Comparing with Caution: Commonalities, Correlates and Variation in Household Water and Sewer Bill Levels in 4 U.S. States

Authors: Gregory Pierce, Ahmed Rachid El-Khattabi, Kyra Gmoser-Daskalakis
March 2023

Report prepared for the Natural Resources Defense Council[1]

[1] This report was funded by the Natural Resources Defense Council (NRDC). The views contained herein are those of the authors and do not necessarily reflect those of NRDC. We thank Laura Feinstein and Janice Beecher for conducting peer review of this report, as well as Claudia Flores, Suzanne Caflisch and Maggie Seay for providing research assistance.

Executive Summary

Over the past decade, rising residential drinking water and sewer bills across the U.S. have raised concerns about households' ability to afford these essential services. The COVID-19 pandemic has further highlighted the importance of water access as a public health concern by laying bare many of the stark economic inequalities related to accessing water-related services. Understanding factors that contribute to variation in bill levels among water and sewer systems is valuable to inform policies to improve household water affordability. Though bill levels are an important factor for the affordability of household water services, this study does not directly examine affordability because it does not incorporate household level data on residential customers' ability to pay their water bills.

This study examines residential household water and sewer bill levels in systems across four states to better understand 1) variation in bill levels, both across and within states, and 2) the relationship between bill levels and system-level characteristics. Our study is unique in examining how bill levels for drinking water, and secondarily sewer service, vary within and across states and by sub-state region, defined as combined metropolitan statistical areas (MSAs). Comparisons using these geographic units allow us to account for potential similarities in regulatory environment, climate, water source availability, and other factors that influence bill levels.

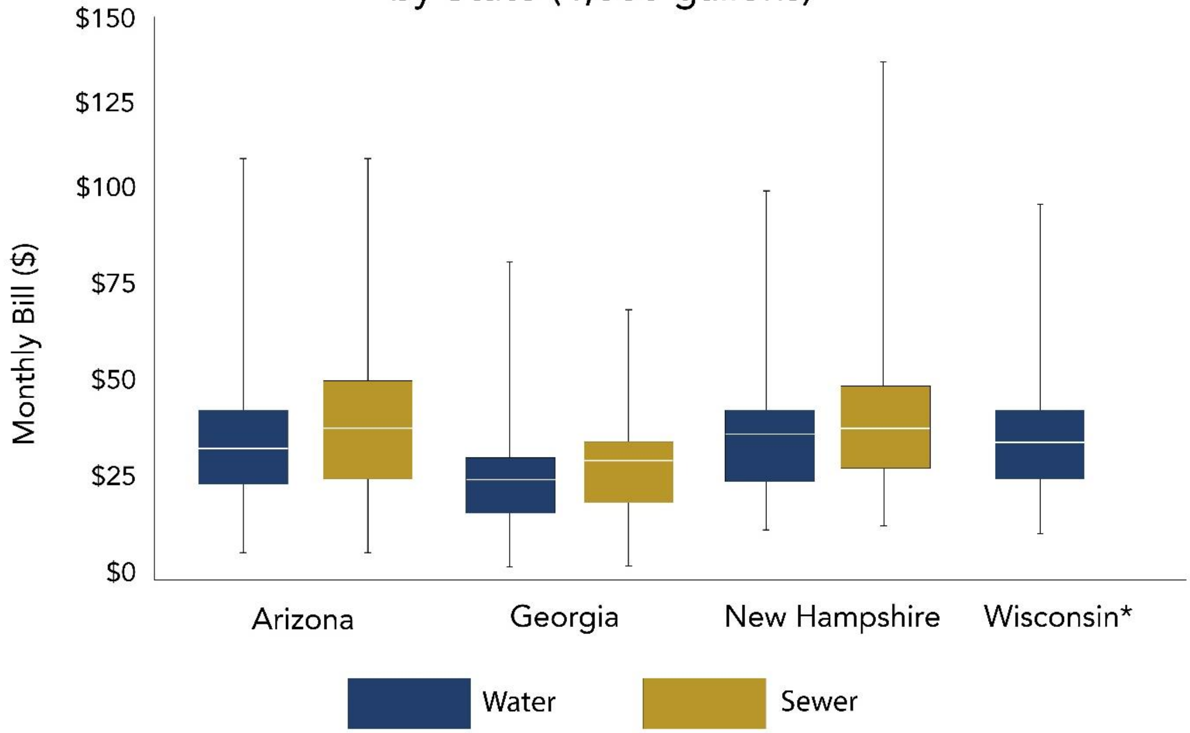
In our analyses, we use data on water system rate structures compiled and made available uniquely by the University of North Carolina Environmental Finance Center. Specifically, we use data for comparable consumption amounts from 1,720 systems across four states in different regions of the U.S. (Arizona, Georgia, New Hampshire and Wisconsin). We use 4,000 gallons per month as our primary billing comparison point to reflect a relatively modest level of household consumption. Using this data, we describe both water and sewer bill levels across and within the four states, and then employ a multivariate regression analysis to examine system-level drivers of water bill levels.

We find remarkable similarity in median bill levels across states, for both water and sewer services (see Figure ES-1). At the same time, we find a wide degree of variation in the distribution of bill levels within states and even within MSAs. Differences between states may partially reflect different ownership structure[2] profiles. Most systems in New Hampshire and Georgia are publicly-owned, whereas there are far more private systems in Arizona, and Wisconsin uniquely regulates rates for all system types. But the degree of system bill level variation we find reflects broader differences in the degree of system fragmentation and governance diversity across the U.S.

Figure ES-1. Distribution of Residential Household Water and Sewer Bills by State (4,000 Gallons)

[2] Ownership types include: municipal (city-run), for-profit systems (including state-regulated investor-owned systems), other government or quasi-governmental systems (non-municipal agencies such as authorities, joint powers authorities, and special districts, depending on the state), and other (including mutual water companies).

Figure ES-1. Distribution of Water and Sewer Bills by State (4,000 gallons)



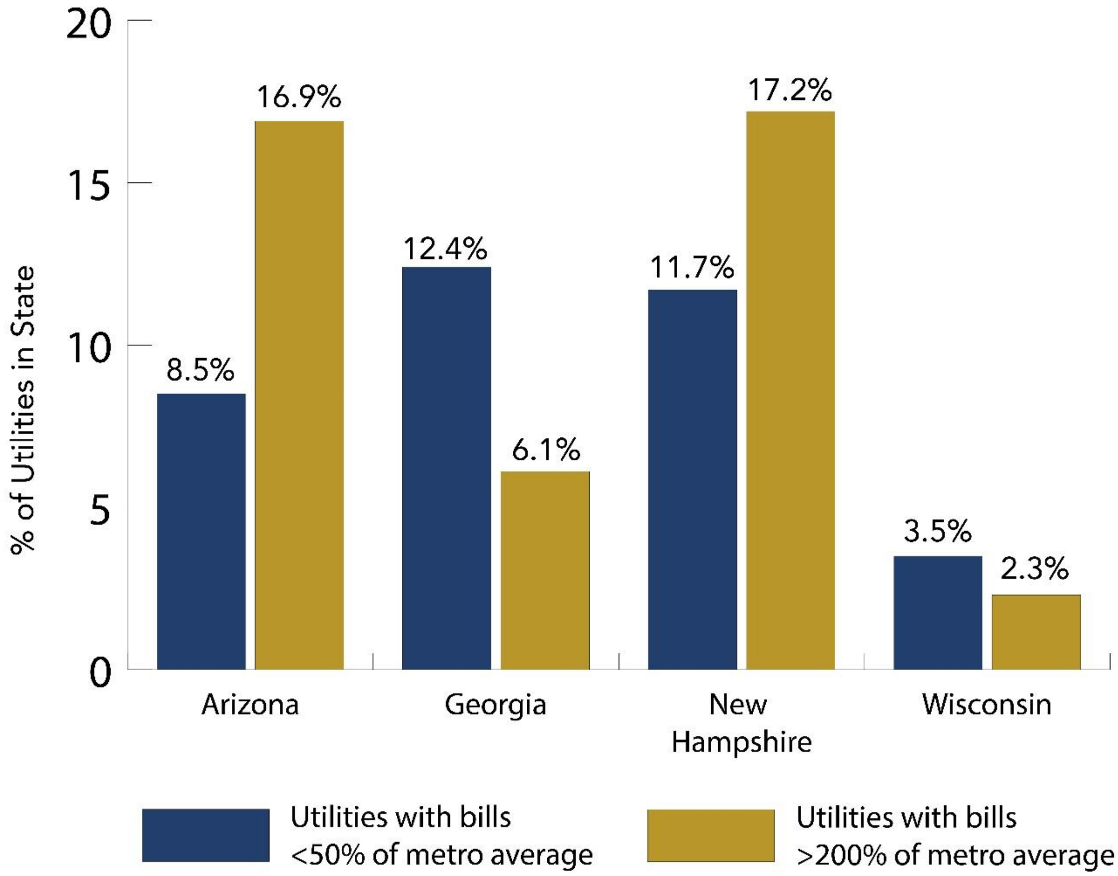
White line in colored box indicates median, Whiskers indicate spread of bill levels for given service and state

*Not enough data available for sewer bills in Wisconsin

To illustrate the variation in billing levels for 4,000 gallons across states and within MSAs, we examine the full distributions of water bill levels. The lowest monthly drinking water system bill for 4,000 gallons is only $2 while the highest is more than $108 (see whiskers in ES-1). When looking at metro-area trends across each state, there are also notable differences. In Georgia, the distribution of water bills within metropolitan areas is skewed to the left: more systems have water bill levels below the average bill level for their respective metropolitan area. The opposite is true for Arizona and New Hampshire: more systems have bills above the average bill level for their respective metropolitan area (see ES-2 and Figure 15 in main report). In Wisconsin, there is relatively less variation (more similarity) in bill levels within metropolitan areas than is observed for metropolitan areas in other states in this study. A likely explanation for this finding is that Wisconsin is the only state in the U.S. where virtually all publicly owned water systems are regulated by a state utility commission (Beecher, 2018).

Figure ES-2. Metro Spread in Drinking Water Bills by State

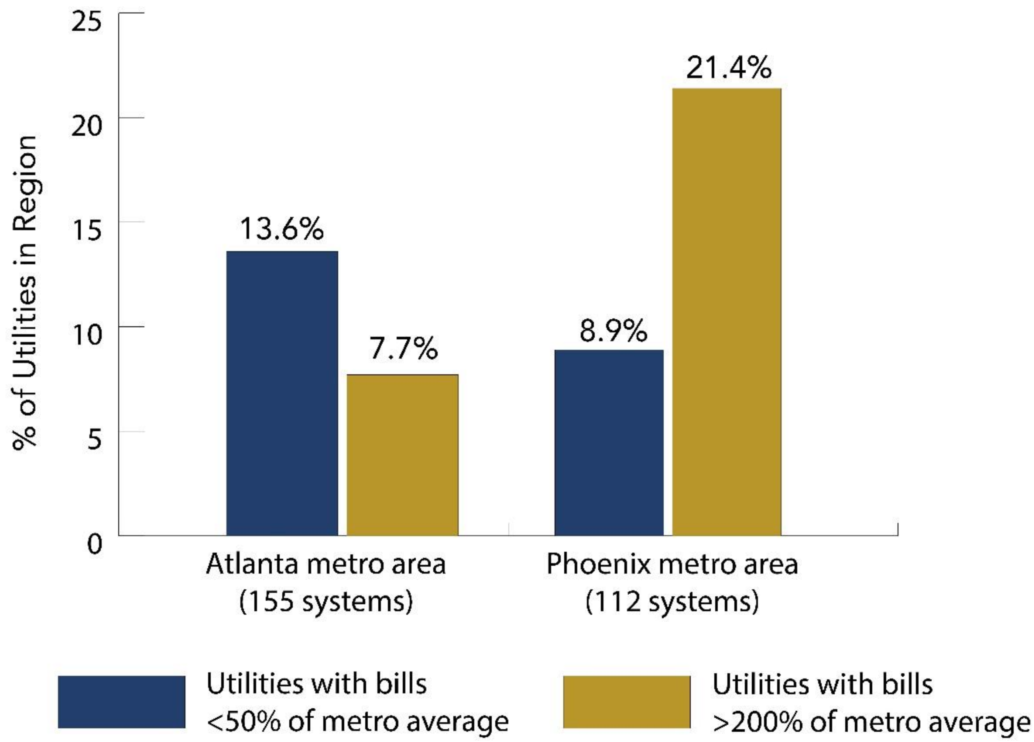
Figure ES-2. Metro Spread in Drinking Water Bills by State



Using data from the two largest metropolitan areas in the sample, Atlanta and Phoenix, we further illustrate the wide ranges of water bills at the 4,000-gallons monthly consumption level (Table ES-3). Among Atlanta area systems, bills range from $2 to $81. In the Phoenix area, the range is $5 to $82. However, the clustering of systems at the high end and low end differ substantially, mirroring the trends across Georgia and Arizona. A higher proportion of systems charge less than half of the metro-wide average in Atlanta (13.6%), as compared to Phoenix (8.9%). Conversely, in the Phoenix area, a higher proportion of systems charge more than double the metro-wide average (21.4%), as compared to Atlanta (7.7%).

Figure ES-3. Metro Area Spread in Drinking Water Bills

Figure ES-3. Metro Area Spread in Drinking Water Bills



To examine correlates of water bill level variation at the system level, we then manually combine our water bill level data with water quality violations data from the Safe Drinking Water Information System (SDWIS), available from the U.S. Environmental Protection Agency, and data on demographic characteristics, from the U.S. Census Bureau. To understand how system characteristics may influence water bill levels we use this combined dataset to analyze the statistical relationship between water bill levels and water quality compliance, the socio-demographic profile of the customer base (including race/ethnicity, income inequality, median household income, and poverty levels), system ownership type, system population size served, water source and the bill levels of neighboring systems.

We find that systems that serve populations with higher levels of income inequality and higher proportions of Non-White population typically have lower water bill levels. These factors were counter to our expectations, and relatively weak in terms of explanatory power. This suggests the need for further study of how systems' customer demographics (beyond median household income) relate to water bill levels. In particular, these relationships have major implications for water affordability and environmental justice efforts.

We also find that a municipal ownership structure (as compared to for-profit), a baseline allowance of water included in a fixed charge, an increasing block rate structure, and a larger service population significantly correlate with lower water bill levels. A purchased water source and higher water bills among neighboring systems significantly correlate with higher water bills. Figure ES-4 shows whether and how the significant variables at the system level affect bill levels after controlling for similarities between systems in a state and metro area (geographic "fixed effects").

Figure ES-4. Significant Correlates in Main Regression Models of Drinking Water Bill Levels

	State Fixed Effects Model (Control for System's State)	MSA Fixed Effects Model (Control for Systems' MSA)
Average Neighboring System Bill	↑	↑
Baseline Monthly Water Allowance	↓	↓
Income Inequality	↓	↓
Increasing Block Rate Structure	↓	↓
Municipal System	↓	↓
Proportion Nonwhite Population	↓	↓
Purchased Water	⇧	↑
Service Population	↓	↓

Blue= Negative Coefficient (predicts lower bills)
Gold = Positive Coefficient (predicts higher bills)
No Fill= Not Statistically Significant

Water bill levels have historically been and largely remain a local matter with some state oversight. While we find consistent averages across states, we find very high levels of bill variation at the local and regional scales. Significant variation in bill levels may be justifiable, and the correlates we identify of high bills vary in terms of the ability for external policy and planning influence. That being said, substantial disparities at local levels still raise concerns regarding both environmental and social justice and the financial sustainability of water systems. Accordingly, such disparities should motivate consideration of various policy options for systems with extreme bill levels, including (but not limited to) increased and equitably allocated federal and state water infrastructure funding, assistance to promote systems' technical managerial financial (TMF) capacity, potential consolidation, customer assistance and affordability programs, and equitable rate design guidance. Regardless of the extent of desire to intervene to address local bill disparities, understanding this variation is important in the context of affordability and larger environmental justice efforts.

Growing recognition of regulators, policy makers and advocates centers around the importance of analyzing three related factors— 1) a water system's technical, managerial, and financial (TMF) capacity, 2) the service population's economic condition, and 3) customer level affordability. Beyond analysis, there is also recognition that the results of these analyses need to be incorporated in water system needs assessment efforts. Although our findings have implications for state and national water assessment efforts, the extent to which these results are generalizable across the U.S. is unclear. Collecting and analyzing bill data from more states will be essential to assess the generalizability of these results. Notwithstanding, this study fills a gap in the literature that compares bill levels across and within states, and examine the factors that drive variation in water bill levels across state boundaries (GAO 2021). As such, the findings of this study provide insight for further water system TMF and affordability policies and identifies future research and data collection needs to make those efforts more robust.

