lines." *Engineering Structures*, 128, 441-452.
Gulf Power (2018). "Unprecedented response from storm team of more than 7,500 ", <https://www.gulfpowernews.com/unprecedented-response-from-storm-team-of-more-than-7500/>.
IEEE Standards Association (2002). *National Electrical Safety Code (NESC)*, IEEE, Piscataway, NJ.
Khawaja, A. H., Huang, Q., Li, J., and Zhang, Z. (2017). "Estimation of Current and Sag in Overhead Power Transmission Lines With Optimized Magnetic Field Sensor Array Placement." *IEEE Transactions on Magnetics*, 53(5), 1-10.
Puzrin, A. M., Alonso, E. E., and Pinyol, N. M. (2010). "Leaning Instability: The Tower of Pisa, Italy." *Geomechanics of Failures*, 45-64.
Ryan, P. C., Stewart, M. G., Spencer, N., and Li, Y. (2016). "Probabilistic analysis of climate change impacts on timber power pole networks." *International Journal of Electrical Power & Energy Systems*, 78, 513-523.
Salman, A. M., Li, Y., and Bastidas-Arteaga, E. (2017). "Maintenance optimization for power distribution systems subjected to hurricane hazard, timber decay and climate change." *Reliability Engineering & System Safety*, 168, 136-149.
Salman, A. M., Li, Y., and Stewart, M. G. (2015). "Evaluating system reliability and targeted hardening strategies of power distribution systems subjected to hurricanes." *Reliability Engineering & System Safety*, 144, 319-333.
Shafieezadeh, A., Onyewuchi, U. P., Begovic, M. M., and DesRoches, R. (2014). "Age-Dependent Fragility Models of Utility Wood Poles in Power Distribution Networks Against Extreme Wind Hazards." *IEEE Transactions on Power Delivery*, 29(1), 131-139.
Tang, Y. J., and Zhao, Y. (2016). "Leaning pagodas in China: laboratory test and analysis of subsidence under frequent earthquakes." *Bulletin of Engineering Geology and the Environment*, 77(2), 823-835.
Wang, C.-h., Leicester, R. H., and Nguyen, M. (2008). "Probabilistic procedure for design of untreated timber poles in-ground under attack of decay fungi." *Reliability Engineering & System Safety*, 93(3), 476-481.
Yu, Y., Dackermann, U., Li, J., and Subhani, M. (2016). "Condition Assessment of Timber Utility Poles Based on a Hierarchical Data Fusion Model." *Journal of Computing in Civil Engineering*, 30(5).
Yuan, H., Zhang, W., Zhu, J., and Bagtzoglou, A. C. (2018). "Resilience Assessment of Overhead Power Distribution Systems under Strong Winds for Hardening Prioritization." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, 4(4).
Zhang, W., Witharana, C., Li, W., Zhang, C., Li, X., and Parent, J. (2018). "Using Deep Learning to Identify Utility Poles with Crossarms and Estimate Their Locations from Google Street View Images." *Sensors (Basel)*, 18(8).

Systems Vary, Affordability Should Not: Trends of Water Sector Affordability Based on City Attributes

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ABSTRACT

Population dynamics can impact water and wastewater infrastructure and lead to changes in residential water pricing. For instance, cities experiencing urban decline must fund the costs of water systems despite fewer customers. This study seeks to assess the association between water and wastewater affordability and city attributes. Statistical modeling is used to examine the link between different classifications of cities (shrinking, stabilizing, and growing) and the median affordability index (service charge as a percentage of median household income). Data for this study is from the 2016 American Water Works Association's Water and Wastewater Rate Survey, spanning utilities in 272 North American cities. Additional data comes from publicly available sources, such as the U.S. Census Bureau. Results show that there is an association between median household affordability and city attributes, specifically, population dynamics, population density, and regional location. Both decision-makers at utilities and government organizations can use these results to inform investment decisions. For instance, utilities in growing cities may devote fewer resources to affordability programs compared to shrinking or stabilizing cities.

