Water & Sewer Affordability in the United States[1]

- Working Paper -

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Abstract

The ability of low-income families to pay for basic water and sewer services is a subject of increasing concern. Large-scale assessments of affordability across large numbers of American utilities are rare, however, and are limited by poor measurement and biased samples. The present study uses improved metrics and data from an original, representative sample of water and sewer utilities in the United States to calculate the affordability of basic single-family residential water and sewer service for low-income households. Results indicate that low-income households must spend an average of 9.7 percent of their disposable income and/or work 9.5 hours at minimum wage to pay for basic water and sewer service, but also that these values vary considerably across the country. Community-level demographic and economic data are used to identify some correlates affordability. Region, utility size, and local income inequality emerge as strong predictors of affordability.

[1] Work in progress; questions, comments, and criticism are welcome. Please do not cite or quote without permission. Thanks to Jeffrey "Jake" Metzler for research assistance.

Infrastructure replacement needs, rising costs of living, and stagnant working-class wages have combined to drive increasing concern about affordability for basic water and sewer services in the United States. In particular, the ability of low-income households to pay for these essential services has drawn significant attention from researchers, utility managers, and policymakers. Despite this widespread and growing interest, empirical assessments of water and sewer affordability remain uncommon and suffer from important methodological limitations. Research and policy discussions about affordability are thus hampered by the a lack of a meaningfully measured, nationally-representative picture of water and sewer affordability.

This study provides a valid, generalizable depiction of water and sewer affordability in the United States. Data from an original, nationally-representative sample of American water utilities are used to calculate basic single-family residential water and sewer service prices. Eschewing the conventional focus on average demands and median incomes, this study focuses on *basic* water demands and *low-income* affordability, following the method suggested by Teodoro (2018). Utility characteristics and community-level demographic and economic data are then used to identify some correlates of water and sewer affordability.

To preview the main findings, results indicate that low-income households must spend an average of 9.7 percent of their disposable income and/or work 9.5 hours at minimum wage to pay for basic water and sewer service, but these values vary considerably across the country. Utility size and local income inequality emerge as strong, consistent predictors of affordability. Together, these metrics provide a national "snapshot" of water and sewer low-income affordability conditions in the United States.

This paper begins by introducing the issue of water and sewer affordability. Prominent studies on the subject are reviewed and their limitations discussed, with special attention to measurement and sampling. Discussion then turns to empirics, with a description of the improved measurement, sampling, and analytical approach employed in here. I summarize the results and identify notable correlates of affordability, providing an overall picture of water and sewer affordability in the United States. The paper concludes by discussing the study's empirical contributions and limitations, directions for future inquiry, and implications for utility management and policy.

Assessing affordability

The affordability of water and sewer utilities—like the affordability of anything else—is a function of their prices relative to the prices of other things and the resources available to pay for them. The present study analyzes the affordability of basic water and sewer utility services at the household level. The phenomenon of interest is the extent to which the price of water and sewer services necessary for human health force economic trade-offs by economically vulnerable households. Importantly, the concern here is for *basic* water and sewer service needed for drinking, cooking, cleaning, and sanitation. The price of outdoor urban water for yard irrigation, swimming pools, car washing, and other discretionary purposes is not relevant for affordability in this context.

It is also worth noting what affordability is *not* for present purposes. This study focuses on single-family residential water and sewer services provided by community utility systems. The affordability of private wells and septic systems are beyond the scope of this inquiry. Water and sewer service costs for agricultural, commercial, and industrial uses can have important effects for local economies, but their affordability are also not the subjects of this study. Finally, household-level affordability is different from system-level *financial capability*, which refers to a community's overall capacity to pay for its capital and operating needs (Davis & Teodoro 2014).

Given the burgeoning interest in water and sewer affordability in America, there is surprisingly little systematic research on the topic. Most studies that attempt to gauge affordability nationally or across large numbers of utility emerge from the non-refereed "gray literature," developed by financial firms (Standard & Poor's 2018), advocacy organizations (Jones & Moulton 2016), or independent or university-affiliated research institutes (Bartlet, et al. 2017; Rockowitz, et al. 2018). The author is aware of just three refereed studies that attempt to gauge affordability broadly in the United States (Mirosa 2015; Mack & Wrasse 2017; Teodoro 2018). These works provide important insights, but both the gray and peer-reviewed literature suffer from significant empirical problems that limit their validity for purposes of assessing affordability conditions nationally. In particular, sample bias and measurement problems plague existing studies of affordability.

Sampling and sources. No comprehensive, publicly available dataset on water and sewer rates in the United States currently exists, and so affordability research draws rates data from a variety of sources. Much of the gray literature relies on secondary compilations of rates and/or discusses rising system-level expenses, rather than measuring household affordability directly (e.g. Jones & Moulton 2016; Bartlett, et al. 2017).

Some prominent studies that measure affordability directly rely on proprietary datasets. Standard & Poor's (2018) recent report, for example, uses that firm's dataset of 1,600 municipal water and/or sewer utilities that for which that firm develops municipal debt ratings. Another commonly employed data source for rate evaluations is the American Water Works Association's (AWWA) biennial rate survey, administered by Raftelis Financial Consulting (AWWA 2016). Mack & Wrasse (2017) use the 2015 AWWA dataset of 318 utilities, for example. The AWWA survey invites its member utilities and selected Raftelis clients to submit rates and financial data. Raftelis uses survey responses to compile a national rates profile. Teodoro (2018) uses an original dataset, but analyzes only the largest 25 U.S. cities.

Each of these studies claims to depict national affordability conditions to some degree, but they all rely on non-random samples. In particular, these data sources are biased in favor of larger utilities. Teodoro (2018) includes only the very largest cities. The Standard & Poor's (2018) study uses a convenience sample of utilities that are engaged in the municipal debt market, which skews the sample in favor of larger systems (as its authors acknowledge). The AWWA surveys' reliance on member utilities and Raftelis clients tips its sample in favor of larger and relatively more sophisticated, resource-rich organizations. Inferring national affordability conditions from such biased samples risks under- or over-estimating costs with error of unknown direction and magnitude. Similarly, sample bias complicates efforts to correlate affordability with other variables.

Mirosa (2015) avoids sample bias by using data from the American Housing Survey (AHS), a household-level dataset that captures a variety of housing, financial, and other social variables. An important merit of Mirosa (2015) is that it captures water expenditure data at the household-level, reflecting the economic trade-offs utilities' end-users. However, Mirosa does not directly measure utility rates, and AHS respondent data cannot be related to specific utilities. Thus, although the AHS provides a useful way to illustrate a national affordability picture, it does not allow inferences about utility-level variation and so has limited relevance for policy and management.

Measurement. Most existing empirical assessments of water affordability rely upon a fundamentally flawed convention of water affordability: average water and sewer bill as a percentage of median household income (%MHI), with a combined value less than 4.0 or 4.5 designated as "affordable." This metric is often erroneously cited as a U.S. Environmental Protection Agency (EPA) standard for household affordability in both the gray (AWWA 2016; Bartlett, et al. 2017) and peer-reviewed literature (Mirosa 2015; Mack & Wrasse 2017). However, the %MHI guidelines as developed by EPA were intended to measure community-level *financial capability* for purposes of negotiating regulatory compliance (EPA 1995, 1997).[2]

As a method of measuring household-level affordability, the %MHI convention is flawed for at least four reasons. First, average residential demand as a basis for affordability analysis inflates the cost of water and sewer service for purposes of affordability analysis. In most of the United States, average residential water consumption is higher than its median—that is, a minority of high-volume customers drive up the average demand that the conventional method uses as the basis for affordability analysis (Teodoro 2018). Much of the high-volume consumption that comprises average demand is used for residential outdoor irrigation, not basic health and sanitation (DeOreo, et al. 2016).

Second, the %MHI convention's focus on *median* income neglects the most relevant subject of affordability analysis: low-income households (see also Rubin 2001; Baird 2010;

[2] See NAPA (2017) for a comprehensive discussion of the %MHI metric and its misapplication to household-level affordability.

Stratus Consulting 2013). In most developed-world contexts, water and sewer service remain inexpensive relative to many other commonly purchased goods and services, and so median-income households are unlikely to face significant water and sewer affordability problems. For low-income households, however, water and sewer bills may present significant affordability challenges (Bartlett, et al. 2017). Gauging affordability with %MHI obscures these low-income customers. The degree to which %MHI conceals affordability problems worsens as income inequality in a community increases (Teodoro 2018).

Third, the %MHI convention does not account for other essential costs of living, such as taxes, food, and home energy. Housing and health care costs present especially acute challenges for assessing affordability, as these costs vary considerably across the United States. For meaningful evaluation of affordability, water and sewer prices as a percentage of total income is less relevant than their prices relative to disposable income (Teodoro 2018), or market-adjusted effective buying power (Standard & Poor's 2018).

Finally, the 2.0 percent or 4.5 %MHI thresholds that EPA uses as financial capability guidelines have been misapplied as an arbitrary standard of affordability. Those guidelines are not based on any theory, empirical analysis, or deliberative process, and yet all of the affordability studies cited here invoke them (the exception is Teodoro (2018), discussed further below). Applying these simple binary standards—either "unaffordable" or "affordable," depending on whether average bills fall above or below a threshold—masks considerable variation within and across utilities.

Seeking to establish a more meaningful and accurate methodology for measuring water and sewer affordability, Teodoro (2018) advances a pair of alternative metrics: the *Affordability*

Ratio (*AR*) and *Hours' Labor at Minimum Wage* (*HM*). Teodoro's *AR* accounts for basic household water needs and essential non-utility costs:

$$AR = (\text{Cost of Basic Water + Sewer Service}) \div (\text{Household Income-Essential Non-water Costs}) \quad (1)$$

This *AR* reflects basic water and sewer costs as a share of disposable income. To focus on low-income households, Teodoro proposes assessing *AR* at the 20th-income percentile (AR_{20}), rather than at median income. A focus on the 20th percentile household is common in assessments of welfare economics, which typically identify the 20th percentile as the lower boundary of the middle class. At this income level, "working poor" households have very limited financial resources, but may not qualify for many income assistance programs. Basic household water and sewer costs expressed in hours worked at minimum wage (*HM*) provides an intuitively-appealing complementary metric. Unfortunately, as noted earlier, Teodoro's (2018) initial inquiry included only the largest 25 U.S. cities, which limits its generalizability and potential for correlational analysis.

To summarize, little existing research measures water and sewer utility affordability across the United States. The few existing studies employ flawed measurement and/or rely upon non-random samples. These methodological problems limit inferences about water and sewer affordability in the United States.

Toward better affordability assessment

The present study applies Teodoro's (2018) metrics to data from an original, representative sample of American water utilities in order to calculate the affordability of basic single-family residential water and sewer service for low-income households. This section describes the study's the sampling, data sources, and measurement methodology.

Frame and sample. The EPA's Safe Drinking Water Information System (SDWIS) was used as the sampling frame. The SDWIS contains basic system information and regulatory compliance data for each of the country's nearly 50,000 community water systems. The SDWIS organizes water systems into several categories based on the size of the populations that they serve. As Table 1 shows, an overwhelming majority of systems serve populations of less than 3,300. A simple random selection would likely result in a sample of mostly small systems that collectively serve a tiny proportion of the total population, and hardly any of the large and medium-sized utilities that serve most of the U.S. population. Nearly half (45.8 percent) of these systems are privately-owned, but system ownership is highly skewed by size: more than half of private systems are very small; larger systems tend to be owned by local governments.

Table 1. Community water systems in the United States

EPA service population category	Number of systems	Share of systems	Population served	Share of population	Privately-owned
100,000 or greater	432	0.9%	143,227,278	46.4%	13.7%
50,000-99,999	567	1.1	39,287,528	12.7	10.8
10,000-49,999	3,345	6.7	72,948,178	23.7	10.2
3,300-9,999	4,986	10.0	29,157,190	9.5	10.0
Less than 3,300	40,553	81.3	23,743,439	7.7	54.0
Total	49,883	100.0%	308,363,613	100.0%	45.8%

Source: EPA Safe Drinking Water Information System.

In order to secure a representative sample of utilities that provides empirical leverage on important correlates of affordability, the sampling frame was stratified in two ways. First, frame was divided into publicly-owned and privately-owned systems. Second, both frames were split into the EPA's five population strata. Seventy five publicly-owned and fifteen privately-owned utilities were then randomly selected into the sample from each stratum. The smallest stratum (systems serving fewer than 3,300 population) was dropped from the sample due to the difficulty of securing reliable rates data for very small systems, and because they collectively serve a very small minority of the total U.S. population.[3] The resulting sample included 300 publicly-owned and 60 privately-owned utilities, for a total of 360. The sampled utilities serve a combined population of more than 38 million. Post-stratification weights are applied in parametric calculations and regression estimates in order to correct for bias introduced by the sampling procedure.

This study seeks to characterize the joint affordability of both drinking water and sanitary sewer services, and so an accompanying sewer system was identified for each sampled water system. In most cases (72 percent), a single organization provided water and sewer services to the same geographic jurisdiction (e.g., a city government that operates water and sewer utilities for its own city, or a joint water-sewer special district). In the cases where separate organizations provide water and sewer services, the study team identified the sewer utility that provides service to the water system's geographic area. In the few cases where multiple sewer utilities serve the same water utility area, the sewer utility that served the largest portion of the city identified in the SDWIS service area was used.

[3] This is not to suggest that affordability in very small systems is not important. Indeed, as we will see, affordability issues may be particularly pronounced in small systems. However, the practical difficulty of gathering rates data for very small systems nationwide outweighed the value of the additional data for inferential purposes in this study. Future research focused on small system rates could yield important insights.

Data. Single-family residential water and sewer rates for the sampled utilities were collected directly by the study team from May-July 2017. For most utilities in highest stratum (serving populations over 50,000) rates data were readily available on websites. When rates were unavailable online—especially common among smaller utilities—the study team inquired by telephone, repeating calls as necessary.[4] Efforts to collect rates data were abandoned after multiple refusals or non-responses. The final dataset included full water and sewer rates data for 329 of the 360 sampled utilities.[5]

Data on other utility system and community characteristics were drawn from a variety of sources. In addition to population and ownership, the SDWIS provides data on primary water source (groundwater, surface water, wholesale purchase) and Safe Drinking Water Act (SDWA) violations over the past five years. Demographic and income data for cities served by each utility were drawn from the U.S. Census Bureau's 2016 American Community Survey (ACS) five-year estimates. Accurately matching demographic and income data to special district, county, and private utility jurisdictions is challenging because utility service areas do not always correspond perfectly with municipal boundaries. Where utilities served multiple cities, the city identified with the city's mailing address in SDWIS was used. The study team coded publicly-owned water systems as either municipalities or special districts, and also directly collected applicable 2017 minimum wage information for each utility's jurisdiction.

Affordability measurement. Affordability was measured with the two-pronged

[4] The process of gathering rates data was strangely difficult in some cases. Some were impossible to contact by telephone. In a few cases, utilities refused to provide rates by telephone or in writing. In one case, a local government required a Freedom of Information Act request before releasing rate information to the study team.

[5] This sample size compares favorably with the 2016 AWWA survey's non-random sample of 260 utilities.

approach advanced by Teodoro (2018). The monthly price of basic water and sewer service was calculated for a family of four at 50 gallons per capita per day (gpcd), or 6,200 gallons (6.2 kgal).[6] This 50 gpcd standard is a typical assumed minimal residential wastewater flow for purposes of sewer system design (Bowne, Naret and Otis 1994), meant to reflect basic indoor water use.[7] The value of customer assistance programs was not included in price calculations, since the goal is to measure affordability in absence of policy intervention.

Table 2. Descriptive summary

Variable	Mean	95% Mean C.I.	Minimum	Maximum
AR_{20}	**9.73**	**[8.68, 10.78]**	**0.58**	**35.46**
HM	**9.53**	**[8.90, 10.17]**	**1.08**	
Special District (1/0)	0.28	[0.21, 0.35]	0	1
Private	0.10	[0.61, 0.13]	0	1
Groundwater source	0.49	[0.42, 0.56]	0	1
Purchased water source	0.30	[0.23, 0.36]	0	1
Population served (000)	35.15	[28.26, 42.04]	3.31	2,333.31
SDWA violations	32.21	[22.02, 42.41]	0.00	593.00
Median income ($1,000)	51.87	[48.73, 55.02]	16.06	170.14
Inequality (Gini coef.)	43.47	[42.68, 44.24]	20.02	60.75
College graduate (%)	25.06	[23.00, 27.12]	0.00	83.10
Homeowner (%)	64.32	[62.33, 66.30]	30.37	97.43
Black/African American (%)	11.31	[8.71, 13.91]	0.00	97.49
Hispanic (%)	13.50	[10.78, 16.21]	0.00	96.30

Note: N=327. Post-stratification weights applied in mean and confidence interval calculations.

[6] About 60 percent of sampled utilities apply volumetric rates in thousand-gallon (kgal) units; 39 percent measure water volume in hundreds of cubic feet (ccf). A few utilities use other volume units.

[7] The Texas Water Development Board recommends 50 gpcd as its standard for indoor water use in conservation planning (2004). California followed suit in 2018, adopting a 50 gpcd indoor water use standard for its long-term planning.

