Water and Sewer Affordability in the United States, 2019[*]

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Abstract

This study uses contemporary 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 in 2019. Results show that affordability conditions have worsened on average since the last such study in 2017: low-income households must spend an average of 12.4 percent of their disposable income (up from 10.9 percent) and/or work 10.1 hours at minimum wage (up from 9.9 h) to pay for basic monthly water and sewer service. Analysis suggests that rising prices combine with underlying economic trends to exacerbate affordability.

[*] This paper is work in progress; please do not cite or quote without permission. Comments and criticisms are welcome.

1 | Introduction

Affordability is a mounting concern for the American water sector, as long-deferred infrastructure replacement needs and upgrades have driven utilities to raise prices. Combined with rising costs of living and uneven wage growth, rising prices for water and sewer services can create significant economic challenges for low-income customers. Poor measurement and a dearth of representative data have hindered meaningful research, media coverage, and policy discussions on affordability for these critical services. In an effort to depict affordability more accurately and meaningfully, Teodoro advanced a set of new affordability metrics (2018) and used them to analyze basic residential water and sewer affordability in 2017 across hundreds of utilities in a nationally-representative sample (2019).

This study replicates, updates, and expands upon Teodoro's (2019) study of affordability in 2017 with similar nationally-representative sample rates in 2019. Following Teodoro's (2018) suggested measurement methodology, we eschew the conventional focus on average demands and median incomes, and instead focus on *basic* water demands and *low-income* affordability. Specifically, we evaluate affordability with Teodoro's Affordability Ratio at the 20^{th} income percentile (AR_{20}) and a transformation of monthly water and sewer bills into Hours of labor at Minimum wage (HM). Comparisons of affordability in 2017 and 2019 provide a useful picture of short-term national trends in affordability.

The main results of this updated analysis indicate that low-income households must now spend an average of 12.4 percent of their disposable income and/or work 10.1 hours at minimum wage to pay for basic monthly water and sewer service—up from 10.9 percent and 9.9 hours in 2017—but these values vary considerably across utilities. Although about two-thirds of the utilities that appeared in the two samples changed their water and/or sewer rates between 2017 and 2019, the changes were relatively small with a weighted average increase of $4.07 a month, not enough to drastically change the affordability measures for most customers. The most analytically notable change over the two-year period is that utility size was strongly correlated with both measures of affordability in 2017; in the 2019 data, utility size remains significantly correlated with *HM*, but not with AR_{20}. This indicates that the affordability challenge is increasingly acute in larger systems, due to a combination of rising essential non-water expenditures, and, in some places, declining 20th percentile income.

We begin with a brief review of research on water and sewer affordability, with an emphasis on measurement and culminating in a summary of Teodoro's measurement methodology (2018). Discussion then turns to data sources, with a review of past approaches. We review the findings from Teodoro's U.S. national affordability assessment using 2017 data (2019). We then describe our update, provide a snapshot of water and sewer affordability in the United States in 2019, and discuss changes in affordability since 2017. The paper concludes by discussing the meaning of the changes between the 2017 and 2019 results with a focus on the empirical contributions, directions for further inquiry, and implications for utility management and policy.

2 | Assessing affordability

Water and sewer affordability is a function of utility prices relative to the prices of other things and the resources that customers have available to pay for them. As in Teodoro (2019), this updated study analyzes the affordability of basic water and sewer utility services at the household level. The phenomenon of interest this time is both the extent to which the price of water and sewer services necessary for human health forces trade-offs by economically vulnerable households in 2019, and the changes in these various measures between 2017 and 2019. Our concern here is for *basic* water and sewer service for drinking, cooking, cleaning, and sanitation. We are interested in *household* affordability, rather than system-level *financial capability*, which refers to a community's overall capacity to pay for its capital and operating needs (Davis & Teodoro 2014).

Popular interest in water and sewer affordability in the United States continues to grow, but rigorous, systematic research on the subject remains rare. Most studies that attempt to gauge affordability nationally or across large numbers of utilities emerge from the nonrefereed "gray literature" (Jones & Moulton 2016; Bartlet, et al. 2017; Standard & Poor's 2018; Rockowitz, et al. 2018). Prior to 2019, just a pair of refereed studies attempted to gauge affordability in the United States across large numbers of communities (Mirosa 2015; Mack & Wrase 2017). These works provided important insights, but suffered from empirical problems that limited their validity. In particular, measurement problems and sample bias plague the majority of past water and sewer affordability studies (Teodoro 2019).

2.1 | Measurement

Past empirical assessments of water affordability generally rely on a flawed convention: 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." Often erroneously cited as a U.S. Environmental Protection Agency (EPA) standard for household affordability, the %MHI guidelines as developed by EPA were intended to measure community-level *financial capability* for purposes of negotiating regulatory compliance (EPA 1995, 1997; see also NAPA 2017).

The %MHI convention is an inappropriate method of measuring household-level affordability for at least four reasons (Teodoro 2018). First, average residential demand inflates the cost of water and sewer service because average residential water consumption is much higher than basic needs would dictate. 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; Stratus Consulting 2013). 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. Third, the %MHI convention does not account for other essential costs of living. 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, 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 arbitrarily as a standard of affordability. Those guidelines are not based on any theory, empirical analysis, or deliberative process, and yet affordability studies still commonly invoke them (e.g., Cromer & Draper 2019). Applying these simple binary standards—either "unaffordable" or "affordable," depending on whether average bills fall above or below a threshold—masks important variation within and across utilities.

Seeking to establish a more meaningful and accurate methodology for measuring water and sewer affordability, Teodoro (2018) advanced 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:

Equation 1

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

This *AR* reflects basic water and sewer costs as a share of disposable income. To focus on low- income households, Teodoro (2018) 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. These "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*) is an intuitively-appealing complementary metric.

2.2 | Sampling & sources

No comprehensive, national, publicly available dataset on water and sewer rates in the United States currently exists. Consequently, studies of affordability often rely on secondary compilations of rates and/or discuss rising system-level expenses, rather than measuring household affordability directly (e.g. Jones & Moulton 2016; Bartlett, et al. 2017). Others rely on proprietary datasets made up of convenience samples (Standard & Poor's 2018) or non-random, skewed samples (Mack & Wrase 2017). Inferring national affordability conditions from biased samples risks under- or over-estimating costs with errors of unknown direction and magnitude. Seeking to address these shortcomings, Teodoro (2019) developed a nationally representative set of U.S. water and sewer rates data by employing a randomized, stratified sampling design.

3 | Affordability update

This study applies Teodoro's (2018) metrics to original data collected during the summer of 2019, following the same sampling techniques used in Teodoro's analysis of 2017 data (2019), but significantly expanding the total sample. The data analyzed here constitute a representative sample of U.S. water utilities and are used to calculate the affordability of basic single-family residential water and sewer service for low-income households. The following section of the paper discusses the data sources and sampling and measurement methodology.

3.1 | Frame and sample

The present study's sampling frame is the EPA's Safe Drinking Water Information System (SDWIS). The SDWIS contains basic system information and regulatory compliance data for each of the country's nearly 50,000 community water systems. The overwhelming majority of the utilities in the United States serve populations of less than 3,000. Therefore, a purely random sample would likely result in a sample of mostly utilities with populations less than 3,300 and very few utilities medium and large utilities, where the majority of the United States population resides. Additionally, almost half of the very small utilities are privately-owned, while larger systems are more frequently owned by local governments.

In order to obtain a representative sample that provides empirical leverage on important correlates of affordability we follow Teodoro (2019) by stratifying the sampling frame in two ways: by public versus private ownership and then by the EPA's five population strata. This study uses the same sample of water utilities analyzed in Teodoro (2019), plus an additional 70 utilities sampled using the same sampling frame. 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. Utilities serving U.S. territories are excluded from the sample, as well. In the present study, the final sample includes 82 public utilities and 19 private, investor-owned utilities in each of the four population strata, for a total of 414 utilities.

As in Teodoro (2019), we applied inverse probability post-stratification weights to parametric calculations and regression estimates, which allows us to obtain unbiased population inferences with the stratified dataset.

Since this study explores the combined affordability of both essential drinking water and sanitary sewer services, an accompanying sewer system was identified for each sampled water utility. In 67 percent of the cases in the 2019 sample a single organization provided both water and sewer services to the same geographic location (e.g., a city government that operates water and sewer utilities for its own city, or a joint water-sewer special district) (Teodoro 2019). In the remaining cases we identified separate organizations that provided the sewer service for the city or county identified in the SDWIS service area.

3.2 | Data sources

We collected single-family residential water and sewer rates for the sampled utilities directly between May and July, 2019. For 86 percent of the utilities rates were available online on the utility websites. We contacted the remaining 14 percent of utilities directly by telephone, email, and postal mail. Sewer rates were unavailable in fourteen cases because the water system's service area had no sanitary sewer service or refused to provide the information; accordingly, those utilities are excluded from the analysis presented here. Only one utility was entirely unwilling to provide rates information. The final dataset of utilities with complete water and sewer rate data is 399 of the 414 sampled utilities (96.4 percent). The utilities in the 2019 sample serve a combined population of almost 44 million, covering an additional 6 million more customers than Teodoro's 2017 sample.