INTRODUCTION

In the U.S., low-income households are often burdened with spending a significant amount of their monthly budget on utility services such as electricity and water (McGraw, 2018); in some cases spending up to three times that of wealthy households (Shahyd, 2016). This means that access to clean water is cost-prohibitive among certain groups, in spite of the presence of physical infrastructure. Indeed, within the U.S., water poverty currently affects 1.6 million people, of which more than 30% report economic affordability as a prominent barrier to access (McGraw, 2018; U.S. Water Alliance, 2018). If unaddressed, current water affordability trends predict that the percentage of people in the U.S. who cannot afford water services will triple by 2020 (Mack and Wrase, 2017). This also poses a concern for utilities as this may set off a cycle where less access also means a decrease in the number of ratepayers contributing to the operations and maintenance of water systems (Mack and Wrase, 2017). This further deteriorates infrastructure systems and necessitates increases in water rates to meet fixed costs, thereby exacerbating the lack of access to water sector services.

Water affordability is not consistent between cities as each city has unique attributes, such as historical population changes and density, or geographic location. These characteristics may be linked to water sector rates and therefore, affordability. For instance, population dynamics—assessed based on U.S. Census Bureau populations from 1930 to 2010—determines the number of ratepayers within a system at any given time. Due to the fixed-grid characteristics of water infrastructure and the demand-dependent performance, these systems are particularly sensitive to such shifts in population (Osman et al., 2019; Faust and Kaminsky, 2018). These challenges can be technical (e.g., augmenting or decommissioning the system; Faust et al., 2018), economic (e.g., pricing the system; Mack and Wrase, 2017) or social (e.g., affordability, water burden; Fankhauser and Tepic, 2005). Thus, although such systems are designed and maintained by engineers, the socio-technical (e.g., the development of water policy) implications of scaling them to meet changing supply and demand require a collaborative effort amongst end-users and providers (Faust et al., 2018; Armanios, 2012).

In addition to population changes, population density poses a further socio-technical challenge to water infrastructure providers. For instance, rural communities whose water infrastructure was designed to meet the demands of a less dense population may have a difficult time accommodating sudden increases in population (Pallagst, 2009). Further, rural populations may be operating under tighter fiscal budgets, and consequently, changes in infrastructure services prices may lead to increased costs and less affordability (McGraw, 2018). Considering that rural areas experience the greatest percentage of water poverty in the U.S. (McGraw, 2018), ensuring affordability within these regions is especially important. Additionally, water sector service affordability can vary by region (e.g., west coast versus east coast) (Ogg and Gollehon, 1989; Schleich and Hillenbrand, 2009). This variance may be attributed to regional differences such as climate, regulatory environment, or water supply source.

Water affordability has been studied through the lenses of alternative water rate structures (Rosenberg, 2009; Olmstead et al., 2007) and the combination of water prices and water system expansion (Dandy et al., 1985). However, few studies have sought to understand how regional variability and city attributes impact water affordability. This study seeks to advance our understanding of the impact of city attributes and regional location on a city's water affordability (i.e., water rates). To accomplish this, multiple linear regression models were used to determine the empirical associations between the median affordability index (in the U.S. and its territories) and (1) population density, (2) population dynamics, and (3) geographic region. This study extends these associations to explore the implications of population changes since 1930 on water affordability for varying city sizes (based on population). The median household affordability index —the service charge as a percentage of the median household income in the city—has historically been used by the United States Environmental Protection Agency to measure affordability and make investment decisions (Ramseur, 2017). Therefore, in this study, we use it as an indicator of price burden and affordability, where a higher value correlates with a greater burden. Moreover, this value allows for the direct comparison of one city's affordability to another. For instance, the median household affordability index for combined water services provided by a utility in Chicago, Illinois was 1.05%, determined by the average yearly water rate of $513.36 divided by the median household income of $48,665. Comparing this value to another city—for instance, San Marcos, Texas whose affordability index was 7.3% in 2016 — indicates that water may be more affordable in Chicago than in San Marcos.

