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The Cost of Water: A Study of How Socioeconomic Factors Impact Water Bills in Austin, Texas

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The Cost of Water: A Study of How Socioeconomic Factors Impact Water Bills in Austin, Texas

by

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Abstract

The Cost of Water: A Study of How Socioeconomic Factors Impact Water Bills in Austin, Texas

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Water providers in Central Texas must adapt, expand, and renew drinking water infrastructure in the coming years to contend with increased drought and flooding wrought by climate change, accommodate the region's growing population, and confront issues of aging and failing infrastructure. Many utilities will turn to increasing water rates to fund these improvements, potentially making water inaccessible for poorer residents. In the face of these looming rate increases, this study uses a lens of water equity to examine how socioeconomic factors, many of which are linked to histories of racism, may affect household water costs. I compare water usage data for both single and multi-family households in Austin, Texas to each household's housing typology, income, owner-renter status, race/ethnicity, social vulnerability, level of heat exposure and home age using regression analysis, correlational analysis, and descriptive statistics. My findings indicate that a household's status as an owner or renter was the most statistically significant determinant of its monthly water costs. This suggests that utilities hoping to improve water equity should focus on affordability and conservation programs for renters.

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Chapter 1: Introduction

The city of Austin ("the City") is a growing metropolis located along the banks of the Colorado River, home to a robust real estate market, a thriving tech and manufacturing sector, and 974,500 (and counting) people (*U.S. Census Bureau QuickFacts*, 2022). For the last several decades, Austin has been characterized by growth: the population in Austin has increased by 32 percent since 2000 (*U.S. Census Bureau QuickFacts*, 2022). Lake Austin, a reservoir along the Colorado River, supplies Austin with its drinking water, and Austin Water is the city-owned utility in charge of pumping, treating and distributing that water to the City's people and businesses. As Austin's population grows, so too does the anticipated water demand. City officials estimate that by 2115, Austin's nearly 4M residents will require 236% more water than it does today (Neely, 2018; *Water Forward*, 2018). At the same time, a historic drought from 2008 to 2016 and increasingly hot and dry summers have led hydrologists to doubt the long-term viability of the Colorado River as Austin's sole source of drinking water (Neely, 2018; *Water Forward*, 2018). As a result, Austin Water has begun to explore alternative water sources and more aggressive demand management strategies.

Adapting to growth and a changing climate will not be cheap tasks for utilities moving forward. Utilities across Central Texas are planning to expand and diversify their water supply portfolios to prepare for droughts that climatologists project will become longer, hotter, and drier over the next fifty years (Hayhoe, 2014; *Water Forward*, 2018). Furthermore, climate projections indicate that wet periods in Central Texas will become more intense, thus impacting the extent of the 100-year floodplain (Hayhoe, 2014). This extension of the floodplain will ultimately require updates, expansions, and retrofits to water and wastewater treatment infrastructure. Nationally, updates to infrastructure to prepare for and adapt to the impacts of climate change may cost up to $36B by 2050 (Jones & Moulton, 2016).

In addition to preparing for growth alongside the existential threat of climate change, utilities must have funds available to repair and replace existing water systems. The last major federal investment in water infrastructure was in the 1970s with the passage of the Clean Water Act. Since then, there has been a 77% decline in federal funding for water infrastructure (*Public Spending on Transportation and Water Infrastructure, 1956 to 2017*, 2018). In the 50-plus years since this investment, much of the water infrastructure has reached the end of its lifespan and significant reinvestment is needed to update and modernize America's water infrastructure. American Water Works Association (AWWA) estimates that $1T will be needed over the next 25 years to replace water systems built in the mid-twentieth century (*Buried No Longer*, 2012). Based on age of infrastructure and regional growth, the Southern United States will likely require the greatest level of investment in water main replacement (*Buried No Longer*, 2012). Water utilities need significant additional funding to cover these expenses – and it is probable that these costs will fall on the utility customers (Baird, 2010).

To fill the funding gap created by these challenges, many utilities will need to increase their rates. Many already are – between 2000 and 2014, water rate increases far outstripped the Consumer Price Index (CPI) (Stratton et al., 2017). Although Austin Water has not increased rates for customers since 2018, reports show that water bills in Austin rose 154 percent between 2010 and 2018 (Lakhani, 2020). While it will undoubtedly vary among utilities and depending on local factors and economic conditions, some estimates predict that water costs will triple or quadruple for consumers (Baird, 2010; *Buried No Longer*, 2012).

Austin Water states that household water and sewage bills account for, on average, 1.21 percent of median household income (MHI) for their customers in 2022 (Austin Water, 2022); however, this statistic may have more to do with the influx of high-paying jobs and rising MHI than the affordability of water. For example, in 2018, AW reported that the average annual water bill accounted for 1.36 percent of the City's MHI. In the same year, 60 percent of the City's low-income households spent over 4 percent of their income on water bills (with 15 percent of these households spending over 12 percent of their income) (Lakhani, 2020). These statistics speak to the inequity that is likely to play out as cities raise water rates: water, a basic necessity, may become increasingly inaccessible for poorer residents, who are disproportionately people of color.