The sample-weighted average monthly price was $36.86 for water and $42.30 for sewer, for a total of about $79.15. These prices were the numerators for both AR_{20} and *HM* calculations.

Values of AR_{20} require estimates of disposable monthly income for a family of four at the 20th income percentile in a given utility's service population. Data for gross income at the 20th percentile were drawn from the ACS' first quintile upper limit. Essential non-water expenditures were estimated with Teodoro's (2018) regression model, which used Bureau of Labor Statistics Consumer Expenditure Survey data to estimate expenditures on taxes, housing, health care, food, and home energy. Coefficients from that model were combined with ACS data on demographics and income for each utility to estimate essential expenditures at the 20th income percentile for a family of four. Subtracting these essential expenditures from 20th percentile income yielded the denominator for AR_{20}. Calculating *HM* simply required dividing monthly combine basic water and sewer prices by the locally applicable minimum wage. The resulting AR_{20} and *HM* values vary considerably, and the two metrics correlate moderately (ρ = .61). Table 2 provides a descriptive summary of AR_{20}, *HM*, and the other variables employed in the subsequent analysis.

Results: Water and sewer affordability in the United States

This section reports overall water and sewer affordability conditions in the United States as measured by AR_{20} and *HM*. Average affordability metrics are also reported by region and ownership. An exploratory analysis of the correlates of affordability follows.

Figure 1. Single-family residential Affordability Ratio at 20th income percentile (AR_{20}) in the United States, 2017

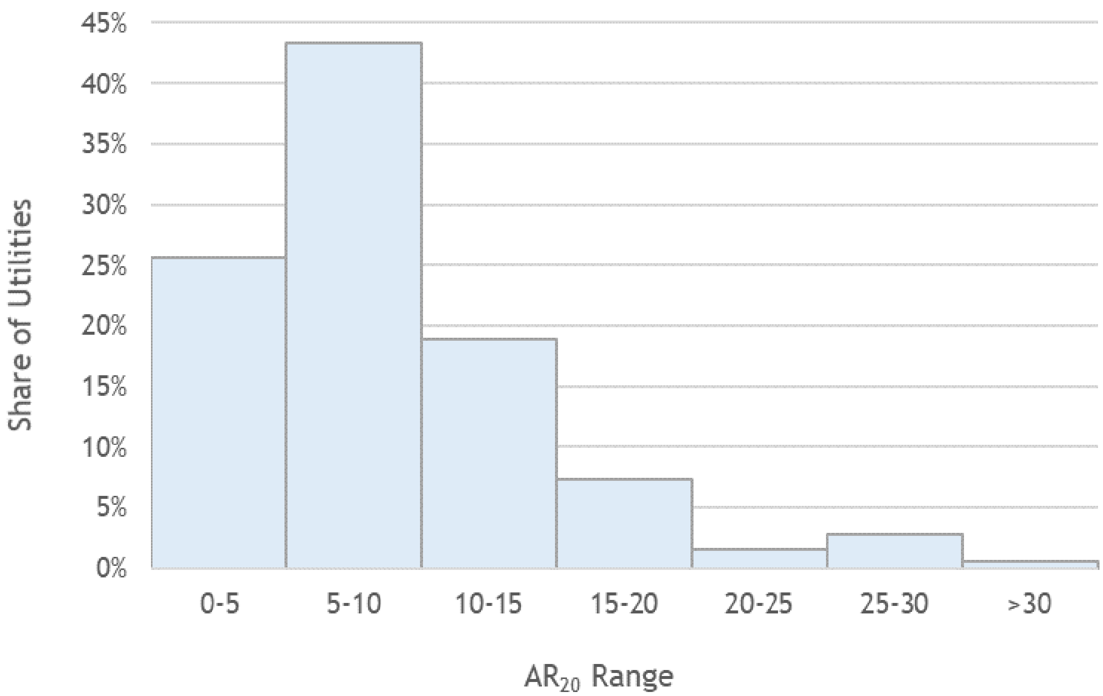
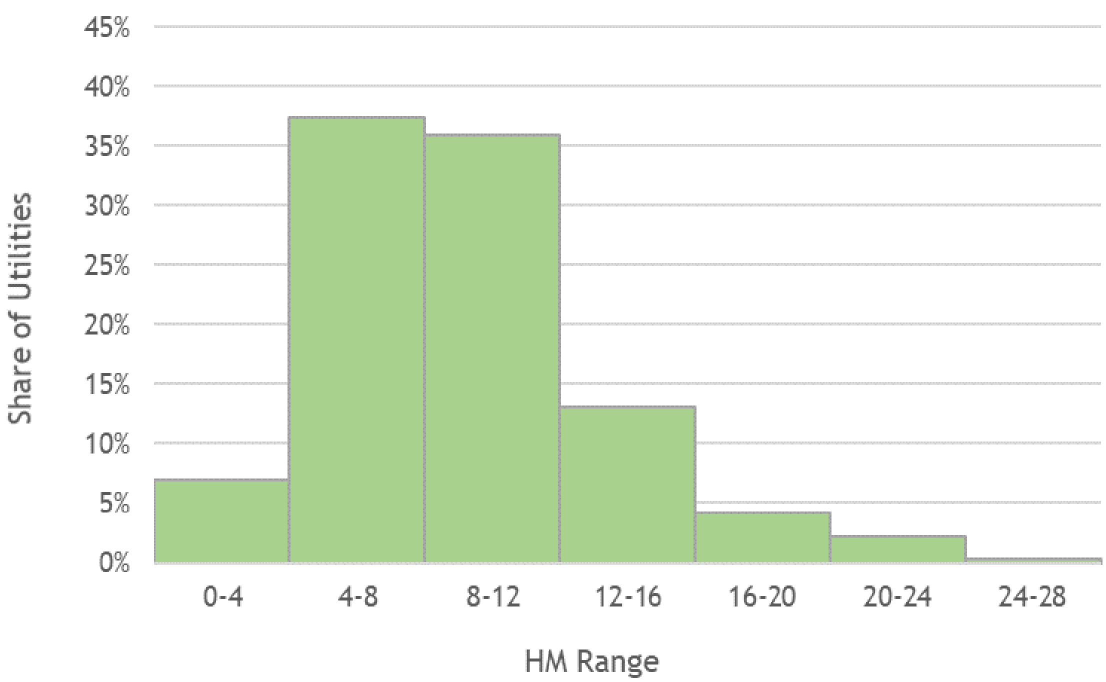