The results contribute to practice and literature by connecting water affordability and exogenous factors. Through this understanding, equitable water rate structures may be established by cities in specific regions, or those experiencing shifts in population. Further, cities that have created or are currently creating equity action plans may find the results useful as they can better structure these plans based on city attributes and regional location. Federal and state funding agencies may also benefit from the results by using them to develop funding mechanisms in which a city's population changes are more explicitly considered.

METHODS

A multiple linear regression (MLR) framework was used to create three separate models that predict water sector affordability indices based on city attributes, specifically population dynamics, population density, and regional location. These independent variables are of interest to this study because previous research indicates that they may be important drivers of water prices (Faust et al., 2016; Ogg and Gollehon, 1989). Data about median household affordability was collected from the 2016 Water and Wastewater Rate Survey (AWWA, 2017). This survey includes financial information from 264 water service providers and 182 wastewater service providers. In order to compare water and wastewater systems, only utilities that responded to both services were included in this analysis. Furthermore, cities that were established after 1930 were excluded because there was incomplete population data, resulting in a sample of 156 utilities spanning 38 U.S. states and Puerto Rico. Service charges vary based on water usage, but an average of the rates across usage was used to provide an overall sense of affordability for each utility provider. To understand population dynamics, each city was classified as either growing, shrinking or stabilizing using U.S. Census Bureau data from 1930 to 2010 (Figure 1). Cities were categorized by their population as either small (under 50,000 people), medium (50,000 to 100,000 people) or large (over 100,000 people) based on the most recent census in 2010; these ranges are commonly used when discussing population trends (U.S. Census Bureau, 2019). Population density (represented as people per mile^2/1,000) was also modeled to provide insight into the impacts of population density on water service affordability (U.S. Census Bureau, 2010).

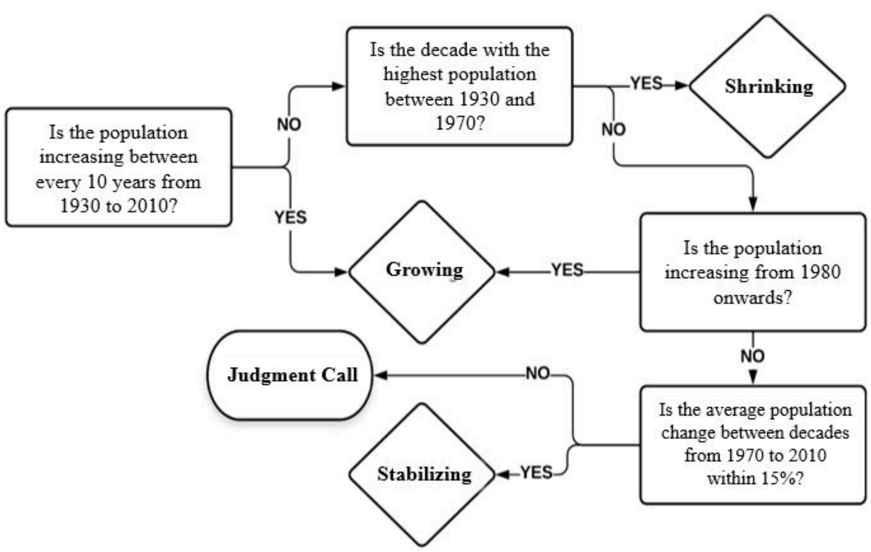

Figure 1. Population dynamics classification

MLR models were developed for each of three dependent variables—water, wastewater, and combined affordability indices. Separating water and wastewater indices provides the opportunity to compare if the drivers are different for each system. MLRs are generally used for either prediction or explanation of associations (Knofczynski and Mundfrom, 2008), however, in this analysis are used for explanation. In this context, MLRs are used to provide information about the directionality and the magnitude of associations between these aforementioned variables. The MLR framework is as follows, where e_i is a random error term and x represents the dependent variables modeled.

$$Y_i = \alpha + x_{i,1}\beta_1 + x_{i,2}\beta_2 + \ldots + x_{i,p}\beta_p + e_i \text{ (Olive, 2017)}$$

Interaction terms between population dynamics and city size were included in the model to test if the impact of population dynamics on affordability was independent of the size of a city. A small percent of the sample was characterized as shrinking (12.8%) or stabilizing (13.5%), meaning the sample sizes for groups modeled by interaction terms (e.g., stabilizing and small, shrinking and large) were too small to be modeled. Consequently, these interaction terms were only included for growing cities.