This professional report will dive deeper into water (un)affordability within the Austin, Texas region, using historical meter data to understand how racial and socioeconomic factors may affect water usage and thus water costs. Furthermore, this report aims to contextualize those racial and socioeconomic factors and link the financial burden of water today to past and present injustices.

Chapter 2 introduces the lens through which this research was undertaken: Water equity. Here, water equity refers to a condition wherein all communities have equal access to safe, clean, and affordable drinking water services. The literature review also enumerates past challenges with quantifying water affordability and explores ways in which various socioeconomic factors may be linked to water usage.

Chapter 3 provides local context about Austin and its publicly owned utility, Austin Water. In this section, readers may begin to understand how present-day socioeconomic factors are linked to historical injustices. In addition, Chapter 3 describes how Austin Water is currently working to improve water conservation and affordability.

Chapter 4 presents the data used in this study and outlines the methodology used to draw conclusions. I also review the limitations of the data and the assumptions required to complete the study.

Chapter 5 reviews the findings of the quantitative study, examining the singular influence of seven different socioeconomic factors: household type, income bracket, household owner-renter status, race/ethnicity, social vulnerability, heat exposure, and home age.

Chapter 6 contextualizes these findings and makes recommendations for future areas of study that will further improve water equity in Central Texas and nationally.

Chapter 2: Water Equity Literature Review

Water affordability is a key component of water equity (Fox & Shafer, 2021; Osman & Faust, 2021). Valuable research has focused on measuring the true state of water affordability in the United States on a nationwide basis and projecting its future impacts; however, reports stress significant variability in water pricing and income levels at this scale (Cardoso & Wichman, 2022; Mack & Wrase, 2017). This report focuses solely on the Austin, Texas metropolitan area, and uses an intersectional framework to place the financial burden of household water bills within the context of historical and ongoing racial and economic inequities. Water bills are compared to factors such as income level, home age, home size, renter-owner status, and urban heat. First, I will explore scholarship focused on defining water equity, and lay out the definition and framework upon which this study builds. Next, I will review research that outlines the difficulty of measuring water unaffordability and highlights the underexplored nature of water unaffordability for low-income communities. Lastly, I will examine how socioeconomic factors may contribute to levels of water use.

DEFINING WATER EQUITY

Recent scholarship has aimed to conceptualize and operationalize a definition of water equity (i.e., equity as it relates to water infrastructure services) (Fox & Shafer, 2021; Osman & Faust, 2021). U.S. Water Alliance presents water equity as occurring "when all communities have access to safe, clean, affordable drinking water and wastewater services; are resilient in the face of floods, drought, and other climate risks; have a role in decision-making processes related to water management in their communities; and share in the economic, social, and environmental benefits of water systems" (2021, p. 12). Osman and Faust distill this concept, defining water equity as "the provision of a consistent minimum quality and quantity, determined at a local level, of water services to all end-users" (2021, p. 1850). Notably, this definition of water equity stresses that water quality, affordability, and access should be determined in a local context. Situating research within this standardized framework of water equity allows for consistency across disciplines and improves transparency and accountability for water utilities (Osman & Faust, 2021). Furthermore, it is necessary to root analyses of water infrastructure services in equity rather than equality, as equal policies may perpetuate historic disinvestment and discrimination (Fox & Shafer, 2021; Harding & Holdren, Jr, 1993).

Gerlak et al. (2022) have called for an intersectional understanding of water equity, such that water quality, affordability, and access are framed as products of underlying power structures, such as segregation, racial capitalism, and settler colonialism. While most research related to water equity thus far has focused on water affordability, they argue that this should not be understood as distinct from water access or water quality but rather, deeply linked (Gerlak et al., 2022). Using an intersectional approach to understanding water affordability and water equity more broadly can extricate the "multiple axes of marginality" at work and link current inequities to histories of oppression and racism (Gerlak et al., 2022, p. 2).

IDENTIFY THE CHALLENGES TO UNDERSTANDING WATER AFFORDABILITY

Measuring water affordability at a national scale is challenging, as there is no national database of community level water rates, nor is there a federally enforceable standard of water affordability (Mack & Wrase, 2017). Income-based benchmarks are the most common way that researchers understand water affordability (Cardoso & Wichman, 2022; Mack & Wrase, 2017). The U.S. Environmental Protection Agency (EPA) recommends that a household spend no more than 2.0 to 2.5% of its income on water charges and no more than 4.5% of its income on combined water and sewer charges (*Affordability Criteria for Small Drinking Water Systems: An EPA Science Advisory Board Report*, 2002; Mack & Wrase, 2017). Because the EPA benchmark relies on median household income (MHI) metrics to measure water affordability, research has critiqued it as overly general and ineffective for measuring affordability in low-income households (Cardoso & Wichman, 2022; Teodoro, 2018).

Recent research has attempted to go beyond MHI to understand water affordability issues for low-income households at a nationwide scale (Cardoso & Wichman, 2022; