Examining conservation-oriented water pricing and programs through an energy lens

An analysis of the energy savings associated with water demand reductions

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Executive Summary

Energy and water are inextricably linked—energy is needed to withdraw, transport, and treat water, and water is needed to produce and distribute energy. This relationship between energy and water, referred to as the *energy-water nexus*, is becoming increasingly important in the United States. Any rise in the demand for energy will further deplete water resources, which are predicted by climate models to be stressed in much of the country by mid-century.[1]

Conservation pricing, or prices that provide an economic incentive for consumers to conserve, is one tool utilities can use to reduce water consumption. Due to the energy-water nexus, lower water consumption results in lower electric demand by water utilities. When electric demand decreases, carbon pollution from the grid, associated with the burning of traditional fuels, is typically also reduced.

Although utilities will occasionally report the perceived success of their conservation programs, little rigorous analysis has been done on the effect of conservation water pricing on water demand and therefore energy consumption. For evaluation and verification of these programs, it would be useful to quantify, analyze, and extrapolate the energy savings associated with various conservation rate structures for water. This information would enable water utilities to better account for energy in their planning.

Yet there are multiple barriers to creating a comprehensive, accurate analysis. For example, there are many gaps, inaccuracies, and inconsistencies on reporting of water quantity and usage throughout the U.S. It is also difficult to make sector-wide comparisons; changes in water demand can be attributed to multiple competing effects including:

- changes in the broader economy;
- weather and climate;
- water conserving technologies;
- other conservation initiatives;
- population growth or decline;[2] and
- consumer education, including the establishment of a conservation culture.

The effect of a rate structure is also dependent on the specific characteristics of both the original and new rate structures. It is therefore impossible to isolate the effects of the rate structure alone on consumer behavior without rigorous statistical analysis, which depends on data that

[1] Natural Resources Defense Council (NRDC). (2010). Climate Change, Water, and Risk: current water demands are not sustainable. Available online at https://www.nrdc.org/sites/default/files/WaterRisk.pdf

[2] Baerenklau, Kenneth A., Schwabe, Kurt A., & Dinar, Ariel. (2013). Do increasing block water budgets reduce residential water demand? A case study in Southern California. Available online at http://www.financingsustainablewater.org/sites/www.financingsustainablewater.org/files/resource_pdfs/WSPC-%282013%29-Do-Increasing-Block-Rate-Water-Budgets-Reduce-Water-Use.pdf

are incomplete or unavailable for many utilities. In addition, the communities most reactive to price changes might be those to adopt conservation pricing structures in the first place.[3]

Part 1 of this paper discusses the foundations of water pricing. Part 2 analyzes four distinct conservation water rate structures in California, Arizona, and Texas. Using these utility case studies, we calculate the changes in residential water demand and the associated energy demands that occur following the implementation of different rate structures.

We conclude that both water demand and associated energy consumption decrease after implementing conservation water rates in these four case studies, but find that the changes cannot be attributed to rate structure alone. Additionally, we resolve that an effective consumer education and awareness campaign is important to the efficacy of these rates. Better and more consistent data collection and dissemination at water utilities is key to providing customers with the appropriate information needed to change behavior, save water, and lower pollution.

I. Part 1- Foundations of water pricing

A. Ratemaking in the water sector

In cost accounting for water, all costs and revenues are separated into two categories: fixed and variable. Fixed costs are generally capital and operating costs that persist regardless of the volume of water delivered.[4] Traditional pricing involves either a flat monthly rate (which does not take into account the volume used) or a volumetric rate (where a meter determines the volume used, and the utility charges the same rate for each additional unit of water consumed). These rates typically contain a high fixed charge component to ensure sufficient recovery of costs due to declining demand,[5] degrading infrastructure, and rising operations and maintenance costs.

Even still, water in the United States is underpriced. Most water pricing today covers the costs of collecting, treating and delivering the water, but does not account for the intrinsic value of

[3] Olmstead, Sheila M., Hanemann, Michael W., & Stavins, Robert N. (2003). Does price structure matter? Household water demand under increasing-block and uniform prices. Available online at https://www.researchgate.net/profile/Robert_Stavins/publication/228916287_Does_Price_Structure_Matter_Household_Water_Demand_Under_Increasing-Block_and_Uniform_Prices/links/0046351668ec2775ea000000.pdf

[4] Spang, Edward S., Miller, Sara, Williams, Matt, & Loge, Frank J. (2015). Consumption-based fixed rates: Harmonizing water conservation and revenue stability. American Water Works Association 107(3): E164-E173. Doi: 10.5942/jawwa.2015.107.0001. Available online at https://www.awwa.org/publications/journal-awwa/abstract/articleid/50838772.aspx

[5] Caused by irrigation efficiency improvements and new standards for water-using appliances and fixtures: see Nagappan, Padma. "How Water Use Has Declined with Population Growth." Water Deeply. November, 2016. Available online at https://www.newsdeeply.com/water/articles/2016/11/08/how-water-use-has-declined-with-population-growth

water. Additionally, suppliers do not always charge prices adequate to replace aging infrastructure, despite efforts to do so.[6]

These traditional rates fall short in not only successful full-cost accounting, but also in sending conservation signals to the consumer. With the high fixed charge, a decrease in demand causes a decrease in utility revenue, which is recovered only by increasing prices, resulting in further reduction of demand. The water utility therefore experiences a financial disincentive to invest in conservation. This exemplifies the difficulty in setting rates- which requires water utilities to prioritize and attempt to balance various objectives that oftentimes contradict each other[7]- and highlights the need for innovation in redefining business models for water utilities.

B. Challenges in innovating the water utility business model

Advances in developing utility business models for the water sector have generally lagged behind those of the electric sector[8] due to additional hurdles the water sector faces. For one, as opposed to many electric utilities, water utilities are often publicly owned (often referred to as publicly-owned utilities, or POUs). Because most water utilities in the U.S. rely on public funding, which must fit within certain appropriations of the overall city or district budget, rate setting is often constrained by various legal and regulatory codes of state and local jurisdictions.[9] Additionally, many energy efficiency programs focus exclusively on the electric sector and therefore do not include water. These structural differences between the electric utilities and water utilities pose unique financing and ratemaking challenges for water.

There are also fewer mechanisms for revenue recovery in the water sector.[10] With more innovative revenue recovery strategies, the high fixed charge- needed to cover declining demand and failing infrastructure- could be reduced. Another challenge is a lack of widespread advanced metering infrastructure (AMI), which is a two-way communication system that allows consumers to accurately monitor their water use on a real-time basis. AMI is far more prevalent in the energy sector as the artificially low price of water, combined with the insufficient business case to invest in a modern water system, has slowed the uptake of such technology in the water sector.

Smart water meters and sensors can empower both the water utility and the customer with information they need to improve efficiency. However, until water-smart metering catches up to

[6] Ajami, Newsha K., Thompson, Barton H. Jr., & Victor, David G. "The Path to Water Innovation." The Hamilton Project & Stanford Woods Institute for the Environment. October, 2014. Available online at https://woods.stanford.edu/sites/default/files/files/path_to_water_innovation_thompson_paper_final.pdf
[7] See Appendix page 21 for more on balancing objectives of utilities in rate making
[8] The electric sector has moved rapidly towards innovative pricing mechanisms. Examples of which are time-of-use, or variable, pricing and demand response (a voluntary tool that rewards homeowners and businesses who shift their energy use to times of day when there is less demand on the power grid or when more renewable energy is abundant).
[9] For more on the public water utility, see the Appendix page 21
[10] See Appendix page 22 for methods of revenue recovery in the electric sector that have been attempted in the water sector

the progress that has been made in the electric sector, water utilities must more heavily rely on conservation pricing and education to change consumer behavior.

C. Conservation pricing for water

Unlike traditional pricing, conservation rate structures are designed with the goals of:

- Reducing water consumption without net negative impacts on utility revenues;
- Rewarding customers for making cost-effective changes in water appliances and behavior through greater savings; and
- Targeting inefficiency in discretionary water uses such as landscape irrigation.

Conservation water pricing has been implemented in different forms for decades, including:

- uniform block;
- marginal;
- increasing block (IBR);
- seasonally adjusted;
- drought; and
- water budget pricing.

Uniform block and IBR pricing are the most widespread, while water budget pricing is garnering more support and gaining popularity. Seasonally adjusted and drought pricing mechanisms are typically employed in combination with uniform, IBR, or water budget pricing.[11]

1. **Uniform block** pricing charges one volumetric fee for all levels of consumption.

2. **Marginal** pricing involves setting the price of a unit of water to equal the cost of supplying an extra unit of water.

3. **Increasing/inclining block** pricing is a form of tiered pricing, where the volumetric cost of water increases with higher consumption.

4. **Water budgets** are a type of price structure that are designed for individual customers based on household-specific characteristics, environmental conditions, and a judgement by the utility on what is considered to be efficient usage. Rates are designed to provide incentives to customers who use less than their budget, and penalize those who exceed it.

5. **Seasonally adjusted or drought** pricing requires increasing the cost of water during certain times of the year. With seasonal pricing, this increase is during the

[11] See Appendix page 24 for more on the benefits and challenges of each of the subsequent rate structures

summer months, when demand is higher, while drought pricing costs increase during water shortage. Drought pricing can manifest as a general surcharge, individual rate surcharge, or class-based surcharge.

6. **Other pricing methods** that might encourage conservation have been developed but not yet implemented. See Appendix page 26.

Predicting the potential efficacy of any of these rates at a specific utility requires a thorough understanding of the service area. This includes characteristics of the area itself (i.e. geography, infrastructure, economy and climate) as well characteristics of the population, including consumer awareness and responsiveness to price (both of which are highly dependent on concurrent conservation programs).

D. Conservation programs and the importance of education

Rate re-structuring is just one way in which water utilities can attempt to increase system efficiency. Usually conservation rates are implemented in tandem with other conservation initiatives. The success of these programs, which can also include indoor and outdoor rebates for efficiency measures and drought restrictions, is dependent on consumer behavior and conservation ethos.