The study is limited by geographic inconsistencies in the data as utilities' service areas do not always align with a city's geopolitical boundaries. The impacts of this should be minimal because this study focuses on macro-trends. The data from the American Waterworks Rate Survey was from a cross-sectional study in 2016, so the results only depict affordability values from one year. Notably, omitted variables may bias the results of this study. The independent variables may be correlated with other factors such as demographic or cultural characteristics of cities. Although this limits the study, these models are not designed for predictive use and are intended to provide insight about associations between affordability and city attributes. In other words, what is more important to this study is not what causes these associations but that these associations exist and that policy efforts should take them into account, regardless of the root cause.

As recognized by experts in industry (Raucher et al., 2019), no one metric can perfectly describe affordability of water sector bills. There are limitations when using the median household affordability index (e.g., it does not connect to poverty, it is not focused on the most vulnerable populations, it does not consider environmental justice issues; e.g., Raucher et al., 2019). In turn, researchers have proposed other metrics that use information such as the number of people who have defaulted on their payments, per capita cost of essential water and sewer services, and the percentage of community households below certain poverty levels (Raucher et al., 2019; Teodoro, 2018). Many of these methods require extensive data that is not easily attainable for all utilities sampled in this study. Further, such measures add more context and granularity but are less generalizable. Given this study was designed to investigate overall trends in pricing, the median household affordability index was used as the first step of analysis and still provides information that can be of use to engineers and policy-makers. This paper can be expanded to include other affordability metrics.

RESULTS

The median household affordability indices tended to be higher for wastewater than water bills (Table 1) which may be because many utilities pay more to provide wastewater services as the treatment process is more costly (Austin Water, n.d.). The majority of the utilities in the sample were in growing cities (73.7%), which is consistent with overall growth rates as the U.S. grew by 125% percent from 1930 to 2010 (U.S. Census Bureau, 1931; U.S. Census Bureau, 2010). Over half of the utilities were located in the South (including Island States) and under 10% were in the Northeast.

Table 1. Descriptive Statistics of the Sample Utilities Used in Modeling

Characteristic	Mean (Standard Deviation)
Median Household Affordability Index-Combined	2.93% (1.49%)
Median Household Affordability Index-Water	1.38% (0.72%)
Median Household Affordability Index-Wastewater	1.55% (1.00%)
Population Density (per square mile)	2,604 (2306.4)
	Count (% of sample)
City Size	
Small (< 50,000 people)	62 (39.7%)
Medium (50-100,00 people)	35 (22.4%)
Large (>100,000 people)	59 (37.8%)
Population Dynamics	
Growing	115 (73.7%)
Shrinking	20 (12.8%)
Stabilizing	21 (13.5%)
Geographic Region	
Northeast	13 (8.3%)
Midwest	27 (17.3%)
West and Pacific	35 (22.4%)
South and Island Territories	81 (51.9%)

Table 2. Multiple Linear Regression Model Results

	Combined		Water		Wastewater	
Independent Variables	Estim (β)	t-stat	Estim (β)	t-stat	Estim (β)	t-stat
Constant	4.011	14.871	1.777	13.193	2.253	14.924
Population Dynamics (1 if true, otherwise 0)						
Growing	-1.451	-5.338	-0.640	-4.715	-0.660	-3.932
Small City, Growing*	0.705	2.628	0.370	2.762	---	---
Region (1 if true, otherwise 0) (Base: South and Island Territories)						
Northeast	-1.026	-2.451	-0.665	-3.181	---	---
West and Pacific	-0.963	-3.532	-0.291	-2.140	-0.621	-3.397
Midwest	-0.938	-3.198	-0.403	-2.747	-0.461	-2.311
Population Density (people per mile^2/1,000)	0.107	2.243	0.068	2.837	---	---
ΔR^{2**}	0.257		0.208		0.180	
ΔR^2_{adj**}	0.227		0.176		0.164	