1. Introduction

Over the last decade, both scholars and policymakers have recognized a growing need to understand rising water bill levels as well as address broader concerns about the affordability of residential water service in the U.S. (Mack & Wrase, 2017[3]; Teodoro, 2019a; Meehan et al., 2020; Teodoro & Saywitz, 2020). The emergence of the COVID-19 public health and economic crises in 2020 also highlights the need to better understand and address drivers of water bill levels and associated debt.

In this study, we conduct an analysis of 2018 and 2019 drinking water and wastewater bill levels for residential customers using a near census of the 1,720 systems with available billing data operating in four states: Arizona, Georgia, New Hampshire and Wisconsin. We obtain these data from the University of North Carolina (UNC) Environmental Finance Center (EFC); the EFC compiles these data primarily for benchmarking and comparison purposes between local systems and is by far the most credible multi-state source of water billing data. The EFC explicitly advises users to "compare [bill levels] with caution. High rates *may* be justified and necessary to protect public health" (emphasis added) (See UNC EFC, 2019). While we acknowledge the validity of this statement, we also recognize that high rates may create affordability challenges for low-income households and in turn create different public health risks (Pierce et al. 2020) and that substantial disparities in rates across water systems may raise valid concerns about the finance, management, organization, or governance of water systems. We follow the spirit of the stated advice by focusing our descriptive and multivariate analyses on documenting the tremendous variation in bill levels at 4,000 gallons of consumption. We examine this variation within and across states and adjacent communities, defined in terms of metropolitan statistical areas (MSAs).

How does one compare bill levels with caution within MSAs? To our knowledge, only one previous study, Thorsten, Eskaf and Hughes (2009), takes a similar data collection approach with a near census of systems with available billing data across an entire state in the U.S.[4] The authors of this study find that systems' bill levels are significantly and positively correlated with bill levels charged by other nearby systems. This finding is somewhat intuitive; one might expect relative parity in price levels, such as is supported for other household staple goods and services, for an essential service such as drinking water.

At the same time, some disparity in bill levels (for a given levels of consumption) among neighboring systems should be expected. Notably, each system faces a different set of costs that depend on local factors that may vary among neighbors. For instance, cost profiles may depend on system size, water source options, ownership types, treatment compliance obligations, the level of subsidies provided to the system by non-ratepayer funding sources (e.g., federal or state funding, property taxes), and a range of other factors. In setting rates, systems are typically expected to recover the cost of service from customers (see AWWA M1 Manual, 2017). Cost differences, therefore, can result in differential bill levels, to the extent that

---

[3] Previous review by Natural Resources Defense Council has noted the methodological limitations of this paper, which we also recognize. For instance, see: https://www.nrdc.org/resources/affordability-insights-obscured-flood-miscalculation-comments-michigan-state-universitys. However, we note this paper given its prominece in the press and citation patterns.
[4] Chica-Olmo, González-Gómez and Guardiola (2013) take a similar study approach in Southern Spain and find similarly to Thorsten, Eskaf and Hughes (2009).

systems face differential costs.[5] The idea that the price of a good or service should reflect the cost of delivering that service to the user is referred to as cost causation or the benefit principle. This principle has been enshrined in internal drinking water system practice to determine how to charge different users with different levels of consumption within a system pricing structure (García-Valiñas, Martínez-Espiñeira, & González-Gómez, 2010-b; Beecher, 2020).

Extreme variation in bill levels, at both the high and low end, among neighboring systems within a metro area may reflect an inequality in expenditure burden for customers and thus be cause for concern. High levels of inequality in bill levels experienced by nearby customers of different systems may also suggest the need for planning or policy intervention to support reductions in cost variations across systems. Previous work examining several metro areas throughout North America—Los Angeles (Pierce, Lai and DeShazo, 2019), Chicago (Gregory et al., 2019), and British Columbia (Honey-Rosés, Gill, Pareja, 2016)—illustrates intra-metro area disparities in drinking water bill levels.

Similarly, a recent study by the Alliance for Water Efficiency found a wide range of monthly fixed charges across U.S. water systems in a 40-systemsystem sample—$3 to $58 (AWE 2021). The study observed a smaller range and smaller sample size for sewer charges—$4 to $21 across only 14 cities (including only those cities in the sample that have fixed charges that vary by meter size, which most in the sample do not). Empirical evidence on variation in wastewater bills is scant, and Beecher and Gould argue that “pricing theory and practice may not be transferable from water to wastewater” because wastewater consumption is largely nondiscretionary and unlikely to be as price-responsive as drinking water (Beecher and Gould, 2018).

Our study builds on this prior work by not only examining variation in drinking water bill levels but also variation in local sewer and combined water-sewer bills (where data are available). Our use of a cross-state sample of systems with available billing data complements work by Teodoro and Saywitz (2019, 2020), who report trends in drinking water and sewer affordability based on a nationally-representative sample of household water bills, and additional work in certain states (Teodoro, 2019b). Other recent studies analyzing water bill levels, such as Colton (2020), Onda and Tewari (2021), Patterson and Doyle (2021), and Zhang et al. (2021) also analyze multi-state or national trends in drinking water affordability over time. Each of these studies has a slightly different focus and contribution to the literature, and we return to many of these in relation to our study’s findings in the discussion section of this report. Each of these studies also finds variation in the achievement of affordability (as variously defined) across systems, but focuses on affordability only among large systems or a convenience sample of systems.

Our study differs from other recent analyses in at least three key ways. First, our dataset of systems, as described below, represents nearly all systems that report billing data in the four states of interest. This is valuable given that most studies which examine variation in water bills focus predominately on large systems, small geographies, or use very limited data (GAO, 2021).

Second, we focus on drivers of disparities in bill levels rather than affordability thresholds. We differentiate our analysis by identifying bill levels that are outliers at the low end and the high end, the latter of which suggest affordability concern.

---

[5] Other factors such as revenue authorities and taxation responsibilities may also contribute to differences in bills by ownership type, but this has not been substantiated empirically in more than case study fashion.

Third, in addition to using available system characteristics, we collect data on water quality violations and customer base characteristics to jointly explore the relationship between these factors and billing levels for water to an extent beyond that in existing studies. Several studies have shown a relationship between race-ethnicity and water quality outcomes (Allaire, Teodoro and Switzer, et al., 2021). The relationship between a system's financial capacity and its ability to respond to regulatory water quality violations, however, is much discussed and assumed in affordability conversations, but rarely documented empirically (see Scott et al., 2018).

The remainder of this study describes the data and methods utilized in the study (Section 2), summarizes trends in system characteristics and water and sewer bill levels across states (Section 3), reviews intra-state and intra-metro area variation in water and sewer bill level (Section 4), presents results of regression models to examine drivers of system-level bill variation (Section 5), and concludes with a discussion and implications for future research (Section 6).

2. Data and Methods Utilized

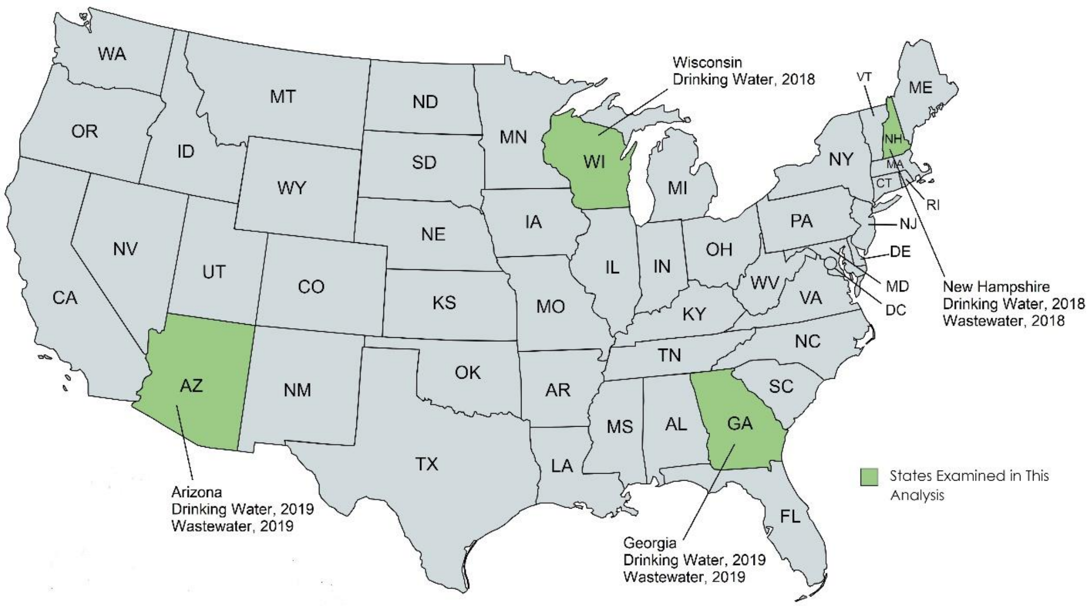
Primary Rate Data Availability and Collection: The UNC EFC Dashboard

We primarily rely on residential rate survey data compiled and made publicly-available by the UNC EFC in the form of state-level rate "dashboards." These data sets are carefully compiled using a refined and well-tested data collection and standardization method. Moreover, even compared to other credible state-level and national-bill-level surveys (such as surveys conducted by AWWA-Raftelis and Circle of Blue) and dashboards (Duke's Nicholas Institute), the UNC EFC dashboards are a unique and valuable resource in several ways. They attempt to provide a census of all systems with available billing data in a given state. The EFC dashboards effectively represent 80-90% coverage of all systems serving 500 or more people (EPA's population cutoff for "very small" systems is 500[6]) and historically have achieved the highest response rate of any such effort.[7]

The dashboard efforts also manually calculate (multiple) bill levels, which leads to much more accuracy and consistency than system or household self-reporting. They provide additional, valuable contextual information with standardized labeling over time and across geographies, such as system size, water sources, billing cycles and rate structures, and ownership arrangements. As of late 2021, the UNC EFC currently had rates dashboards available for 18 states. All the dashboards employ very consistent, albeit not uniform, methodologies and some of them have multiple years of data. [8] For the purposes of this study, after initial exploration of the data available for all states, four states provided the best fit for the envisioned analysis (see Figure 1).

Figure 1. Four States Included in this Study and Data Available

[6] See https://www3.epa.gov/region1/eco/drinkwater/small_dw_initiative.html
[7] The actual # of CWS in each state is much larger than EFC dashboard (AZ= n 742; WI= 1,034; GA=1725; NH=710 respectively). This equates to 40% of all systems, but 86% of non "very small" systems serve a population of 500+ (GA=1100; WI=541; AZ=434; NH=581). The 500-customer population threshold is the cutoff for EPA's "very small" designation.
[8] See https://efc.sog.unc.edu/systemsystem-financial-sustainability-and-rates-dashboards.



The selection of states included the consideration of the most recent year of billing data available in states, consistency in available time periods of data across the states, metro area representation, and the presence of rate data for both drinking water and wastewater. Despite these parameters, it is not possibly to achieve both uniformity in year of data and services provided while maintaining the goal of metro area representation. (The rates data in two of the four selected states are from 2018 and in the two others are from 2019. Three of the four selected states have both water and wastewater rates data available; Wisconsin only has drinking water rates data available.)

The UNC EFC made available a near-standardized Excel spreadsheet version of data for each state analyzed, with the exception of Wisconsin. In each spreadsheet, data on most variables available in UNC EFC's online dashboards are available for each system, with one key exception noted below. For Wisconsin, the dashboard data required manual scraping from PDF forms into Excel in order to analyze alongside other states.

Joining water quality and census data to billing data led to some reduction in the number of systems analyzable along all dimensions of interest in the second phase of analysis. Table A-2 in the appendix shows the number of systems for which key data points were available. A final count of 1,558 systems in the four states had available rate, violation, and census data available.

Joining U.S. Environmental Protection Agency Water Quality Data to Systems

Given the lack of readily available data from state-level databases,[9] we queried the U.S. EPA's publicly-available Safe Drinking Water Information System (SDWIS)[10] search function by state, and then by system name based on the EFC database to identify and scrape data system by

[9] Except Arizona's, which can be found here: https://azsdwis.azdeq.gov/DWW_EXT/

[10] As with rate data, SDWIS data on water violations and system characteristics must also be compared with caution, based on potential missing or incorrectly classified data (Beecher et al. 2021).

system.[11] We only considered and scraped violation records data between the years of 2009 and 2020, although in our analysis we narrow the temporal frame as noted. To determine year of violation, we used the compliance period start date in the SDWIS data.

For each system (referred to as community water system in SDWIS) in each of four states, we collected and recorded each violation as an individual row in a spreadsheet in order to allow for maximum flexibility in analysis by violation type/time period per system. For analytical purposes, we define health-based compliance shortcomings (our primary water quality category of interest) in terms of Maximum Contaminant Level (MCL) violations, Lead Copper Rule (LCR) exceedances, and treatment technique violations. We also include an additional measure of water quality compliance shortcomings that includes all “monitoring and reporting,” “notification” and other miscellaneous violation types.[12] Combining these data allows for studying water quality in relation to other system characteristics which may be explored in future studies. In this study, we primarily focus on the relationship between water quality and billing levels.

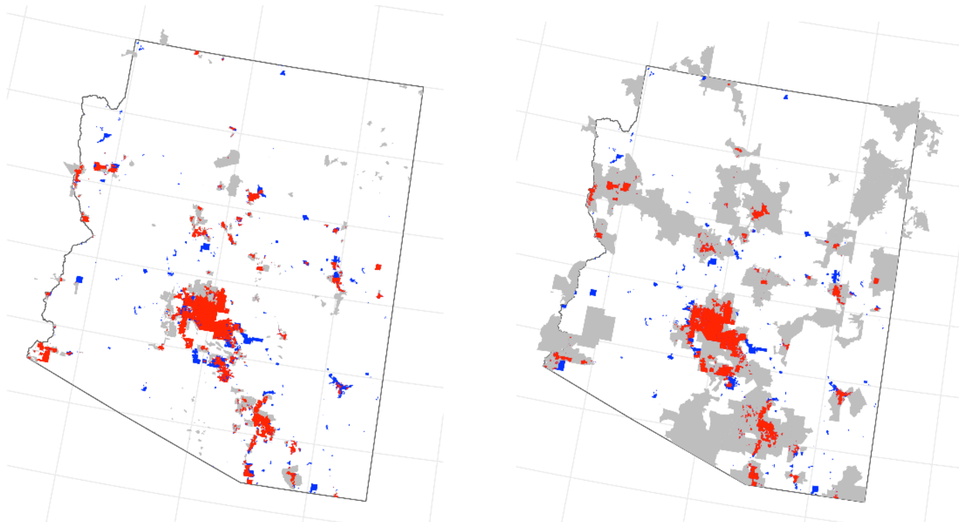
Joining U.S. Census Data to System Locations

We combine our data with socio-demographic characteristics of the residential customer base for water and combined water-sewer systems for the systems in our dataset using boundaries for Census Designated Places (CDP). Though geographic information system (GIS) shapefiles for water systems represent the best currently available approach (albeit still imperfect) to approximating water system boundaries, shapefiles are only available for the state of Arizona among the four states analyzed (McDonald et al., 2022). We use shapefiles for Arizona to examine alternative approaches to approximating system boundaries (as done in North Carolina by Berazher et al., 2022). We explored the possibility of using zip codes and single address information, but found these approaches to be inferior to our selected method. Figure 2 shows how zip codes are much less accurate than CDPs in matching system boundaries, especially for smaller systems. Remarkably, using a single valid address for each system is not a reliable strategy given that the public-facing SDWIS is missing any address for some systems, and some of the addresses provided are out of county or even out of state P.O. boxes (Beecher et al. 2021).

Figure 2. Comparison of System Shapefile, CDP (left hand panel) and ZIP (right hand panel) boundary layers in Arizona

[11] Base link: https://www.epa.gov/enviro/sdwis-search. We used Column C (system name), Column E (county served), Column G (institution) and Column M (population served) to determine a match between the EFC and SDWIS system name. If there was no population entry to match up with, and the county served did not match up, and the name was not a complete match, then we did not enter any quality data for that system.