The remaining data used in this study comes from SDWIS, the U.S. Census Bureau's 2017 American Community Survey (ACS) five-year estimates, and the 2016 and 2017 Consumer Expenditure Surveys. The SDWIS provided data on the population served, ownership, primary water source, and Safe Drinking Water Act (SWDA) violations over the past five years. Demographic and income data for the cities served by the water utilities were obtained from the ACS. We used the same method for matching demographic and income data to special district, county, and private utility jurisdictions as in Teodoro (2019) to ensure consistency between samples. We also directly collected the applicable minimum wage data for 2019 for every utility's jurisdiction.

3.3 | Affordability measurement

We measured affordability using the two-pronged approach detailed in Teodoro (2018). The monthly price of basic single-family residential 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) per month. The present study does not assess the affordability of private wells and septic systems, nor the affordability of water service for agricultural, commercial, or industrial uses. The 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. The Texas Water Development Board (2004) recommends and California State Water Resources Control Board (2018) each have adopted 50 gcd as a standard for basic indoor water use. The value of customer assistance programs was not included in price calculations, since the goal is to measure affordability in absence of policy intervention. The sample- weighted average monthly price was $39.99 for water and $43.72 for sewer, for a total of about $83.72. These prices were the numerators for AR_{20} and *HM* calculations. Combined, these prices reflect an overall increase in average water and sewer price of about 5.1 percent relative to 2017 (discussed further, below).

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' lowest quintile upper limit. Essential non-water expenditures were estimated with a 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.

4 | Results: Water and sewer affordability in the United States, 2019

Table 1 provides a descriptive summary of AR_{20}, *HM*, and the other variables employed in the subsequent analysis. Figures 1 and 2 show the overall distribution of AR_{20} and *HM*, respectively. The weighted average AR_{20} is 12.4, ranging from 1.4 percent to more than 100 percent; for analytical purposes AR_{20} are capped at 100.0 percent. Values of *HM* range from 1.6 to 27.0 with a weighted average of 10.1. Although AR_{20} and *HM* in 2017 were moderately correlated (ϱ = .61), in 2019 the correlation between the two affordability metrics is considerably weaker (ϱ = .33) We discuss the reasons for this change in greater depth, below.

Figure 1 Single-family residential Affordability Ratio at 20th income percentile (AR_{20}) in the United States, 2019

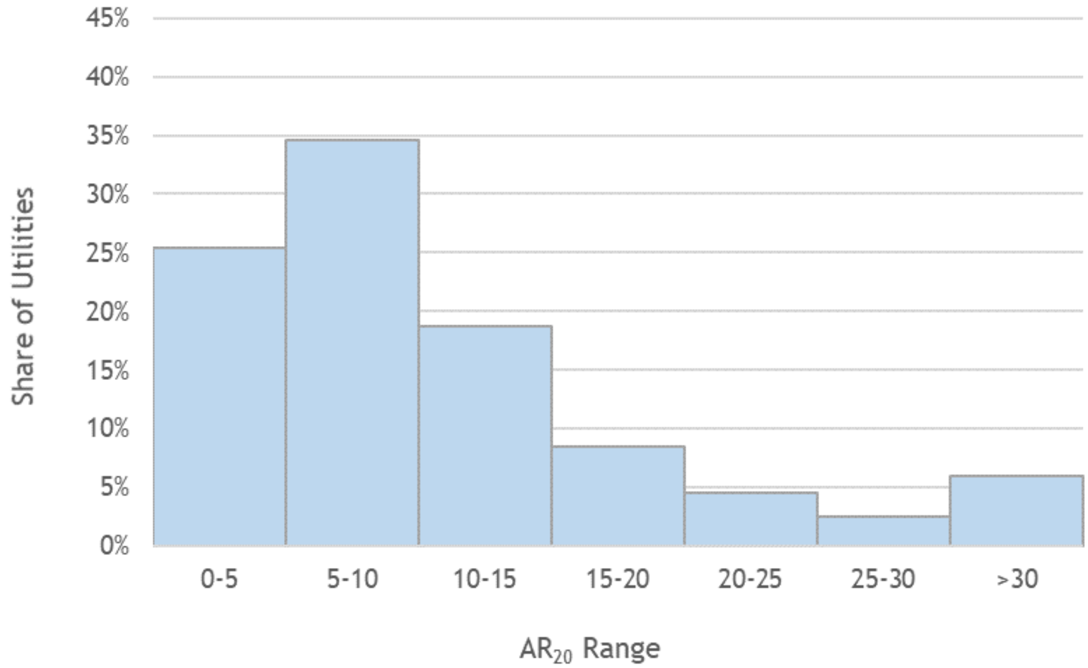


Figure 2 Basic single-family residential water and sewer price in Hours of Minimum Wage labor (HM) in the United States, 2019

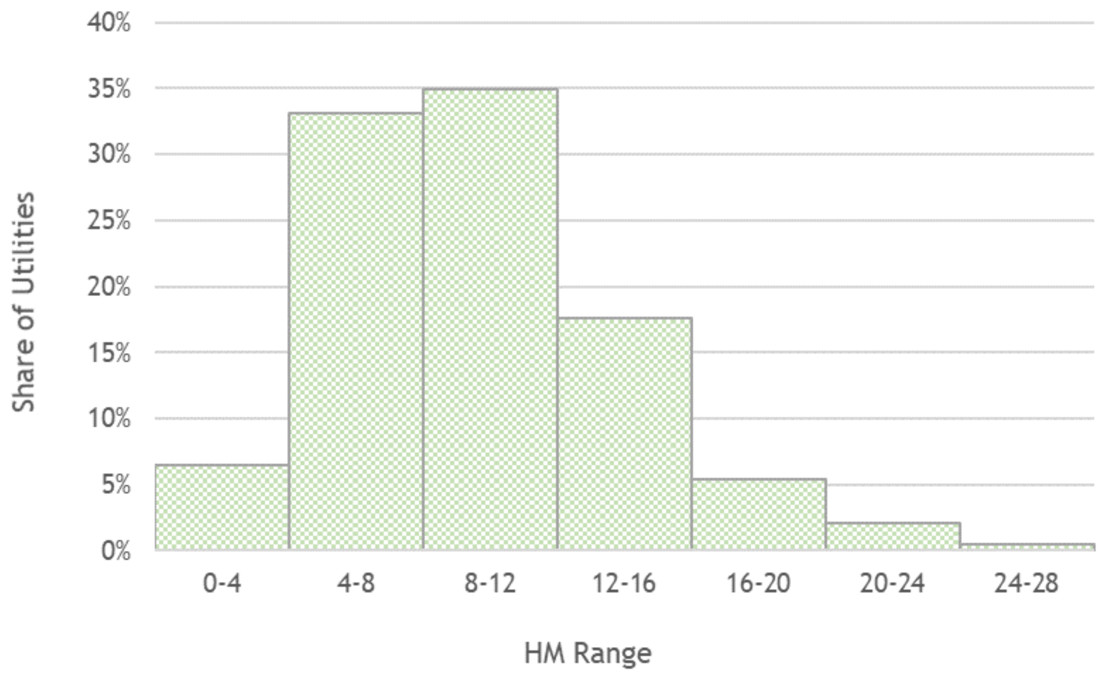


Table 1 Descriptive Summary of 2019 Data

Variable	Mean	95% Mean C.I.	Minimum	Maximum
HM	10.14	[9.5, 10.74]	1.57	27.04
AR_{20}	12.42	[10.91, 13.93]	1.42	100
Special district	0.23	[0.18, 0.29]	0	1
Investor-owned	0.20	[0.15, 0.25]	0	1
Groundwater source	0.49	[0.42, 0.55]	0	1
SDWA violations	32.87	[25.94, 39.79]	0	2257
Purchased water source	0.30	[0.24, 0.36]	0	1
Population served (log)	9.42	[9.31, 9.52]	8.12	14.66
Population served (thousands)	25.25	[25.21, 35.28]	3.32	2319.60

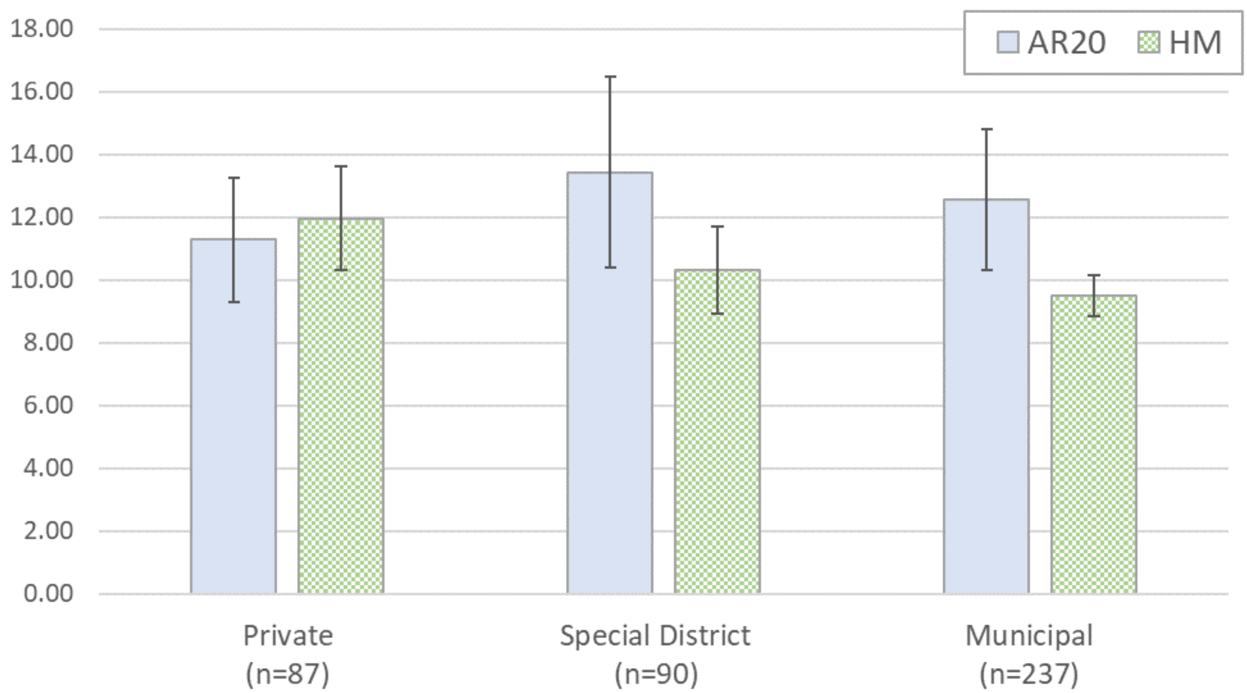
Note: N=399. Post-stratification weights applied in parameter calculations.