*Interaction Term

*Lower R2 values indicate greater error, however associations are still observable (Mason et al., 1991)

The results of the MLRs are shown in Table 2. The geographic regions were loosely correlated; the variance inflation factor (VIF) and tolerance statistics were calculated in the final models for these variables. All variables used in modeling had a VIF less than 10.0 and tolerance statistics higher than 0.1 (Stevens, 1992; Norusis, 1998). In general, the same variables were found to be significant in all three models, except in the regression on solely wastewater affordability. The variables representing population density, location in the Northeast and the interaction term between small cities and population growth were not found significant in the wastewater model.

DISCUSSIONS

From the results, it is evident that population dynamics, geographic region, and population density all influence the affordability of water sector bills. However, their relative contributions vary as shown in the model results in Table 2. Consistent with literature, results show that growing cities tend to have more affordable bills (Ahmad, 2016). For the water only and combined regression models, the magnitude of the association between population growth and affordability is not consistent in cities of different sizes. For smaller cities, the association is weaker, indicated by a smaller magnitude β, which may be due to overhead costs being spread to fewer ratepayers (Osman et al., 2019; Faust et al., 2016). These results align with findings from Chong et al. (2012) that smaller cities—by population—have less ability to subsidize water rates, compared to larger cities.

The models revealed regional differences in water and wastewater affordability. Previous studies have found regional differences in water demand due to events such as climate change or seasonal irrigation schedules for specific crops (Ogg and Gollehon, 1989; Schleich and Hillenbrand, 2009). Often, water demand can be directly tied to water rates as increased demands and limited water supplies often translate to increased costs. Such findings align with results showing cities in certain regions tend to have higher water sector affordability rates. For instance, in the South, Texas faced a drought from 2010 to 2015 (NDRP, 2019). Such droughts place larger water price burdens on residents that live in these regions, creating affordability challenges for utilities. Notably, the regulatory environment around water affordability programs, such as customer assistance programs (CAPs), vary state by state which may be captured in the model results. In fact, few states have authorized these programs, and some states' policies create barriers that make it hard for utilities to create assistance programs to help low-income users pay bills (Kane, 2018). Future studies may extend this analysis to investigate the differences between affordability programs based on current state legislation.

Interestingly, results indicate a difference in affordability between water and wastewater systems. Often, such systems are considered together, particularly in cities where the bills are combined. In the model, three variables were found insignificant in the wastewater model but significant in the water model even though the services were provided by the same organization. This may signal differences in affordability between these systems and imply that water and wastewater systems should be discussed independently rather than collectively when addressing affordability concerns. For example, utilities may choose to create affordability programs that hold wastewater rates steady when water rates are increasing, or vice-versa.

Although these findings are focused on largescale trends, individual utilities can use the results in planning and decision making. Awareness of these trends may lead to improved management techniques because decision-makers can consider such trends while addressing day-to-day tasks. On a larger scale, results can be used by the federal government when making legislation or administering grant funding. There is minimal federal legislation aimed to support water sector affordability programs, but there have been recent efforts proposed in Congress.

This analysis should be taken into account as policy-makers continue to work on this issue. For instance, a bill being proposed that provides funding for affordability programs may consist of flexible requirements that take into account both current and projected city attributes (e.g., population dynamics, population density).