[12] The difference between compliance start and end dates captures length of time out of compliance during the time period of interest. But this was not used as a variable of interest in analysis given variability and degree of missingness in the quality of compliance date entry. While the original intention of the effort was to code the full detail of each violation, it quickly became impossible given some systems (especially in Arizona) have dozens of monitoring and reporting violations, so we only coded full detail of each violation for systems with less than 5 violations.



Notes: Red shading represents portions of a CDP or zip code that overlap with formal water system boundaries (correct identification). Areas shaded in gray represent portions of a CDP or zip code that do not overlay with a formal system service area (error of inclusion). Blue shading represents portions of a system area that do not overlay with CDP or Zip (error of exclusion).

In the figure above, the left-hand panel compares CDPs to shapefile boundary areas, whereas the right-hand panel compares zip codes to shapefile boundary areas. Gray indicates that the area of a CDP or zip code does not overlay with a formal system service area, i.e., the areas that would be incorrectly attributed to a water system if using CDP/Zip (error of inclusion). Blue means a system area does not overlay with CDP or Zip, i.e., the areas that would be missed by CDP or Zip (error of exclusion). Red represents the area of intersection, i.e., what areas would be correctly predicted by CDP or Zip.

Our use of CDP boundaries is consistent with collection efforts by the UNC EFC for some of its state dashboards, as well as other recent studies which evaluated similar alternatives (Berazher et al., 2022). Using CDP boundaries also has the additional benefit of allowing us to compile and approximately match income and race-ethnicity data from the U.S. Census to characterize the socioeconomic status of customer bases.

Where CDPs could not be obtained (no primary CDP served was noted in the UNC EFC data), we supplemented these data with the primary Census County served, which is available from SDWIS codes. Census demographic data was collected at the CDP and County level from the NHGIS database (Manson et al. 2021) and matched to systems based on the primary location served. We also run a sensitivity test which excludes systems with county-matched data, as noted below. We recognize substantial shortcomings with this approach; there is no perfect way to match system customer base demographic data, and we return to this in the discussion.

Using CDP data allows us to approximate, for each system, its total population, the proportion of population which is Non-White (as well as Hispanic/Latino and Black respectively), its median household income, the proportion of its population under 100%, 150%, and 200% of poverty level, and its GINI Index, which is a measure of income inequality.

Key Variables Analyzed

The dependent variable in each core analysis in this report is a consistent residential customer bill level for drinking water service. The bill level calculation aims to represent all service-related charges on a bill that a customer must pay for the relevant service.

Accordingly, the determination of consumption levels for points of comparison is important. We generally aim to assess the bill amount for levels of consumption that meet modest indoor household use standards—in other words, levels of monthly household consumption that allow for essential needs but do not extend to substantial discretionary use. However, essential indoor needs vary by household size; and some studies find indoor use to be greater in some U.S. metro areas than others (Rockaway et al., 2011). Various reasonable levels of consumption in studies comparing bill levels range from 3,000 gallons in North Carolina (Thorsten, et. al, 2009), and 4,488 gallons in California (Pierce, Chow and DeShazo, 2020) to between 3,740 gallons (5 CCF, commonly used in AWWA-Raftelis surveys) and 6,200 gallons across the U.S. (Teodoro and Saywitz 2020).

All state dashboard databases provide system level monthly-equivalent drinking water bill data for 0 gallons and 4,000 gallons as well as higher levels. We select 4,000 gallons as the main consumption level of comparison based on the extant literature and a desire to focus on modest usage mostly for essential indoor purposes as opposed to outdoor irrigation. Monthly consumption of 4,000 gallons reflects roughly 45 gallons per capita per day for a three-person household, which represents modest use. The decision was also motivated by the fact that bill data at this level was available for all systems in the dataset (some states lacked data at other consumption levels). We also analyze 5,000-gallons as a sensitivity check and 0-gallon level to examine how base "customer" charges vary among systems.

Key system-level variables available and analyzed in this study to contextualize our understanding of system bill levels were:

- system type (e.g., ownership structure)
- system size (e.g., approximate population served),
- type of water source (ground water, surface water, or other—e.g., purchased),
- geographic location (state, county, metro area)
- rate structure type (e.g., flat fee, uniform rate, increasing/decreasing blocks)
- billing period (e.g., monthly, quarterly, other)
- base pricing (e.g., none, constant, by meter size)
- water quality regulatory standard compliance (health-based, monitoring and reporting violations)
- socio-demographic characteristics of the customer base (race/ethnicity, income levels, income inequality)

The system ownership type variable includes four categories: for-profit, municipal, other government, and other. For-profit refers to private systems including investor-owned utilities which, depending on the state and size of the system, may or may not be regulated by a state or state-level public utilities commission. Municipal refers to city-owned and operated water or sewer systems; while other government refers to special districts, county authorities, or joint powers authorities, depending on the state. Other encompasses all other system types, particularly mutual water companies that do not fit in the for-profit, municipal, or other government categories[13].

In the context of rate structure, a flat fee or charge refers to systems charging customers a single monthly amount regardless of water use. Uniform rates charge a single volumetric rate per unit of consumption (e.g., the rate is multiplied by monthly consumption). Uniform rates differ from block or tiered rates, in which the volumetric rate changes based on which ‘block’ of consumption a customer falls in. Increasing-block rates occur when the volumetric rate increases for customers in higher consumption levels, while decreasing block rates charge lower rates for customers with higher water usage. Many systems have bills that include a combination of flat fixed charges and volumetric charges. The flat fixed charge is often called a base charge in this situation, as it is assessed even for customers with no water usage with volumetric charges (whether uniform or block rates) then included on top of this base charge.

Analytical Methods

We start by providing basic descriptive statistics across states to look for general state-level trends. Our examination includes median bills at the three consumption levels by state for water, sewer, and combined services along with trends in other systems at the state and local levels. Section 3 provides a discussion of cross-state comparisons for these variables.

We develop models to examine what system-level characteristics most significantly influence costs for water bills at the 4,000-gallon consumption level. We estimate these models using ordinary least squares linear regression. Our models capture the contribution of different system characteristics, including ownership type, rate structure, and water source type, to predict a system’s monthly bill for services.

We estimate two sets of models to assess both intra-state and intra-metro area bill variation using fixed effects (i.e., geographic control variables). This approach enables the models to examine the influence of system-level characteristics on water and sewer costs while taking into account variation due to location (state-level or metro area-level cost variation). To study intra-state variation, we include state fixed effects. To study intra-metro area variation, we also include fixed effects for the metro area in which a system is located. We define metro areas primarily in terms of metropolitan statistical areas (MSAs); where applicable, we use combined statistical areas (CSAs) to account for arbitrary boundaries that separate contiguous MSAs. A little fewer than 25% of all systems considered in this study are not located within an MSA—we label these systems as “non-MSA” for the purposes of analysis and categorize them in a single group of rural systems within each state. In Section 4 of the report, we illustrate the spread of bill levels within states. We descriptively characterize trends in relatively high bill values for a system as those above 200% of the average[14] (e.g., double the average or above) of the comparator group of systems and relatively low bill values as those below 50% of the average of the comparator group. Results from this analysis are presented in Section 5.

3. Trends and Cross-State Comparisons in System Characteristics and Bill Levels

[13] Not-for-profit (e.g. mutual and cooperative water companies), as classified in the EFC database, only accounted for 24 systems total. Due to the very small size of this category compared to the overall sample, these were combined with the 3 systems classified as ‘other’ into a single category for analysis in this study.
[14] We computed and compared using medians as the reference point for deviations from central tendency within a metro area, and the results were largely similar. We also considered a method looking at top and bottom deciles within a metro area but found the artificial bounds this poses on the range of deviation to be less helpful than our primary method.

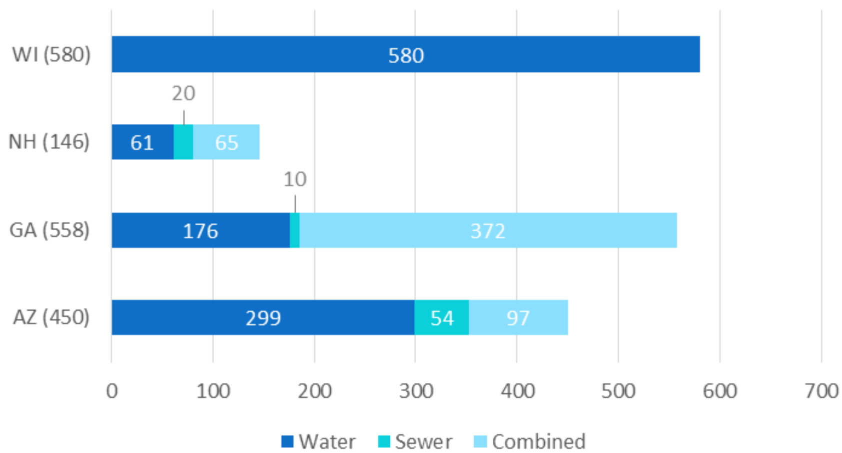
Certain patterns emerge when we examine system characteristics, rates, and bill levels across the four states selected for analysis. In particular, distinctive distributions emerge for system characteristics within states despite very similar median bill levels for drinking water service between states.

Trends in Utility System Characteristics: Services, System Structures, and Water Sources

Drinking water service systems are disproportionately represented in the data as compared to sewer systems (1,650 systems providing water service versus 618 providing sewer service or 1,720 serving either). The unbalanced representation is in part due to the Wisconsin dataset only including drinking water systems. Additionally, the other three states have far fewer sewer than drinking water systems, reflecting both relative consolidation in the sewer sector as compared to the drinking water sector (U.S. CISA, 2021) and the higher proportion of households in the U.S. unconnected to any type of sewer service as compared to water service. (2019 American Housing Survey).

The differences in services that systems across the three states provide reflect broader U.S. regional trends.[15] Figure 2 shows the total number of systems in each state based on the services they provide. Arizona has mostly water-only systems, while Georgia has mostly combined systems. Judging by available UNC EFC dashboard data, these state-level differences appear to reflect broader trends in the U.S. Southwest and Southeast respectively. New Hampshire, by contrast, has roughly equal numbers of systems providing only water or both water and sewer service.

Figure 2. System Service Provision by State

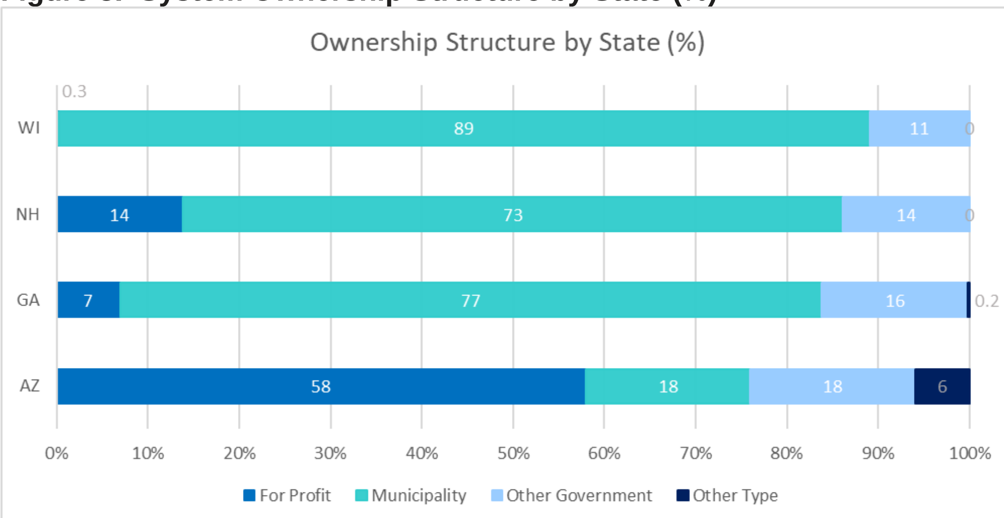


The states exhibit similar makeups of ownership type diversity, with the exception of Arizona (see Figure 3). Over 75% of all systems in Georgia, New Hampshire, and Wisconsin are municipal; in contrast, in Arizona, 58% of systems are for-profit. Appendix Tables A-1 to A-3 provide additional detail on the interaction between ownership type and services provided by systems in each state. The statewide patterns remain apparent across services provided, with some limited exceptions. In Arizona, where a majority of water systems are for-profit, sewer systems are more evenly split between for-profit and other (non-municipal) government

[15] Other types of system services also included in combination with water and wastewater on some bills include stormwater and trash. We do not include charges for other system services in our analysis.

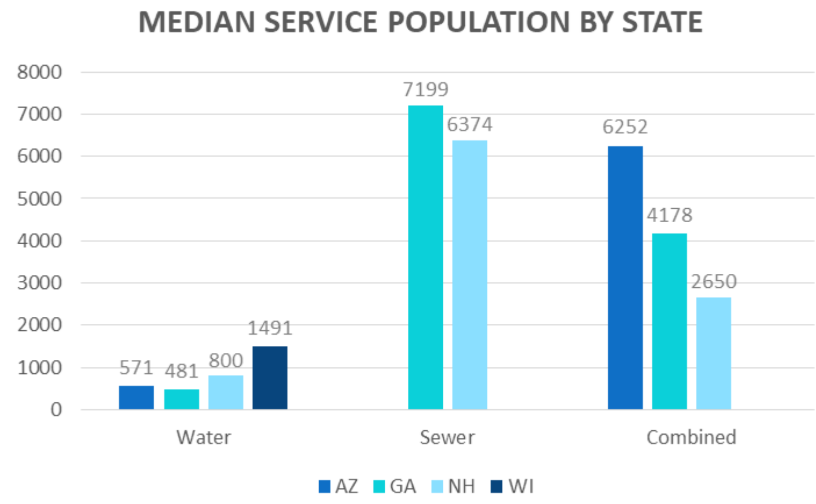
providers (e.g., special districts). For combined water and sewer services in Arizona, however, more municipalities than for-profit systems tend to provide both services. In Georgia, municipalities are the most common service provider across all services; while in New Hampshire, more municipal systems provide sewer service and combined services than water alone.

Figure 3. System Ownership Structure by State (%)



For water systems, the median service populations for systems in each state show that New Hampshire and Wisconsin systems tend to serve more people per system. Although again, we note that EFC billing data are much more representative of systems serving 500 or more people than "very small" systems serving less than 500, and roughly half of the water-only systems in Arizona and Georgia appear very small (see Figure 4). These trends between states generally hold for sewer and combined service provision, with the median service population generally higher for systems providing sewer and combined services than for systems providing water service. Notably, none of the 54 sewer systems in Arizona provided approximate service populations in the dataset, so we cannot compare them. As noted earlier, sewer and combined systems data was not available for Wisconsin.

Figure 4. Median Service Population for Services by State



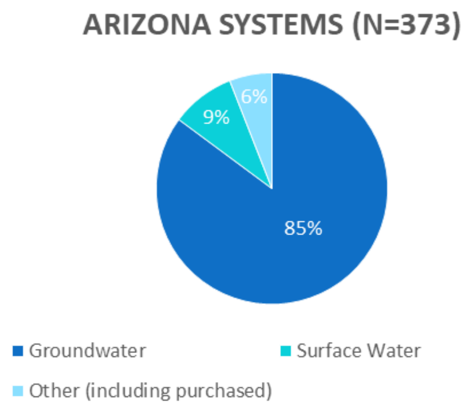
Examining the date of the last rate change for systems can help evaluate the extent to which rates reflect recent cost conditions in systems in each state. Table 1 shows the median date of last rate change for systems in each state. Across the four states, the median length of time since the most recent rate change varied between two to four years. However, some systems had not changed their rates for many decades.