Effective implementation of demand management and water conservation strategies is strongly supported by an understanding and knowledge of how consumers perceive and use their water. Despite growing awareness of the need for water conservation amongst the public, studies have shown that householders' perceptions of their water use are often not well matched with their actual water use.[12] In addition, some customers may not fully understand their bills, or even bother to read them. Conservation rate structures can get complicated, which inhibits the consumer's decision-making regarding use. Transparency in pricing and implementation, which is generally lacking, is therefore very important.

When utility conservation programs are designed with outreach and education as components – such as informing the public on the volumes of water needed for daily activities, specific actions needed to reach conservation goals, how rates work, and how to interpret bills –rates and other initiatives are more effective in encouraging people to conserve.[13]

1. Smart metering as an education tool

As previously discussed, AMI for water is not yet widespread, but has proven effective as an educational tool for informing consumers on their use. Not only does AMI expedite the process of leak detection, which benefits both the utility and the

[12] Bryx, Danya, & Bromberg, Gidon. "Best Practices in Domestic Water Demand Management." Friends of the Earth Middle East. March, 2009. p 2. Available online at http://ecopeaceme.org/uploads/publications_publ106_1.pdf
[13] See Appendix 27 for studies that demonstrate the effectiveness of public awareness campaigns and education on consumer behavior

residential end-user, but it also allows customers to make timely adjustments to their usage. This is important for utilities using price tiers or water budgets, where the bill available at the end of the month comes too late to inspire change in behavior. AMI has also created a greater knowledge of the energy embedded in water, which motivates customers to conserve.[14] Educating consumers about AMI may then be a crucial first step in educating them on their water use.

When smart metering is combined with advanced technological tools, such as WaterSmart Software, consumers' perceptions of their water use are much more informed. The WaterSmart service utilizes social-norms-based efficiency programs, which provide households with periodic information on their current water use, and compare it to their past use, the average use of similar households, and the use of the most efficient similar households. WaterSmart self-reports a 5 percent water savings resulting from customized home water reports for its pilots.[15] Such findings suggest that programs, facilitated by smart metering software such as WaterSmart, may be effective in reducing water demand and be a channel for other utility conservation programs.

If consumers are unaware or misinformed about their water use, water rates, or options for efficiency, the efficacy of any part of a holistic utility conservation program diminishes. It is therefore important to situate a water rate structure in the context of the entire water agency demand management strategy.

II. Part 2- The Case Studies

For methodology, please see the Appendix page 29.

A. Introduction

This section of the paper calculates and analyzes the energy savings associated with different rate structures and conservation practices at four water utilities in the U.S.

Estimates vary,[16] and the amount of water used per day is highly dependent on geographic location and time of year, but the USGS estimates that today, the average American uses

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[14] Lovely, Lori. "How to Educate the Public About the Benefits of AMI." Forester Daily News. July, 2017. Available online at http://foresternetwork.com/daily/water/water-meter/how-to-educate-the-public-about-the-benefits-of-ami/

[15] See Appendix page 28 for more smart water software and WaterSmart evaluation, from:
Mitchell, David L., & Chesnutt, Thomas W. "Evaluation of East Bay Municipal Utility District's Pilot of WaterSmart Home Water Reports." California Water Foundation, East Bay Municipal Utility District, M. Cubed, & A&N Technical Services. December, 2013. p 7. Available online at http://www.financingsustainablewater.org/resource-search/evaluation-east-bay-municipal-utility-districts-pilot-watersmart-home-water-reports

[16] Water utilities use gallons per capita per day (gpcd) as the metric for consumption. It is not unusual, however, for gpcd figures to vary due to different methods of calculation. See Appendix page 29

between 80 and 100 gallons per day.[17] The Water Research Foundation estimates 88,000 residential gallons per American household per year,[18] or about 95 residential gallons per capita per day (r-gpcd).[19] Average daily *indoor* water use for 2016 is estimated to be 58.6 gallons per capita per day (gpcd), which is predicted to decrease to 36.7 gpcd in the upcoming years due to homeowner replacement of old water-consuming appliances with higher efficiency appliances.[20] Average consumption for select states can be seen in Table 1.

Table 1. Average per capita water demand by state[21]

State	**Average Consumption**
Texas	138 gpcd (2015)[22], 84 r-gpcd (2013)[23]
California	128 gpcd, 85 r-gpcd (2016) [24]
Arizona	100 r-gpcd (updated April 2017) [25]

This following case studies represent different conservation water rate structures in the states of California, Texas, and Arizona. While the results of these four conservation programs and pricing practices are specific to these case studies, this analysis informs a conversation on successful water and energy saving practices in various service areas. The selected cases are:

[17] U.S. Geological Survey (USGS). "Water Questions & Answers: How much water does the average person use at home per day?" December, 2016. Available online at http://water.usgs.gov/edu/qa-home-percapita.html
[18] Water Research Foundation. "Residential End Uses of Water, Version 2." April, 2016. p 3. Available online at http://www.circleofblue.org/wp-content/uploads/2016/04/WRF_REU2016.pdf
[19] Calculated from Water Research Foundation estimate, divided by an average of 2.53 people per American household in 2016 (available online at https://www.statista.com/statistics/183648/average-size-of-households-in-the-us/), divided by 365 days in a year.
[20] Water Research Foundation. "Residential End Uses of Water, Version 2." April, 2016. p 11. Available online at http://www.circleofblue.org/wp-content/uploads/2016/04/WRF_REU2016.pdf
[21] For more on the difference between gpcd and r-gpcd see Appendix page 29. While a comparison by per capita usage across states for both r-gpcd and gpcd in the same year is the most beneficial, it is not possible due to the differences in reporting across states. This table represents the most updated data publicly available in each state.
[22] Calculated by dividing total municipal water by total state population. From Texas Water Development Board (TWDB), "Water Use Survey Historical Summary Estimates (includes reuse) by Region." 2015. Available online at http://www2.twdb.texas.gov/ReportServerExt/Pages/ReportViewer.aspx?%2fWU%2fSumFinal_RegionReportWithReuse&rs:Command=Render
[23] Texas Water Development Board (TWDB). "Annual Statewide Water Use." June, 2015. Available online at http://www.twdb.texas.gov/waterplanning/waterusesurvey/estimates/data/TexasStatewideReport_6_12_15_Revision.pdf
[24] Personal communication with Jelena Hartman, Senior Scientist for Climate Change at California State Water Resources Control Board. Calculated from August 1, 2017 Water Conservation Dataset. Methodology available at http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/docs/ws_tools/guidance_estimate_res_gpcd.pdf.
[25] Arizona Department of Water Resources. Residential Home Page. April, 2017. Available online at http://www.azwater.gov/AzDWR/StatewidePlanning/Conservation2/Residential/Residential_Home2.htm

Table 2. Case study locations and rate structures

Water utility	State	Rate structure
Eastern Municipal Water District	CA	IBR water budget
El Paso Water Utility	TX	IBR water budget using average winter consumption (PeakSet Base variation[26])
San Antonio Water System	TX	Seasonal IBR
Phoenix	AZ	Seasonal pricing

B. Eastern Municipal Water District (EMWD)

EMWD serves the region of southern California between Los Angeles and San Diego. The service region covers 542 square miles and has a population of more than 768,000. EMWD is headquartered in Perris, CA, which has a mild Mediterranean climate. On average, the area receives 10 inches of rain and 275 days of sunshine each year, and experiences low humidity year-round. The July high temperatures average to 97°F and the January low temperatures average to 35°F.[27]

As of 2012, EMWD provided around 90,000 acre-feet (AF) of water to approximately 136,000 domestic water service accounts and agricultural and irrigation water service accounts.[28] This is equivalent to approximately 105 r-gpcd for the district.[29] The primary supplier of the EMWD is the Metropolitan Water District of Southern California, which provides up to 75 percent of its water supply through the Colorado River Aqueduct and its connections to the State Water Project. The remaining 25 percent of potable water demand is supplied by EMWD groundwater wells, the majority of which comes from wells in the Hemet and San Jacinto areas.[30]

Beginning in April 2009, EMWD changed from flat-rate pricing to a household-specific inclining block water budget. The indoor budget is based on the number of residents in the household (each at 60 gallons per day). Outdoor budgets are based on the amount of water required to maintain a property's irrigated area, under the assumption that there is turf grass in

[26] See Appendix page 26 for more on the PeakSet Base variation pricing
[27] City of Perris. "Climate." Accessed on August 8, 2017. Available online at http://www.cityofperris.org/about/climate.html
[28] Baerenklau, Kenneth A., Schwabe, Kurt A., & Dinar, Ariel. (2013). Do increasing block water budgets reduce residential water demand? A case study in Southern California. P 5. Available online at http://www.financingsustainablewater.org/sites/www.financingsustainablewater.org/files/resource_pdfs/WSPC-%282013%29-Do-Increasing-Block-Rate-Water-Budgets-Reduce-Water-Use.pdf
[29] Calculated by converted 90,000 AF to gallons and dividing by the population of the district (768,000)
[30] Eastern Municipal Water District. Available online at https://www.emwd.org/about-emwd

that area. The number of billing units varies each month depending on daily weather information. In addition to the changing rate, EMWD has undertaken other conservation measures including residential rebates for water efficient household appliances and free outdoor water efficiency kits for customers who have trouble staying within their water budget.

A three-year period, starting from the 2009 rate implementation, was analyzed. A study by the Water Science and Policy Center at the University of California, Riverside, Do Increasing Block Rate Water Budgets Reduce Residential Water Demand? A Case Study in Southern California,[31] attempts to attribute changes in residential water demand to the 2009 rate change of interest. They estimate that three years after rate implementation, demand under this IBR water budget was at least 18 percent below the level it would have been under a comparable flat-rate price structure. This figure was used as the baseline for the embedded energy calculations. The grid energy associated with this water demand was found to be 727 kWh/capita in 2009 and 599 kWh/capita in 2012, resulting in a 17.6 percent reduction in associated per capita energy consumption. This is an emissions reduction from 464 lbs CO_2 per capita in 2009 to 392 lbs per capita in 2012.