4.1 | Affordability by ownership & region

Differences in rates between publicly-owned and investor-owned utilities continue to be subjects of frequent interest. Figure 3 depicts average AR_{20} and *HM* by three types of ownership: investor-owned utilities, municipal government utilities, and special district utilities.

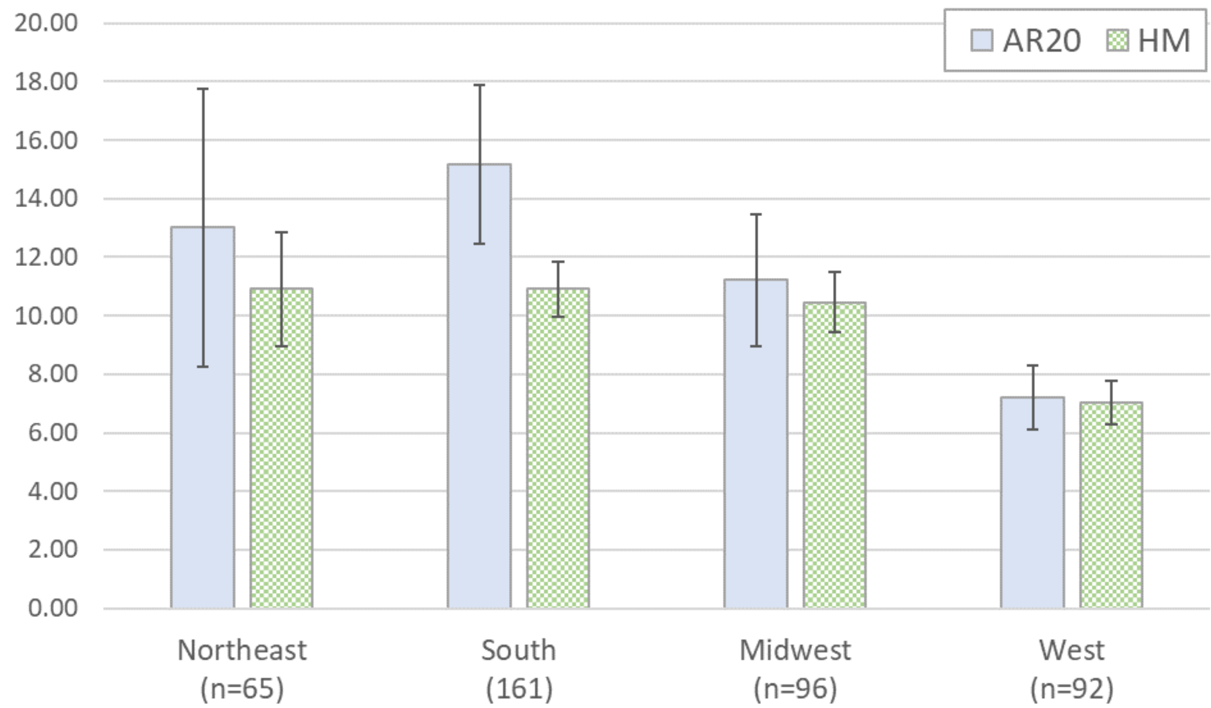
Average AR_{20} does not vary significantly by ownership. Investor-owned utilities' AR_{20} average of 11.3 was less than municipal utilities' average of 12.6 and less than special districts' 13.4, but none of these differences are statistically significant by conventional standards. Affordability measured as *HM* also does not vary significantly by ownership, although investor-owned utilities average 12.0 *HM*, which is about an hour and 45 minutes more than the special district average and two hours and 30 minutes more than the weighted average for municipal utilities. The differences between the two measures of affordability suggest that 20th-percentile incomes are, on average, higher in communities served by investor-owned utilities relative to special district and municipal systems.