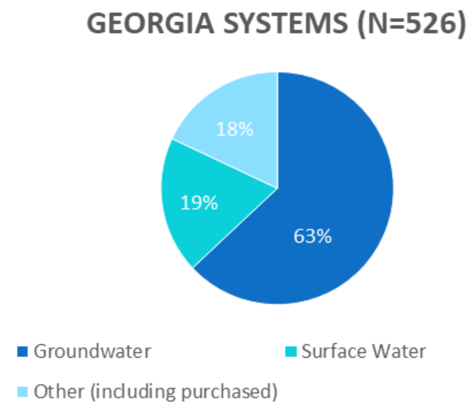
Table 1. Median Year of Last Rate Change by State

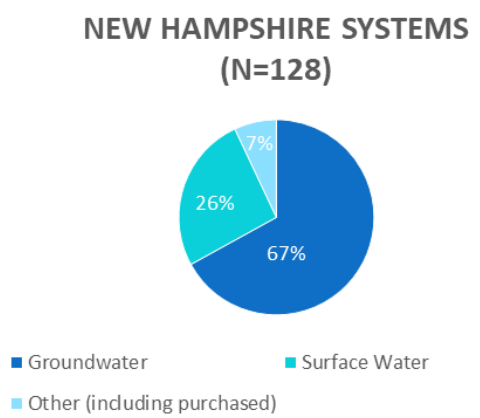
	Year of Rate Data in Study	Median Year	Range
Arizona	2019	2015	(1961-2019)
Georgia	2019	2017	(1989-2019)
New Hampshire	2018	2016	(1993-2018)
Wisconsin	2018	2015	(1975-2018)

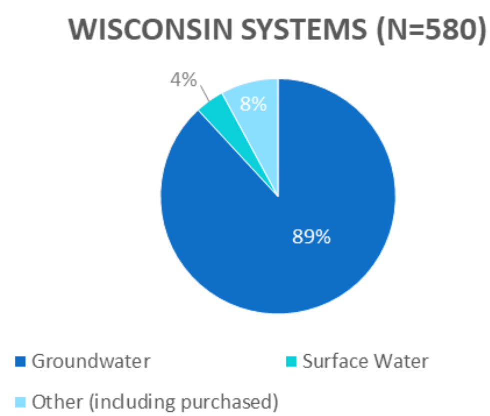
In terms of water source, though percentages differ by state (see Figure 5), groundwater is the most common water source for water systems across all four states. In Arizona and Wisconsin, less than 10% of systems use surface water and other sources (i.e., purchased water). In Georgia, 19% of systems use surface water, while 18% of systems use other sources (i.e., purchased water). In New Hampshire, 26% of systems use surface water as a source; and only 7% use other sources.

Figure 5. Water Source for Drinking Water Systems by State









Water Systems: Billing Frequency, Rate Structures and Bill Level Trends

Our master dataset contains monthly-equivalent water bills at major consumption points across states. Given that systems use billing structures with differing frequencies (e.g., monthly, quarterly, annually), the actual bills customers face in each system may be different. Previous research finds potential affordability consequences for households depending on how frequently water bills are assessed (Beecher 1994); in some cases, smaller amounts paid more frequently may be less taxing on household finances than larger bill amounts. Some variation also exists in the billing period between states (see Table 2): Arizona and Georgia systems almost entirely use monthly billing cycles, while New Hampshire systems mostly use quarterly bills (63%) followed by other periods (e.g., bimonthly, semi-annually, annually). Wisconsin systems mostly use quarterly bills (58%) followed by monthly bills (40%).

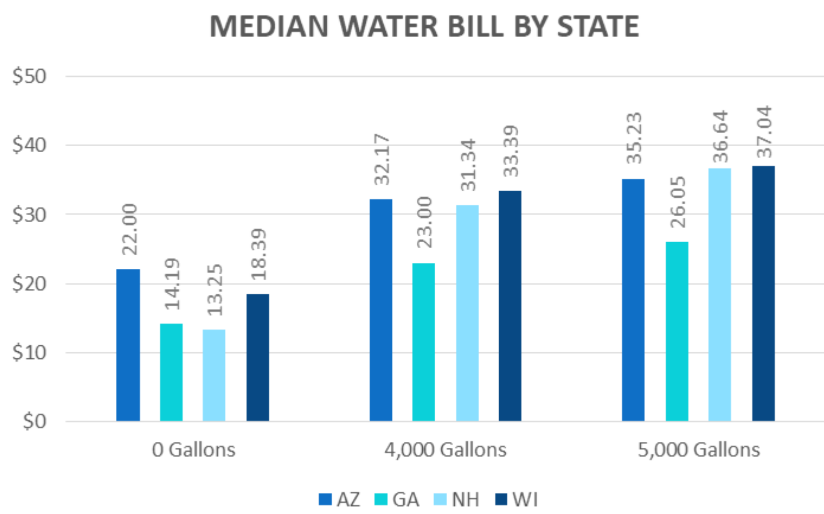
Table 2. Water Service Billing Frequency by State

	Monthly	Quarterly	Other
Arizona	99.2%	0.3%	0.5%
Georgia	99.2%	0%	0.8%
New Hampshire	16%	63%	21%
Wisconsin	40%	58%	2%

The monthly equivalents presented in this report provide an accurate estimate of the amount of monthly expenditure necessary for a household for comparative purposes even if the customer does not necessarily see a bill each month. The median water bills at typical consumption points of 4,000 and 5,000 gallons per month are strikingly similar across states (Figure 6). However, differences in rate structure result in bill variability at other levels of consumption (Figure 7). Composite water rate structures can be comprised of fixed rate elements, volumetric rate elements with rates per unit of consumption, or a combination of both. Rates can also be flat (e.g., a single fixed rate or a single volumetric rate assessed to all customers) or tiered (e.g., rate varies within blocks of consumption).

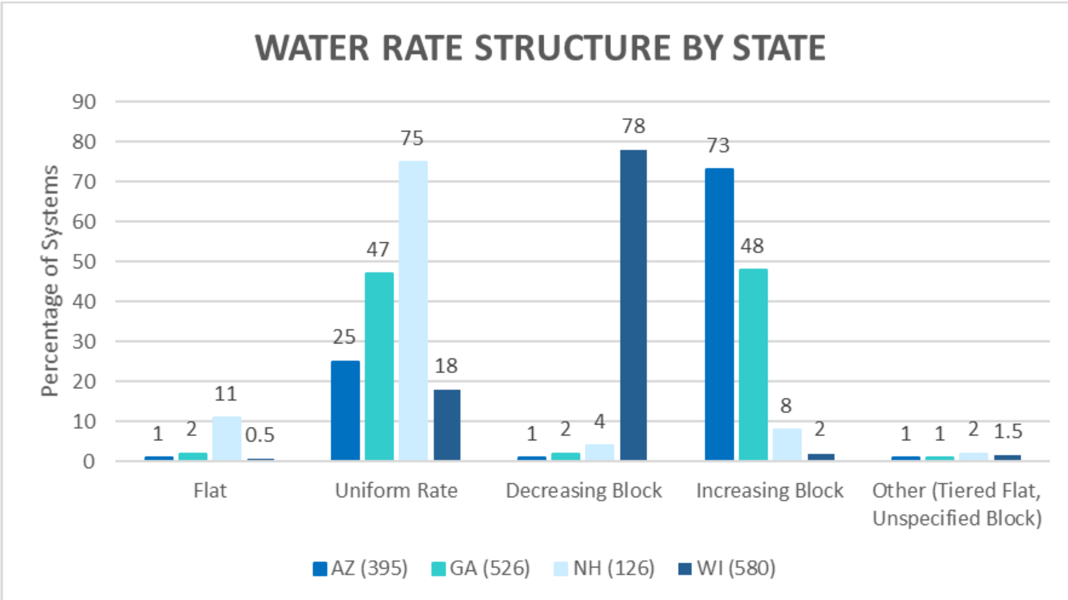
Arizona, New Hampshire, and Wisconsin have nearly identical median water bills for the 4,000-gallon and 5,000-gallon consumption points around $31 to $33 and $35 to $37 respectively. Georgia, however, has consistently lower bills for 4,000 and 5,000 gallons at around $23 and $26 respectively. Arizona followed by Wisconsin appear to have the highest monthly base charges, as evidenced by slightly higher median fixed charges at 0 gallons ($22 for Arizona and $18 for Wisconsin compared to $14 and $13 for Georgia and New Hampshire).

Figure 6. Median Water Bill by State



However, there are clear differences in water rate structures for systems in each state. Notably, the predominant rate structure in each of the four states is different. In Arizona, 73% of systems use increasing-block rate structures, whereas 78% of Wisconsin systems use decreasing block rate structures, and 75% of New Hampshire systems use uniform rate structures. Georgia sees a more even split between uniform rate structures (47%) and increasing-block rates (48%). Flat and other rate structures are uncommon in all four states.

Figure 7. Water Rate Structure by State



We also observe differences in the method that systems use for determining base pricing. The majority of systems in Arizona calculate base pricing by meter size (67%), although some use constant pricing (32%). New Hampshire systems show a more even distribution between constant base pricing (48%), by meter size (33%) and no base pricing (19%). Georgia and Wisconsin are similar in that a majority of systems in both states use constant base prices (84% and 99.7% respectively).

Other Data: Quality and Socio-Economic Status

In this study, we limit the scope of our examination of water quality compliance to focus on its relationship to billing levels, starting with a brief description of univariate and bivariate trends to describe water quality violations and socio-economic demographics. We then conduct multi-variate regression analysis, presented in Section 5, to provide a clearer picture of relationships between different system and customer-level characteristics.

We do not fully analyze water quality compliance and relationships between socioeconomic status of the customer base and system size and type in this study, as we retain our focus on billing levels as the outcome of interest.

Figure 8 shows the average number of health-based violations per water system by state. The vast majority of systems (1158 of 1558 systems, or 74%) incurred no primary health-based violations from 2009 to 2020. Resulting health-based violation averages vary from 1 to 2 violations for all states, with the lowest average of 1.05 violations per system in Georgia and the highest average of 2.17 violations per system in Arizona. However, the median number of violations for systems in each state is 0, with several outliers such as a maximum of 290 for one system in Wisconsin (see Table 3)[16]. This helps explain the lack of significance of the correlation between health-based violations and system size (i.e., service population) which is

[16] Further analysis would be required to ascertain the extent of data limitations from SDWIS violation data. Observed differences in water quality compliance data across states may in part reflect actual compliance variation but also may reflect potential inconsistencies in state programs monitoring compliance or in the way in which violation data were coded and entered between states. Efforts were made to clean data to ensure unique violation entries, but SDWIS data should also be used with caution (Beecher et al. 2021).

positive and non-significant, despite evidence that smaller system size predicts more health-based violations than much larger systems (Pierce et al. 2019; Rubin 2013).

The proportion of Hispanic/Latino residents served by a system, however, is significantly positively correlated with more health-based violations (see results of bivariate correlations in Appendix Table A-1). This echoes existing research findings regarding potential inequities in water quality by race and ethnicity (McDonald & Jones 2018).

Figure 8. Average System Health-Based Violations (2009-2020) by State

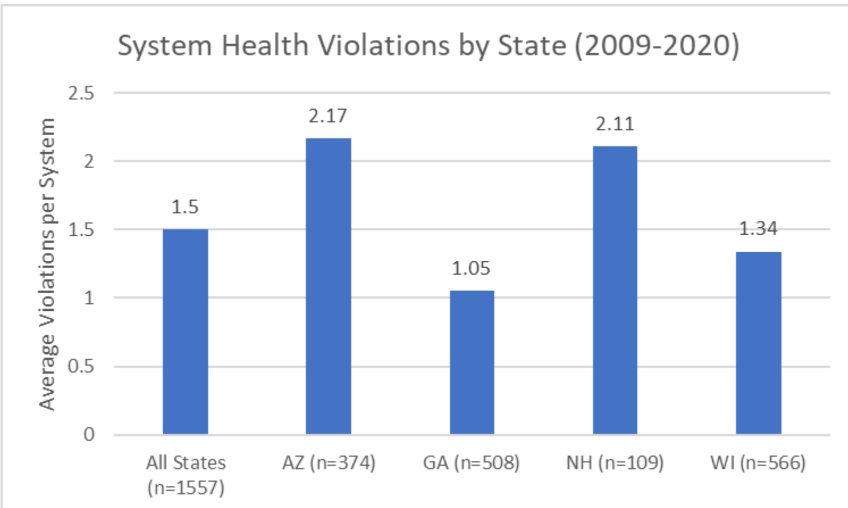


Table 3. Descriptive Statistics of System Health-Based Violations by State

	All States	AZ (n=374)	GA (n=508)	NH (n=109)	WI (n=566)
Mean (SD)	1.50 (8.80)	2.17 (6.47)	1.05 (3.54)	2.11 (8.02)	1.34 (12.71)
Median	0	0	0	0	0
Range	(0, 290)	(0, 76)	(0, 37)	(0, 72)	(0, 290)

We observe substantially more variation in the number of monitoring and reporting violations; this variation is largely driven by a very high number of monitoring and reporting violations among systems in Arizona (see Figure 9). The state-level averages follow a similar pattern to health-based violations, with the highest average in Arizona (38.45 violations per system) and the lowest in Georgia (2.49 violations per system). It is unclear what may be driving these disparate trends in monitoring and reporting violations and whether or not they are related to either system or regulatory enforcement behavior. For additional insight, we direct readers to other national comparisons of water quality violations (Allaire et al. 2018; Rubin 2013).

Examining the median and range of monitoring and reporting violations provides a better picture of system performance in each state (See Table 4). Half of the systems in Arizona have 14 or fewer monitoring and reporting violations, but one system has a maximum of 774 violations. A total of 15 systems have more than 200 monitoring and reporting violations, of which 13 are located in Arizona and 2 in Wisconsin. The maximum of 427 for one system in Wisconsin also contributes to its larger average compared to Georgia and New Hampshire. Overall, the median monitoring and reporting violations per system in all states is 2. Monitoring and reporting violations are included in the regressions presented in Section 5, and kept separate from health violations given the difference in violation nature (failing standards in water quality versus water system information provision).

Figure 9. Average System Monitoring and Reporting Violations (2009-2020) by State

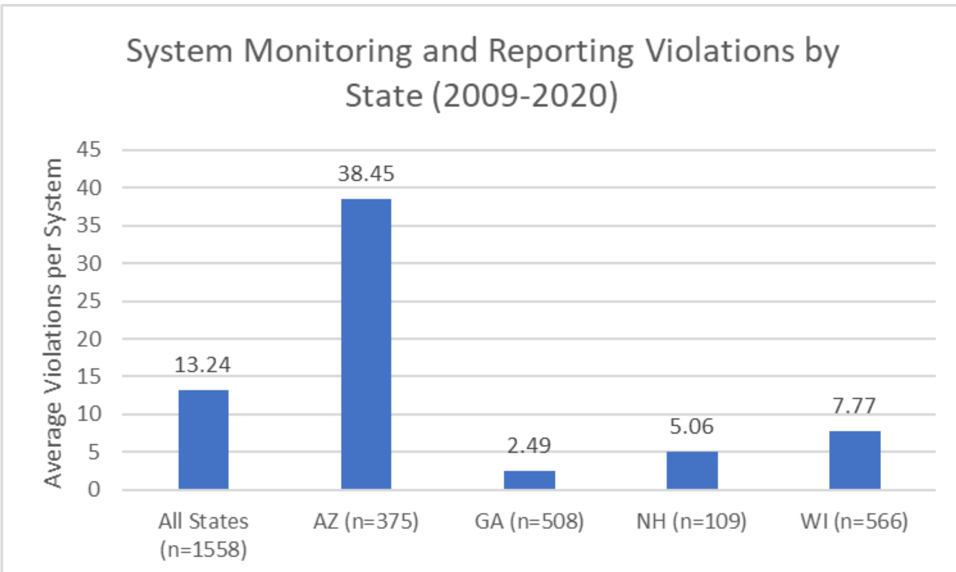


Table 4. Descriptive Statistics of System Monitoring and Reporting Violations by State