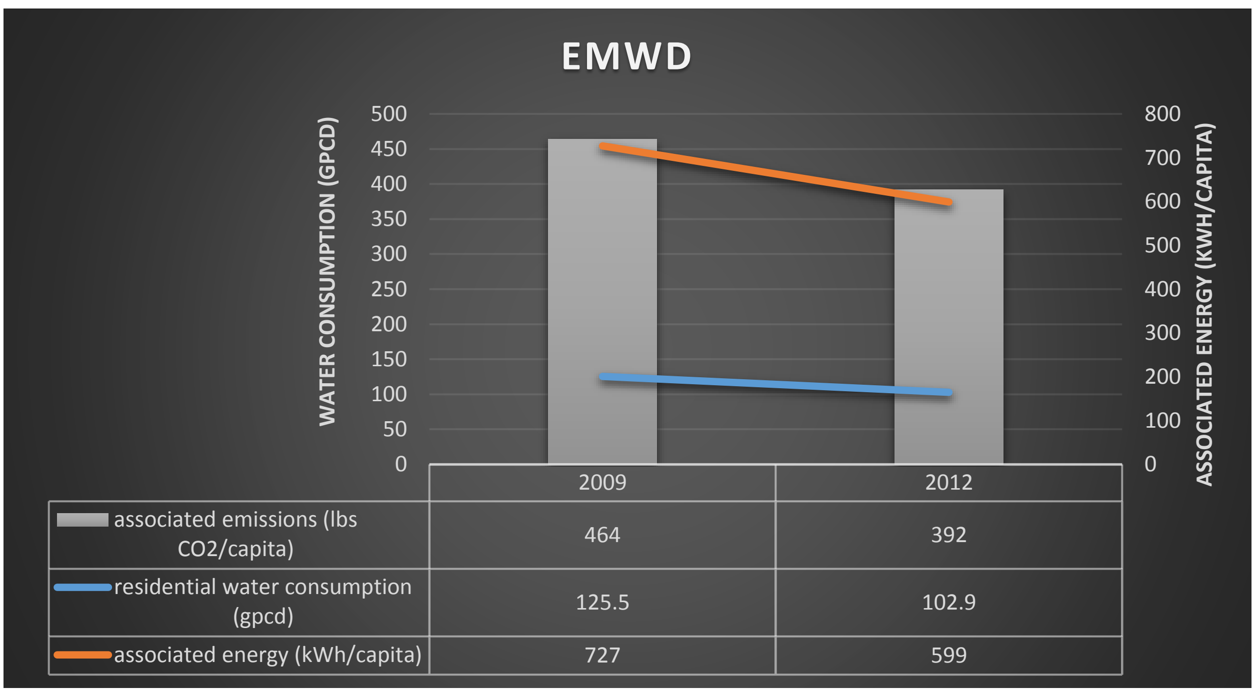

Figure 2. EMWD water, energy, and emissions reductions

C. El Paso Water Utility (EPWU)

[31] Baerenklau, Kenneth A., Schwabe, Kurt A., & Dinar, Ariel. (2013). Do increasing block water budgets reduce residential water demand? A case study in Southern California. Available online at http://www.financingsustainablewater.org/sites/www.financingsustainablewater.org/files/resource_pdfs/WSPC-%282013%29-Do-Increasing-Block-Rate-Water-Budgets-Reduce-Water-Use.pdf

El Paso is located in the northern extreme of the Chihuahuan Desert, with an average winter high of 59°F, an average summer high of 94°F.[32]The city sees over 300 days of sunshine each year, and an average rainfall of 8 inches, compared to the annual average of 34 inches received by the capital city, Austin. Like other parts of Texas, El Paso has cycled between drought and non-drought conditions. It is the sixth largest city in Texas with an estimated population of 787,208. EPWU reached its goal of 130 gpcd by 2020 in 2013.[33] It serves customers inside and outside city limits, providing retail water service to customers in the City of El Paso, Westway, Canutillo and Homestead. It also provides wholesale service to several communities in El Paso County.

Total water demand peaked in the mid-1990s at 132,000 AF and has been declining since the late 1990s due to various conservation and pricing strategies. Current total demand is about 118,000 AF per year.[34] EPWU uses groundwater and surface water for its potable supply. Groundwater sources include the Hueco Bolson and the Mesilla Bolson aquifers, while surface water is supplied by the Rio Grande. The Rio Grande is notoriously over-allocated and over-extracted, and faces a potential "permanent drought" if climate change effects of continued declines in water flow persist.[35] Reclaimed water, an alternative source for continued extraction, is currently used for non-potable demands including turf irrigation and industrial uses, at 5.83 million gallons per day.[36]

El Paso implemented a water budget rate structure in 1989, before the start of an aggressive conservation program in 1992. It is an inclining block structure with monthly minimum charges based on meter size, and a volumetric charge per block that is calculated for each customer based on average winter consumption (AWC), which is the amount of water used during the previous December, January, and February billing periods. Other components of EPWU's conservation plan include rebate programs for replacement of inefficient water fixtures, introduction of native landscaping to reduce irrigation requirements, public education, and enforcement.

In 1989, before the implementation of the water conservation ordinance and new rate structure, residential water consumption was at 200 gpcd. Two years after implementation, in 1991, demand dropped to 170 gpcd, representing a 15 percent reduction in per capita water consumption and an associated 16 percent reduction in associated residential energy consumption. While maintaining the same rate structure, 10 years later, in 2001, EPWU

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[32] US Climate Data. "Climate El Paso- Texas." 2017. Available online at http://www.usclimatedata.com/climate/el-paso/texas/united-states/ustx0413
[33] El Paso Water Utilities (EPWU). "El Paso Water Utilities 2014 Water Conservation Plan As per Rule 363.15 Required Water Conservation Plan Texas Water Development Board." 2014. P 1-2. Available online at http://www.epwu.org/conservation/pdf/Conservation_Plan_2014.pdf
[34] El Paso Water Utilities (EPWU). "Water: past and present water supplies." 2016. Available online at http://www.epwu.org/water/water_resources.html
[35] Paskus, Laura. "Is the Rio Grande Headed for a 'Permanent Drought'?" January, 2016. Available online at http://nmindepth.com/2016/01/05/is-the-rio-grande-headed-for-permanent-drought/
[36] El Paso Water Utilities (EPWU). "Reclaimed Water: water shouldn't only be used once!" 2016. Available online at http://www.epwu.org/reclaimed_water/

implemented a rate increase. By 2013, EPWU reached its 2020 goal of achieving 130 gpcd, representing a 35 percent reduction in residential demand in the 24 years since the introduction of the conservation rate structure. This is associated with a 32 percent reduction in embedded energy, which leads to a nearly 50 percent reduction in CO_2 emissions since 1989.

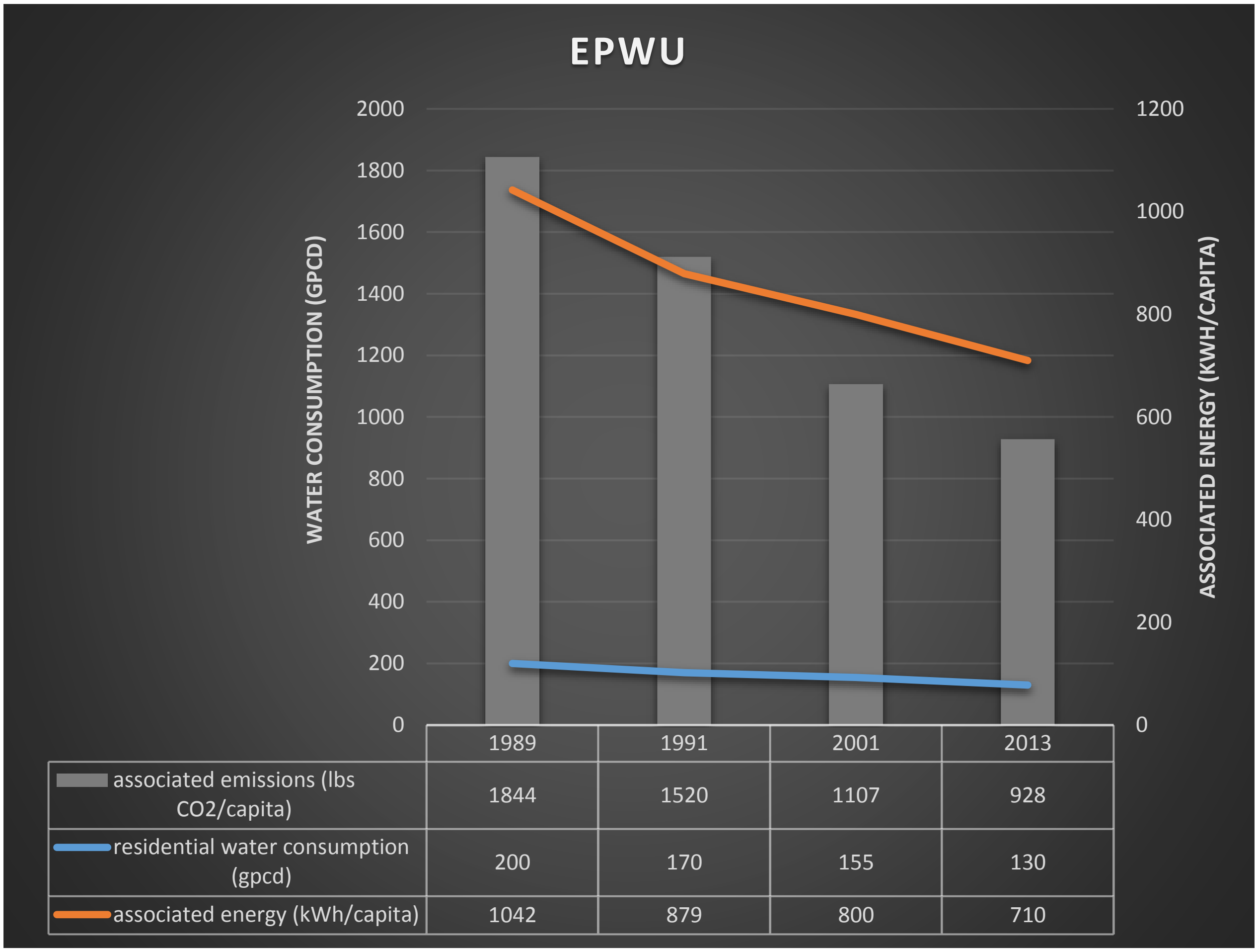

Figure 3. EPWU's water, energy, and emissions reductions

D. San Antonio Water System (SAWS)

The City of San Antonio, the seventh largest city in the U.S., is located in south-central Texas, at the edge of the gulf Coastal Plains, and has a modified subtropical climate. Normal mean temperatures range from 50.7°F in January to a high of 84.7°F in July. The normal annual amount of rainfall is 28 inches.[37]

[37] US Climate Data. "Climate San Antonio- Texas." 2017. Available online at http://www.usclimatedata.com/climate/san-antonio/texas/united-states/ustx1200

SAWS serves more than 1.6 million people in Bexar County, as well as parts of Medina and Atascosa counties, with a 2016 average consumption rate of 117 gpcd.[38] This population includes more than 460,000 water customers and 411,000 wastewater customers.[39] SAWS boasts the largest direct recycled water delivery system in the nation, and provides numerous outdoor conservation programs and rebates.