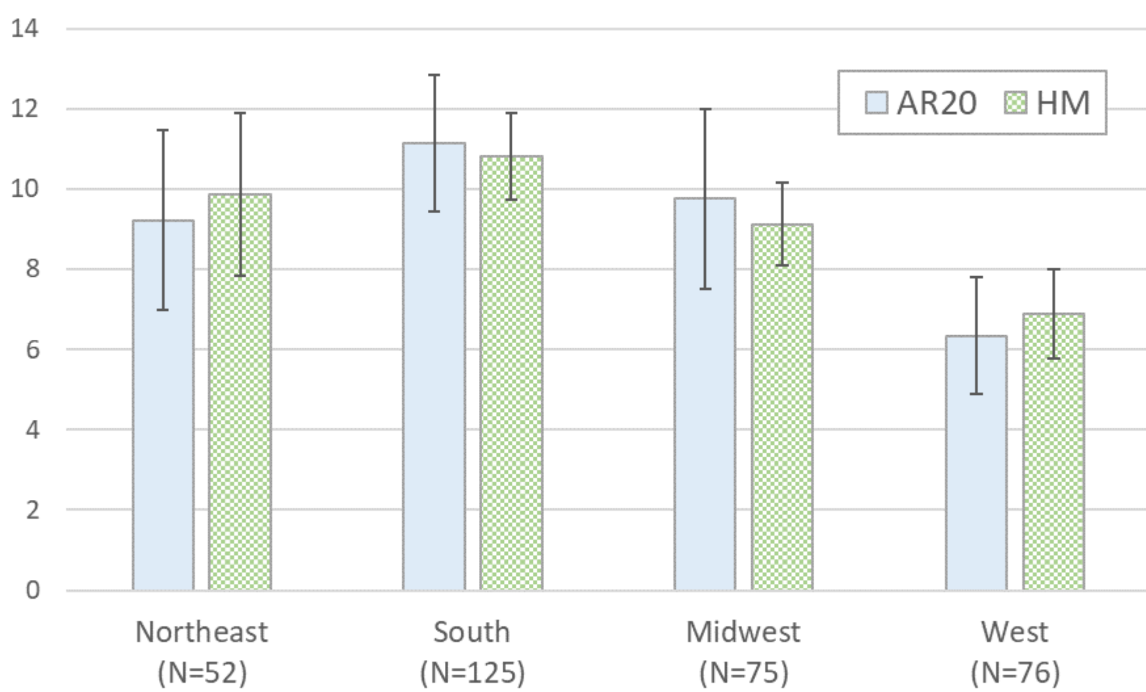
Figure 2. Basic single-family residential water and sewer price in Hours of Minimum Wage labor (HM) in the United States, 2017



Figures 1 and 2 illustrate the distribution of water and sewer affordability measured by AR_{20} and *HM*. AR_{20} ranges from 0.6 to 35.5, with a weighted mean of 9.7. In substantive terms, these results indicate that in more than two-thirds of utilities, basic water and sewer service cost less than ten percent of disposable income for households at the 20th income percentile. The weighted mean *HM* is 9.5 and ranges from 1.1 to 25.6.

Region. Figure 3 shows weighted mean AR_{20} and *HM* values by census region. Average affordability is broadly similar across three of the four regions, with no statistically significant regional differences in either metric. However, average affordability is markedly lower among western utilities relative to other regions.

Figure 3. Mean AR_{20} and HM by region, 2017



Note: Spikes represent 95% confidence intervals. Post-stratification weights applied in mean calculations.

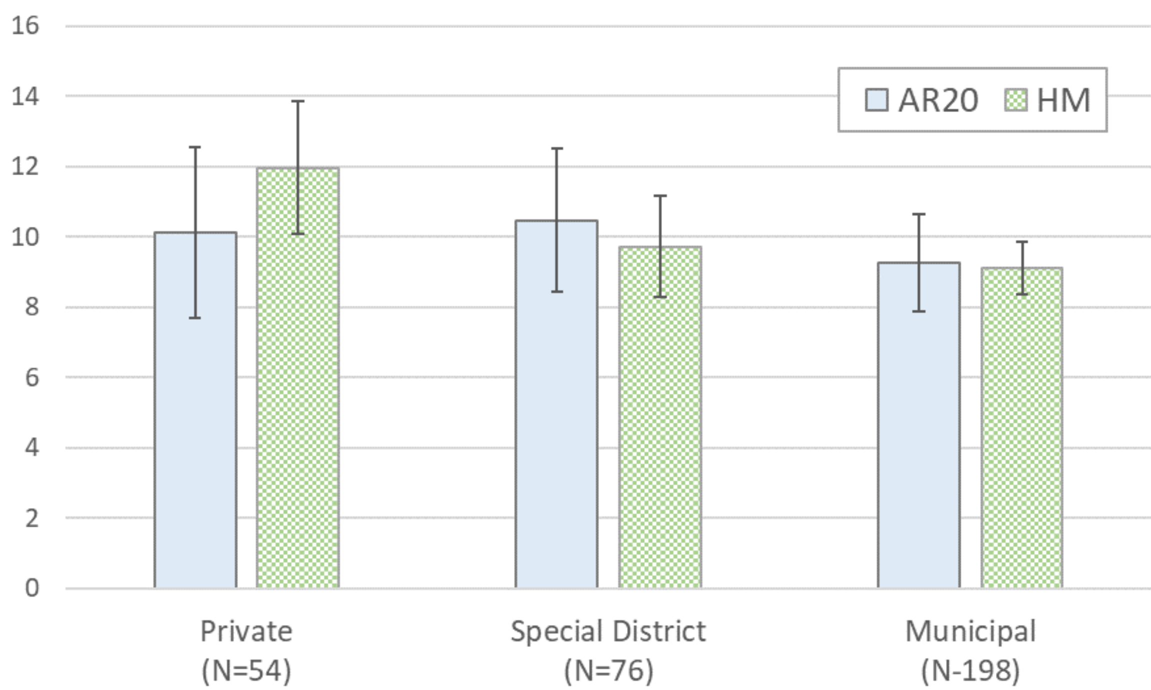
Ownership. Differences in rates between publicly-owned and investor-owned utilities are subjects of frequent interest in the popular media and gray literature. For example, a 2016 Food & Water Watch (F&WW) study reports that “public service is the most affordable option,” based on their finding that “on average, private for-profit utilities charged households 59 percent more than local governments charged for drinking water service” (2016, 3). The F&WW (2016) analysis was based on water rates in the 500 largest U.S. utilities, with prices calculated at 12kgal per month.[8] This level of water demand implies average consumption of 100 gpcd for a family of four—greater than the U.S. national average of 91 gpcd (DeOreo, et al. 2016) and twice the 50 gpcd basic indoor demand assumed in calculating AR_{20} and *HM*. The F&WW affordability claims about public and private systems also are based purely on comparative prices, with no consideration for relative economic conditions.