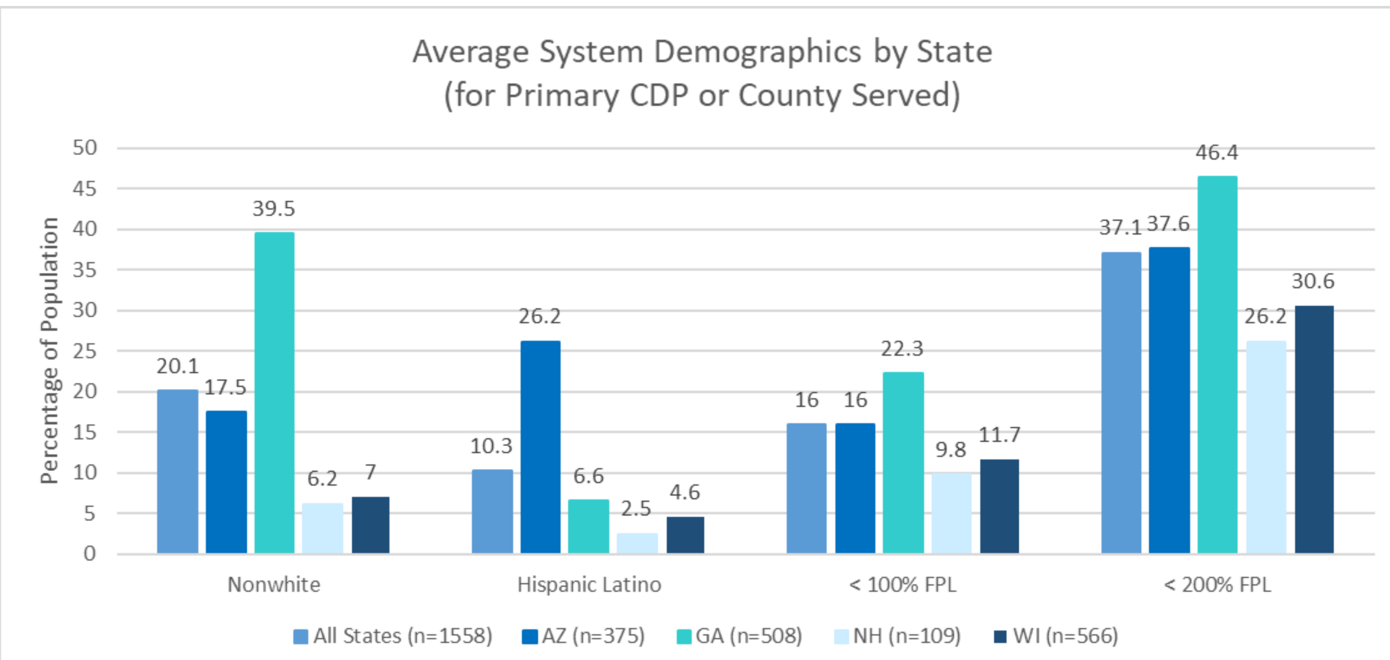
	All States	AZ (n=375)	GA (n=508)	NH (n=109)	WI (n=566)
Mean (SD)	13.24 (45.42)	38.45 (81.92)	2.49 (5.41)	5.06 (11.14)	7.77 (25.00)
Median	2	14	1	1	2
Range	(0, 774)	(0, 774)	(0, 55)	(0, 49)	(0, 427)

We collect socio-economic data from the U.S. Census (American Community Survey 2015-2019, 5-year estimates) at both the CDP and county-levels: race, ethnicity, median household income, and poverty status. We collect these variables from the NHGIS database for (Manson et al. 2021). Using these data, we create the following five variables: Non-White population proportion, Hispanic/Latino population proportion, median household income, and proportion of the population under 100% and 200% of the federal poverty level (FPL). We match these census variables to systems using the system's primary CDP as listed on the EFC dashboard or SDWIS.[17] If the system's primary CDP is missing, we assign the system county-level estimates.

Figure 11 shows the average proportion of customers that are Non-White, Hispanic/Latino, below poverty level, and below twice the poverty level in the primary locations served by systems in each state.[18] Systems in Georgia have the highest average proportion of Non-White and low-income populations, while Arizona has the highest proportion of Hispanic/Latino populations. New Hampshire systems have the lowest average proportions across all four demographic variables. Meanwhile, the median household income for systems across the states is within a tight range (see Figure 10), with the lowest in Georgia ($43,000) and the highest in New Hampshire ($63,000), as expected from the poverty status demographics. The proportion of both Non-White and Hispanic/Latino populations are highly correlated with larger service population and higher proportions of the population under the 100 and 200% of the FPL (see Appendix Table A-1 for correlations).

The association of these variables with water rates is less clear; the base rate for water (0 gallons) has a high positive correlation with the proportion Hispanic/Latino but negative correlation with the proportion of Non-White. Among the socio-economic variables analyzed, only median household income is significant for 4,000- and 5,000-gallon water bill levels (positive correlation).

Figure 10. Average System Demographics by State for Primary CDP or County Served

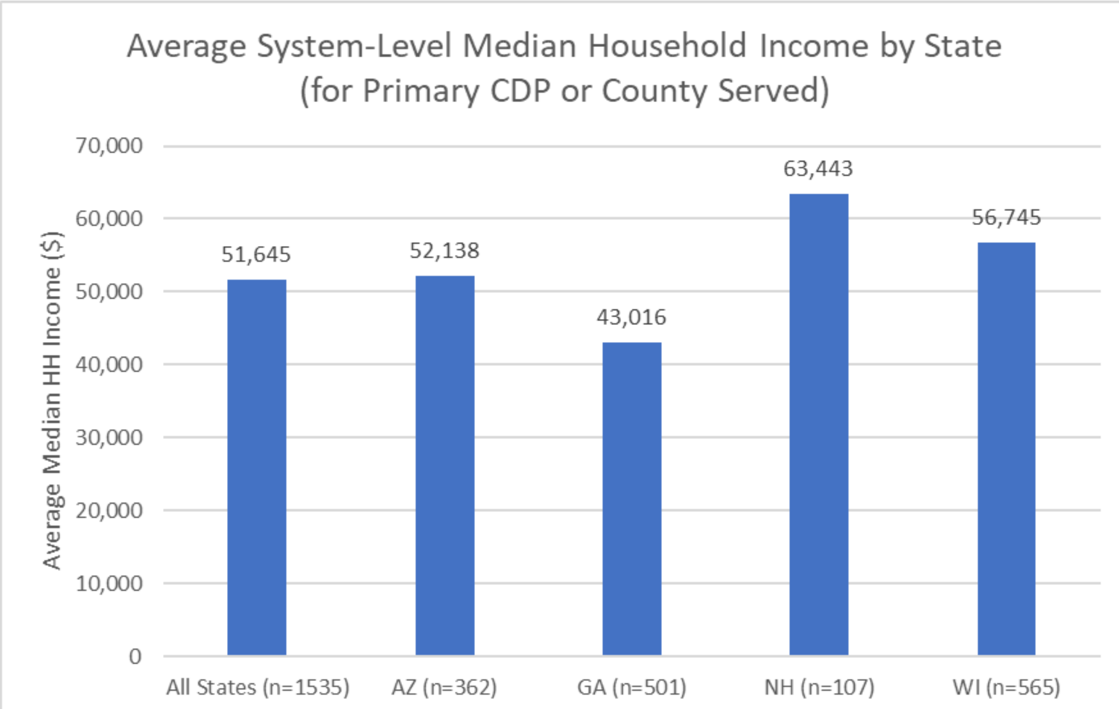


---

[17] If the EFC dashboard did not provide a primary CDP/county or one that did not match census data (144 systems), the CDP was obtained from SDWIS. In the event the SDWIS CDP did not match available census data (35 cities), the primary county was used.

[18] Any method to attribute population characteristics from the census to small water systems is likely to have a high degree of inaccuracy, given that the smallest census geography at which population characteristic data are available (the block group, serving between 600 and 3,000 people) is larger than any very small system. For very small and some small systems, only manually-collected socioeconomic characteristic survey data will be sufficient.

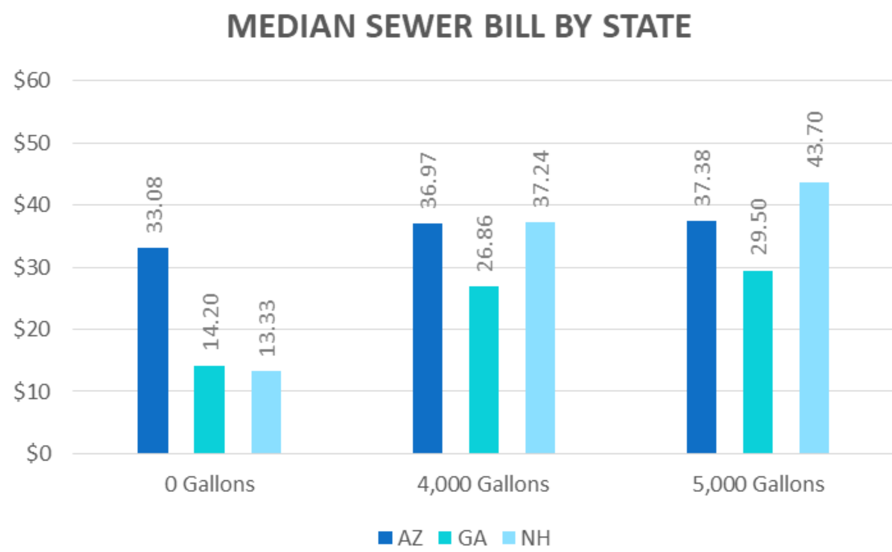
Figure 11. Average System-Level Median Household Income by State for Primary CDP or County Served



Sewer Systems: Billing Levels and Rates

Similar trends to water bills are seen in sewer bills in terms of similarities and overall rates between states. For 4,000-gallon and 5,000-gallon consumption points, Arizona and New Hampshire have similar median bills around $30 to $40 with consistently lower median bills in Georgia (see Figure 12). The median sewer bills in each state are very similar to the water bills, although slightly higher ($37, $27, and $37 for 4,000 gallons in AZ, GA, and NH respectively for sewer versus $32, $23, and $31 for water).

Figure 12. Median Sewer Bill by State

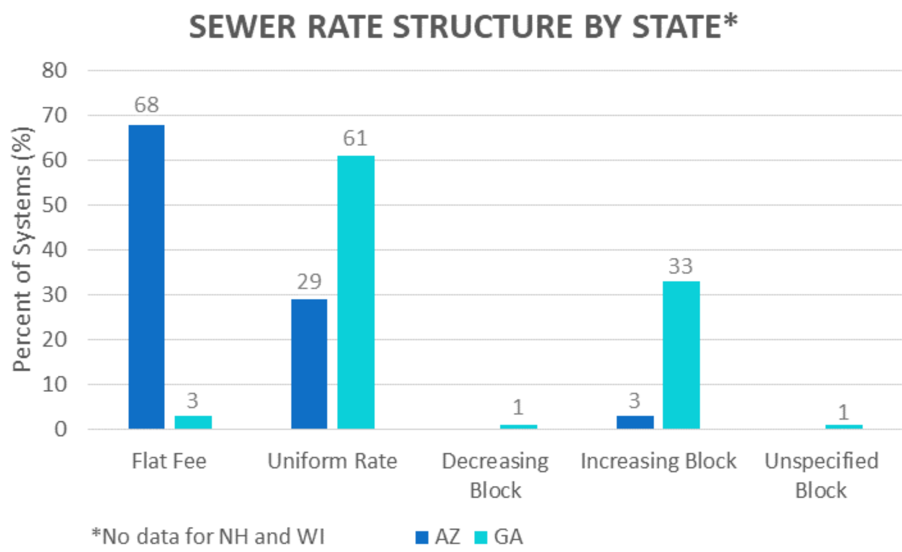


Where data are available, differences in sewer rate structures by state are also apparent (see Figure 13). For instance, the majority of Arizona systems (68%) use flat fees; while most of Georgia's systems (61%) use uniform rates. No sewer rate structure data was available for New Hampshire. The distribution of sewer billing-periods across states are similar to water service. Arizona and Georgia systems overwhelmingly use monthly billing periods, while New Hampshire systems have mostly quarterly billing systems (67%), followed by systems using other bill structures (25%) (see Table 5).

Table 5. Sewer Service Billing Frequency by State

	Monthly	Quarterly	Other
Arizona	95%	5%	0
Georgia	98.9%	0.3%	0.8%
New Hampshire	8%	67%	25%

Figure 13. Sewer Rate Structure by State*



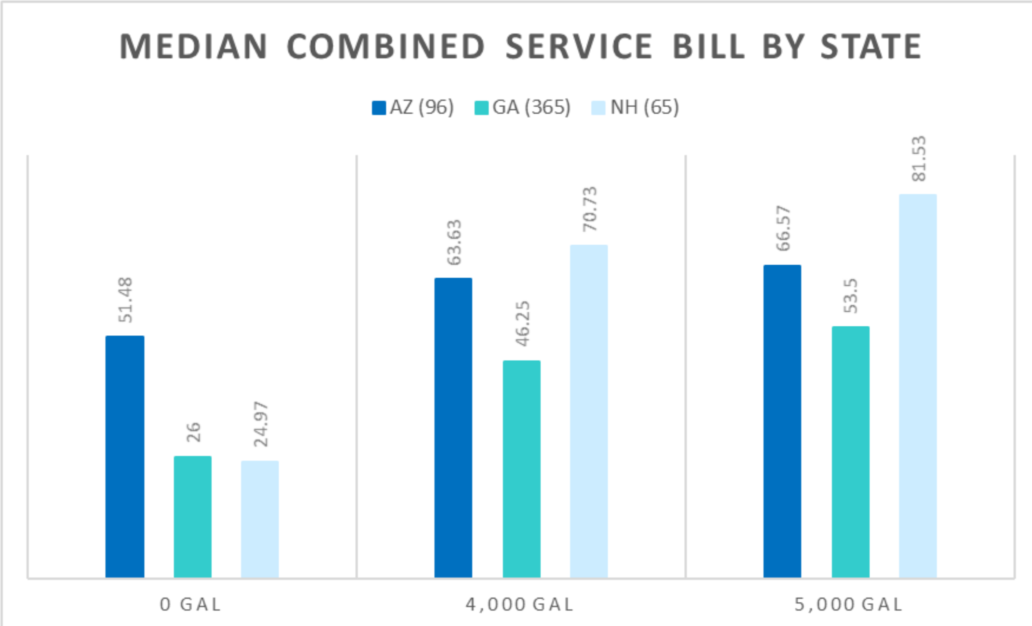
Combined Systems: Bill Levels and System Types

Systems that provide both water and sewer services have separate monthly equivalent bill totals for water and sewer bill totals at various consumption points in the EFC data. We have data on the total bill a customer would face from these systems for both services each month (presuming equal consumption levels of water and sewer). This sample is less than one-third of all systems in our dataset (N=526), as these are the only ones that report providing combined services. Thus, this set is a non-representative sample of total water and sewer costs for most households in the four states included in this study.[19]

For a given level of consumption, differences by state in combined service bill levels are higher than differences observed in bills for water or sewer service alone (see Figure 14). For instance, differences by state observed for combined service bills range from $10 to $30 for a given consumption level whereas differences for water or sewer service only range from $5 to $10. Systems in Georgia have by far the lowest median combined service bills across reasonable consumption points, while New Hampshire has the highest median bills for 4,000 and 5,000 gallons of water and sewer consumption but a lower median base charge (i.e., bill at 0 gallons). As with water and sewer separately, combined systems in Arizona have the highest median base charge ($51.48 for 0 gallons) but fall in between combined systems in Georgia and New Hampshire for bills at 4,000 and 5,000 gallons (i.e., 8,000 and 10,000 gallons of water and sewer use total). These figures suggest that higher base charges for combined service do not necessarily lead to higher bills at modest levels of usage.

Figure 14. Median Combined Service Bill (Water & Sewer) by State

[19] For most households in areas that receive both water and sewer service from centralized systems, the total water and sewer expenditure is the sum of two separate bills from systems with service areas which may not be co-extensive. This study does not attempt to calculate total bills for such households.



4. Intra-State and Intra-metro area Variation

Next, we explore and illustrate levels of intra-state and local area variation in water bills.

Trends in Local, State, and National Relatively High and Low Bill Levels

We further explore trends in system-level deviation from the central tendency of local, state and national comparator groups for drinking water bills and, secondarily, sewer bills. We use MSA-CSA as our local area boundary; a little less than 25% of systems are not in a MSA. These systems are labeled as “non-MSA”. We define relatively high bill values as above 200% of the average of the comparator group and relatively low bill values as below 50% of the average of the comparator group.

As Table 6 shows, we find fairly consistent relationships in the ratio of relatively low and high drinking water bill values across the distributions of different comparator groups, whether using the mean bill of the local area, individual states, or the four combined states as the point of comparison. For instance, 8.4% of systems have water bill levels below 50% of the average of their MSA-CSA, whereas 9.1% have water bill levels below 50% of their state average, and 9.7% have water bills below 50% of the 4-state average. The distribution of relatively low and high values at each scale is also fairly similar to a bottom-top decile approach for identifying values of potential concern.

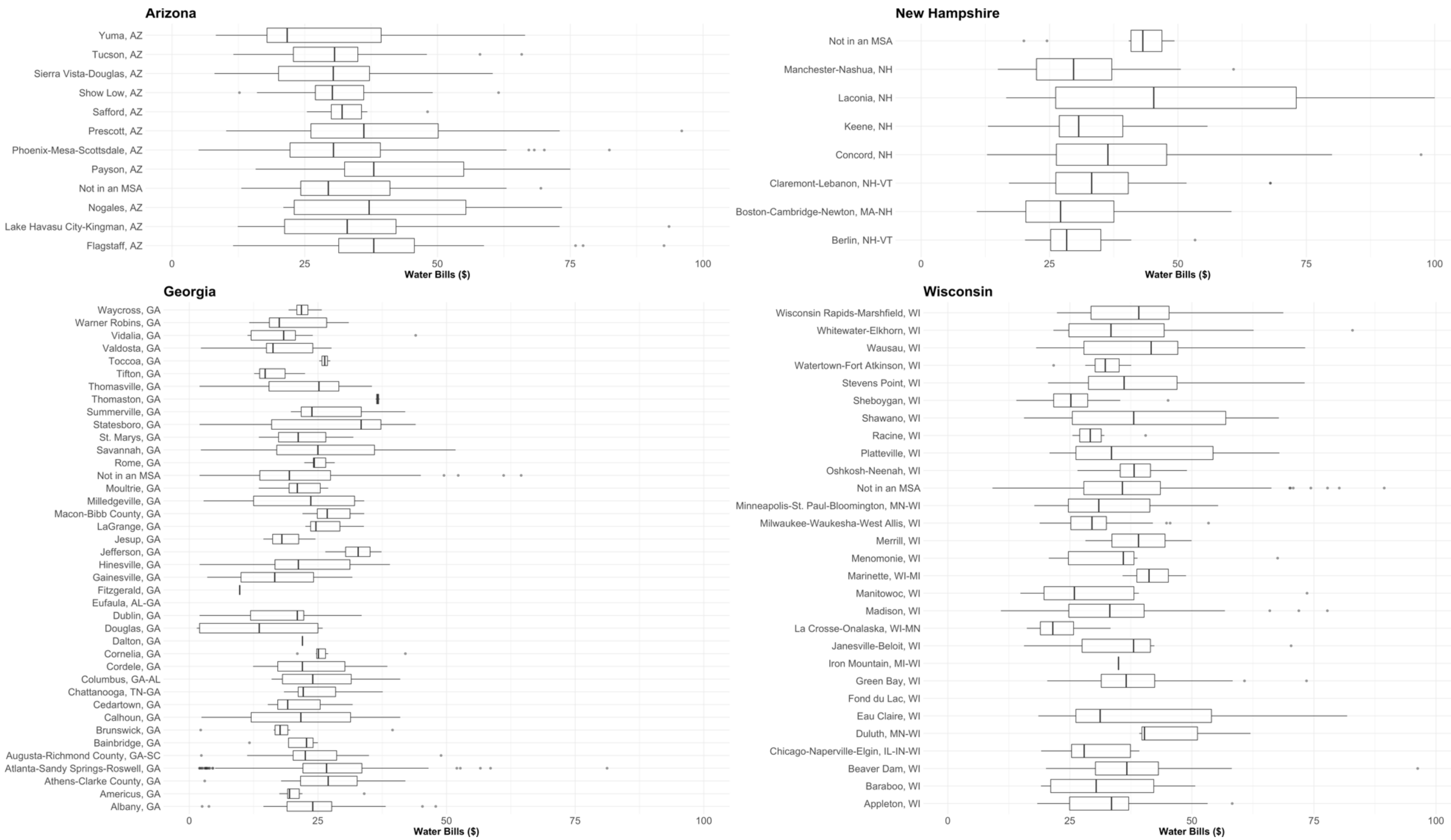
Table 6. Percentage of Systems with Extreme Household Water Bills

Comparison group	Below 50% of average (“relatively low”)	Above 200% of average (“relatively high”)
Local (MSA-CSA) average bill	8.4%	8.6%
State average bill	9.1%	8.7%
Average bill across all four states included in study	9.7%	9.8%

On the other hand, we find notable differences across states and ownership types in the distribution of relatively low and high bills, using only the local area as a comparator group. (See Table 7.) Bill levels for systems in Wisconsin show least amount of variance within local areas by far. This perhaps reflects the central regulation of rate-making for all systems in the state, which is uncommon for other states (UNC EFC 2017; Beecher, 2018). Georgia has the highest proportion of systems with relatively low bill values but the second lowest proportion of relatively high values. Arizona and New Hampshire have similarly large proportions of relatively high bill values. New Hampshire has the second largest proportion of relatively low values.

Echoing these findings, Figure 15 below highlights the variation across metro areas for water bills at 4,000 gallons of monthly consumption. The spread of each MSA visually substantiates the results presented in previous sections on state-level and Metro area-level variation in water bills. Despite similar mean water bills across states noted earlier, systems in Georgia have consistently lower median bills compared to other states. Georgia also exhibits the fewest outlier systems with extreme bill levels within metro areas. Meanwhile, Arizona demonstrates the largest spread of water bills both within and between metro areas compared to other states.

Figure 15. Distribution of System Water Bills at 4,000 Gallons per Month, by Metropolitan Statistical Areas in Each State



Notes: The spread of water bills in each metropolitan statistical area is depicted using a box-and-whisker plot. The vertical line within each plot depicts the median bill amount, the box is bounded by the 25th (left edge) and 75th (right edge) percentiles. The horizontal lines beyond the box, also referred to as whiskers, extend to minimum (left) and maximum (right) values assuming a gaussian distribution. Dots beyond these lines represent potential outliers.

Across the three main ownership types[20]—for-profit, municipalities and other-governmental systems—clear trends emerge, especially in terms of relatively high bill levels. Municipalities are much less likely to have high bill levels compared to local neighbors and are slightly less likely to have relatively low values as well.

Table 7. Percentage of Systems with Extreme Water Bills by State and Ownership Type

Comparison to MSA-CSA average bill	Below 50% of average (relatively low)	Above 200% of average (relatively high)
States		
Arizona	8.5%	16.9%
Georgia	12.4%	6.1%
New Hampshire	11.7%	17.2%
Wisconsin	3.5%	2.3%
Major Ownership Types		
For-profit	9.2%	14.6%
Municipalities	8.0%	4.7%
Other-governmental	8.9%	15.0%
All systems	8.4%	8.6%

Table 8. Percentage of Systems with Extreme Sewer Bills by Ownership Type

Comparison to MSA-CSA average bill	Below 50% of average (relatively low)	Above 200% of average (relatively high)
Major Ownership Types		
For-profit	10.2%	7.4%
Municipalities	11.6%	1.5%
Other-governmental	7.5%	2.5%
All systems	10.9%	2.3%

Comparing the results of Table 7 and Table 8, among the 608 systems with 4,000-gallon per month sewer bills across three states, there are slightly more relatively low bills (10.9% versus 8.4%) but far fewer relatively high bills (2.3% versus 8.6%) as compared to drinking water-only bills. Differences across ownership type are sizable at the high end, with for-profit systems being much more likely to maintain high bill levels (7.4% versus 2.5% for two other types). (See Table 8.)

To illustrate differences in intra-metro area parity or inequality in drinking water bill levels, we further focus on systems within the largest MSAs in Georgia and Arizona. The Atlanta-Sandy Springs-Roswell metropolitan area in Georgia contains 155 systems, while the Phoenix-Mesa-Scottsdale metropolitan area in Arizona contains 112 systems. As Table 9 shows, each metro area features a wide absolute spread in drinking water bill levels, from below $5 in each to above $80 for a 4,000-gallon bill. However, mirroring state-level differences, the Atlanta metro

[20] Not-for-profit (e.g. mutual water companies) and ‘other’ water system types, as classified in the EFC database, only accounted for 27 systems total. Due to the very small sample compared to the other system types, these were combined into a single other category and are not large enough to be compared as a main ownership type to examine trends in extreme bills.

shows a notably higher proportion of systems with relatively low bill values while the Phoenix metro has more than 20% of its systems above 200% of its local average.

Table 9. Metro area Spread in Drinking Water Bills- Atlanta versus Phoenix Metro Areas

Comparison group	Average (median) 4000-gallon bill	Below 50% of average (relatively low)	Above 200% of average (relatively high)	Low/High
Atlanta metro area	$26.42 ($26.83)	13.6%	7.7%	$2.00/$81.20
Phoenix metro area	$32.28 ($30.41)	8.9%	21.4%	$5.00/$82.37
All systems included in the study	$31.37 ($29.06)	8.4%	8.6%	$1.46/$108.10

5. Factors Correlating with System-Level Variation in Bill Levels

Finally, we estimate multiple specifications of linear regression models to better assess correlations between water bill levels at the 4,000-gallon consumption level and other system-level characteristics. The purpose of the models is to provide insight into the potential driving factors for variation in water bills at the system-level. While we originally ran parallel sewer bill level models in the first stage of the analysis, the inclusion of compliance and socio-demographic data in the second stage was only feasible for drinking water systems. We report our more limited sewer bill regression model in Appendix 2 (see Table A-9).

The two primary drinking water bill level models include fixed effects for state and MSA, respectively, to examine correlation of bills with system characteristics. The first model controls for the effect of the state a system is located in while the second controls for the MSA in which the system is located.

Linear Regression Model Specifications and Hypotheses

Each of the model specifications includes data on system-level characteristics very similar to those cited in a recent U.S. Government Accountability Office (GAO) report as affecting water bills (GAO 2021).

The following list describes the predictor variables included in the primary specifications as well as secondary regression model runs (see Appendix 2) for drinking water systems:[21]

- water quality compliance (total health based and monitoring and reporting violations 2009-2020)
- socio-demographics of the customer base (income inequality (GINI index), race/ethnicity, median household income)
- nearest neighbors' cost (average bill for all other systems in the county of the system and systems in the counties contiguous to the system's county)

[21] We also considered and constructed model specifications accounting for the binary presence and level of bill structure (fixed versus variable charge) components, the date of last rate change and categorical rather than continuous system size (i.e., small versus large). However, some of these variables were highly collinear with existing correlates; and their addition did not change the model's explanatory power statistically or strengthen it conceptually in our view. Accordingly, we did not include these results in our primary reported specifications.

- ownership type
- system customer base size (e.g., approximated system service population)
- rate structure type
- presence of a monthly allowance (i.e., binary variable where a 1 indicates system provides a baseline water allocation within the fixed charge)
- type of water source (ground water, surface water, purchased from either source)
- Included in secondary regression model runs only (see Appendix 2):
    - population below federal poverty level (in place of income inequality)

While previous research on drivers of variation in bill levels is limited (GAO 2021), we draw on prior studies to generate hypotheses on the expected influence of the system-level variables on system bill levels. A review of multiple rate studies by the GAO suggests that public or quasi-public system ownership types (e.g. municipal, other government) will correlate with lower bills than for-profit systems (GAO 2021). We anticipate that larger system customer base size will correlate with lower bill levels based on the potential for economies of scale (Pierce et al. 2019). We also hypothesize that higher nearest neighboring system bills will lead to higher bills, as local similarities to some extent reflect cost and political similarities (Chica-Olmo et al. 2013; Thorsten et al. 2009). We expect that purchased water sources will also lead to higher bills than systems with ground or surface water source rights due to the costs of purchasing raw water which may be reflected in the bill price for customers, as seen in a study in North Carolina (Thorsten et al. 2009). However, we note that we did not have data on source water quality, which may also impact bill levels via higher treatment costs; levels of salinity or contaminants may increase treatment costs and geographic or topographical factors can influence delivery costs (GAO 2021). Extending from this line of reasoning, a lack of water quality compliance (in the form of health violations) could either reflect lower than cost-recovery bill levels or could result in high bill levels to fund necessary treatment technology.

Existing research shows that progressively-tiered rate structures tend to lead to lower monthly bills at modest levels of consumption (García-Valiñas, Martínez-Espiñeira, & González-Gómez, 2010a; Hoque & Wichelns, 2013). On the other hand, there are concerns that inappropriately structured blocks or imprecise targeting can hinder the affordability benefits of this rate structure type (Brown and Heller, 2017; Pierce et al. 2021). Prior research in Michigan has found higher self-reported water bills faced by minority populations (Butts & Gasteyer 2011); if this finding extends beyond this state we would see larger Non-White customer populations correlate with higher water bills. Thorsten et al. (2009) find that both higher income disparity (in the form of poverty levels) and higher median household incomes in a community correlated with higher bills in North Carolina. Thus, we hypothesize positive effects of income and income inequality on bill levels. Finally, we expect household bills to be lower for systems that provide a baseline allocation of water each month, as customers are not charged for the baseline allocation that is a portion of the 4,000 gallons.

Linear Regression Model Results: Model for 4,000 Gallon Monthly Water Bill Levels

Table 10 presents the results from the final regression models for water bills for 4,000 gallons per month consumption. Our primary specification excludes systems that matched sociodemographic data based on County rather than CDP characteristics. Although we note that modeled relationships between correlates and bill levels were very stable across specifications which variously[22]:

[22] We also compared models using Census Block group joined socioeconomic data versus CDP data for systems in Arizona, the only state in the study where such a comparison is possible because of the presence of system

- *included systems with matched County sociodemographic data*
- *excluded systems with under 500 population served*
- *substituted FPL for the Gini index,*
- *excluded M&R violations due to collinearity concerns.*

See Appendix 2 tables for the full results of model specification sensitivity tests.

Table 10. Primary Linear Regression Model Specifications for 4,000 Gallon Monthly Water Bill Levels

Predictor	State Fixed Effects	MSA Fixed Effects
Cost of 4,000 Gallons in Neighboring Systems	0.806*** (0.085)	0.957*** (0.121)
Income Inequality	-9.810* (5.646)	-11.165* (5.884)
Monthly Baseline Allowance	-4.735*** (0.929)	-4.938*** (0.960)
Ownership: Municipality	-3.435** (1.528)	-3.535** (1.581)
Ownership: Other Government Type	-0.508 (1.674)	-0.506 (1.716)
Proportion Population Non-White	-6.379*** (2.172)	-6.268*** (2.278)
Rate Structure: Flat	-0.619 (3.097)	-1.307 (3.193)
Rate Structure: Increasing Block	-2.438* (1.281)	-2.851** (1.346)
Rate Structure: Other block	-3.614 (3.138)	-4.569 (3.197)
Rate Structure: Uniform Volumetric	-0.889 (1.134)	-1.310 (1.167)
Service Population	-0.00002*** (0.00001)	-0.00002*** (0.00001)
Source: Purchase	1.776 (1.212)	2.139* (1.299)
Source: Surface	-0.021 (1.193)	0.593 (1.289)
Total Health-Based Violations	0.051 (0.038)	0.057 (0.038)
Total Monitoring and Reporting Violations	-0.001 (0.008)	-0.001 (0.008)
Constant	13.334*** (4.134)	11.509** (5.690)
Spatial FE	State	MSA
Observations	1,385	1,385

boundary shapefiles. While coefficients are slightly different across the models, none of the signs or significance levels changed, indicating that CDPs are not notably distorting results compared to the use of shapefiles (echoed in analysis of North Carolina data by Berazher et al., 2022).

R^2	0.267	0.299
Adjusted R^2	0.257	0.260
Residual Std. Error	12.500 (df = 1366)	12.479 (df = 1311)
F Statistic	27.591*** (df = 18; 1366)	7.644*** (df = 73; 1311)
Note: Robust standard errors in parentheses.		*p<0.10 **p<0.05 ***p<0.01

The adjusted R^2 value is a measurement of model fit that describes the portion of variation in bills explained by the correlates in the model. These models account for approximately 26% of the variation observed in bills (for state and Metro area fixed effects respectively). Adjusted R^2 values in this range are common in regression models due to the many unobserved factors likely influencing a social phenomenon such as levels of local water and sewer bills. Significant results (denoted by ** or *** in the table) indicate factors that are correlated with bill levels even when accounting for uncertainty in the model. They indicate with 95 and 99% confidence or above that the predictor does influence bill levels.

The significant correlates in the model were nearest neighbors' bills, ownership type (municipal as compared to for-profit), monthly allowances, service population, income inequality, percentage of Non-White population, and source water (purchased as compared to the baseline of groundwater). Significant correlates do not vary between the model controlling for state location and the model controlling for Metro area location, except with respect to the presence of tiered rate structure.

As hypothesized, water bills are significantly higher among systems where neighboring systems charge more for water (see Thorsten et al. 2009, Chica-Olmo et al. 2013) and significantly lower for systems that provide a baseline monthly allocation of water. Additionally, municipal systems tend to levy significantly lower water bills than for-profit systems (for instance, see Onda and Tewari 2021; the baseline of for-profit systems is not included as a variable in the model to enable comparison). The other government ownership types were not significant correlates in the model compared to the for-profit system type baseline. As hypothesized, a larger service population is also associated with significantly lower bills.

Contrary to prior findings specific to North Carolina (Thorsten et al. 2009), higher income inequality, which is strongly correlated with a greater proportion of Non-White population, is significantly associated with lower bill levels. Higher Non-White population in our model is significantly associated with lower bills, contrary to our expectation after controlling for other factors. However, both these factors were relatively weak in terms of explanatory power. Further exploration into the two-way relationship between a system's customer demographics (beyond median household income) and water bill levels is essential given the implications for water affordability and broader environmental justice efforts.

The presence of a tiered water rate structure is also significantly correlated with lower bill levels in the model. Source water is a significant correlate; as hypothesized, systems with purchased water sources have significantly higher bills than systems with groundwater sources. On the other hand, we did not find evidence of water quality violations, either health or procedural, influencing bill levels.

6. Discussion and Next Steps

In this study, we compile data on water and sewer system bills from four states to analyze variation in local bill levels at modest levels of consumption. We then examine characteristics of systems and bill levels across the four states—Arizona, Georgia, New Hampshire and

Wisconsin—selected for analysis, with a focus on drinking water bill levels. Despite similar median bill levels for drinking water and sewer service between states, we find differences in system characteristics across states.

Wide variation in bill levels also persists at each scale we analyzed, including within MSAs. We are able to explain some of the variation in water bill levels across systems based on system ownership type, size, water source, rate structure, and the bill levels of neighbors as well as race-ethnicity and income inequality of customers. Municipal ownership type, larger service population, and a baseline monthly allowance of water all predict systems with lower bills, supporting hypotheses from existing studies. Additionally, we find that higher bills of nearby systems and using purchased water as the main water source predicts higher bills for a system, as hypothesized. We also find that increased income inequality and higher proportions of Non-White customers correlate with lower bills for systems, but that these factors were counter to our expectations, and relatively weak in terms of explanatory power.[23] Further exploration into the two-way relationship between a system's customer demographics (beyond median household income) and water bill levels is essential given the implications for water affordability and broader environmental justice efforts.

But much of the variation in bill levels remains unexplained. This helps underline the unique degree of variation found in residential bill levels across neighboring water systems compared to bill levels charged by local providers for other essential services and goods (Pierce, Lai and DeShazo, 2019). One potential reason for the unexplained variation is that water system data are limited. Existing available data sources require comparisons be done with 'caution' (UNC EFC, 2019; Beecher et al. 2021). We could not capture all drivers of water costs, or consider historic drivers of water rates as our bill derived data from a single point in time. Other potentially interesting variables, suggested by Teodoro (2020) and the UNC EFC (2019), are not readily available for collection and matching at the local system level but could potentially be collected for pilot analyses for individual or small groups of states. These include system capital replacement rates; receipt of general fund, state, or federal assistance; physical and uncollectible non-revenue water levels; customer class composition ratios; staffing levels and compensation; and quality treatment requirements. A null finding regarding water quality compliance and bill levels, despite exploring multiple specifications, also deserves further exploration, particularly to understand links between water affordability and access to safe, clean water.

In terms of next steps, we also note that, while we chose four states with different climate types and different metropolitan area profiles for comparison, these states cannot be considered representative of the entire U.S. The results from this study potentially motivate an effort to widen the states included. While expanding to include additional states with UNC EFC-collected

[23] Although our findings in this study are that bills at a modest level of use are lower in systems with more income inequality and higher proportion of non-white population, we recognize that the actual affordability of water bills is (by definition) adversely affected by the prevalence of low-income households within a system's service area. Further, low-income households in some cases use more than a modest amount due to older housing with leaky/inefficient plumbing, fixtures, and appliances. There is also some evidence that non-white households have higher actual water bills than white households (see Butts & Gasteyer, 2011). This is a different phenomenon than the one we study: whether systems with a higher percentage of non-white population have higher bill levels for a standardized level of modest usage. Cardoso and Wichman (2020) also find a racial disparity in water affordability (operationalized in their study as the water and sewer bill for a modest level of usage as a percentage of household income).

data appears feasible, it is less clear if other national association and states' ad hoc system bill collection efforts, such as in California, will be consistent, accurate, and extensive enough to be included in a master dataset. New Jersey's new law which requires all water and sewer utilities to report monthly data regarding rates, average and median customer bills, usage and more at the zip code level, may be the most promising state-level precedent to build upon (Levine, 2022).

A unified database on residential household system bills would be useful, perhaps combining rates dashboard efforts by the UNC EFC, which still offer by far the most coverage, reliability and flexibility of any multi-state source, with more recent efforts such as those at Duke's School of the Environment (Patterson and Doyle, 2021). Reforms to address SDWIS data collection and include bill levels may also be a unique opportunity to create a more comprehensive database of water systems (Beecher et al. 2021). Future and ongoing national and multi-state analysis could greatly benefit from better national system spatial location information and more efficient ways to incorporate SDWIS data. We recognize that there are several ongoing efforts which may yield great progress along these fronts in terms of improved understanding of water system structures and governance (GAO 2021).

This study expands upon previous state and metro-specific bill variation analyses in multiple ways which can inform future efforts. However, this study does not provide definitive answers on the best metrics to compare local bill variation at the low or high end, or factors contributing to this variance. Water bill levels have historically been and remain largely a local matter with some state oversight. While we find consistent averages across states, we find very high levels of bill variation at the local and regional scales. Significant variation in bill levels, as opposed to water quality, may be inevitable and justifiable. Moreover, external policy and planning efforts vary in their ability to influence the correlates of high bills we identify. That being said, substantial disparities at local levels still raise concerns regarding both environmental and social justice and the financial sustainability of water systems. Accordingly, such disparities should motivate consideration of various policy options, including (but not limited to) increased and equitably allocated federal and state water infrastructure funding, assistance to promote systems' technical managerial financial (TMF) capacity, potential consolidation, customer assistance and affordability programs, and equitable rate design guidance, for systems with extreme bill levels.

Further assessment is needed if the goal is to specify thresholds of concern for bill level differences, much less how to address local disparities and inequalities. Regardless of the extent of desire to intervene to address local bill disparities, understanding this variation is important in the context of affordability and larger environmental justice efforts. Overall, our analysis helps fill an ongoing gap in national studies of water bills that consider the influence of system-level and regional factors on water system TMF and customer affordability, and helps inform ongoing efforts and pressing next steps to expand data collection and needs analysis efforts nationally.

7. References

Allaire, M., Wu, H., & Lall, U. (2018). National trends in drinking water quality violations. *Proceedings of the National Academy of Sciences, 115*(9), 2078-2083.

Alliance for Water Efficiency (AWE). (2021). A Review of Connection Fees and Service Charges by Meter Size. Available at https://www.allianceforwaterefficiency.org/sites/www.allianceforwaterefficiency.org/files/highlight_documents/AWE-Meter-Size-Connection-Fee-Research.pdf

American Water Works Association (2017). *M1 Manual: Water Rates, Fees, and Charges*. 7th edition.

Beecher, J. (2018). "Potential for Economic Regulation of Michigan's Water Sector: Policy Brief for the Incoming 2019 Gubernatorial Administration," Michigan State University, November 7-8, 2018. https://ipu.msu.edu/wp-content/uploads/2018/12/Policy-Brief-for-the-Incoming-2019-Gubernatorial-Administration.pdf.

Beecher, J., Redican, K., & Kolioupoulos, M. (2021). (Mis)Classification of Water Systems in the United States. Available at SSRN: http://dx.doi.org/10.2139/ssrn.3627915

Beecher, J., & Gould, T. (2018). Pricing wastewater to save water: Are theory and practice transferable?. *SystemsSystems Policy*, *52*, 81-87.

Beecher, J. (1994). Water affordability and alternatives to service disconnection. *Journal—American Water Works Association,* 86 (10), 61-72. https://doi.org/10.1002/j.1551-8833.1994.tb06261.x

Brown, C., & Heller, L. (2017). Affordability in the provision of water and sanitation series: Evolving strategies and imperatives to realise human rights. *International Journal of Water Governance*, 5(2), 19–38. https://doi.org/10.7564/16-IJWG128

Butts, R., & Gasteyer, S. (2011). More Cost per Drop: Water Rates, Structural Inequality, and Race in the United States—The Case of Michigan. *Environmental Practice, 13*(4), 386-395.

Cardoso, D., & Wichman, C. (2020). Water affordability in the United States. Working Paper *Manuscript submitted to Water Resources Research*, 1-24. See http://caseyjwichman.com/wp-content/uploads/2022/04/wa_wp.pdf.

Chica-Olmo, J., González-Gómez, F., & Guardiola, J. (2013). Do neighbouring municipalities matter in water pricing?. *Urban Water Journal*, 10(1), 1-9.

García-Valiñas, M. A., Martínez-Espiñeira, R., & González-Gómez, F. (2010a). Affordability of residential water tariffs: Alternative measurement and explanatory factors in southern Spain. *Journal of Environmental Management*, 91(12), 2696–2706. https://doi.org/10.1016/j.jenvman.2010.07.029

Gregory, Ted; Reyes, Cecilia; O'Connell, Patrick M.; and Caputo, Angela; Same Lake, Unequal Rates: Why our water rates are surging – and why black and poor suburbs pay more. (October 25, 2017). Chicago Tribune, Available at http://graphics.chicagotribune.com/news/lake-michigan-drinking-water-rates/index.html;

Honey-Rosés, J.; David Gill, Claudio Pareja (March 2016), British Columbia Municipal Water Survey 2016. have illustrated intra-Metro area disparities in drinking water bill levels

Hoque, S. F., & Wichelns, D. (2013). State-of-the-art review: Designing urban water tariffs to recover costs and promote wise use. *International Journal of Water Resources Development*, 29(3), 472–491. https://doi.org/10.1080/07900627.2013.828255

Levine, L. (September 13, 2022). “NJ Adopts Nation’s Best Water Affordability Transparency Law.” https://www.nrdc.org/experts/larry-levine/nj-adopts-nations-best-water-affordability-transparency-law

Manson, S., Schroeder, J., Van Riper, D., Kugler, T., & Ruggles, S. (2021). IPUMS National Historical Geographic Information System: Version 16.0 [dataset]. Minneapolis, MN: IPUMS. 2021. http://doi.org/10.18128/D050.V16.0

Marcillo, C., Krometis, L. A., & Krometis, J. (2021). Approximating Community Water System Service Areas to Explore the Demographics of SDWA Compliance in Virginia. *International Journal of Environmental Research and Public Health*, *18*(24), 13254

McDonald, Y.J., & Jones, N.E. (2018). Drinking Water Violations and Environmental Justice in the United States, 2011-2015. *American Journal of Public Health, 108*(1), 1401-1407.

McDonald, Yolanda J., Kayla M. Anderson, Mariah D. Caballero, Ke Jack Ding, Douglas H. Fisher, Caroline P. Morkel, and Elaine L. Hill. "A systematic review of geospatial representation of United States community water systems." *AWWA Water Science* 4, no. 1 (2022): e1266.

Onda, K. S., & Tewari, M. (2021). Water systems in California: Ownership, geography, and affordability. *SystemsSystems Policy*, *72*, 101279.

Patterson, L. A., & Doyle, M. W. (2021). Measuring water affordability and the financial capability of systemssystems. *AWWA Water Science*, *3*(6), e1260.

Pierce, G., Lai, L., & DeShazo, J. R. (2019). Identifying and addressing drinking water system sprawl, its consequences, and the opportunity for planners’ intervention: evidence from Los Angeles County. *Journal of Environmental Planning and Management*, *62*(12), 2080-2100.

Pierce, G., Chow, N., DeShazo, J.R., & Gmoser-Daskalakis, K. (2020). Recommendations for Implementation of a Statewide Low-Income Water Rate Assistance Program. California State Water Resources Control Board Report. https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/assistance/docs/ab401_report.pdf

Pierce, G., El-Khattabi, A. R., Gmoser-Daskalakis, K., & Chow, N. (2021). Solutions to the problem of drinking water service affordability: A review of the evidence. *Wiley Interdisciplinary Reviews: Water*, e1522.

Rockaway, T. D., Coomes, P. A., Rivard, J., & Kornstein, B. (2011). Residential water use trends in North America. Journal-American Water Works Association, 103(2), 76-89.

Rubin, S. (2013). Evaluating violations of drinking water regulations. Journal-American Water Works Association, 105(3), E137-E147.

Scott, T. A., Moldogaziev, T., & Greer, R. A. (2018). Drink what you can pay for: Financing infrastructure in a fragmented water system. *Urban Studies*, *55*(13), 2821-2837.

Teodoro, M. P. (2019a). Water and sewer affordability in the United States. AWWA Water Science, 1(2), e1129.

Teodoro, M.P. (2019b). Water & Sewer Service Affordability in Ohio: Assessment & Opportunities for State Policy. Report to the Alliance for the Great Lakes & Ohio Environmental Council. https://greatlakes.org/wp-content/uploads/2019/11/AGLOEC-Affordability-Final-Report_1Nov2019.pdf

Teodoro, M. P., & Saywitz, R. R. (2020). A snapshot of water and sewer affordability in the United States, 2019. Journal—American Water Works Association, 112(8), 10–19.

Thorsten, R. E., Eskaf, S., & Hughes, J. (2009). Cost plus: Estimating real determinants of water and sewer bills. *Public Works Management & Policy*, *13*(3), 224-238.

University of North Carolina Environmental Finance Center (UNC EFC). (2017). Navigating Legal Pathways to Rate-Funded Customer Assistance Programs. Retrieved from https://efcnetwork.org/navigating-legal-pathways-to-rate-funded-customer-assistance-programs/

University of North Carolina Environmental Finance Center (2019). "Water and Wastewater Rates and Rate Structures in Arizona as of July 2019 (Residential Water Structure tab)." See https://efc.sog.unc.edu/resource/arizona-rates-resources/

University of North Carolina Environmental Finance Center, Glenn Barnes (2019). The Perils of Comparing Water Rates. See https://efc.web.unc.edu/2019/02/12/the-perils-of-comparing-water-rates/.

U.S. Census Bureau. (2021). The American Housing Survey. Washington, DC: Author. Retrieved from https://www.census.gov/programs-surveys/ahs.html

U.S. Cybersecurity and Infrastructure Agency (2021). "Water and Wastewater Systems Sector" https://www.cisa.gov/water-and-wastewater-systems-sector

U.S. Government Accountability Office, 2021. Private Water SystemsSystems: Actions Needed to Enhance Ownership Data. See https://www.gao.gov/assets/gao-21-291.pdf

Zhang, X., Rivas, M. G., Grant, M., & Warner, M. E. (2021). Water pricing and affordability in the US: public vs private ownership.

