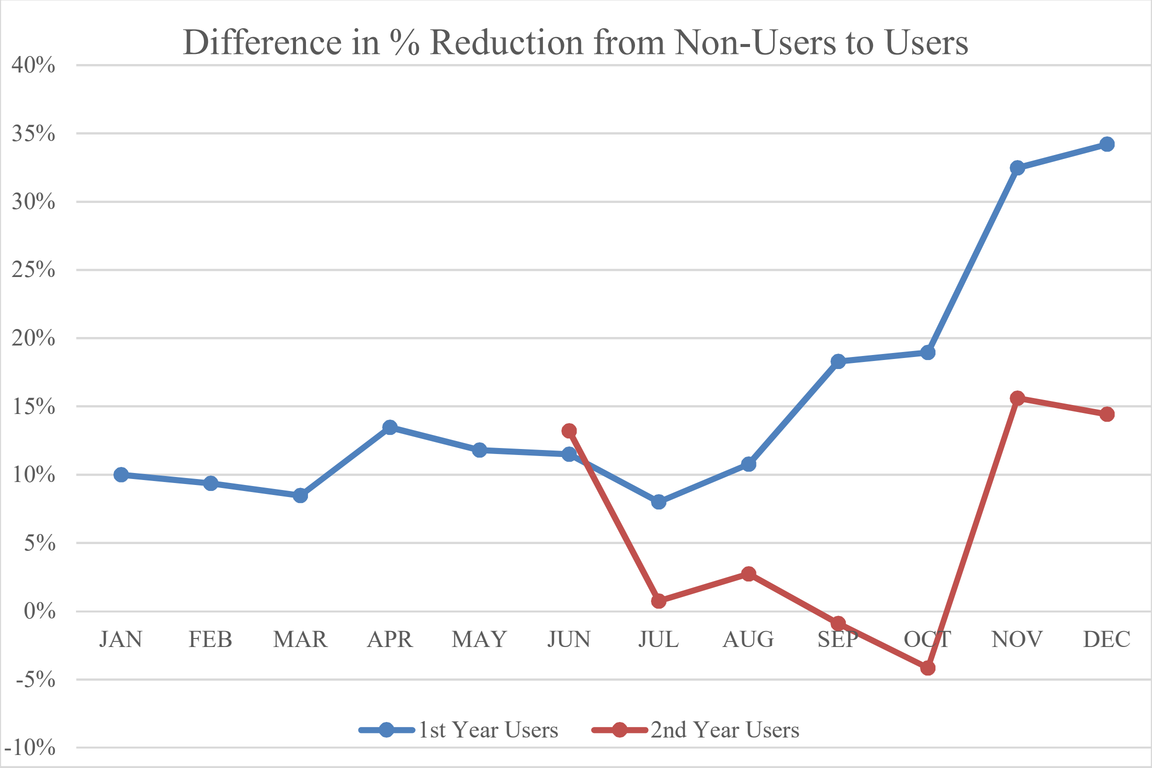

Figure 2: Difference In % Reduction Of Usage Between 2014 and 2015 of Non-Users And Users

As seen in Table 14, there were months during which usage had increased from 2014 to 2015, indicated by the negative percent reduction. Though there were monthly consumption increases from 2014 to 2015, the total amount of water saved by the Users in their first year of joining the portal was still positive (roughly 7.5 million gallons).

The positive difference in percent reduction between the portal Users and Non-Users could indicate that the Users increased their consumption less than the Non-Users. This could mean that access to the portal has a lowering effect on user consumption.

The Users in their first year of joining the portal were found to have reduced consumption more than the Non-Users in all months, whereas Users in their second year of joining the portals increased consumption in two months. This is possibly due to the fact the Users in their first year of joining the portal had signed up for the portal more recently, the experience still novel, and are more likely to check the portal to monitor their use. However, this could also be due to the fact the Users in their second year of joining the portals had already reduced their consumption greatly in the previous year, and so further reduction would be difficult to accomplish.

4.5 Comparison of 2014 and 2015 usage cost 1st and 2nd year portal Users

The data from the previous usage comparison was used to calculate to monetary savings for the Users in their second year of joining the portals and the Users in their first year of joining the portal. As in the previous cost comparison, price structure, found in Table 11, was applied to both the 2014 and 2015 data.

Table 17 and Table 18 are similar to Table 12 and Table 13, showing the number of accounts, the monthly usage, reduction, percent reduction, and average reduction per account of the Users in their first year of joining the portal. However, these tables show data for the 1st and 2nd year Users. Table 19 contains the difference in percent reduction between the Non-Users and the two types of Users. This data is also shown graphically in Figure 3. The first half of Table 17, Table 18, and Figure 3 have no data for the 2nd year Users as there are no portal Users who are in their second year of portal use during these months. This is because the portal had not gone online until June of 2014.

Table 17: Total Monthly Cost And % Reduction for 1st year Users

1st Year Users						
Month	Number of Accounts	2014 Cost	2015 Cost	Reduction in Usage (gal)	% Reduction of Total Usage	Average Reduction Per Account
Jan	416	4,580	4,310	$270	6%	$0.66
Feb	436	4,508	4,820	$(312)	-7%	$(0.73)
Mar	446	6,535	3,985	$2,550	39%	$5.73
Apr	512	9,783	5,552	$4,231	43%	$8.30
May	578	17,031	5,913	$11,118	65%	$19.30
Jun	424	11,140	8,108	$3,032	27%	$7.20
Jul	207	7,691	6,887	$804	10%	$3.92
Aug	95	4,372	5,267	$(895)	-20%	$(10.29)
Sep	108	3,338	2,958	$380	11%	$5.00
Oct	128	3,978	3,133	$845	21%	$7.75
Nov	131	2,897	1,257	$1,640	57%	$13.44
Dec	135	2210	1399	$811	37%	$6.19
Total Gallons Saved:				$24,474		$66.48

Table 18: Total Monthly Cost and % Reduction for 2nd year Users

2nd Year Users						
Month	Number of Accounts	2014 Cost	2015 Cost	Reduction	% Reduction of Total Usage	Average Reduction Per Account
JAN	-	-	-	-	-	-
FEB	-	-	-	-	-	-
MAR	-	-	-	-	-	-
APR	-	-	-	-	-	-
MAY	-	-	-	-	-	-
JUN	151	$3,350	$2,429	$921	27%	$6.10
JUL	424	$14,047	$14,202	$(155)	-1%	$(0.37)
AUG	565	$23,074	$31,528	$(8,454)	-37%	$(14.96)
SEP	584	$18,532	$23,333	$(4,801)	-26%	$(8.22)
OCT	588	$14,091	$15,750	$(1,659)	-12%	$(2.82)
NOV	608	$8,145	$5,372	$2,774	34%	$4.56
DEC	604	$6,259	$5,635	$625	10%	$1.03
Total Saved:				$(10,750)		$(20.77)

Table 19: Difference In % Reduction Of Cost Between Non-Users And Users

User Category	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st Year	13%	14%	10%	17%	11%	17%	13%	19%	35%	24%	41%	44%
2nd Year	-	-	-	-	-	17%	1%	3%	-3%	-9%	18%	18%