Figure 3 Mean AR20 and HM by system ownership, 2019



As Figure 4 indicates, affordability by region remains similar the values observed in 2017: average affordability indicators are broadly similar across the Northeastern, Southern, and Midwestern United States, but significantly lower among Western utilities relative to other regions.

Figure 4 Mean AR_{20} and HM by region, 2019



4.2 | Correlates of affordability

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

Table 2 reports the results of Ordinary Least Squares (OLS) regression models that estimate AR_{20} and *HM* only utility characteristics drawn from the SDWIS. The models include dummies (1/0) for *special district* and *investor* 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 health violations over the past five years. Finally, the models include utility size, measured as the natural log of the *population* served by the utility.

Table 2 Correlates of Water and Sewer Affordability Ratio at the 20th income percentile and hours minimum wage

	Dependent Variable: AR_{20}		Dependent Variable: *HM*	
	Coefficient (Robust St. Error)	**p**	**Coefficient (Robust St. Error)**	**p**
Special district	0.35 (1.89)	0.86	0.58 (0.77)	0.46
Investor-owned	-1.04 (1.54)	0.50	2.51 (0.90)	<0.01
Groundwater source	-2.61 (1.96)	0.18	-0.63 (0.77)	0.42
SDWA violations	0.01 (0.01)	0.20	0.00 (0.00)	0.31
Purchased water source	-2.42 (2.11)	0.25	0.01 (0.82)	0.90
Population served (log)	-0.95 (0.56)	0.09	-0.52 (0.23)	0.02
Intercept	23.12 (5.84)		14.65 (2.40)	
R^2	0.02		0.06	
N	399		399	

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

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.

Among utility characteristics, no characteristic emerges as a consistently strong, statistically significant predictor of affordability. Although utility size negatively predicts AR_{20} and *HM*—that is, affordability improves as a utility's size increases—for AR_{20} the correlation falls short of conventional standards of statistical significance (p=.10). The strong relationship between size and *HM* is consistent with the idea that larger utilities enjoy economies of scale that translate into more affordable rates. The somewhat weaker correlation with AR_{20} suggests that underlying distributions of income and other essential costs of living may affect larger systems more than they do smaller systems.

4.3 | Changes in affordability, 2017-2019

Resampling the same utilities that Teodoro analyzed in 2017 affords us the unique opportunity to analyze how affordability changes over time. We calculated the mean weighted changes discussed throughout this section by subtracting the mean weighted averages from 2017 from the mean weighted averages in 2019. The mean weighted change in total water and sewer charges is +$4.07 in 2019, which can be broken down into a +$3.23 mean change in water charges and a +$0.84 mean change in sewer charges.

Table 3 Descriptive summary of change in rates between 2017 and 2019

Variable	Mean 2017 ($)	Mean 2019 ($)	Change in Means ($)	Change in Means (%)
Total water and sewer charges	79.65	83.72	4.07	5.1
Water charges	36.77	39.99	3.23	8.78
Sewer charges	42.89	43.72	0.84	1.94
First gallon total	36.68	40.89	4.22	11.50
First gallon water	16.53	18.68	2.15	13.03
First gallon sewer	20.16	22.20	2.05	10.19
AR_{20}	10.97	12.42	1.45	13.20
HM	9.90	10.14	0.24	2.44

Turning to affordability, between 2017 and 2019 *HM* increased by just over two percent, and AR_{20} increased sharply from 10.87 to 12.42–a 13.2 percent increase. Municipal utilities and special districts saw greater average increases in AR_{20} (+19.5 percent and +22.3 percent, respectively), compared to investor-owned utilities (+4.9 percent). Changes in *HM* varied less by ownership, with special district *HM* increasing by +6.2 percent, and municipal utilities by +3.3 percent, and investor-owned utilities experiencing a *decrease* in *HM* by -0.3%. Figure 5 depicts these changes by ownership.