SAWS has been using increasing block rates to incentivize efficiency and conservation since the 1980s, maintaining the general structure but making modifications through the years. One of those modifications was a seasonal variation on the inclining block rate structure. The blocks are not customer-specific, but each block charges a higher fee in the summer months, beginning on or about May 1 and ending after five complete billing months, on or about September 30 (depending on the customer's billing cycle). Sewer service charges for all metered residential connections are computed based on average water use for the three consecutive billing periods beginning after November 15 and ending March 15 of each year.

Additionally, the utility relies on a "three-legged stool" of education and outreach, regulation through city ordinances, and healthy financial investment towards conservation efforts.[40] The city has grown 80 percent in the past 30 years, but the amount of water needed to sustain the population has only grown by 20 percent.[41] The Edwards Aquifer currently provides more than 90 percent of drinking water used by SAWS customers but access to its permitted groundwater withdrawal rights is subject to availability depending on drought restrictions.[42]

San Antonio was required by a federal judge to address access issues to the Edwards Aquifer, and they were severely restricted. A 1993 ruling limited withdrawals from the aquifer, resulting in the creation of caps on water permits,[43] which required SAWS to get aggressive and creative with water conservation. This, manifesting itself in years of media campaigns, education events, and home consultations has made San Antonio residents very water aware. One aspect of this public education is the weekly delivery of an e-newsletter, containing water-saving gardening tips, to 11,000 households in the utility's service area.

Between 2009 and 2014, after the implementation of a new seasonal inclining block pricing, SAWS experienced an overall reduction in per capita residential demand of water. However, in

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[38]San Antonio Water System (SAWS). "2017 Water Management Plan- DRAFT." P 5. Available online at http://www.saws.org/Your_Water/WaterResources/2017_wmp/docs/2017_Water_Management_Plan_DRAFT_20170629.pdf

[39] San Antonio Water System (SAWS). "Service Areas." 2017. Available online at http://www.saws.org/who_we_are/service/index.cfm

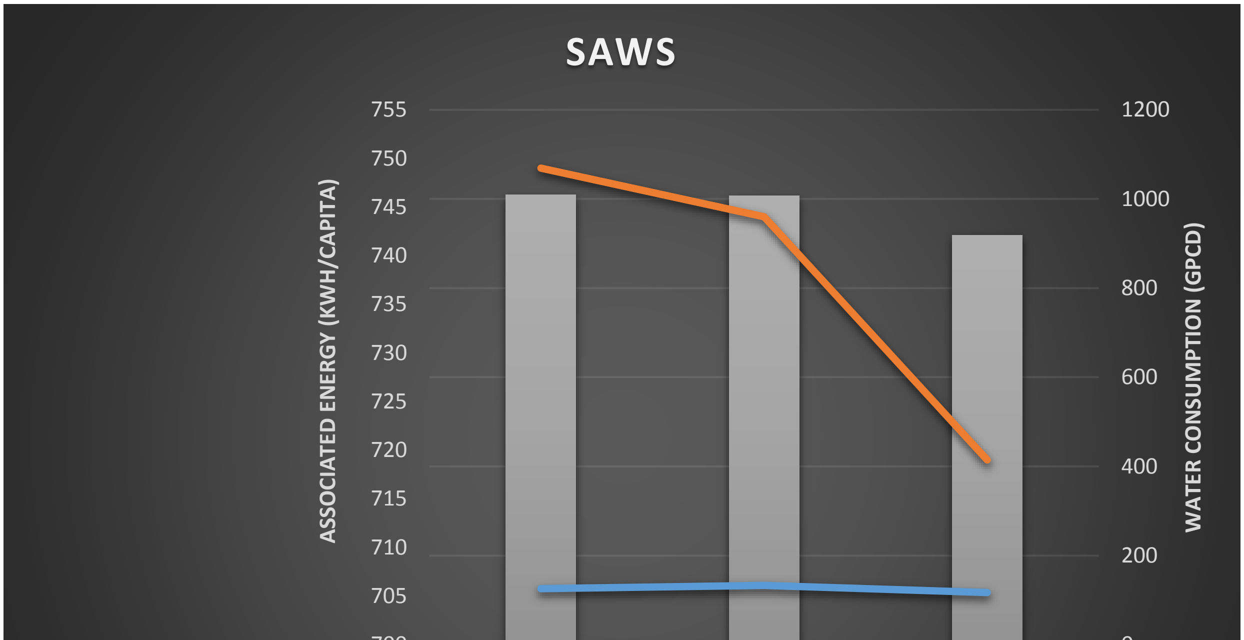
[40] Aboii, Sheyda. "The Secrets Behind San Antonio's Water Conservation Success." StateImpact Energy and Environment Reporting for Texas. May, 2012. Available online at https://stateimpact.npr.org/texas/2012/05/22/the-secrets-behind-san-antonios-water-conservation-success/

[41] Texas Living Waters Project. "How San Antonio reduced its daily water use by 85 gallons per person." May, 2017. Available online at http://texaslivingwaters.org/water-conservation/how-san-antonio-reduced-its-daily-water-use-by-85-gallons-per-person/

[42] San Antonio Water System (SAWS). "Edwards Aquifer- pumping rights acquisition." 2017. Available online at http://www.saws.org/Your_Water/WaterResources/Projects/edwards.cfm

[43] Eckhardt, Gregg. "Laws and Regulations Applicable to the Edwards Aquifer." The Edwards Aquifer Website. 2017. Available online at http://www.edwardsaquifer.net/rules.html

2011, per capita water demand spiked from 126 gpcd in 2009 to 133 gpcd, before falling to 117 gpcd in 2014. It is likely that water consumption and overall associated energy consumption increased in 2011 because this was the worst single-year drought in recorded history in Texas. From 2009 to 2014, however, the overall water demand decreased 7 percent, resulting in a 4 percent reduction in associated embedded energy, and a 9% reduction in carbon emissions.



	2009	2011	2014
associated emissions (lbs CO2/capita)	1010	1007	919
residential water consumption (gpcd)	126	133	117
associated energy (kWh/capita)	749	744	719

Figure 4. SAWS's water, energy, and emissions reductions

E. Phoenix Water and Wastewater

Phoenix is the fifth most populous city nationwide. Situated in the Sonoran Desert, the city receives an annual average of 8 inches of rain, and is often characterized as being in a perpetual state of drought. The average January low temperature is 46°F and the average July high temperature is 106°F.[44] Phoenix Water and Wastewater Department serves over a 1.5 million water and 2.5 million wastewater customers in a 540 square mile service area. The city's first water conservation program was approved by the city council in March 1982. Conservation

[44] US Climate Data. "Climate Phoenix- Arizona." 2017. Available online at http://www.usclimatedata.com/climate/phoenix/arizona/united-states/usaz0166

efforts since then have enabled the city to reduce its consumption from highs of 267 gpcd in 1980, 281 gpcd in 1981, 258 gpcd in 1989, a record hot year,[45] to 101 gpcd in 2016.[46]

In 1982, Phoenix adopted an increasing block rate structure with higher prices during the six-month summer period. After three years of study, in 1990, the rates were restructured again to promote additional conservation as well as to simplify the rate structure and make it more equitable. This new rate structure had no customer classes or rate blocks, but increased the seasonal differentials, charging higher rates during a four-month summer period and lower rates during a four-month winter period. Spring and fall rates fell between the extremes.

Overall per capita demand has declined 25 percent in the last 15 years, contributing factors being improved plumbing fixture standards, smaller residential lots, fewer new pools, growing acceptance of desert landscaping, and increased customer awareness and higher water rates.[47] This increased customer awareness came as a product of various public education campaigns. Early in its conservation efforts, Phoenix used television and radio public service advertising, newsletters, bill inserts, billboards, and public workshops. In 1984, the city successfully developed and began an elementary education program for public and private schools, focusing on the importance of water and the need to conserve it. Over 40,000 school children participated annually.[48]

In 2000, Phoenix was a founding member of the regional Water Use It Wisely conservation program, one of the longest-running and most successful conservation campaigns in the country.[49] This program has since expanded to a multi-million dollar campaign with more than 250 water companies nationwide. The city currently offers free landscape irrigation and planting workshops to residents year-round, and teaches free conservation classes to schools, homeowner associations, organizations, and businesses.