With prices calculated based on a much more conservative 50 gpcd and a focus on low-income economic tradeoffs, the present AR_{20} and *HM* provide a useful alternative means of evaluating differences in affordability between publicly- and privately-owned utilities. Figure 4 depicts average AR_{20} and *HM* by three types of ownership: private, investor-owned utilities, municipal government utilities, and special district utilities. As Figure 4 indicates, average AR_{20} does not vary significantly by ownership. Private utilities’ AR_{20} average 10.1, which is greater than municipal utilities’ average of 9.3, but less than special districts’ 10.5; none of these differences are statistically significant. However, *HM* varies significantly by ownership: private utilities average 12.0 *HM*, which is 2.25 hours more than the special district average and nearly three hours more than the average for municipal utilities; the difference in *HM* between private

[8] This level of water demand implies average consumption of 100gpcd for a family of four—twice the volume assumed in calculating AR_{20} and *HM*.

and municipal utilities is statistically significant ($p<.001$). These results offer weak support for claims that privately-owned water utilities are less affordable than publicly-owned utilities.

Figure 4. Mean AR_{20} and HM by system ownership, 2017



Note: Spikes represent 95% confidence intervals. Post-stratification weights applied in mean calculations.

Correlates of affordability. A large, diverse set of data on utility affordability provides an opportunity to investigate the relationship between affordability and various organizational and social variables. To that end, some simple regression models are offered here as a descriptive exploration. The goal here is not to advance theoretical claims or evaluate specific hypotheses, but rather to provide an initial picture of important correlates of affordability.

A set of simple Ordinary Least Squares (OLS) regression models of AR_{20} and *HM* are presented here in Tables 3 and 4, respectively. Each table reports an estimate using only utility characteristics drawn from the SDWIS (Models A and C) and an estimate that adds demographic and economic covariates (Models B and D) from the ACS.[9] At the utility level, models include dummies (1/0) for *special district* and *private* ownership (municipal utilities are the reference category) and primary water source (*groundwater* or *purchased water*, with surface water as the reference category). The models also include a count of SDWA violations over the past five years. Finally, the models include utility size, measured as the natural log of the *population* served by the utility. The logarithmic transformation is important because the effects of scale on affordability are expected to be nonlinear, with the greatest effects at the lower end of the distribution. For example, the substantive difference between a utility that serves a population of 10,000 and one that serves 75,000 is greater than the difference between utilities that serve 500,000 and 565,000. All models employ post-stratification weighting.

Models B and D introduce data from the ACS, including community *median income* and *inequality,* measured with the Gini coefficient. The Gini coefficient measures income inequality, ranging from zero (perfectly equal) to one (perfectly unequal). The Gini coefficient was multiplied by 100 when entered into the models in order to ease interpretation. Also included is the percentage of the adult population who are *college graduates,* the percent of households that are *homeowners,* and the percentages of the population that are *Black/African American* and *Hispanic*.

[9] As discussed earlier, employing city-level ACS demographic and economic data for special districts and private utilities involves a degree of measurement error because the ACS geographic units do not align perfectly with special district and private utility service areas. This measurement error is nonrandom and correlated with other independent variables, raising the specter of bias in coefficient estimation. As a robustness check, Models A-D were re-estimated for only municipal utilities. Results for municipal utilities only yielded substantively similar results for Models A-C; estimates of HM in Model D were consistent in direction, but larger standard errors reduced the statistical significance of inequality (p=.28).

Table 3. Correlates of water and sewer Affordability Ratio at 20th income percentile (AR_{20})

	Model A		Model B	
Dependent Variable: AR_{20}	Coefficient (Robust St. Error)	p	Coefficient (Robust St. Error)	p
Special district	0.93 (1.21)	.45	-0.67 (1.00)	.50
Investor-owned	0.65 1.45	.65	0.65 1.15	.57
Groundwater source	-0.11 (1.55)	.94	0.13 (1.35)	.92
Purchased water source	0.56 (1.79)	.76	1.77 (1.57)	.26
Population served (log)	-1.08 (0.41)	.01	-0.73 (0.37)	.05
SDWA violations	0.01 (0.01)	.59	0.01 (0.01)	.59
Median income ($000)			-0.11 (0.04)	.01
Inequality			0.49 (0.10)	<.01
% College graduates			-0.08 (0.05)	.10
% Homeowner			-0.07 (0.05)	.15
% Black / African American			0.01 (0.04)	.70
% Hispanic			-0.05 (0.02)	.04
Intercept	19.40 (4.51)		-1.51 (6.67)	
R^2	.04		.41	
AIC	2181.20		2032.93	
N	327		327	

Note: Ordinary least squares regression. Post-stratification weights applied in estimation.