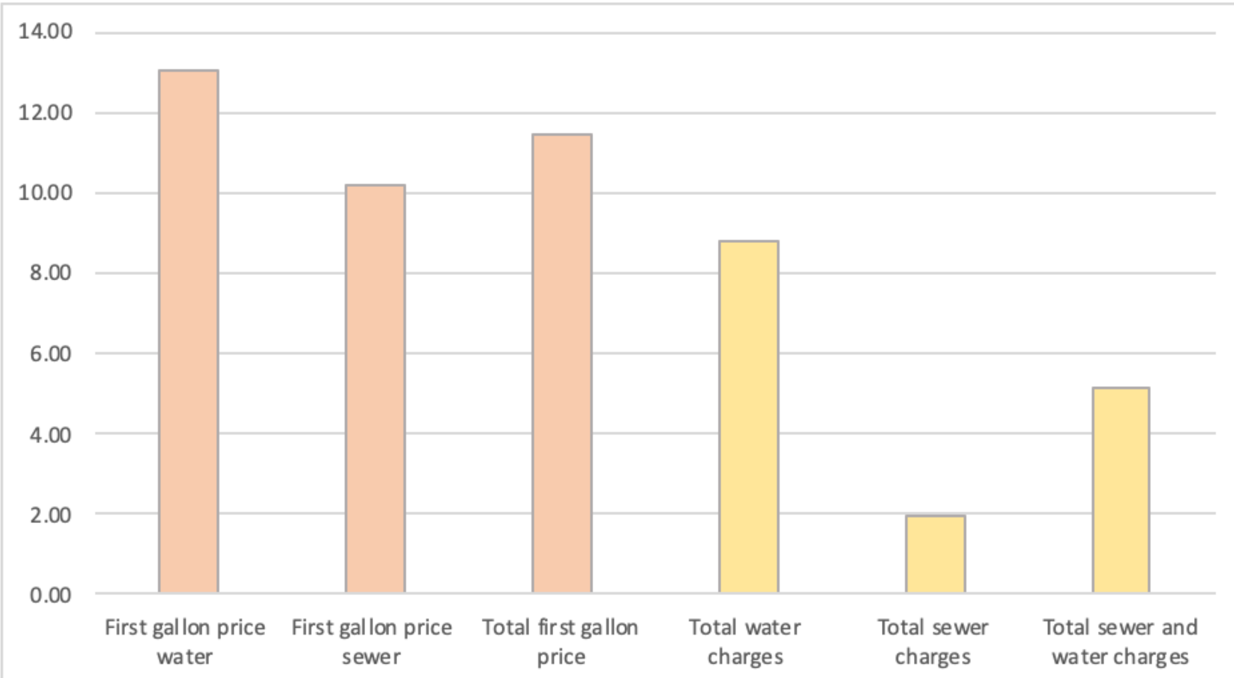
Figure 5 Percent change in mean AR20 and HM by system ownership

In terms of region, the South and West experienced the greatest mean changes in AR_{20} (+28.1 percent and +26.8 percent, respectively), while the Northeast decreased by -13.1 percent relative to 2017. The results for change in *HM* are slightly different, with the Midwest experiencing the greatest average change in *HM* at approximately +1.3 hours in 2019 and other regions experiencing only slight increases since 2019. These regional mean changes are summarized in Figure 6.

Figure 6 Percent change in mean AR_{20} and HM by region

To understand where in the pricing scheme these increases are coming from we analyzed the first gallon prices for water and sewer service. The first gallon price is the price a customer pays for using any water at all: any fixed charges plus the price of the first unit of water or sewer service. For example, if there is a $20 fixed charge for water service and the first ccf of water is $2.00 then the first gallon price for water service is $22.00. Between 2017 and 2019 the first gallon price for water and sewer service increased by 13.0 percent and 10.2 percent, respectively. The percent increases in first gallon price outpace the overall monthly price increases for water and sewer service at 6,200 gallons, 8.8 percent and 2.0 percent respectively. Figure 7 shows how average first-gallon prices changed compared with 6,200 gallon monthly prices.

Figure 7 Percent change in first gallon price and total monthly charges at 6,200 gallons for sewer and water service between 2017 and 2019 prices



A handful of utilities experienced reductions in water and sewer charges, *HM,* and *AR20*, but these were rare and mostly the results changes in rate structure. Although more than two thirds of the 325 utilities that appeared in both the 2017 and 2019 samples changed their water prices, only 60 changed their rate structures. Table 4 summarizes these changes.

The results are similar for sewer rates, as about two-thirds changed prices, but just 56 of 296 sewer utilities changed their rate structures between 2017 and 2019. For water utilities the most common rate structure change was from uniform or declining block to inclining block, with 23 utilities changing opting for more progressive rates. Nineteen changed to declining block and eleven changed to uniform. For sewer, the most common rate structure change was also to inclining block, (21 utilities), followed by 17 changing to uniform and nine changing to declining block.

Table 4 Summary of changes in rate structures between 2017 and 2019

	Water	Sewer
Changed in rate structure	60	56
Changed in total price	221	208
Added fixed charge	11	14
Changed to incline	23	21
Changed to decline block	19	9
Changed to uniform	6	17
Total	325	296

5 | Discussion

This study provides a descriptive summary of water and sewer affordability for low- income households in the United States in 2019. Results indicate that households at the local 20th percentile income level must spend an average of 12.4 percent of their disposable income and/or work 10.1 hours at minimum wage to pay for basic monthly water and sewer service. These figures are markedly increased compared with their values in 2017.