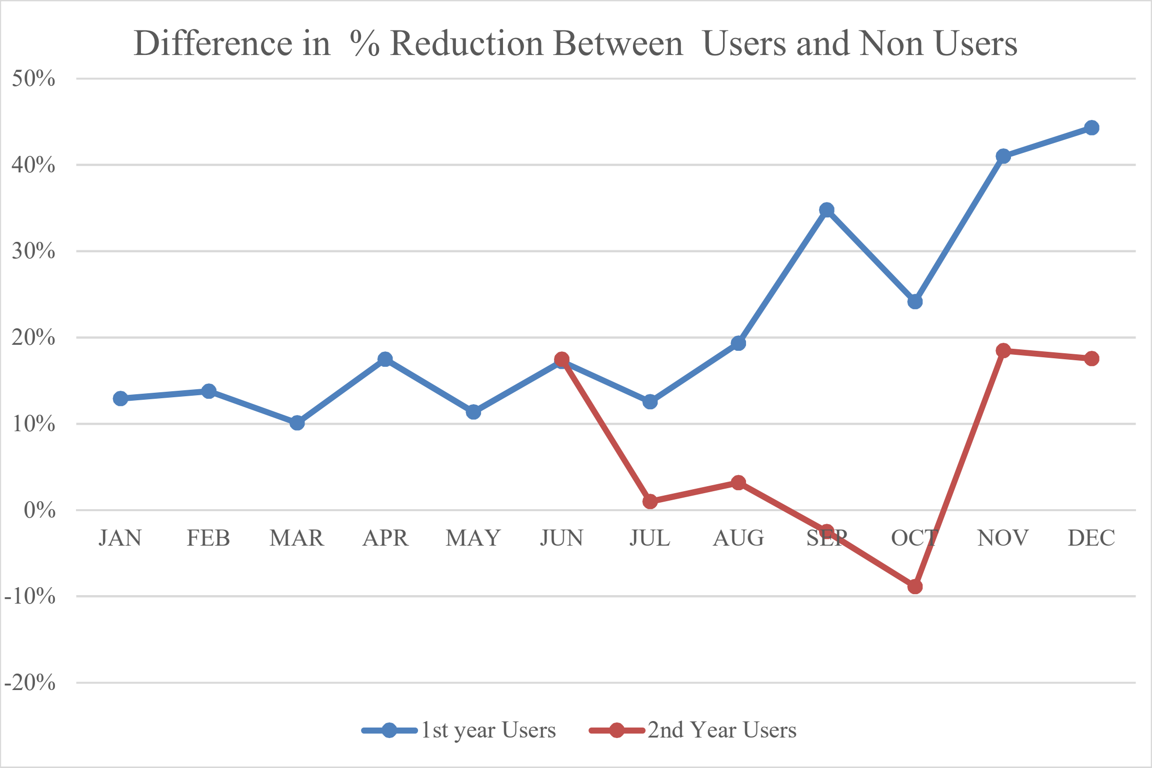

Figure 3: Difference In % Reduction Of Cost Between 2014 and 2015 of Non-Users And Users

Not surprisingly, the months during which usage increased in Table 14 also showed an increase in monthly cost. However, the New User account group still reduced their consumption by roughly $24,500. The Users in their first year of joining the portal decreased their cost when compared to the Non-Users, as they had their consumption, more than the Users in their second year of joining the portals though this could still be due to the fact that Users in their second year of joining the portals may have already decreased their normal usage greatly.

4.6 Comparison of historic and 2015 usage of Users and Non-Users

During this comparison scenario, the account categories are limited to User and Non-User. This is because the 2015 data is being compared to historic normal usages. This means that regardless of whether a resident signed up to view the portal in 2014 or 2015, they would not have been a portal user during the historical data period so there is no need to differentiate between the two user types. This historical comparison allows for water reductions to be calculated for more established usage patterns of the customers and weather conditions.

The comparison of 2015 data and historic data after both rounds of outliers were removed is shown in the tables below. Table 20 and Table 21 contain the monthly usage totals, usage reduction, and percent reduction for the Non-User and User groups respectively. Table 22 contains the difference in monthly percent reduction between the Non-Users and the Users. This data is also shown graphically in Figure 4.

Table 20: The Total Monthly Usage And % Reduction for Non-Users

Non-Users						
Month	Number of Accounts	Historic Usage (gal)	2015 Usage (gal)	Reduction in Usage	% Reduction of Total Usage	Average Reduction Per Account
Jan	4,447	28,427,383	24,261,859	4,165,524	15%	937
Feb	4,422	23,736,067	23,754,489	-18,422	0%	-4
Mar	4,244	21,492,967	18,210,615	3,282,352	15%	773
Apr	4,376	26,171,450	20,349,242	5,822,208	22%	1,330
May	4,327	29,062,900	21,028,460	8,034,440	28%	1,857
Jun	4,347	35,570,283	30,221,942	5,348,341	15%	1,230
Jul	4,264	45,264,450	43,569,082	1,695,368	4%	398
Aug	4,412	55,401,533	56,274,533	-873,000	-2%	-198
Sep	4,417	54,412,205	43,411,422	11,000,783	20%	2,491
Oct	4,378	40,822,659	35,152,197	5,670,462	14%	1,295
Nov	4,365	29,807,200	20,304,791	9,502,409	32%	2,177
Dec	4,409	27,944,318	21,175,755	6,768,563	24%	1,535
Total Gallons Saved:				60,399,028		13,821

Table 21: Total Monthly Usage And % Reduction for Users

Users						
Month	Number of Accounts	Historic Usage (gal)	2015 Usage (gal)	Reduction in Usage	% Reduction of Total Usage	Average Reduction Per Account
Jan	57	248,833	276,315	-27,482	-11%	-482
Feb	57	209,400	238,018	-28,618	-14%	-502
Mar	66	267,000	237,840	29,160	11%	442
Apr	74	358,417	330,667	27,750	8%	375
May	95	679,917	442,797	237,120	35%	2,496
Jun	99	884,950	780,578	104,372	12%	1,054
Jul	87	1,032,900	1,137,626	-104,726	-10%	-1,204
Aug	89	1,412,583	1,520,220	-107,637	-8%	-1,209
Sep	86	1,479,183	1,278,456	200,727	14%	2,334
Oct	81	1,149,566	967,064	182,502	16%	2,253
Nov	81	759,000	449,048	309,952	41%	3,827
Dec	86	680,000	495,432	184,568	27%	2,146
Total Gallons Saved:				1,007,688		11,530

Table 22: Difference In % Reduction Of Usage Between Non-Users And Users

User Category	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Users	-26%	-14%	-4%	-15%	7%	-3%	-14%	-6%	-7%	2%	9%	3%