There is an interesting dynamic that occurs in this desert city, whereby rigorous conservation efforts throughout the past few decades have allowed the city to experience a declining water demand despite great population growth. The City of Phoenix attributes this occurrence to evolving cultural attitudes and a shift towards a “desert mentality,” in addition to the aforementioned factors. The city’s population growth is a product of relocations from other parts of the country. Those coming to the desert assume a water scarcity in this area. This

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[45] Mee, William R. “Highlights of the City of Phoenix Water Conservation Program.” City of Phoenix Water and Wastewater Department. 1990. Available online at http://opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=1478&context=jcwre

[46] Personal communication with Cynthia Campbell, Water Resources Management Advisor for the City of Phoenix, November 2017

[47] City of Phoenix Water Services Department. “2011 Water Resource Plan.” 2011. P 29. Available online at https://www.phoenix.gov/waterservicessite/Documents/wsd2011wrp.pdf

[48] Mee, William R. “Highlights of the City of Phoenix Water Conservation Program.” City of Phoenix Water and Wastewater Department. 1990. P 27. Available online at http://opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=1478&context=jcwre

[49] City of Phoenix Water Services Department. “When You Think Ahead of the Curve.” 2015. Available online at https://www.phoenix.gov/waterservicessite/Documents/PhoenixWaterSmart_Brochure.pdf

conservation mindset has led to changes in household technologies (such as toilets, mashing machines, and drip irrigation) that have helped save water without large rebate programs.[50]

For the case studies examined in this paper, data was the most limited for Phoenix. Better data on how much water flows through the system is actually treated as wastewater needs to be collected, and historical treatment plant capacities and daily flows should be made publicly available.

With the available data from the Phoenix 2011 Water Resource Plan[51] and assumptions about the treatment capacities of the wastewater facilities, system losses, and the water sources, post-1990 seasonal pricing implementation, residential water demand decreased 2 percent in the first 10 years from 142 gpcd to 139 gpcd, and then decreased an additional 18 percent in the following 10 years, to 113 gpcd. The embedded energy savings followed directly, with 2 percent savings from 1990 to 2000, and 18 percent savings from 2000 to 2010. Carbon emissions decreased 23 percent in the twenty years following the rate change.

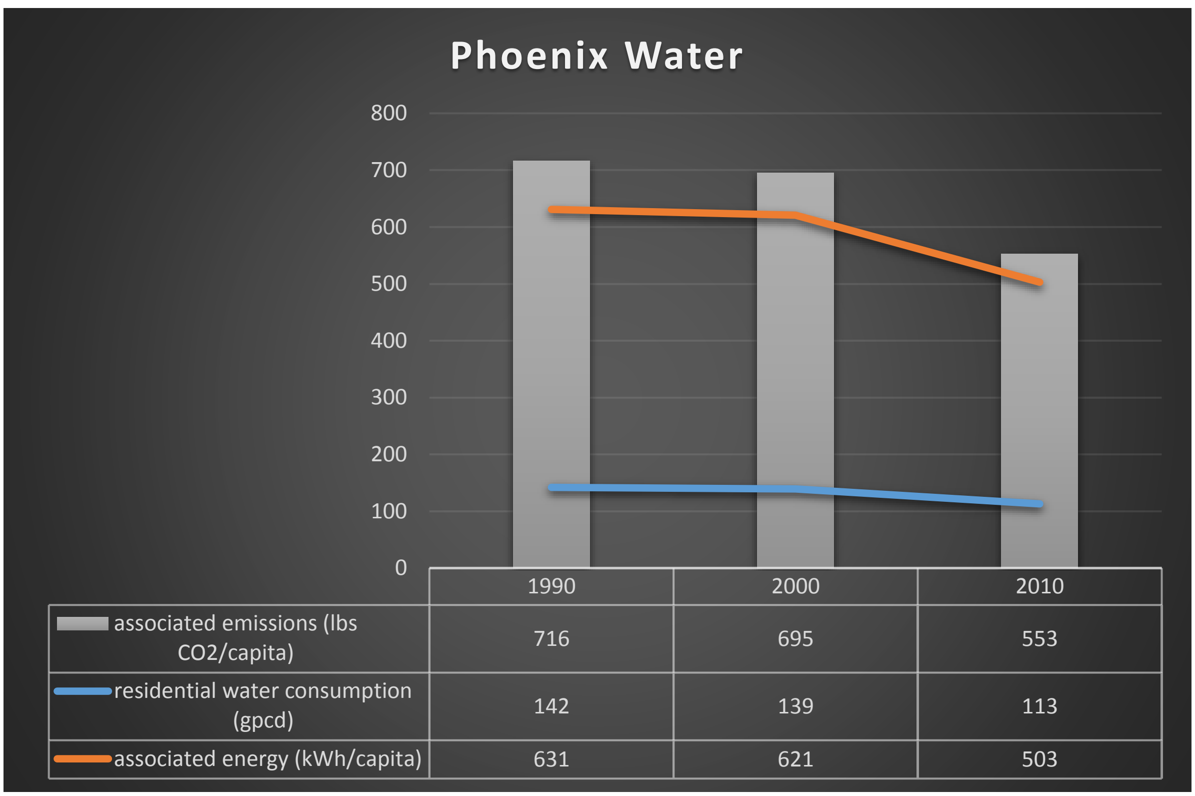

Figure 5. Phoenix's water, energy, and emissions reductions

[50] Personal communication with Cynthia Campbell, Water Resources Management Advisor for the City of Phoenix, November 2017
[51] City of Phoenix Water Services Department. "2011 Water Resource Plan." 2011. Available online at https://www.phoenix.gov/waterservicessite/Documents/wsd2011wrp.pdf

III. Recommendations and Conclusions

This paper presented four case studies to begin to explore the changes in energy consumption and carbon emissions associated with residential water demand reduction, following the implementation of conservation programs and rate structures. In each of the case studies, all three factors (water demand, energy consumption, and carbon emissions) declined over the time period of interest. Challenges remain in applying the results of these case studies more broadly. However, clear regulatory signals, in the form of effectively communicated rates, are needed in order to save water as we move towards an unpredictable climate future.

Inconsistent data and data gaps in the water sector hinder comprehensive or comparative analysis. The following recommendations could help water utilities make water and energy-smart program changes in the future:

1) A nationally standardized method for collecting and reporting data on water source and use at *all* power plants, required to be reported by utilities annually. This data is currently compiled by the EIA, but it is incomplete and insufficient;

2) A standardized method for collecting and reporting data on energy consumption at water and wastewater treatment facilities, and require water utilities to make this data publicly available in a national database;

3) More investments in smart water metering infrastructure. When tied with billing software, rate design becomes significantly less labor intensive, and utilities will be more likely to consider alternative price structures;

4) Implementation of utility education campaigns on rates and conservation initiatives, delivered in an unexpected, engaging way. Such programs may help residential consumer behavior more closely align with the economic perfect price assumption. It has been shown that price-related information on bills will increase a customer's response to price by as much as 30 percent.[52] Successful pricing practices therefore require educated customers. Advanced (smart) metering in combination with billing software capable of monitoring customer usage will be particularly useful in providing real-time feedback for consumers;

5) More testing, by way of randomized control trials, of how various rate structures affect demand and how more frequent price information affects demand. Such trials should attempt to control for non-price influences on water consumption including weather,

[52] Gaudin, S. (2006). Effect of price information on residential water demand. Applied Economics 38(4): 383-393. http://dx.doi.org/10.1080/00036840500397499

demographics, housing vintage, water-using appliances in the home, seasonal behavioral patterns, and lot size;

6) Studies on commercial and industrial customer demand for water. There is far more research on the residential sector, and the heterogeneity of commercial and industrial water uses can make generalizations in these sectors more difficult;

7) Mandatory data collection on "substitutes" to public water supply, such as greywater and rainwater harvesting, as well as rural county residents harvesting their own groundwater from private wells, which is not currently measured by water development boards; and

8) Mandatory data collection on the end use of water at the residential level; a majority of the embedded energy in each case study was attributed to end-use water heating, which was assumed to be a flat percentage of metered water across all cases.

More and better data need to be collected across the board to improve the understanding of the embedded energy in water and to quantify the potential benefits of reducing water demand through conservation pricing mechanisms. There is a great opportunity, beyond pricing, for water, wastewater and energy utilities to work together in increasing efficiency nationwide.

IV. Appendix

A. Balancing goals of the utility in ratemaking

As seen in Figure 1, some of the objectives of water utility ratemaking include revenue stability, economic development, conservation promotion, and affordability. One of the most challenging conflicts in balancing rate objectives are between consumer conservation and utility revenue stability. For example, if the main goal is avoiding variability and volatility in utility revenue, there is typically a higher fixed portion of the ratepayer cost, which fails at sending a strong conservation signal to consumers. Rates that decrease the high fixed charges of traditional pricing, and rely more heavily on the variable charge, as seen with many of the conservation rate structures employed today, are more affordable for the consumers but less stable for the utility.

Rate simplicity is another important consideration, which is not pictured in Figure 1.

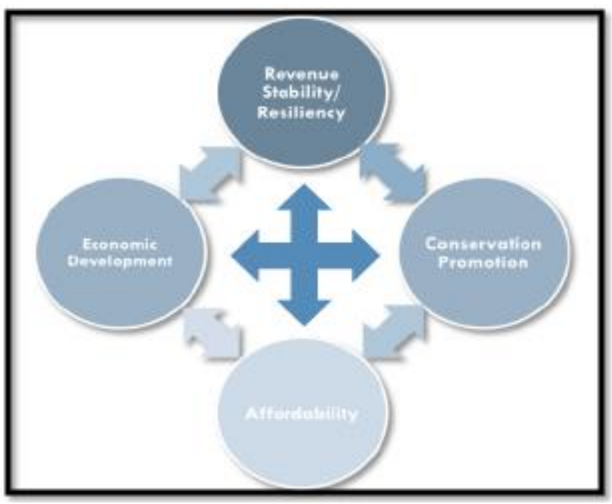

Figure 1.[53] Balancing objectives of ratemaking

B. Water utility structure

In the U.S., electric POUs serve 14.5 percent of electricity customers.[54] Comparatively, of the people who have piped water service in the United States, 87 percent are served by POUs,[55]

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[53] Tiger, Mary, Hughes, Jeff, & Eskaf, Shadi. "Designing Water Rate Structures for Conservation & Revenue Stability." UNC Environmental Finance Center. February, 2014. p 8. Available online at https://efc.sog.unc.edu/sites/www.efc.sog.unc.edu/files/Texas%20Rate%20Report%202014%20Final.pdf