The main drivers behind the increase the in AR_{20} between 2017 and 2019 were increases in total water and sewer charges, increases in essential expenditures, and stagnant or—more alarmingly—decreasing 20th percentile incomes in some cases. All three of these factors contributed to increasing the mean AR_{20} in 2019. The increase in essential expenditures was especially meaningful in communities where essential expenditures were already high and the 20th percentile income was already low. Even small changes in water and sewer charges can have a substantial impact on affordability where disposable income is very low. This reality is reflected in the far more dramatic rise in AR_{20} (+13.2 percent), compared with the more modest increase in *HM* (+2.4 percent).

The effect of essential expenditures and 20th percentile income can also be seen in Figure 3, where investor-owned utilities have a lower average AR_{20} than municipal utilities or special districts. The main reason for this counterintuitive result is that 20th percentile income is on average about $1,000 higher for customers served by investor-owned utilities compared with municipal utility customers. The difference between investor-owned utilities and special districts even more striking: average 20th percentile income is around $4,000 higher for investor-owned systems than for special districts. Meanwhile, customers of municipal and private utilities have almost the same average essential expenditures, $967.58 and $964.58 respectively; special district customers have lower average essential expenditures at $878.23 monthly. These underlying differences help explain why investor-owned systems' average AR_{20} is relatively low, even as their average *HM* remains relatively high.

The changes in rate structure and first gallon price shows that utilities are continuing to push more of their total costs into the fixed costs as part of their pricing strategies (Walton 2018). Eleven water utilities and fourteen sewer utilities that did not previously have fixed charges added them between 2017 and 2019. Moreover, as observed earlier, first gallon prices increased faster between 2017 and 2019 than did the overall water and sewer prices analyzed here.

Among the system characteristics analyzed here, utility size emerges remains the most notable correlate of *HM*, although it is not as strongly correlated with AR_{20} as it was in 2017. Larger utilities may enjoy economies of scale that translate into more affordable rates for low-income customers. However, non-water/sewer essential expenditures appear to be rising faster in larger systems, and so AR_{20} and *HM* are less closely correlated than they were two years ago.

5.1 | Limitations

As with any empirical study, this one has limitations. The AR_{20} calculations here rely on estimates of disposable income developed with a regression model built with national data, which necessarily introduces measurement error to AR_{20} values. 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} do not suffer from significant bias, and inferential analyses will favor of a null finding. 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.

The purpose of the present study is to measure and describe affordability 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. Affordability is important, but not necessarily the most important aspect of water and sewer service. This national assessment of water and sewer price impacts on low-income customers allows water sector leaders and policymakers to evaluate affordability alongside other utility goals.

Although this study's sample allows for more nationally-representative analysis than most previous research, it is nonetheless limited. The present sample does not provide the statistical 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 (especially for very small systems) remains a serious barrier to larger sample studies. Finally, the two-wave time series (2017 and 2019) limits our ability to infer trends in affordability. We hope in the future to capture changes in these utilities over a longer time horizon.

5.2 | Directions for future research

A clear avenue for study is to connect affordability to utility-level financial policies and practices. Capital financing arrangements and rate design, for example, have potential 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 simply lower utility costs, or do they 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.

Finally, the increasing use in the United States of utility rates to fund storm and surface water management may require analysts and researchers to include these prices in future assessments of affordability, at least for communities that fund surface water management in this way.

5.3 | Implications and applications

Are water and sewer service affordable in the United States? What is "affordable" is ultimately a normative question, and suggests a philosophical inquiry beyond the scope of this study. Although no specific level AR_{20} or *HM* defines affordability in an objective sense, Teodoro (2018) suggests values of AR_{20} less than 10 percent and *HM* less than 8.0 as rules-of-thumb to guide policy consideration. By these guidelines, 60 percent of the sampled utilities are affordable as measured by AR_{20} and 39 percent are affordable according to *HM.* However, affordability varies considerably across utilities, providing managers, regulators, and policymakers with a valuable snapshot of the varied 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.

We close with a reminder about the dangers of comparing affordability metrics across utilities when making policy or management decisions. A national profile of affordability and comparative analyses are useful for developing broad regulatory strategy or assessing the water sector nationally. However, comparative affordability analysis is not appropriate for setting policy in any specific utility, as local infrastructure and socioeconomic conditions vary in ways that can make comparisons deceptive. More fundamentally, affordability is a household-level phenomenon, and so cross-utility comparisons are not especially useful. The price of basic water service in Denver and Detroit are not meaningful to a low-income family in Dayton. Utility leaders should seek to maintain affordability levels that are consistent with their own communities' goals and values.

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