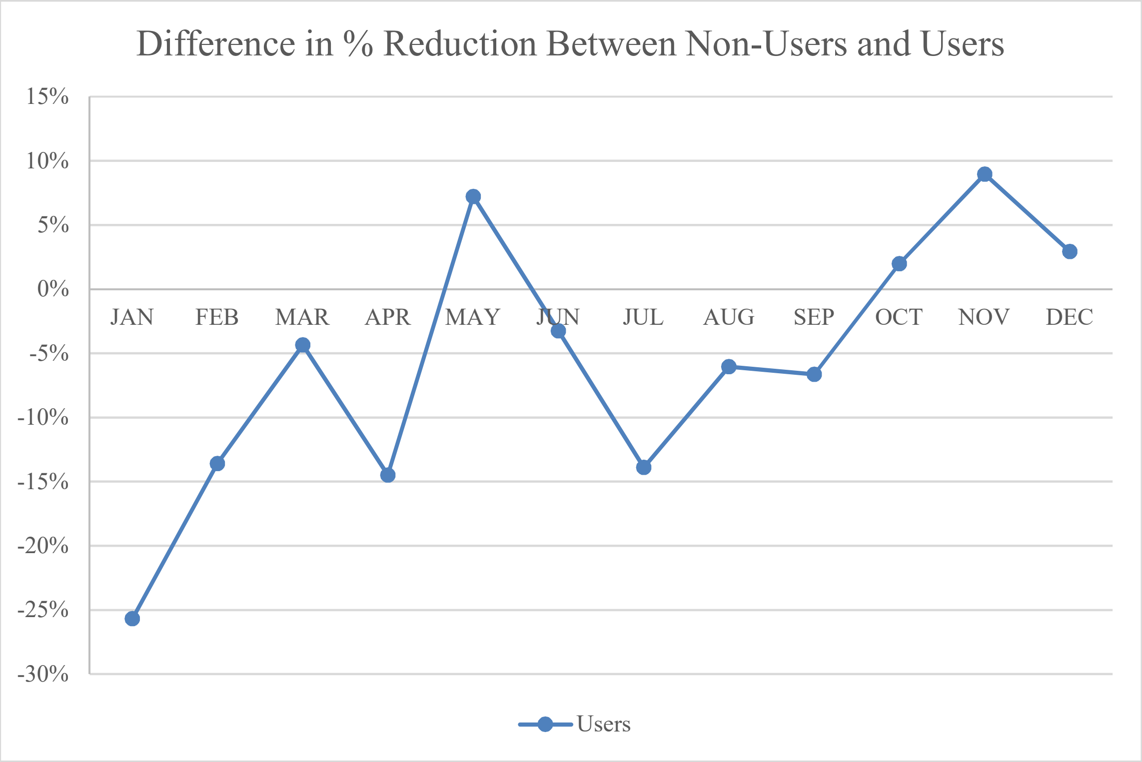

Figure 4: Difference In % Reduction Of Usage Between Historic Data Perioc and 2015 of Non-Users And Users

Table 20-Table 22 and Figure 4 show that the portal Users had worse usage reduction than the Non-Users indicating that having access to the portal was not having the effect on usage that had been seen in the previous scenario. Even though 61.4 million gallons were saved in comparison to the historic norms, the average reduction per account of the Non-Users was larger than that of the Users. The lack of usage

reduction by the Users was concerning given that the results from Section 4.2. It was thought that an examination of the GPAD and the precipitation experienced during this year would help to explain these results.

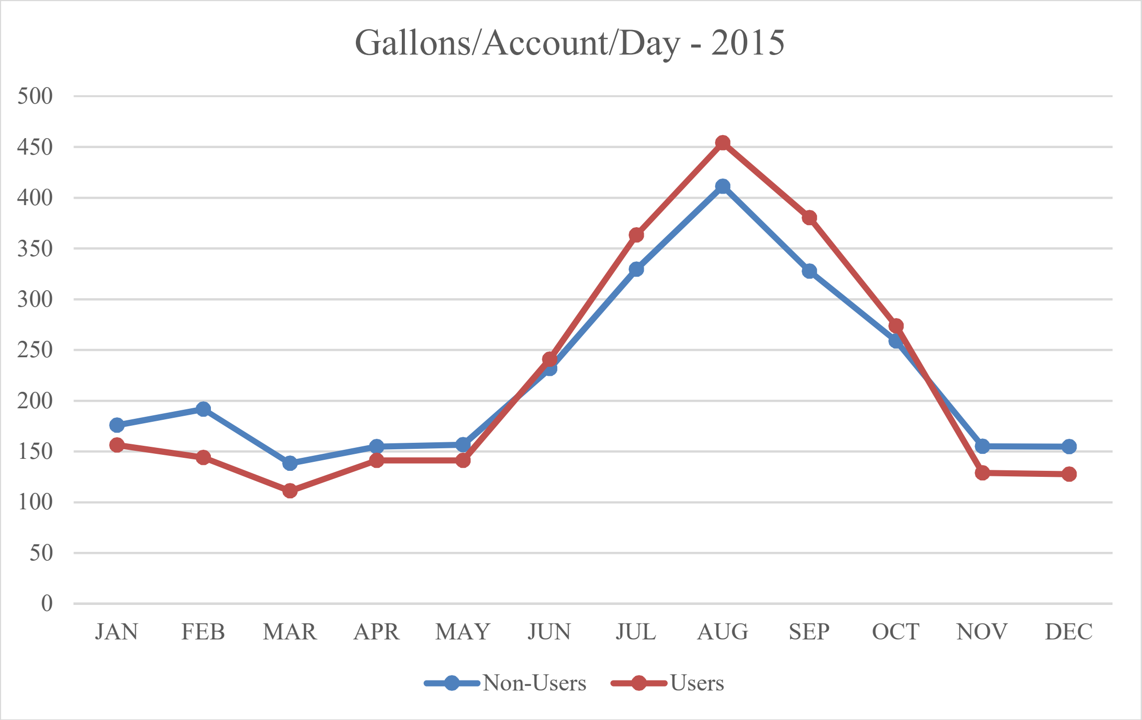

Figure 5: Comparison of User and Non-User 2015 GPAD

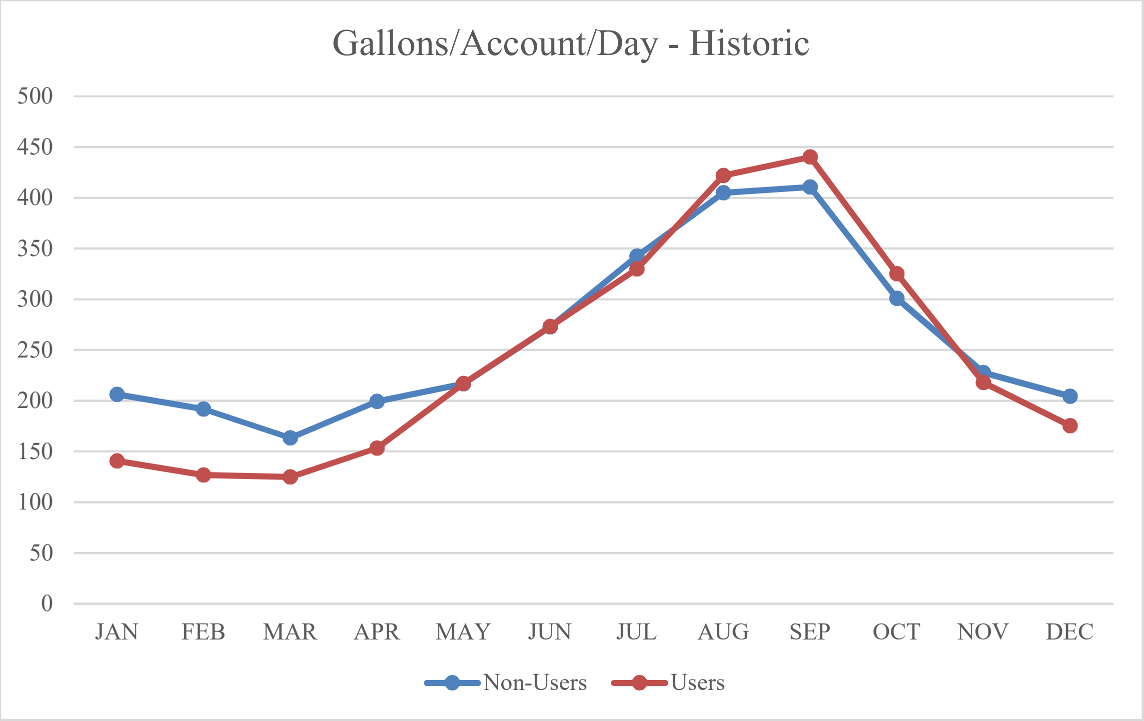

Figure 6: Comparison of User and Non-User Historic GPAD

While the poor reduction in consumption by the Users was unfortunate, it can be seen above in Figure 5 and Figure 6 that Users had a lower GPAD for most of the year, both historically and in 2015. Though the Users may not have decreased their consumption as dramatically as the Non-Users, they were actually consuming less water on average to begin with during most of the year.