Table 4. Correlates of basic water and sewer price in Hours at Minimum Wage (*HM*)

Dependent Variable: HM	Model C Coefficient (Robust St. Error)	Model C p	Model D Coefficient (Robust St. Error)	Model D p
Special district	0.49 (0.81)	.55	0.22 (0.78)	.78
Investor-owned	2.85 (1.01)	<.01	2.70 (1.00)	.01
Groundwater source	-0.41 (0.77)	.59	-0.32 (0.72)	.66
Purchased water source	0.27 (0.85)	.75	0.39 (0.87)	.66
Population served (log)	-0.70 (0.22)	<.01	-0.51 (0.25)	.04
SDWA violations	0.00 (0.01)	.62	0.01 (0.01)	.63
Median income ($000)			-0.01 (0.02)	.73
Inequality			0.12 (0.70)	.09
% College graduates			-0.04 (0.03)	.23
% Homeowner			0.07 (0.03)	.15
% Black / African American			0.01 (0.02)	.66
% Hispanic			-0.02 (0.02)	.40
Intercept	19.40 (4.51)		5.78 (4.03)	
R^2	.07		.12	
AIC	1872.19		1865.15	
N	327		327	

Note: Ordinary least squares regression. Post-stratification weights applied in estimation.

Estimation yields several interesting findings. First, the inclusion of demographic and economic variables markedly improves fit in both sets of estimates. In Table 3's models of AR_{20}, R^2 jumps from .04 in Model A to .41 in Model B (ΔAIC = -148.3).[10] Estimates of *HM* in Table 4 improve less dramatically but still notably, from R^2 = .07 in Model C to .12 in Model D (ΔAIC = -7.0). Demographic and economic conditions evidently predict affordability as well as or better than do utility characteristics.

Among utility characteristics, only *log population* emerges as a consistently significant predictor of affordability: AR_{20} and *HM* improve as utility size increases across all four models. Holding all else equal, Model B predicts AR_{20} for a utility one standard deviation below the mean in size on a logarithmic scale (population 4,400) at 10.6; Model D estimates that utility's *HM* at 10.1. For a utility one standard deviation above the mean (population 40,900), AR_{20} drops to 8.9 and *HM* falls to 9.0. At two standard deviations above the mean (population 124,700) AR_{20} is just 8.1 and *HM* falls to 8.4. As in Figure 4, *private* utilities yield mixed findings: AR_{20} does not vary significantly between public and private utilities, but *HM* is substantively and statistically greater for private utilities than for municipal utilities. Source water and regulatory compliance have no significant correlation with affordability.

Analysis of community demographic variables generates some interesting correlations, as well. *College graduate* and *home ownership* levels negatively correlate with AR_{20} in Model B, but in Model D these variables correlate with *HM* in opposite directions and do not reach

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[10] Marked improvements in fit from Model A to Model B are unsurprising since AR_{20} is partially a function of the demographic variables (percent *college graduates*, *home ownership*, *Black/African American*, and *Hispanic*) included in Model B. This kind of endogeneity does not occur in estimates of *HM* and the corresponding improvements from Model C to Model D.

conventional standards of statistical significance in either model after controlling for median income. Percent *Black/African American* population is essentially uncorrelated with affordability by either population. *Hispanic* population negatively predicts AR_{20} and *HM*, but with statistical significance only for the former.

Turning to economic variables, *median income* negatively correlates with AR_{20} as expected, but not with *HM.* Income inequality very strongly correlates with affordability. According to Model B, a one standard deviation increase in the Gini coefficient correlates with a .41 increase in AR_{20}, all else equal. A one standard deviation increase in inequality correlates with a .16 increase in *HM,* although the correlation is less statistically robust (p=.09). Importantly, the Gini coefficient is essentially uncorrelated with basic water and sewer price (ϱ=-.04) or water and sewer prices at 12 ccf per month (ϱ=-.03).

Discussion

This study provides a descriptive summary of water and sewer affordability for low-income households in the United States, applying the two metrics suggested by Teodoro (2018) –AR_{20} and *HM*—to a nationally-representative set of utilities. Results indicate that households at the local 20th percentile income level must spend an average of 9.7 percent of their disposable income and/or work 9.5 hours at minimum wage to pay for basic water and sewer service.

Affordability varies considerably across utilities, however. Water and sewer service are, on average, more affordable in the western U.S. than in other regions. Greater affordability in western utilities may reflect generally newer systems with lower average maintenance costs. It is also possible that western utilities employ rate structures that generate more affordable bills at the 6.2 kgal monthly volume measured here. Results provide mixed support for claims that privately-owned water utilities are less affordable than publicly-owned utilities: AR_{20} does not vary significantly by ownership, but *HM* is significantly higher for private, investor-owned utilities compared with their local government counterparts.

Among the system characteristics analyzed here, utility size emerges as the most notable correlate of AR_{20} and *HM*: by both measures, affordability improves significantly as utility size increases. Larger utilities may enjoy economies of scale that translate into more affordable rates for low-income customers. It is also possible that larger utility organizations and their social/political contexts drive policies and practices that lead to greater affordability.

Somewhat surprisingly, demographic variables are generally poorly correlated with affordability: education, home ownership levels, and race do not strongly correlate with either affordability metric. Ethnicity emerged as a strong predictor of affordability, with percent *Hispanic* population associated with more affordable water and sewer service measured by AR_{20}, but only weakly associated with *HM*.[11]

Perhaps the most intriguing result to emerge from this initial analysis is the strong and consistent relationship between income inequality and affordability. The Gini coefficient is not significantly correlated with water and sewer prices, but AR_{20} and *HM* both increase as the Gini coefficient increases. Taken together, these results suggest that income inequality is an important facet of water and sewer affordability challenges. This result also provides further evidence that assessments of affordability based on median income are unsuitable for purposes of understanding household-level affordability for low-income households.