8. Appendix 1: Additional Descriptive Statistics

Figure A-1: System Ownership by State for Water Systems

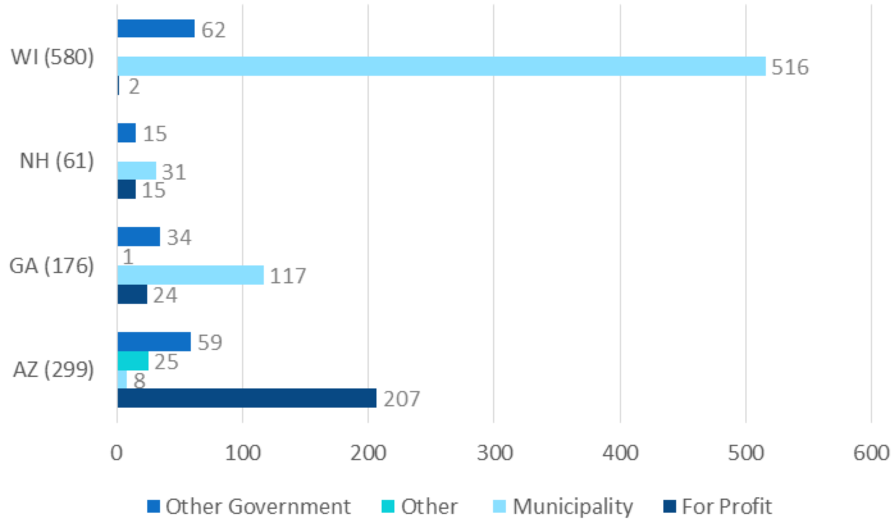


Figure A-2: System Ownership by State for Sewer Systems

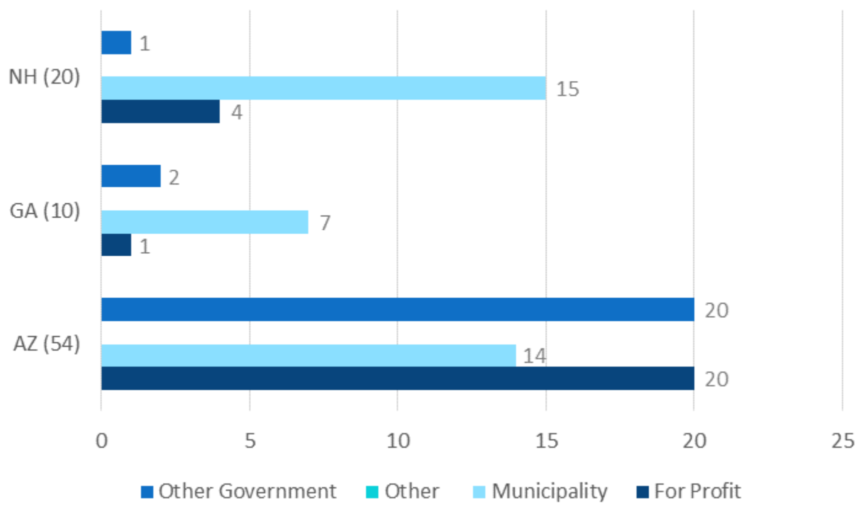


Figure A-3: System Ownership by State for Combined Water & Sewer Systems

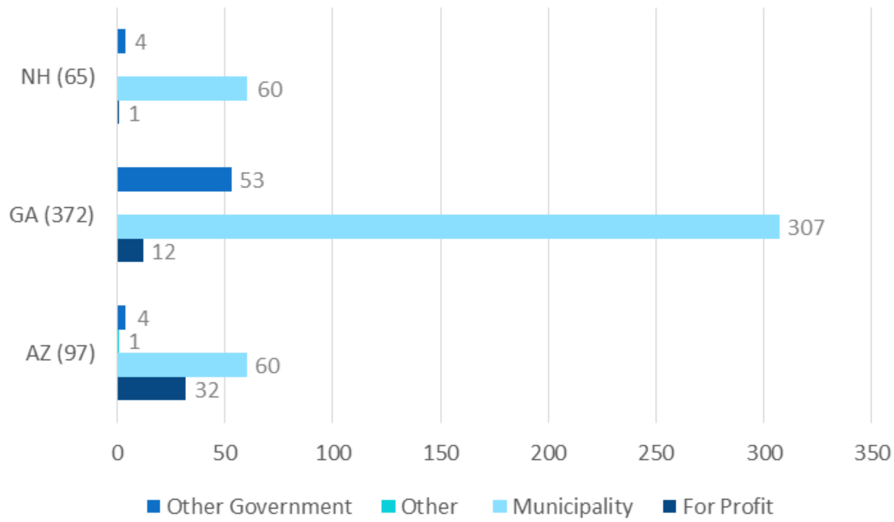


Table A-1. Bivariate Correlations for Water Quality and Socio-Economic Variables (* indicates significance at p-value <0.05)

	M & R Violations	Health Violations	Service Pop	Rate (0 Gal)	Rate (4k Gal)	Rate (5k Gal)	Non-White	Hispanic Latino	Med HHI	<100% FPL
M & R Violations										
Health Violations	0.24*									
Service Pop	0.06	0.01								
Rate (0 Gal)	0.06	0.03	-0.12*							
Rate (4k Gal)	0.02	0.04	-0.11*	0.76*						
Rate (5k Gal)	0.02	0.04	-0.10*	0.70*	0.92*					
Non-White	-0.04	0.01	0.12*	-0.22*	-0.31*	-0.30*				
Hispanic Latino	0.25*	0.07*	0.09*	0.10*	-0.00	-0.01	0.06			
Med HHI	0.01	0.02	0.07*	0.04	0.13*	0.13*	-0.40*	-0.09*		
<100% FPL	-0.01	-0.00	0.00	-0.15*	-0.22*	-0.22*	0.59*	0.15*	-0.70*	
<200% FPL	-0.01	-0.01	-0.02	-0.11*	-0.20*	-0.20*	0.54*	0.22*	-0.83*	0.86*

Table A-2. Overview of Systems with Available Data for Analysis

Data Type	Number	Notes
Total Systems with Billing Data (from Phase I)	1721	Systems used in regressions for Phase I
Total Water Systems with Billing Data (from Phase I)	1637	Systems with water or both water and sewer (sewer providers lack water quality data for Phase I)
Total Water Systems with Violation Data Available	1558	Systems found with violation data in SDWIS
Total Water Systems with Rate, Violation, and Census Data Available Total Water Systems with CDP level Census Data Total Water Systems with County level Census Data	1558 1373 185	All systems paired with a CDP or County if CDP unavailable Note: 5 systems primarily served consolidated city-counties (data was technically CDP level though is a county)

9. Appendix 2: Additional Model Results

Table A-3. Phase 1 Linear Regression Model Specifications for 4,000 Gallon Monthly Water Bill Levels

Predictor	State FE Model Coefficients (Standard Error in Parentheses)	MSA FE Model Coefficients (Standard Error in Parentheses)
Cost of 4k Gallons in Neighboring Systems	0.767*** (0.077)	0.691*** (0.211)
Ownership: Municipal	-2.984** (1.380)	-3.729** (1.551)
Baseline Monthly Allowance	-4.153*** (0.945)	-4.152*** (1.139)
Ownership: Other	3.326 (2.744)	2.143 (2.956)
Ownership: Other Government	0.305 (1.511)	1.078 (1.722)
Rate: Flat	1.044 (2.828)	-0.892 (3.7945)
Rate: Increasing Block	-0.362 (1.511)	-0.920 (1.849)
Rate: Other Block	-0.524 (3.265)	-2.067 (4.028)
Rate: Uniform	-0.086 (1.284)	-1.855 (1.562)
Service Population	-0.00002*** (0.00001)	-0.00002*** (0.00001)
Source: Purchase	4.229*** (1.152)	4.784*** (1.425)
Source: Surface	-0.317 (1.191)	0.630 (1.457)
Constant	5.830* (3.438)	9.873 (9.034)
Observations Adjusted R2 F Statistic	1,549 0.242 33.930*** (df=15)	1,155 0.178 4.793*** (df=66)
Robust standard errors in parentheses. ** indicates significance at .05 p-value (95%) level, *** indicates significance at .01 p-value (99%) level		

Table A-4. Main model including systems matched with county census data

Predictor	State Fixed Effects	MSA Fixed Effects
Cost of 4k Gallons in Neighboring Systems	0.836*** (0.083)	0.971*** (0.117)
Monthly Baseline Allowance	-4.965*** (0.886)	-5.164*** (0.909)
Ownership: Municipality	-1.664 (1.389)	-2.071 (1.423)
Ownership: Other Government Type	1.880 (1.442)	1.404 (1.477)

Prop. Population Non-White	-5.429*** (2.100)	-5.490** (2.211)
Prop. Population Under 100% FPL	-5.911 (5.682)	-7.448 (5.893)
Rate Structure: Flat	-0.550 (2.767)	-2.002 (2.862)
Rate Structure: Increasing Block	-2.184* (1.270)	-2.477* (1.326)
Rate Structure: Other Block	-3.500 (3.066)	-4.680 (3.119)
Rate Structure: Uniform Volumetric	-1.178 (1.136)	-1.616 (1.168)
Service Population	-0.00002*** (0.00001)	-0.00002*** (0.00001)
Source: Purchase	2.837** (1.126)	3.330*** (1.205)
Source: Surface	-0.232 (1.145)	0.267 (1.231)
Total Health-Based Violations	0.059 (0.038)	0.062 (0.039)
Total Monitoring and Reporting Violations	-0.006 (0.008)	-0.006 (0.008)
Constant	10.877*** (4.092)	9.997* (5.486)
Spatial FE	State	MSA
Observations	1,555	1,555
R^2	0.252	0.283
Adjusted R^2	0.243	0.248
Residual Std. Error	12.872 (df = 1536)	12.829 (df = 1481)
F Statistic	28.707*** (df = 18; 1536)	8.022*** (df = 73; 1481)

Note: Robust standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01

Table A-5. Main model substituting FPL for GINI index

Predictor	State Fixed Effects	MSA Fixed Effects
Cost of 4k Gallons in Neighboring Systems	0.821*** (0.086)	0.958*** (0.123)
Monthly Baseline Allowance	-4.819*** (0.938)	-5.037*** (0.970)
Ownership: Municipality	-3.819** (1.542)	-3.914** (1.597)
Ownership: Other Government Type	-0.824 (1.688)	-0.794 (1.732)
Prop. Population Non-White	-6.662*** (2.357)	-6.239** (2.480)
Prop. Population Under 100% FPL	0.447 (4.242)	-0.324 (4.568)
Rate Structure: Flat	-0.797 (3.129)	-1.547 (3.230)

Rate Structure: Increasing Block	-2.422* (1.295)	-2.946** (1.361)
Rate Structure: Other Block	-3.674 (3.169)	-4.652 (3.233)
Rate Structure: Uniform Volumetric	-1.062 (1.144)	-1.532 (1.178)
Service Population	-0.00002*** (0.00001)	-0.00002*** (0.00001)
Source: Purchase	1.726 (1.233)	1.983 (1.314)
Source: Surface	-0.339 (1.198)	0.164 (1.290)
Total Health-Based Violations	0.051 (0.038)	0.055 (0.039)
Total Monitoring and Reporting Violations	-0.001 (0.008)	-0.001 (0.008)
Constant	9.206*** (3.500)	7.543 (5.413)
Spatial FE	State	MSA
Observations	1,387	1,387
R^2	0.263	0.293
Adjusted R^2	0.253	0.254
Residual Std. Error	12.626 (df = 1368)	12.621 (df = 1313)
F Statistic	27.072*** (df = 18; 1368)	7.448*** (df = 73; 1313)

Note: Robust standard errors in parentheses. $^{*}p<0.10$ $^{**}p<0.05$ $^{***}p<0.01$

Table A-6. Main Model excluding systems with population under 500

Predictor	State Fixed Effects	MSA Fixed Effects
Cost of 4k Gallons in Neighboring Systems	0.730*** (0.088)	0.869*** (0.125)
Monthly Baseline Allowance	-3.724*** (0.948)	-3.533*** (0.983)
Ownership: Municipality	-3.605** (1.574)	-3.534** (1.637)
Ownership: Other Government Type	-0.231 (1.723)	-0.503 (1.779)
Prop. Population Non-White	-6.102*** (2.239)	-6.058** (2.385)
Prop. Population Under 100% FPL	-7.896 (6.455)	-12.298* (6.810)
Rate Structure: Flat	6.681 (5.232)	7.450 (5.457)
Rate Structure: Increasing Block	-2.253* (1.348)	-2.383* (1.424)
Rate Structure: Other Block	-2.771 (3.124)	-3.226 (3.179)

Rate Structure: Uniform Volumetric	-0.069 (1.221)	-0.633 (1.278)
Service Population	-0.00002*** (0.00001)	-0.00001*** (0.00001)
Source: Purchase	2.931** (1.157)	3.432*** (1.262)
Source: Surface	0.593 (1.123)	1.214 (1.234)
Total Health-Based Violations	0.021 (0.038)	0.022 (0.039)
Total Monitoring and Reporting Violations	-0.002 (0.008)	-0.003 (0.008)
Constant	13.882*** (4.518)	10.588* (6.181)
Spatial FE	State	MSA
Observations	1,185	1,185
R^2	0.243	0.281
Adjusted R^2	0.232	0.234
Residual Std. Error	11.986 (df = 1166)	11.970 (df = 1111)
F Statistic	20.835*** (df = 18; 1166)	5.946*** (df = 73; 1111)

Note: Robust standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01

Table A-7. Arizona-only model w CDP matched data

Predictor	State Fixed Effects	MSA Fixed Effects
Cost of 4k Gallons in Neighboring Systems	0.634** (0.286)	0.321 (0.820)
Monthly Baseline Allowance	-6.052*** (2.134)	-6.410*** (2.225)
Ownership: Municipality	-2.469 (2.288)	-3.307 (2.435)
Ownership: Other Government Type	6.680*** (2.348)	6.358** (2.481)
Prop. Population Non-White	-4.845 (6.525)	-1.755 (7.040)
Prop. Population Under 100% FPL	8.904 (10.544)	7.300 (11.057)
Rate Structure: Flat	21.942 (13.392)	24.166* (13.908)
Rate Structure: Increasing Block	14.447 (9.504)	15.159 (9.919)
Rate Structure: Other Block	16.061 (16.566)	15.781 (17.304)
Rate Structure: Uniform Volumetric	8.299 (9.572)	9.469 (9.887)
Service Population	-0.00001 (0.00001)	-0.00001 (0.00001)

Source: Purchase	4.912 (4.786)	4.418 (4.964)
Source: Surface	-1.430 (2.966)	-0.824 (3.269)
Total Health-Based Violations	0.233* (0.121)	0.270** (0.128)
Total Monitoring and Reporting Violations	-0.007 (0.009)	-0.007 (0.009)
Constant	-2.577 (14.497)	9.571 (29.776)
Spatial FE	State	MSA
Observations	269	269
R^2	0.187	0.207
Adjusted R^2	0.132	0.107
Residual Std. Error	13.198 (df = 251)	13.391 (df = 238)
F Statistic	3.403*** (df = 17; 251)	2.066*** (df = 30; 238)

Note: Robust standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01

Table A-8. Arizona-only model w Shapefile-Block Group matched data

Predictor	State Fixed Effects	MSA Fixed Effects
Cost of 4k Gallons in Neighboring Systems	0.623** (0.287)	0.360 (0.819)
Monthly Baseline Allowance	-6.012*** (2.137)	-6.410*** (2.227)
Ownership: Municipality	-2.173 (2.304)	-3.079 (2.451)
Ownership: Other Government Type	6.759*** (2.349)	6.405** (2.483)
Prop. Population Non-White	-3.245 (6.333)	-0.423 (6.813)
Prop. Population Under 100% FPL	-0.623 (11.998)	0.404 (13.179)
Rate Structure: Flat	21.235 (13.418)	23.657* (13.955)
Rate Structure: Increasing Block	13.903 (9.497)	14.723 (9.906)
Rate Structure: Other Block	16.624 (16.599)	16.152 (17.384)
Rate Structure: Uniform Volumetric	8.089 (9.583)	9.313 (9.894)
Service Population	-0.00001 (0.00001)	-0.00001 (0.00001)
Source: Purchase	4.973 (4.798)	4.460 (4.982)
Source: Surface	-1.865 (2.950)	-1.091 (3.289)

Total Health-Based Violations	0.246** (0.120)	0.280** (0.128)
Total Monitoring and Reporting Violations	-0.006 (0.009)	-0.006 (0.009)
Constant	-0.622 (14.357)	9.396 (29.806)
Spatial FE	State	MSA
Observations	269	269
R^2	0.185	0.205
Adjusted R^2	0.130	0.105
Residual Std. Error	13.216 (df = 251)	13.404 (df = 238)
F Statistic	3.352*** (df = 17; 251)	2.048*** (df = 30; 238)

Note: Robust standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01

Table A-9. Initial model of sewer bills (no water quality compliance variables)

Predictor	Sewer- State FE Model Coefficients (Standard Error)	Sewer- MSA FE Model Coefficients (Standard Error)
Cost of Bill in Neighboring Systems	0.389*** (0.126)	0.351 (0.250)
Monthly Baseline Allowance	-3.131*** (1.195)	-1.910 (1.540)
Ownership: Municipal	-6.615** (2.662)	-6.422** (3.031)
Ownership: Other Government	0.330 (3.225)	-0.604 (3.763)
Rate Structure: Flat	-1.021 (7.210)	-0.537 (8.987)
Rate Structure: Increasing Block	4.630 (4.613)	5.061 (6.047)
Rate Structure: Other Block	6.205 (6.250)	11.147 (8.230)
Rate Structure: Uniform	3.348 (4.535)	3.512 (5.884)
Service Population	-0.00001 (0.00001)	-0.0000 (0.00001)
Source: Purchase	-0.941 (1.830)	-1.123 (2.383)
Source: Surface	0.279 (1.567)	0.087 (2.034)
Constant	21.815*** (6.693)	19.295* (10.605)
Observations Adjusted R2 F Statistic	507 0.218 11.861*** (df=13)	386 0.158 2.447*** (df=50)

Note: Robust standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01