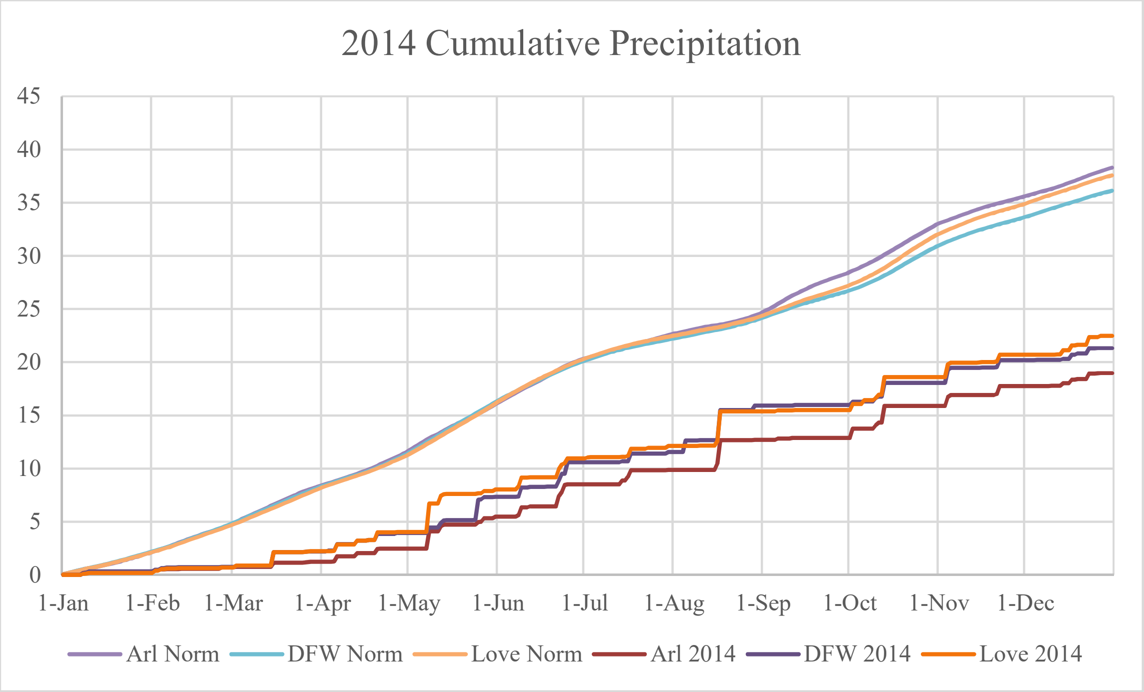

Figure 7: Cumulative 2014 and Normal Precipitation at Arlington Area Airports

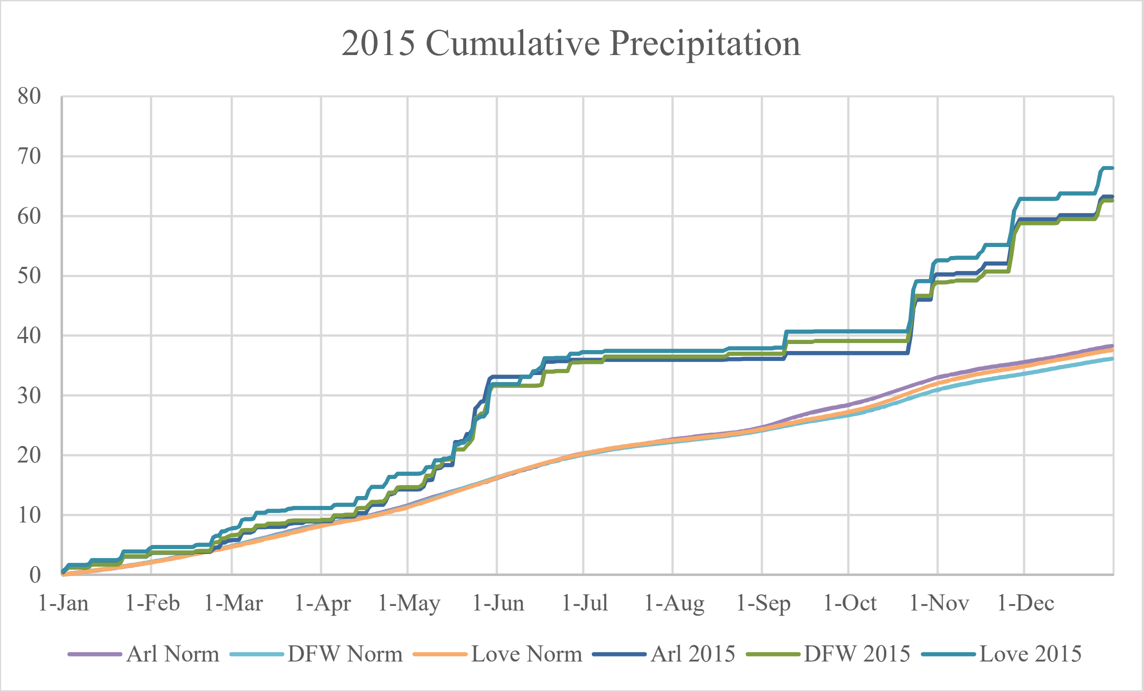

Figure 8: Cumulative 2015 and Normal Precipitation at Arlington Area Airports

From the figures above, the precipitation in 2014 was much less than normal while in 2015 is was much greater. During 2014 water restrictions were imposed, forcing residents to reduce their normal water consumptions. Because of this the drastic reduction in water usage between 2014 and 2015 seen in Section 4.4 is even more impressive. The fact that the residents went from a period of time when they were force to reduce their consumption to a time when their consumptions were unrestrained and still reduced their consumptions is likely caused by the reducing effects of the data portal.

It can also be seen in Figure 8 that in 2015 it rained on a fairly regular basis during the year until June, after which there was a relatively dry period. From January to July the Users did not reduce their consumption as well as the Non-Users had. The Users might have seen the rain as an excuse to not closely monitor their consumption because there was not a risk of shortages. Conversely, the Non-Users might have viewed this as a chance to save water, letting the rain maintain their yards for them. It is important to note, however, that during the extended dry period of August and September the Users more greatly reduced their consumption than the Non-Users. The Non-Users may have increased their usage to compensate for the lack of rain that had been watering their lawns in the previous months. However, the Users would have been monitoring their usage and would not have so dramatically increased their usage. This is also important because during these months, which typically would have a higher water demand due to higher temperatures, there had been an extended period with little rain. Water conservation is especially important during dry periods because it can help to prevent shortages.

4.7 Comparison of historic and 2015 usage cost of Users and Non-Users

As in previous cost comparisons, the 2015 rate structure in Table 11 was used to calculate the amount of savings that was generated by the usage reduction. Table 23 and Table 24 shows the monthly, totals, reductions, and average reductions in cost for the Non-Users and Users, respectively. The difference in percent reduction between these two groups is shown in Table 25 and Figure 9.