[54] American Public Power Association. "U.S. Electric Utility Industry Statistics." 2016. Available online at http://www.publicpower.org/files/pdfs/uselectricutilityindustrystatistics.pdf

[55] Food & Water Watch. "The State of Public Water in the United States." February, 2016. p 2. Available online at https://www.foodandwaterwatch.org/sites/default/files/report_state_of_public_water.pdf

operating as non-profit entities managed by local or state governments. Rates for water POUs are set by a governing board. While publicly-owned water utilities outnumber privately-owned, or investor-owned utilities (IOUs), water IOUs still serve over 36 million people in the United States.[56] These for-profit systems are typically managed by investors or shareholders, and rates are monitored by a state's public commission. The water POUs are subject to competing interests of the country, city, regional governing boards, water authorities, and commissions.[57]

C. Revenue recovery mechanisms

Traditional water rates often have high fixed charge components. Revenue recovery through decoupling, a method employed in the electric sector, is one plausible solution to lowering those fixed charges. Decoupling refers to the separation of a utility's profits from its sales. A rate of return is set to allow a utility to meet its revenue targets, and rates are adjusted up or down to meet the target at the end of the adjustment period. While not a conservation measure in and of itself, decoupling removes the disincentive for such an investment. This makes the utility indifferent to selling less product and improves the ability of efficiency to operate within the utility environment. The break in the sales-revenue link in current rate design motivates utilities to consider all the options when planning and making resource decisions on how to meet their customers' needs. This can be beneficial for both the utility and the customer, as it allows for conservation that reduces the need for new infrastructure and allows the utility to recover costs, while simultaneously avoiding charging customers higher prices for using less. However, it can also discourage economic sales, and undermine price efficiency by shielding utilities from true consumer behavior.

In 2006, California became the first state to try decoupling water rates, with a pilot program applying to IOUs with more than 10,000 customers.[58] Following this pilot, in 2008, as part of its Water Action Plan, the California Public Utility Commission formally adopted two decoupling mechanisms for water IOUs: the Water Revenue Adjustment Mechanism (WRAM) and the Modified Cost Balancing Account (MCBA).[59] The two are combined into a single credit or surcharge added to the customers' bills. The former charge enables utilities to collect any revenue shortfalls that result from water conservation by calculating the difference between actual and predicted sales revenues. The latter tracks variations in system costs for providing the

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56 Kopaskie, Andrea. "Public vs Private: A national overview of water systems." UNC Environmental Finance Blog. October, 2016. Available online at http://efc.web.unc.edu/2016/10/19/public-vs-private-a-national-overview-of-water-systems/

57 Stallworth, Holly. "Water and Wastewater Pricing: an informational overview." U.S. Environmental Protection Agency Office of Wastewater Management. April, 2000. p 3. Available online at http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0ahUKEwjKwdDmt9zUAhVINSYKHSMMCWUQFgg5MAQ&url=http%3A%2F%2Fwww.azwifa.gov%2Fdownload.aspx%3Fpath%3Dpublications%2F%26file%3DPricingGuide.pdf&usg=AFQjCNGDFGIQkQkOyDFSLDeSjK4gogZpsg

58 Ajami, Newsha K., Thompson, Barton H. Jr., & Victor, David G. "The Path to Water Innovation." The Hamilton Project & Stanford Woods Institute for the Environment. October, 2014. Available online at https://woods.stanford.edu/sites/default/files/files/path_to_water_innovation_thompson_paper_final.pdf

59 Donnelly, Kristina, Christian-Smith, Juliet, & Cooley, Heather. "Pricing Practices in the Electricity Sector to Promote Conservation and Efficiency: lessons for the water sector." Pacific Institute. September, 2013. p 14. Available online at http://www2.pacinst.org/wp-content/uploads/2013/09/pacinst-pricing-practices-full-report.pdf

water. The recovery of the surcharges, in the case of under-collection, is divided up over multiple bills and recouped over the course of a few years to prevent the appearance of a single lump sum on a ratepayer's bill. Similarly, in the case of over-collection, the ratepayer receives a credit on his/her bill the following year.

WRAMs were established in various forms for most of the water utilities by the California Public Utilities Commission (CPUC). By 2009, the ten largest water IOUs had decoupled policies in place.[60] The adoption of the policy, however, occurred during the global recession and a period of wet years in California. After the January 2014 declaration of a Drought State of Emergency, sales fell far below forecasts and WRAM balances increased. Under the Commission's rate case plan, the utilities could not adjust their forecasts fast enough to keep up with the quickly declining customer usage. The Commission's regular process of scheduling general rate case applications every three years was not able to keep up with the pace of declining sales.[61] The decoupling of sales from revenues was accomplishing its purpose, but was building balances that customers would need to pay in the future.

Still in effect today, the decoupling mechanisms are less popular with consumers. The Division of Ratepayer Advocates argued customers should not have to reimburse utilities for budget shortfalls related to economic slowdown and climate.[62] Additionally, the surcharges are delayed, so the costs for water consumed in one year are collected in following years. These rate lags distort the water market, leaving customers confused and frustrated. Water utilities are also challenged by having to collect non-drought revenues in drought years. There are financial risk management tools that exist in the electric sector but have yet to break into the water sector, which can mitigate those demand swings.[63]

In place of decoupling, water systems also have the option to use rate stabilization funds to provide a reserve for mitigation of unexpected changes in revenue that may result from changes in demand associated with, for example, cool temperatures, drought restrictions, economic downturn, and increased conservation and efficiency. Rate stabilization funds must be carefully

[60] Id.
[61] St. Marie, Stephen, & Zafar, Marzia. "Water Rates Scenario Planning." California Public Utilities Commission Policy & Planning Division. April, 2017. Available online at http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Divisions/Policy_and_Planning/PPD_Work/PPD_Work_Products_(2014_forward)/WaterRates-ScenarioPlanning2017-04-27.pdf
[62] Donnelly, Kristina, Christian-Smith, Juliet, & Cooley, Heather. "Pricing Practices in the Electricity Sector to Promote Conservation and Efficiency: lessons for the water sector." Pacific Institute. September, 2013. p 14. Available online at http://www2.pacinst.org/wp-content/uploads/2013/09/pacinst-pricing-practices-full-report.pdf
[63] White, Richard, & Zafar, Marzia. "Evaluating Forecast Models: water revenue adjust mechanism." California Public Utilities Commission Policy & Planning Division. August, 2015. p 2. Available online at http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Divisions/Policy_and_Planning/PPD_Work/PPDtheWRAM.pdf

structured to ensure they are effective.[64] Gainesville, Florida is one city that utilizes rate stabilization funds.[65]

D. Benefits and challenges of conservation rates

1. Uniform block: It sends a simple linear volumetric price signal and is simple and easy to implement, but the conservation signal is weak.

2. Marginal pricing: Many economists recommend this method as the most efficient water pricing structure as it rewards individual customers for conservation and efficiency in a way that does not burden or benefit other customers. It can be complicated to implement, however, as calculating marginal cost is data-intensive and requires forecasting future demand and estimating the cost of new capacity or supply.

3. Inclining block (IBR): As consumers cross set volumetric consumption thresholds (i.e. blocks), IBR pricing is believed to send a stronger conservation price signal than uniform rates. Those who favor IBR over uniform pricing also claim that it better addresses equity objectives and is more effective in reducing peak demand.[66]

   However, there are difficulties involved in teasing out the conservation benefits of IBR rates alone—some economists say that there might be little effect at all.[67] One such investigator used a residential water market in Southern California and found strong evidence that consumers respond to average rather than marginal/expected marginal price when faced with nonlinear pricing for water.[68] A study conducted in 2007 found that price increases, not the tiered pricing structure, were responsible for the decline in water usage.[69] The presence of block pricing seems to affect both water demand *and* price elasticity; there is a possibility that the difference in price elasticities is due to some factor other than true consumer response to the different price structures.[70] Economists

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[64] Donnelly, Kristina, Christian-Smith, Juliet, & Cooley, Heather. "Pricing Practices in the Electricity Sector to Promote Conservation and Efficiency: lessons for the water sector." Pacific Institute. September, 2013. p 15. Available online at http://www2.pacinst.org/wp-content/uploads/2013/09/pacinst-pricing-practices-full-report.pdf

[65] Borisova, Tatiana, Asci, Serhat, Unel, Burcin, & Rawls, Colin. "Conservation Pricing for Residential Water Supply." University of Florida IFAS Extension. October, 2008. p 5. Available online at http://edis.ifas.ufl.edu/pdffiles/FE/FE75600.pdf

[66] Brandes, Oliver M., Renzetti, Steven, & Stinchcombe, Kirk. "Worth Every Penny: A primer on conservation-oriented water pricing." University of Victoria POLIS Project on Ecological Governance. May, 2010. p 21. Available online at http://poliswaterproject.org/sites/default/files/Pricing%20Primer%20Final.pdf

[67] See Appendix page 24 for more on the debate around IBR efficacy

[68] Ito, Koichiro. "How Do Consumers Respond to Nonlinear Pricing? Evidence from household water demand." April, 2013. Available online at http://home.uchicago.edu/ito/pdf/Ito_Water_Irvine.pdf

[69] Olmstead, Sheila M., & Stavins, Robert N. "Comparing Price and Non-price Approaches to Urban Water Conservation." September, 2008. Available online at http://ageconsearch.umn.edu/bitstream/42919/2/66-08.pdf

[70] Olmstead, Sheila M., Hanemann, Michael W., & Stavins, Robert N. "Does Price Structure Matter? Household water demand under increasing-block and uniform prices." October, 2003. Available online at https://www.researchgate.net/profile/Robert_Stavins/publication/228916287_Does_Price_Structure_Matter_Household_Water_Demand_Under_Increasing-Block_and_Uniform_Prices/links/0046351668ec2775ea000000/Does-Price-Structure-Matter-Household-Water-Demand-Under-Increasing-Block-and-Uniform-Prices.pdf

who favor uniform pricing over IBR claim that introducing different rates for different volumes is inefficient because it creates price distortions and may not incent strong conservation for all since the highest blocks only affect the highest users.[71]

4. Water budgets: Water budgets, while a relatively new tool, were implemented first in the early 1990s in Southern California. They are typically combined with an IBR structure and in this form are perceived to be one of the most equitable structures by charging lower prices for the most essential water uses. They also create a strong conservation incentive, charging higher prices for additional water when total consumption exceeds the deemed “efficient” level.