[11] In estimates not reported here, percent *Hispanic* population remains significantly correlated with affordability in models that control for region.

Limitations. As with any empirical inquiry, this one has important limitations. The AR_{20} calculations used here rely on estimates of disposable income developed with a regression model built with national data, which necessarily introduces measurement error. The degree to which this measurement error mischaracterizes affordability for a given utility depends on how much local consumer expenditures vary from national patterns, but so long as the error is random, estimates of AR_{20} are not likely to suffer from significant bias. Similarly, the 50 gpcd basic water use level assumed in the analysis may not align with basic use in all utilities. This assumption is reasonable for purposes of crafting an overall national assessment and identifying important correlates of affordability, but may not be appropriate for evaluating affordability in a particular utility.

Second, the purpose of the present study is to measure and describe affordability strictly in terms of the financial tradeoffs created by water and sewer rates; the present dataset includes no information about water supply conditions, demand patterns, sewer flows, wastewater strength, service quality, or system financial and physical conditions. In other words, the present analyses do not account for water and sewer service *quality* (except insofar as SDWA violations measure quality). As such, the affordability figures provided here do not reflect the *value* of water and sewer service or capture utility-level tradeoffs involving cost and quality. The author makes no claim that affordability is the most important aspect of water and sewer service, rather merely that affordability is important and merits valid measurement.

Finally, although this study's sample allows for more nationally-representative analysis than previous research, it is nonetheless limited. The sample provides statistical power sufficient to address some important questions, but a larger sample would provide greater traction on a wider range of phenomena. The present sample does not provide power necessary to analyze state-level policy effects on water and sewer affordability, for example. The labor-intensity of data collection for water and sewer rates remains a serious barrier to larger sample studies. Very small utilities (serving populations fewer than 3,300) are excluded, and their rates remain vexingly elusive to researchers.

Directions for future research. The data marshaled here provide a useful baseline and platform from which to investigate the causes and consequences of water and sewer affordability. Beyond the obvious need for repeated and expanded sampling (especially to very small systems), the present findings suggest some potentially important directions for future research to inform utility management, policy, and regulation.

One clear avenue for study is to connect affordability to utility-level financial policies and practices. Capital financing arrangements and rate design, for example, have clear implications for low-income affordability. How do fixed and volumetric rate structures relate to low-income affordability? How do inclining block, declining block, and uniform rates affect affordability? Does affordability necessarily stand in tension with other ratemaking goals like equity, efficiency, and revenue stability? Or can rate design help accomplish these goals simultaneously? What is the relationship between affordability and System Development Charges and other capital connection fees? Analysis of affordability across many utilities can provide empirical leverage on these questions.

The relationship between utility operating and capital costs and affordability is another important direction for future inquiry. Which aspects of utility organization and management account for the relationship between size and affordability observed here? How do present and deferred capital maintenance and replacement costs relate to affordability? How do regulatory requirements affect affordability? How does affordability relate to other aspects of utility performance, like water quality, system loss, capital replacement schedules, workplace safety, financial strength, and so on? Do state and federal grant and loan programs translate into more affordable water and sewer service for low-income households? Unfortunately, no comprehensive national data for utility system conditions and performance currently exist beyond the EPA's compliance datasets. New Jersey's recent 2017 Water Quality Accountability Act (WQAA) offers a promising means to generate such data. The WQAA requires all water utilities with more than 500 customer connections to develop, submit, and implement asset management plans, along with a host of other maintenance, monitoring, and reporting requirements. The data generated by New Jersey's WQAA may allow careful analysis of the affordability in relation to overall system management and investment.

Finally, measurement of affordability across many utilities provides an opportunity for rigorous social science research on the links between affordability and institutional, social, and economic variables. The possible directions for research are many, but this initial inquiry points to at least three intriguing directions for further research to understand the causes underlying the patterns observed here. One is regional variation, as utilities in the western United States are, on average, more affordable than the rest of the country. The second is ethnicity, as percent *Hispanic* population is also positively associated with affordability measured as AR_{20} (though not as *HM*). Third and perhaps most intriguing is income inequality, which is strongly associated with unaffordable water and sewer service.

Implications and applications. How affordable are water and sewer service in the

United States? What is "affordable" is ultimately a normative question beyond the scope of this inquiry. Although no specific level AR_{20} or *HM* defines affordability, Teodoro (2018) suggests values of AR_{20} less than 10% and *HM* less than 8.0 as rules-of-thumb to guide policy consideration. By these guidelines, 51 percent of the sampled utilities are affordable as measured by AR_{20} and 39 percent are affordable according to *HM.*[12] However, affordability varies considerably across utilities, providing managers, regulators, and policymakers with a valuable picture of the affordability landscape. This picture and the preliminary analyses reported here suggest that smaller utilities and communities with severe income inequality may be particularly vulnerable to affordability challenges. These factors bear consideration as governments and water sector leaders seek to maintain affordability while fulfilling their environmental and public health missions.

I close with a caution on the use of comparative affordability metrics in policymaking and management. A general profile of affordability and comparative analyses are useful for developing broad regulatory and financial strategies. However, comparative affordability analysis is not appropriate for setting policy in any specific utility, and in fact might be counterproductive. Affordability is a household-level phenomenon: if a low-income family in Portland is struggling to pay its bills, the fact that they would be better off in Pasadena and even worse off in Providence is irrelevant. Rather than comparing their own affordability metrics with other communities,' utility leaders should seek to maintain affordability levels that are consistent with their own organizational goals and values.

[12] 95 percent confidence intervals are [43.3, 58.0] for AR_{20} and [32.0, 46.2] for *HM.*

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