Table 23: The Total Monthly Cost And % Reduction for Non-Users

Non-Users						
Month	Number of Accounts	2014 Cost	2015 Cost	Reduction in Cost	% Reduction of Total Cost	Average Reduction Per Account
Jan	4,447	$65,386	$55,035	$10,351	16%	$2.33
Feb	4,422	$52,703	$54,412	$(1,708)	-3%	$(0.39)
Mar	4,244	$47,186	$39,191	$7,996	17%	$1.88
Apr	4,376	$59,231	$45,210	$14,021	24%	$3.20
May	4,327	$67,802	$46,188	$21,613	32%	$5.00
Jun	4,347	$87,253	$74,206	$13,047	15%	$3.00
Jul	4,264	$121,354	$119,771	$1,583	1%	$0.37
Aug	4,412	$157,596	$166,900	$(9,304)	-6%	$(2.11)
Sep	4,417	$154,604	$117,863	$36,741	24%	$8.32
Oct	4,378	$105,952	$88,797	$17,156	16%	$3.92
Nov	4,365	$70,154	$44,516	$25,638	37%	$5.87
Dec	4,409	$64,106	$46,542	$17,563	27%	$3.98
Total Savings:				$154,696		$35.38

Table 24: Total Monthly Cost And % Reduction for Users

Users						
Month	Number of Accounts	Historic Cost	2015 Cost	Reduction in Cost	% Reduction of Total Usage	Average Reduction Per Account
Jan	57	$533	$620	$(87)	-11%	$(1.52)
Feb	57	$434	$508	$(73)	-14%	$(1.29)
Mar	66	$562	$495	$67	11%	$1.02
Apr	74	$774	$717	$57	8%	$0.78
May	95	$1,566	$953	$613	35%	$6.45
Jun	99	$2,118	$1,887	$231	12%	$2.33
Jul	87	$2,645	$3,170	$(525)	-10%	$(6.04)
Aug	89	$3,953	$4,563	$(609)	-8%	$(6.85)
Sep	86	$4,184	$3,630	$553	14%	$6.43
Oct	81	$3,006	$2,439	$567	16%	$6.99
Nov	81	$1,721	$950	$771	41%	$9.52
Dec	86	$1,508	$1,046	$462	27%	$5.37
Total Gallons Saved:				$2,026		$23.20

Table 25: Difference In % Reduction Of Cost Between Non-Users And Users

User Category	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Users	-32%	-14%	-5%	-16%	7%	-4%	-21%	-10%	-11%	3%	8%	3%

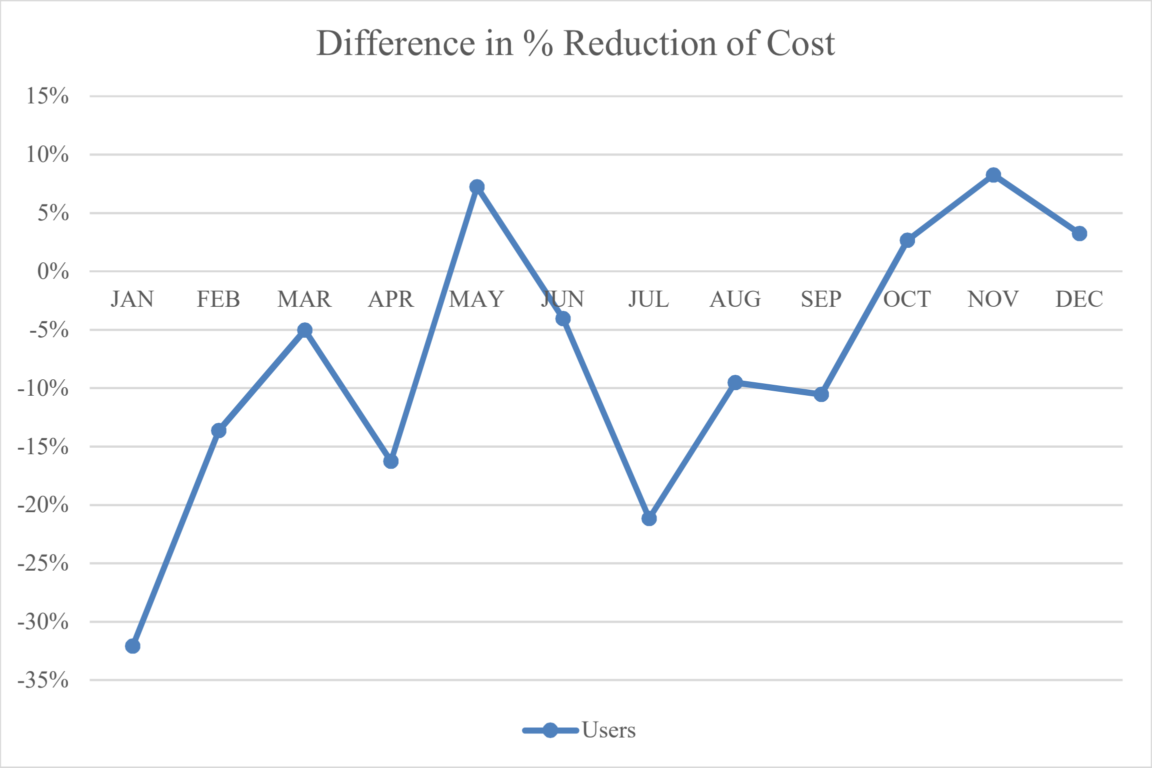

Figure 9: Difference In % Reduction of Cost Between Historic Data Period and 2015 of Non-Users and Users

As in section 4.6, the Users exhibited poor reduction in cost for most of the year. Even still, the total savings for this scenario were over $150,000. Though almost all of the savings were generated by the Non-Users, the Users were already using less water on average than the Non-Users as seen by their respective GPAD values. Because of this, it is not surprising that the Users would save less water and money.

4.8 Data pool shrinkage

The amount of account matches between the 2015 and historical data was much lower than the number of matched with the 2014 data. While some of this could be caused by data manipulation by the utility, this difference in the number of matches was too great for this to likely be the only cause. The moving rate within Arlington was calculated and applied to the stable number of accounts in the 2014-2015 comparisons to determine if this was the cause of the reduced matches.

Table 26: 2011-2015 United State Census Bureau Estimates

Year Householder Moved into Unit	% of Occupied Housing Units
Moved in 2015 or later	2.20%
Moved in 2010 to 2014	38.40%
Moved in 2000 to 2009	35.60%
Moved in 1990 to 1999	14.40%
Moved in 1980 to 1989	5.30%
Moved in 1979 and earlier	4.10%
Year Structure Built	% of Housing Units
Built 2014 or later	0.00%
Built 2010 to 2013	1.00%
Built 2000 to 2009	14.70%
Built 1990 to 1999	17.40%
Built 1980 to 1989	28.60%
Built 1970 to 1979	21.70%
Built 1960 to 1969	9.20%
Built 1950 to 1959	5.80%
Built 1940 to 1949	1.10%
Built 1939 or earlier	0.50%

The information in Table 26 was used to calculate the average length of time a resident would reside in a housing unit. This was done by first finding the average year that a unit was moved into for each of the move in brackets in the first part of Table 26. The average year of the first five brackets were easily calculated, but the sixth bracket (1979 and earlier) was more difficult. It was assumed that the average move in year for this bracket would be the average year that houses were built during this time. This was calculated using the information in the second part of the above table.

Table 27: Finding the Average Year Houses Were Built Before 1980

Year Built Bracket (1)	% of all Units (2)	% of Units Built pre 1980 (3)	Starting Year (4)	Ending Year (5)	Average Year (6)	(7) = (3) *(6)
Built 1970 to 1979	21.70%	57%	1970	1979	1974.5	1118.71
Built 1960 to 1969	9.20%	24%	1960	1969	1964.5	471.89
Built 1950 to 1959	5.80%	15%	1950	1959	1954.5	295.98
Built 1940 to 1949	1.10%	3%	1940	1949	1944.5	55.85
Built 1939 or earlier	0.50%	1%	1930	1939	1934.5	25.25
Weighted Average Year House was Built:						1967.69

It was assumed that the starting year for the 1939 and earlier bracket was 1930. Using the percentages from the third column in of Table 27 and the average year in the sixth column, an average build year of 1967.7 was calculated. This was used as the starting year for the 1979 and earlier moving bracket.