SUMMARY AND CONCLUSIONS

This study investigated the association between water sector rate affordability and a city's regional location, population dynamics, and density. Affordability was conceptualized using the median affordability index for water bills, wastewater bills, and combined total water sector bills. The models showed that empirical associations differed between water and wastewater sector infrastructure. This implies that water sector affordability should not only be considered holistically but also should be investigated by specific system. These results are especially useful to utilities that have created equity action plans to address equity issues, such as Austin Water and the Portland Water Bureau (City of Austin, n.d.; City of Portland, n.d.). For example, managers of these and similar programs can analyze their data with the knowledge that water and wastewater system affordability may differ.

The associations identified in this study help planners and policymakers understand why certain cities may experience challenges providing affordable water sector services. For instance, cities experiencing population decline should closely monitor water sector affordability as this population change may impact equitable access to these services. It is evident that regionally, there is a difference between household water sector bill affordability, which has implications for federal policy. Policymakers should acknowledge that some regions of the U.S. may face equity problems to a greater extent than others. This should be taken into account in federal legislation concerning water sector loans or other funding support.

This study is not only practically useful to employees at utilities and policymakers but also contributes to literature by identifying associations between population dynamics and regional location on water sector affordability throughout the U.S. and its territories. Future studies can build upon this research by including other variables that may be associated with affordability, such as demographic data about race, poverty and employment levels. Extending this study would reduce omitted variable bias and provide additional insight into water sector equity.

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REFERENCES

Ahmad, S. (2016). Managing Water Demands for a Rapidly Growing City in Semi-Arid Environment: Study of Las Vegas, Nevada. *Int. J. Water Resources. Arid Env.*, *5*(1), 35-42.

AWWA, Raftelis Financial Consultants Inc. (2017). 2016 Water and Wastewater Rate Survey. Denver.

Armanios, D. E. (2012). Sustainable development as a community of practice: insights from rural water projects in Egypt. *Sust. Development*, *20*(1), 42-57.

Austin Water. Wastewater Averaging FAQ. Retrieved July 12, 2019 from http://www.austintexas.gov/department/ wastewater-averaging-faq.

Chong, E., Saussier, S., & Silverman, B. S. (2015). Water under the bridge: city size, bargaining

power, prices and franchise renewals in the provision of water. *Journal of Law, Economics and Organization*, *31*(1), 3-39.
City of Austin. (n.d.). Operationalizing Racial Equity. Retrieved July 03, 2019, from http://www.austintexas.gov/department/operationalizing-racial-equity.
City of Portland. (n.d.). Bureau Racial Equity Plans. Retrieved July 3, 2019, from https://www.portlandoregon.gov/oehr/70048.
Dandy, G. C., McBean, E. A., & Hutchinson, B. G. (1985). Pricing and expansion of a water supply system. *Journal of Water Resources Planning and Management*, *111*(1), 24-42.
Fankhauser, S., & Tepic, S. (2007). Can poor consumers pay for energy and water? An affordability analysis for transition countries. *Energy Policy*, *35*(2).
Faust, K. M., Hernandez, S., & Anderson, J. (2018). Willingness to Pay for Perceived Increased Costs of Water and Wastewater Service in Shrinking US Cities: A Latent Class Approach. *Journal of Water Resources Planning and Management*, *144*(7), 04018033.
Faust, K.M., and Kaminsky, J. (2018). Gardoni, P., Ed. “Population Dynamics and the Resiliency of Water and Wastewater Infrastructure”. Chapter 18, The Routledge Handbook of Sustainable and Resilient Infrastructure.
Kane, J. W. (2018, January 25). Water affordability is not just a local challenge, but a federal one too. Retrieved July 24, 2019 from https://www.brookings.edu/blog/the-avenue/2018/01/25/water-affordability-is-not-just-a-local-challenge-but-a-federal-one-too/.
Knofczynski, G.T., & Mundfrom, D. (2008). Sample Sizes When Using Multiple Linear Regression for Prediction. *Educ. and Psych. Meas.*, *68*(3), 431-442.
Mack, E. A., & Wrase, S. (2017). A burgeoning crisis? A nationwide assessment of the geography of water affordability in the US. *PloS one*, *12*(1), e0169488.
Mason, Charlotte H., and William D. Perreault Jr. "Collinearity, power, and interpretation of multiple regression analysis." *Journal of Marketing Research* 28.3 (1991): 268-280.
McGraw, G. (2018, March 28). For millions of Americans, lack of access to water isn’t just a drought problem. Retrieved July 24, 2019, from http://uswateralliance.org/news/la-times-millions-americans-lack-access-water-isnt-just-drought-problem.
National Drought Resilience Partnership (NDRP) (2019). National Integrated Drought Information System- Drought in Texas. Retrieved July 03, 2019, from https://www.drought.gov/drought/states/texas.
Norusis, M. J. (1998). *SPSS 8.0: Guide to data analysis*. Upper Saddle River, NJ: Prentice Hall.
Ogg, C. W., & Gollehon, N. R. (1989). Western irrigation response to pumping costs: a water demand analysis using climatic regions. *Water Resources Research*, *25*(5), 767-773.
Olive, D.J. (2017). *Linear Regression. Regression Methods in Biostatistics.* Cham, Switzerland. Springer International Publishing.
Olmstead, S. M., Hanemann, W. M., & Stavins, R. N. (2007). Water demand under alternative price structures. *J. of Env. Econ. and Mgmt.* *54*(2), 181-198.
Olmstead, S.M. And Stavins, R.N., 2009. Comparing Price And Nonprice Approaches To Urban Water Conservation. *Water Resources Research*, 45(4).
Osman, K. K., Claveria, J. B., Faust, K. M., & Hernandez, S. (2019). Temporal Dynamics of Willingness to Pay for Alternatives That Increase the Reliability of Water and Wastewater Service. *Journal of Construction Engineering and Management*, *145*(7), 04019041.
Pallagst, K. (2009). “Shrinking cities in the United States of America: Three cases, three planning stories.” *The future of shrinking cities: Problems, patterns and strategies of urban transformation in a global context*, 81–88.