   However, water budgets are difficult to implement because they require detailed analysis of individual household characteristics and can often be misunderstood by the consumer. A consumer may not understand the limits of his/her allotment and exceed them, resulting in frustrating and unexpectedly high charges at the end of the month. Other barriers include complexity, data requirements, software requirements, lack of local precedent, cost of service concerns, revenue requirements, institutional resistance and political resistance. Additionally, because the efficiency level is determined, in part, on historic consumption, very few utilities will charge commercial, industrial, and institutional consumers using water budgets because they tend to allot inefficient limits.[72]

   Water budgets may be best suited for homogenous communities. In places where there is enormous diversity in how discretionary water is used, it is difficult to craft budgets based on lot size. Lot size is not strongly correlated with increased water use, which has more to do with irrigation system habits and expectations of landscape appearance of the individual community members.[73]

5. Seasonal/drought: These methods of pricing are easily implemented and practical, even on unmetered systems. Because it is a simpler structure than other conservation rates, there is a strong signal to the consumer to conserve in the hot summer months when the availability of water is low.

   Drought pricing, however, has unique challenges that are related to the timing of water meter readings. Big utilities read meters on over 20 days of the month, and the bills are created right after these reads. Because of this, when a drought begins, half of the water customers have already paid their bills. If the utility waits until the next billing cycle to

[71] Brandes, Oliver M., Renzetti, Steven, & Stinchcombe, Kirk. “Worth Every Penny: A primer on conservation-oriented water pricing.” University of Victoria POLIS Project on Ecological Governance. May, 2010. p 21. Available online at http://poliswaterproject.org/sites/default/files/Pricing%20Primer%20Final.pdf
[72] Alliance for Water Efficiency Clearinghouse. “Water Rates and Charges: water budget rate structures.” 2008. p 2. Available online at http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiMvpq-mYnVAhWCOiYKHSA1D_YQFggiMAA&url=http%3A%2F%2Fwww.allianceforwaterefficiency.org%2FWorkArea%2FDownloadAsset.aspx%3Fid%3D716&usg=AFQjCNH4Sv5mzY2Axrx91xG1kqLoeg6Ghg
[73] Personal communication with Karen Guz, Conservation Director at San Antonio Water System, November 2017

charge drought prices, there is a delayed price message that is sent to that half of customers.[74]

6. Other pricing methods: The Environmental Finance Center (EFC) at University of North Carolina-Chapel Hill has developed the **PeakSet Base**[75] charges individualized base (fixed) costs calculated using a three-year rolling average of a customer's historical maximum month of consumption. In this structure, variable commodity charges are a lower proportion of the bill. This builds more cost recovery into the fixed charge but still sends a price signal to conserve by using the customer's actual consumption to establish that base.

   Also from the EFC, the **CustomerSelect**[76] model allows individual customers to choose an allotment plan of use that meets their needs and charges a fixed amount for that allotment. Any usage beyond the allotment is automatically charged at a high rate. Each available plan has its own uniform price, which increases as the water volume allotted also increases. This model is similar to that used by cell phone companies, which often use overage fees, but faces additional hurdles in the water sector. Utilities would need to be able to accurately predict the plans that customers would choose in order to set rates that would recover all the costs of supplying the water.

   The Center for Water-Energy Efficiency at the University of California-Davis has developed the **Consumption-Based Fixed Rates (CBFR)**[77], which bases both the variable revenue and a large portion of the fixed revenue on volumetric consumption, splitting the revenue requirement into three components: fixed-fixed, fixed-volumetric, and variable. The fixed-fixed portion is determined by dividing a percentage of the total costs equally over all customers, or equally among customers within customer classes, based on characteristics such as meter size (this component is a very small portion of overall fixed costs—fire protection services, meter reading and billing). The fixed-volumetric comprise the remainder of the previously fixed costs that are not allocated to the new fixed-fixed portion. These costs include purchasing water rights or building and maintaining new water infrastructure. This revenue is distributed proportionally among ratepayers based on their share of total metered water use. Finally, the variable component of the revenue is just the direct cost of providing water to customers for a

[74] Ibid.
[75] Tiger, Mary. "PeakSet Base: a pricing model for utility revenue stability and customer conservation." UNC Environmental Finance Blog. July, 2012. Available online at http://efc.web.unc.edu/2012/07/10/peakset-base-a-pricing-model-for-utility-revenue-stability-and-customer-conservation/
[76] Boyle, Christine E. "CustomerSelect Rate Plan: how would a cell phone rate plan work for water service?" UNC Environmental Finance Blog. August, 2012. Available online at http://efc.web.unc.edu/2012/08/28/customerselect-rate-plan-how-would-a-cell-phone-rate-plan-work-for-water-service/
[77] Spang, Edward S., Miller, Sara, Williams, Matt, & Loge, Frank J. (2015). Consumption-based fixed rates: Harmonizing water conservation and revenue stability. American Water Works Association 107(3): E164-E173. Doi: 10.5942/jawwa.2015.107.0001. Available online at https://www.awwa.org/publications/journal-awwa/abstract/articleid/50838772.aspx

given period of time. The variable cost to the utility in providing additional units of water is simply passed on to the customers in the variable portion of their bills.

CBFR was adopted by the City of Davis in 2013, and the new rate structure was to go into effect in January 2015. In 2014, however, Davis voters chose to repeal the CBFR rates and prompted the City Council to launch another water rate study and selection committee. Shortcomings in messaging and public education played a role in its ultimate rejection, as voters saw it as complex and misunderstood various aspects.[78] It has yet to be applied elsewhere.

These innovative conservation rate structures have yet to be implemented in practice.

E. Efficacy of education and public awareness initiatives

There are many utilities that have been able to employ public education programs in times of drought or interruptions in water supply. One study found that education and public awareness campaigns, in combination with water restrictions, water-wise urban development, and a rebate and subsidy program, may have reduced statewide water consumption in Melbourne, Australia by 57 percent from 2004 to 2007 during the nine-year drought.[79] A similar study reported an 18 percent decrease in consumption in Zaragoza, Spain due to improved conservation awareness in the decade following the end of Spain's five-year drought.[80] In the U.S., a 20 percent reduction in water consumption of California residents, as part of the Governor's directive post-2009 drought, is attributed to conservation awareness programs.[81]

One study investigated the differences between perceived and actual residential water consumption in South-east Queensland, Australia.[82] This study found that self-nominated low water users underestimated their water use while self-nominated high water users overestimated their actual usage. Those who self-reported as medium water users consumed more water, on a per household basis, than self-reported high water users. This disparity

[78] Spang, Edward S., Loge, Frank J., Abernathy, William, Dove, Douglas R., Tseng, Catherine, & Williams, Matt. (2015). Implementing consumption-based fixed rates in Davis, California. American Water Works Association 107(7): E380-E388. Doi: 10.5942/jawwa.2015.107.0085. Available online at https://www.awwa.org/publications/journal-awwa/abstract/articleid/51703343.aspx
[79] Bryx, Danya, & Bromberg, Gidon. "Best Practices in Domestic Water Demand Management." Friends of the Earth Middle East. March, 2009. p 2. Available online at http://ecopeaceme.org/uploads/publications_publ106_1.pdf (as cited in Fan, L., et al. (2014). Public perception of water consumption and its effects on water conservation behavior)
[80] Id. at 3
[81] Id. at 3
[82] Beal, Cara D., Stewart, Rodney A., & Fielding, Kelly. (2011). A novel mixed method smart metering approach to reconciling differences between perceived and actual residential end use water consumption. Journal of Cleaner Production 60: 116-128. Available online at http://ac.els-cdn.com/S0959652611003386/1-s2.0-S0959652611003386-main.pdf?_tid=36092c7a-67f6-11e7-9826-00000aab0f6b&acdnat=1499969462_39104b9c2219830924dad3bc66922aec

between perceived and actual water use persisted across gender, education and socio-demographic groups.

F. Smart water software

WaterSmart's Home Water Reports (HWR) service pilot in the East Bay Municipal Utility District's (EBMUD) demonstrates that advanced technology may be crucial in empowering consumers to make water-efficient choices. An independent study was conducted on EBMUD to verify WaterSmart's reported 5 percent water savings, and found that mean effects of the HWR program was between 4.6 percent and 6.6 percent water savings for the pilot year between 2012 and 2013.[83] The investigators also found that households receiving paper reports saved about 1 percent of the mean household use more than households receiving email reports, and estimated that households receiving the HWRs were 2.3 times more likely to participate in other efficiency programs than households who did not receive reports.[84]

Similar to WaterSmart, Dropcountr is software company that works with utilities to better manage data. It provides instant feedback on efficient budgets for households, current water usage, comparison to previous usage, and comparison to similar nearby households, all of which proves invaluable in educating customers on their consumption. A study on the city of Folsom (in California) showed that a Dropcountr opt-in pilot program there had a statistically and economically significant conserving effect on water consumption for all customers who enrolled. Using 2 years of historical usage data and 20 months of pilot program data from January 2013 through September 2016, investigators showed a 7 percent reduction in average monthly consumption for the enrolled households. This represents an average of 24 fewer gallons per day per household.[85] A similar study in the Austin Water Utility service area (in Texas), using 4 years of historical usage data and 13 months of program data spanning July 2011 to July 2016, found that introduction of Dropcountr services for participating households caused an aggregate 9 percent reduction in water usage.[86]

Despite these significant successes in demand reduction through WaterSmart and Dropcountr technology and others in the industry, consumers are generally unaware of how advanced metering infrastructure (AMI), like the smart metering typically used by these two companies, can benefit them.