Table 28: Finding the Average Year Houses Were Moved Into

Move in Bracket (1)	% of Units (2)	Starting Year (3)	Ending Year (4)	Average Year (5)	(6) = (2) *(5)
Moved in 2015 or later	2.20%	2015	2015	2015	44.33
Moved in 2010 to 2014	38.40%	2010	2014	2012	772.61
Moved in 2000 to 2009	35.60%	2000	2009	2004.5	713.6
Moved in 1990 to 1999	14.40%	1990	1999	1994.5	287.21
Moved in 1980 to 1989	5.30%	1980	1989	1984.5	105.18
Moved in 1979 and earlier	4.10%	1967.68	1979	1973.34	80.91
Weighted Average Move in Year:					2003.84

The weighted average move in year was calculated to be 2003.8. When subtracted from 2015, the average length of time that a resident has been living in their home is found. This length of stay is 11.2 years. By taking the inverse of the length of stay the average turnover rate of Arlington, Texas is found to be 9%. This means that in a given year there is a 91% probability that a resident would not have moved. If this rate is applied every year for six years (from 2009 to 2015) to the number of steady 2015 accounts, the result should be the number of residents who have historical matches. Unfortunately, the calculated number of historical matches is just below 12,000. Even before outliers are removed there were roughly 7,200, matches between historic and 2015 data. The difference in these two numbers mean that the shrinkage of the data pool can only be partially explained by residential turnover rate.

Other possible sources of shrinkage may come from the data itself. As mentioned in Section 3.1, the utilities records are sometime altered by the billing department to reflect what a customer was charged for rather than what they actually used. These usage manipulations lead to the idea that account numbers may have been altered as well, contributing to a lower number of accounts matched than expected.

4.9 Analysis of User and Non-User characteristics

The comparison of the Users and Non-Users characteristics is important because it could indicate whether consumption reductions are influenced by access to the portal or by other factors such as behaviors and habits or ethnicity and income. As described in Section 3.4, the average survey results for Users and Non-Users were calculated for comparison.

Table 29: Average Total Survey Category Score for Non-Users and Users

Survey Category	Average Total Score		
	Non-Users	Users	% Difference
Personal Capabilities	13.22	13.73	-3.8%
Efficient Infrastructure	21.88	21.55	1.6%
Habits	36.75	36.59	0.4%
Attitudes	52.30	52.96	-1.2%
Perceived Barriers	47.83	47.33	1.0%
Household Culture	8.94	9.11	-1.9%
Procedural Knowledge	36.48	36.61	-0.3%

As shown in Table 29, the average User and Non-User had similar responses to the conservation and consumption questions from the survey, with differences of less than 5% in all categories. This outcome indicates that the User and Non-User accounts tend to share the same behavior, attitude, and knowledge level of their water utilities, though the portal Users are less likely to own water efficient infrastructure, but more inclined to believe that they are personally capable of limiting their water usage.

Table 30: Ethnicity Percentages For Non-Users And Users

Ethnicity	% of Non-Users	% of Users
Hispanic or Latino	7%	7%
Black or African American	5%	4%
White	79%	85%
Asian	5%	2%
American Indian or Alaska Native	1%	0%
Native Hawaiian or Other Pacific Islander	0%	0%
Some other race	3%	2%

Table 31: Age Range Percentages For Non-Users And Users

Age Range	% of Non-Users	% of Users
Under 18	0%	0%
18-29	5%	3%
30-39	12%	13%
40-49	19%	15%
50-59	29%	24%
60-69	25%	28%
70-79	9%	12%
80-89	2%	5%
90+	0%	0%

Table 32: Education Percentages For Non-Users And Users

Education	% of Non-Users	% of Users
Less than High School	1%	1%
High School Diploma or GED	19%	15%
2 Year Degree (e.g. Associates or Technical Degree)	22%	22%
4 Year Degree (e.g. Bachelor's Degree)	37%	37%
Post Graduate Degree	21%	25%

Table 33: Income Bracket Percentages For Non-Users And Users

Income	% of Non-Users	% of Users
Less than $10,000	2%	1%
$10,000 to $19,999	3%	4%
$20,000 to $29,999	6%	6%
$30,000 to $39,999	7%	7%
$40,000 to $49,999	9%	11%
$50,000 to $59,999	12%	10%
$60,000 to $69,000	10%	6%
$70,000 to $79,999	8%	8%
$80,000 to $89,999	7%	9%
$90,000 to $99,999	5%	9%
$100,000 to $149,999	17%	18%
$150,000 or more	14%	10%
Weighted Average Income:	$80,805.37	$79,272.39

Likewise, Table 30-33 display that the distribution of the socio-economic characteristics addressed by the survey was comparable for the Users and Non-Users. From these tables, it can be seen that the average portal user is older, more highly educated, less likely to be a minority, and earns less than the Non-Users. Despite this, the ethnicity, income bracket, education level, and age ranges proportions of the Users and Non-Users were very similar, differing by six percent or less for all characteristic responses. The similarity of the survey results serves to indicate these factors do not influence whether a resident would sign up for the portal. It also indicates that any reduction in consumption by Users is directly influenced by their ability to closely monitor their water usage.

5. CONCLUSIONS

This thesis served to explore the ways in which water is traditionally managed and how water management is evolving to include integrated management systems and advanced metering systems. Demand management in the form of price, education, legislation, infrastructure, and maintenance were discussed. As the literature review illustrates, the price of water is inelastic, as increases in water prices will cause consumption to be reduced. Because of this, pricing is an effective demand management strategy though it needs to be combines with other practices to increase effectiveness. Education and legislative programs can also create water reductions, though the mandatory legislative programs are significantly more effective than voluntary education programs as it is not surprising that communities are more likely to conserve water when they are forced to than when they do it by choice. The installation of water saving devices and maintenance of existing infrastructure can also save water. However, the efficiency created by these maybe overtaken by behavioral changes of the residents. Maintaining pipe networks and repairing leaks reduce the amount of water lost in a distribution system significantly.

Despite the effectiveness of these practices, there is still a need for different management practices and a shift in how water management is viewed because of growing pressures on water supply. The integration of many water sources, rather than just the typical surface and ground sources, allow for demands to be met in ways that match the quality of the water used to its intended purpose. However, for this to be effective the water demands, and factors that affect it, need to be understood at a resolution that has not yet been accomplished on a large scale. This resolution will come from the widespread implementation of advanced metering.

The push for advanced metering could bring about many benefits such as customized consumption feedback, dynamic pricing structures, earlier detection of leaks and more. The demands of the utility services will be better understood, and can therefore be better met, by analyzing the usage patterns and data collected. Advanced meters have also been shown to help reduce consumption in many of the reviewed studies, as well as in this one.

The comparisons of portal Users and Non-Users done during the study help to answer the four research questions posed in Methodology section. The first question, “Do the AMI portal Users have different indoor consumptions than then Non-Users?” is answered in the first data comparison. As outdoor water demands are low during the winter months, this comparison illustrates that the indoor consumption of the Users and Non-Users is very similar. These average uses were also fairly low likely because less water is used during the winter since lawn watering needs are low.

The second question of “Did the AMI portal Users have different water consumptions during 2015 than the Non-Users?” Is answered in part by the comparison of the annual 2015 data. From this comparison, it was found that the similarities in consumption from the winter months did not continue throughout the year. The difference in consumption of near 20%, suggests that the portal Users have higher outdoor water demands than the Non-Users. As the difference in outdoor demands was so large, is was wondered if this was a regular occurrence for the portal Users. This was explored in the comparison of the historical and 2015 usage data. From Figure 6 is can be seen that in the past, the portal Users had typically used less water than the Non-Users during the beginning of the year, and only slightly more during the end of the year. Because the trends seen in the historical data did not match that of the 2015 data, an examination of the weather during 2015 was sought in order to help explain this inconsistency. From Figure 8 is can be seen that, while 2015 was a relatively wet year, there was an extended dry period during the summer months.