Ramseur, J. L. (2017). EPA Policies Concerning Integrated Planning and Affordability of Water Infrastructure (CRS Report No. 44223). www.crs.gov

Raucher, R., Clements, J., Rothstein, E., Mastracchio, J., & Green, Z. (2019). Developing a New Framework for Household Affordability and Financial Capability Assessment in the Water Sector. Retrieved July 17, 2019, from https://www.awwa.org/Portals/0/AWWA/Government/DevelopingNewFrameworkForAffordabilityReport.pdf.

Rosenberg, D. E. (2009). Residential water demand under alternative rate structures: simulation approach. *Journal of Water Resources Planning and Management*, *136*(3), 395-402.

Schleich, J., & Hillenbrand, T. (2009). Determinants of residential water demand in Germany. *Ecological economics*, *68*(6), 1756-1769.

Shahyd, K. (2016, December 15). Study Highlights Energy Burden for Households and How Energy Efficiency Can Help. Retrieved July 17, 2019, from https://www.nrdc.org/experts/khalil-shahyd/study-highlights-energy-burden-households-and-how-energy-efficiency-can-help.

Stevens, J. (1992). *Applied multivariate statistics for the social sciences* (2nd ed.). New York: HarperCollins.

Teodoro, M. P. (2018). Measuring Household Affordability for Water and Sewer Utilities. *Journal AWWA*, *110*. 13-24.

U.S. Census Bureau (1931). "Population: Number and Distribution of Inhabitants" 1930 Census. Retrieved July 24, 2019.

U.S. Census Bureau (2010). "American Fact Finder: Profile of General Population and Housing Characteristics." 2010 Census. Retrieved July 16, 2019.

U.S. Census Bureau. (2019). Fastest-Growing Cities Primarily in the South and West. Retrieved July 17, 2019, from https://www.census.gov/newsroom/press-releases/2019/subcounty-population-estimates.html.

U.S. Water Alliance. (2019). An Equitable Water Future – A National Briefing Paper. Retrieved July 26, 2019 from, http://uswateralliance.org/sites/uswateralliance.org/files/publications/uswa_waterequity_FINAL.pdf.