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[83] Mitchell, David L., & Chesnutt, Thomas W. "Evaluation of East Bay Municipal Utility District's Pilot of WaterSmart Home Water Reports." California Water Foundation, East Bay Municipal Utility District, M. Cubed, & A&N Technical Services. December, 2013. p 7. Available online at http://www.financingsustainablewater.org/resource-search/evaluation-east-bay-municipal-utility-districts-pilot-watersmart-home-water-reports
[84] Id. at 44
[85] Nemati, Mehdi, Buck, Steven, & Soldati, Hilary. "The Effect of Social and Consumption Analytics on Residential Water Demand." January 6, 2017. Available online at http://ageconsearch.umn.edu/bitstream/252738/2/Nemati_Buck_Soldati_The_Effect_of_Social_and_Consumption_Analytics_on_Residential_Water_Demand.pdf
[86] Nemati, Mehdi & Steven Buck. "Summary Report: Analysis of Dropcountr Pilot Program for Austin Water Utility." Sent via personal communication with Robb Barnitt, CEO at Dropcountr on July 31, 2017.

G. GPCD

Gpcd is usually calculated as the annual net use allocated to the water user group in gallons, divided by a population estimate, divided by 365 days. Net use is defined as the volume of water taken into the system or systems of a city, excluding water sales to other water systems and large industrial facilities.[87] It is not unusual, however, for gpcd figures to vary due to different methods of calculation. For example, the U.S. Geological Survey (USGS) defines per capita water use as the total amount of water *withdrawn* from all water suppliers divided by the population. Water for domestic, commercial, industrial, and thermoelectric power is included in that per capita calculation.[88] On the other hand, residential gallons per capita per day, sometimes referred to as r-gpcd, reflects only the water billed to single and multi-family residences for both indoor and outdoor use. In the case of r-gpcd, water for commercial businesses and government institutions is therefore not included.

While most utilities do not calculate r-gpcd, it is perhaps a more accurate representation of per capita consumption. With gpcd for total municipal water use, defined not only by use in homes but also by most services (supplied to more than a local demand base), all other things being equal, larger cities with a greater concentration of those services appear to have a higher water use per resident. Other factors that can affect per capita use include variations in regional climates, population and building density, regional economic conditions, quality of water supplies in a given region, extent and effectiveness of local water conservation programs, and rates of unaccounted for or lost water in a distribution system.[89]

H. Methodology

1. Introduction

In this section, we estimate the water conserved following the implementation of the conservation rates in each of the four utilities chosen as case studies. We then estimate the energy saved, from the decrease in demand for water, at each utility. The water conserved is considered to be the change in the amount of water consumed by the residential end-user. The embedded energy is recognized as the energy needed to withdraw, transport, and treat water from its source, to heat for use by the residential end-user, and to treat as wastewater. The water conserved does *not* include water saved through reduced withdrawal and consumption for energy processing.

2. Assumptions

[87] Texas Water Development Board (TWDB). "Frequently Asked Questions for Water Use Survey." 2016. Available online at http://www.twdb.texas.gov/waterplanning/waterusesurvey/faq.asp
[88] Javey, Shahram. "What Does per Capita Daily Use Really Mean?" Aguanomics. July, 2009. Available online at http://www.aguanomics.com/2009/07/what-does-per-capita-daily-use-really_06.html
[89] Texas Water Development Board. "Frequently Asked Questions for Water Use Survey." 2016. Available online at http://www.twdb.texas.gov/waterplanning/waterusesurvey/faq.asp

Energy inputs of a typical water-use cycle can be broken down into five basic stages: source and conveyance, treatment, distribution, end use, and wastewater treatment. In order to analyze the energy savings associated with the changes in water demand, the following data had to be acquired for both a period in time before the rate implementation and after the rate was implemented:

1) The sources of the water, and the total volume of water collected from each source (i.e. surface water, groundwater, recycled water, desalination, imported water);
2) The collection and conveyance, treatment, and distribution energy intensity associated with each water source and/or treatment facility;
3) The volume of water consumed by residential users;
4) The end use of the water consumed by residential users (or the volume of total water delivered to residential consumers that is collected and treated as wastewater);
5) The wastewater treatment plant sizes, level of treatment, and energy intensity;
6) The volume of water recycled for residential use;
7) The energy intensity of treating and re-distributing recycled water (if applicable); and
8) The carbon emissions intensity of the local grid.

Specific data at the plant level, for both electric and water utilities, is recorded differently across utilities (or in some cases, not at all), and is often only available through open records requests. For example, even within one water utility, water management reports may disaggregate water supply and deliveries, defining terms and allocating differently from what is presented in their newsletters, presentations, or online statistic books, where most data was drawn from. To conduct the embedded energy analysis with the data that was readily available, several assumptions had to be made.

In cases where there was no disaggregated data on water supply, an estimated 93 percent of water recorded as "supply" was assumed to be delivered to the residential end-user for metering and billing, due to system losses. This was calculated by taking an average of system losses across cases where data was available. This number does, in reality, vary from place to place and through time, based on specific characteristics of the infrastructure, but it is the best approximation available for this analysis. Metered/billed water volumes were then considered for embedded energy in end-use and wastewater treatment. Water production volumes, defined here as the total water that is extracted, treated, and distributed, but including the water lost in the system, was used in determining the embedded energy in the water supply. It is important to note that actual system losses vary greatly by location and through time, as infrastructure upgrades over time can improve system efficiencies, and determining specific losses is not always possible.

If the daily average flows through the utility's wastewater treatment plants were provided, that was taken to the be the amount of water that is used for indoor purposes, and the remaining water metered/billed was assumed to be used for discretionary outdoor purposes such as car washes, sprinklers, and swimming pools, in which case no further treatment of the water is necessary by public utilities. This assumption was made because if the water is not being treated as waste, it is not going down the drain in the residence. For the amounts of water calculated to be consumed indoors, it was estimated that 25 percent of that domestic water is heated and 75 percent of that water is cold. These numbers are based on a calibration of the 2009 Residential Energy Consumption Survey,[90] administered by the Energy Information Administration (EIA). This calibration was completed by the American Council for an Energy Efficient Economy.[91] When calculating the energy savings associated with a reduction in consumption of residential hot water, it was assumed that 41 percent of residential customers has electric storage water heaters and 51 percent has gas storage water heaters, another assumption made by the ACEEE based on the 2009 RECS results. This means that 41 percent of the water that is heated for residential end use is using electricity and therefore has associated grid emissions in the emissions reductions calculations.

In cases where the total flows through the wastewater treatment system was not available, it was assumed that 65 percent of the water delivered to the residential customer entered into the wastewater treatment process. This is based on an average taken across the cases where the data was available. If the total wastewater flows were provided, but disaggregated wastewater treatment plant flows were not available, it was assumed that the percent of treatment *capacity* at each wastewater facility (out of total utility wastewater treatment capacity) was representative of the percent of the volume of wastewater treated at each plant in the system.

For the energy intensity of the water extraction, treatment and distribution, we used default values for the Pacific Institute's Water to Air Model.[92] While there is no one-size-fits all for energy intensity of water treatment plants, especially across various terrains and geographies where some systems may be gravity-fed and others require intensive pumping, there is also limited to no available data on the energy intensity of the specific treatment plants looked at in these case studies. The default values in the Pacific Institute Model were compared to other prominent reports on the topic. In particular, we used for comparison the River Network's 2009 report *The Carbon Footprint of Water*[93] and the California Energy Commission (CEC) 2005 report *California's Water-Energy*

[90] U.S. Energy Information Administration. "Residential Energy Consumption Survey (RECS)." 2009. Available online at https://www.eia.gov/consumption/residential/data/2009/
[91] Young, Rachel. "Watts in a Drop of Water: savings at the water-energy nexus." American Council for an Energy-Efficient Economy (ACEEE). November, 2014. P 10. Available online at http://aceee.org/sites/default/files/watts-in-drops.pdf
[92] Wolff, Gary, Guar, Sanjay, & Winslow, Maggie. "User Manual for the Pacific Institute Water to Air Models." The Pacific Institute. October, 2004. P 28. Available online at http://pacinst.org/wp-content/uploads/2013/02/water_to_air_manual3.pdf
[93] Griffiths-Stattenspiel, Bevan, & Wilson, Wendy. "The Carbon Footprint of Water." The River Networ. May, 2009. P 13. Available online at https://www.csu.edu/cerc/researchreports/documents/CarbonFootprintofWater-RiverNetwork-2009.pdf

Relationship,[94] which report the same numerical ranges with each other. With the exception of the surface water intensity, which is recorded as 0 kWh/MG by the River Network in acknowledgement of gravity-fed systems only, the Pacific Institute default values were higher. For groundwater, the Pacific Institute's values were 6 percent higher, and for desalination, they were 9 percent higher. Because this portion of the total energy intensity, water sourcing, was found to be very small in comparison to end-use embedded energy of water, this disparity was assumed to be insignificant in the analysis.

In calculating embedded energy in the wastewater processing, a similar process for energy intensity was needed. For this analysis, the energy intensities presented by the Electric Power Research Institute (EPRI) in its widespread 2002 report *U.S. Electricity Consumption for Water Supply & Treatment- the Next Half Century*[95] were used. EPRI provides the energy intensities by both size and level of treatment of the plant. ACEEE found this report to be one of the only reports that attempted to give ranges of energy intensities for the United States as a whole, which makes the values easier to extrapolate. A power regression was used to interpolate between the treatment capacities provided in the report.

Finally, with regard to the carbon emissions associated with energy consumption, the EIA state profiles were used.[96] These provide estimated carbon emissions associated with the electric grid by state and year. While they are not utility-specific, having the data by year was deemed more important than having the data by region or utility within the state. Additionally, the use of these numbers simplified calculations, which were likely to be error-prone based on the data gaps and reporting discrepancies of generation mixes in the electric utilities.

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[94] Klein, Gary. "California's Water-Energy Relationship." California Energy Commission. November, 2005. Available online at http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF
[95] "Water and Sustainability: U.S. Electricity Consumption for Water Supply & Treatment—The Next Half Century." EPRI. P 3-5. Palo Alto, CA: 2000. 1006787.
[96] Available online at https://www.eia.gov/electricity/state/