The analysis of 2014 and 2015 data answered the next research question, “Does the AMI portal lead to significant year to year water reductions?” Comparing the 2014 and 2015 water consumptions of the Users and Non-Users showed that while both groups reduced their consumptions from 2014 to 2015, the Users reduced their consumptions much more per account. From Figure 1 it is seen that the Users reduced their consumption more than the Non-Users had throughout the year, except in August and September. It is important to remember that during this time a long dry spell was occurring. Because of this the portal Users likely justified increasing their consumption slightly to make up for a lack of rainfall. The cumulative precipitation of 2014 must also be examined to fully understand the results and answer this research question. The precipitation data for 2014, in Figure 7, shows that it was a much drier year than seen in normal years, as well as in 2015. However, the rainfall events throughout the year were fairly regular. As mentioned in the literature review, consumer react to the event of rain as well as the amounts. Therefore, the regular rainfall during this year may have helped to decrease the total amount of water consumed. This, in addition with the water restrictions that were in place during this year, make the reducing effects that the portal has even more apparent when considering the reductions seen from 2014 to 2015.

The final research question, “Do the reductions in caused by the AMI portal change with time after account holders have joined the portal?” is answered through the comparison of the reductions seen by the 1st and 2nd year Users. Figure 2 illustrates the reducing effect the portal has on consumption over time by showing the difference in percent reduction between the Users and the Non-Users. As the Users enter their second year of portal usage, their reductions lessen. This is likely due to the fact that these Users had already reduced their consumption greatly during their first year of portal access, and that any further reductions are unlikely.

It was also noticed during these comparisons, that when working with water data records from multiple years like the ones used in this analysis a large amount of data pool shrinkage can be expected. It was suggested that this could be attributed to the movement of customers in and out of the city, as found in Section 4.3.3. A residential turnover rate of 9% indicates that there is a 91% chance that a resident will stay in their home and keep their water utilities account. When this rate was applied of the six-year period, from the beginning of the historical period to 2015, the number of accounts was still lower than the average number of matched that occurred between 2015 and historical data. While some of the data shrinkage can be attributed to residential movement, there are still other factors that reduce the number of data matches.

Analysis of the survey data was done to determine if there were any characteristics that appeared to influence the likelihood of an account holder signing up to use the data portal. The analysis of the survey revealed trivial differences in account characteristics between the Users and the Non-Users. Attitudes towards water conservation and conservational habits did not play a role in whether or not a customer accessed the portal, nor did the perceived barriers to conserving, knowledge of the water utilities or other survey categories as the difference in scores was less than five percent for all categories. Though the studies discussed in the literature review suggest that socio-economic factors can have an impact on conservation attitudes, these factors do not seem to have any effect on the decision to sign up for the data portal. The lack of difference in survey responses suggest that any conservation done by the portal Users is a result of being able to monitor their consumption data, and not a result of other outside factors.

The comparison scenarios, on a whole, suggest that when residents have access to their consumption data they will react by reducing their use. When considering that Users in their second year of joining the portals may have already modified their water consumption habits and lowered their usage, and that the Users in their first year of joining the portal were shown to have consistently decreased their use from 2014 to 2015 more that the Non-Users, it would not be difficult to come the conclusion that having access to the data has some reducing effects. Additionally, the portal Users were shown to have decreased water use by 1 million gallons and $2,000 from their historical averages. Though these reductions may seem small, they reflect a small portion of a single city. If these same results were found across the state or country, the amounts conserved would be much larger. Conservation of all amounts will be important in the future as water demands rise with population growth and climate change and supply management becomes more crucial.

NOMENCLATURE

AMI	Advanced Metering Infrastructure
DSM	Demand Side Management
IBR	Increasing Block Rate
DBR	Decreasing Block Rate
IUWM	Integrated Urban Water Management
GPAD	Gallons per Account per Day
WDMS	Water Demand Management Strategies

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APPENDIX A

```
        Sub Flag_Overlap_Months_Same_CustID()
        '
        ' Copyright Kelly Brumbelow, 2016. All rights reserved.
        '
        '
           Dim StartRoww, UniqueCustRoww, ThisCustID, ThisMeterID,
NumMetersThisCust, SearchRoww, SearchColumnn, NumValues, OverlapFound
           Dim CollapsedRoww, CollapsedData(5), ThisCustMeters(30), DataYear,
ThisMeterl
           Dim CopyArray(30, 7), PasteStartRoww

           Sheets("JAN-Collapsed").Select
           Range("A2").Select
           CollapsedRoww = 1

           Sheets("JAN-Overlap").Select
           Range("A2").Select
           PasteStartRoww = 1

           Sheets("_01_JAN_AMI").Select
           Range("B2").Select
           StartRoww = 1

           Do Until StartRoww > 147385   'Change this for other data files

              ThisCustID = ActiveCell(StartRoww, 1).Value
              ThisMeterID = ActiveCell(StartRoww, 2).Value
              UniqueCustRoww = 0    'Find if multiple meters associated with this
customer
              Do
                 UniqueCustRoww = UniqueCustRoww + 1
              Loop Until ActiveCell(StartRoww + UniqueCustRoww, 1).Value <>
ThisCustID

              NumMetersThisCust = UniqueCustRoww

              If UniqueCustRoww = 1 Then
                 OverlapFound = False
              End If

              If UniqueCustRoww > 1 Then
```

```
                  OverlapFound = False
                  For SearchColumnn = 3 To 7  'Upper limit may change for other data
files. This is for 5 years of data.
                     NumValues = 0
                     For SearchRoww = 0 To NumMetersThisCust - 1
                        If ActiveCell(StartRoww + SearchRoww, SearchColumnn) <> ""
Then
                           NumValues = NumValues + 1
                        End If
                     Next SearchRoww
                     If NumValues > 1 Then OverlapFound = True
                  Next SearchColumnn

               End If

               If OverlapFound = False Then

                  For SearchColumnn = 3 To 7  'Upper limit may change for other data
files. This is for 5 years of data.
                     DataYear = SearchColumnn - 2
                     CollapsedData(DataYear) = ""
                     For SearchRoww = 0 To NumMetersThisCust - 1
                        If ActiveCell(StartRoww + SearchRoww, SearchColumnn) <> ""
Then
                           CollapsedData(DataYear) = ActiveCell(StartRoww +
SearchRoww, SearchColumnn)
                        End If
                     Next SearchRoww
                  Next SearchColumnn

                  SearchColumnn = 2
                  For ThisMeter = 1 To NumMetersThisCust
                     ThisCustMeters(ThisMeter) = ActiveCell(StartRoww + ThisMeter - 1,
SearchColumnn)
                  Next ThisMeter

                  Sheets("JAN-Collapsed").Select
                  Range("A2").Select

                  ActiveCell(CollapsedRoww, 1) = ThisCustID
                  For DataYear = 1 To 5
                     ActiveCell(CollapsedRoww, 1 + DataYear) =
CollapsedData(DataYear)
```

```
                Next DataYear
                For ThisMeter = 1 To NumMetersThisCust
                    ActiveCell(CollapsedRoww, 7 + ThisMeter) =
ThisCustMeters(ThisMeter)
                Next ThisMeter
                CollapsedRoww = CollapsedRoww + 1

            End If

            'Do something if there is overlap
            If OverlapFound = True Then
                For SearchRoww = 1 To NumMetersThisCust
                    For SearchColumnn = 1 To 7
                        CopyArray(SearchRoww, SearchColumnn) = ActiveCell(StartRoww
+ SearchRoww - 1, SearchColumnn)
                    Next SearchColumnn
                Next SearchRoww

                Sheets("JAN-Overlap").Select
                For SearchRoww = 1 To NumMetersThisCust
                    For SearchColumnn = 1 To 7
                        ActiveCell(PasteStartRoww + SearchRoww - 1, SearchColumnn) =
CopyArray(SearchRoww, SearchColumnn)
                    Next SearchColumnn
                Next SearchRoww
                PasteStartRoww = PasteStartRoww + NumMetersThisCust

            End If

            Sheets("_01_JAN_AMI").Select
            Range("B2").Select

            'Move to next customer
            StartRoww = StartRoww + UniqueCustRoww

        Loop


    End Sub
```

APPENDIX B

Survey Categories and Questions

Personal Capability: Please indicate your level agreement regarding the following:

	Strongly Disagree (1)	Disagree (2)	Somewhat Disagree (3)	Somewhat Agree (4)	Agree (5)	Strongly Agree (6)
Water conservation technologies (e.g. low-flow shower heads) are easily accessible to me. (1)	○	○	○	○	○	○
Water conservation technologies are economically feasible for me to purchase. (2)	○	○	○	○	○	○
Participating in water conservation behaviors are physically possible for me and my family members. (3)	○	○	○	○	○	○

Efficient Infrastructure: Do you have a(n)

	Yes (1)	No (2)
Swimming pool (1)	○	○
Swimming pool cover (2)	○	○
Hose with trigger or timed sprinkler (3)	○	○
Automatic lawn sprinkler (4)	○	○
Water-wise plants or gardens (5)	○	○
Duel-flush or composting toilet (6)	○	○
Shower timer (7)	○	○
Gray water reuse system (8)	○	○
Rainwater harvesting system (9)	○	○
Water-wise washing machine (10)	○	○
Water-wise dishwasher (11)	○	○
Low-flow faucets (12)	○	○
Low-flow shower heads (13)	○	○

Habits: Please indicate how frequently you engage in the following conservation habits

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	All of the Time (5)
Check for leaks (1)	○	○	○	○	○
Fix leaks (2)	○	○	○	○	○
Intentionally take shorter showers (3)	○	○	○	○	○
Use half-flush on toilets (4)	○	○	○	○	○
Do not flush every time (5)	○	○	○	○	○
Only wash full loads of laundry (6)	○	○	○	○	○
Re-use water for dishes or fill the basin with water for washing (7)	○	○	○	○	○
Only washing full loads of dishes in the dishwasher (8)	○	○	○	○	○
Turn off taps when brushing teeth (9)	○	○	○	○	○
Water the lawn/garden in late evening or morning hours (10)	○	○	○	○	○
Refrain completely from watering the lawn (11)	○	○	○	○	○

Attitudes: Please indicate your attitude regarding the value of the following conservation behaviors

	Extremely Worthless (1)	Worthless (2)	Somewhat Worthless (3)	Somewhat Valuable (4)	Valuable (5)	Extremely Valuable (6)
Checking for leaks (1)	○	○	○	○	○	○
Fixing leaks (2)	○	○	○	○	○	○
Intentionally taking shorter showers (3)	○	○	○	○	○	○
Using half-flush on toilets (4)	○	○	○	○	○	○
Not flushing every time (5)	○	○	○	○	○	○
Only washing full loads of laundry (6)	○	○	○	○	○	○
Re-using water for dishes or filling the basin with water for washing (7)	○	○	○	○	○	○
Only washing full loads of dishes in the dishwasher (8)	○	○	○	○	○	○
Turning off taps when brushing teeth (9)	○	○	○	○	○	○
Watering the lawn/garden in late evening or morning hours (10)	○	○	○	○	○	○
Refraining completely from watering the lawn (11)	○	○	○	○	○	○

Perceived Barriers: Please indicate your level of agreement regarding the following statements:

	Very Difficult (1)	Difficult (2)	Somewhat Difficult (3)	Somewhat Easy (4)	Easy (5)	Very Easy (6)
Checking for leaks (1)	○	○	○	○	○	○
Fixing leaks (2)	○	○	○	○	○	○
Intentionally taking shorter showers (3)	○	○	○	○	○	○
Using half-flush on toilets (if applicable) (4)	○	○	○	○	○	○
Not flushing every time (5)	○	○	○	○	○	○
Only washing full loads of laundry (6)	○	○	○	○	○	○
Re-using water for dishes or filling the basin with water for washing or rinsing (7)	○	○	○	○	○	○
Only washing full loads of dishes in the dishwasher (8)	○	○	○	○	○	○
Turning off taps when brushing teeth (9)	○	○	○	○	○	○
Watering the lawn/garden in late evening or morning hours (10)	○	○	○	○	○	○
Refraining completely from watering the lawn (11)	○	○	○	○	○	○

House Culture: Please indicate your level of agreement regarding the following statements

	Strongly Disagree (1)	Disagree (2)	Somewhat Disagree (3)	Somewhat Agree (4)	Agree (5)	Strongly Agree (6)
We think of ourselves as a water conserving household (1)	○	○	○	○	○	○
All members of my household think that reducing water use around the house is valuable (2)	○	○	○	○	○	○

Procedural Knowledge: Please indicate your general level of knowledge about items

	Very Poor (1)	Poor (2)	Somewhat Poor (3)	Somewhat Good (4)	Good (5)	Very Good (6)
Current water supplies for the City (1)	○	○	○	○	○	○
Projected water needs for the City (2)	○	○	○	○	○	○
Primary sources of freshwater for the City (3)	○	○	○	○	○	○
City water rates (4)	○	○	○	○	○	○
Drought conditions facing the City (5)	○	○	○	○	○	○
Drought stages imposed by the City (6)	○	○	○	○	○	○
How much water is used inside your home (7)	○	○	○	○	○	○
How much water is used on your lawn or landscape (8)	○	○	○	○	○	○
How much water is used by your neighbors (9)	○	○	○	○	○	○
How much water is used within the City (10)	○	○	○	○	○	○

Ethnicity: What is your Ethnicity?
○ Hispanic or Latino (1)
○ Black or African American (2)
○ White (3)
○ Asian (4)
○ American Indian or Alaska Native (5)
○ Native Hawaiian or Other Pacific Islander (6)
○ Some other race (7)

Age Range: Which age range do you fall in?
○ Under 18 (1)
○ 18-29 (2)
○ 30-39 (3)
○ 40-49 (4)
○ 50-59 (5)
○ 60-69 (6)
○ 70-79 (7)
○ 80-89 (8)
○ 90+ (9)

Education: What is the highest level of education you completed?
- ○ Less than High School (1)
- ○ High School Diploma or GED (2)
- ○ 2 Year Degree (e.g. Associates or Technical Degree) (3)
- ○ 4 Year Degree (e.g. Bachelor's Degree) (4)
- ○ Post Graduate Degree (5)

Income: What is your total household income?
- ○ Less than $10,000 (1)
- ○ $10,000 to $19,999 (2)
- ○ $20,000 to $29,999 (3)
- ○ $30,000 to $39,999 (4)
- ○ $40,000 to $49,999 (5)
- ○ $50,000 to $59,999 (6)
- ○ $60,000 to $69,000 (7)
- ○ $70,000 to $79,999 (8)
- ○ $80,000 to $89,999 (9)
- ○ $90,000 to $99,999 (10)
- ○ $100,000 to $149,999 (11)
- ○ $150,000 or more (12)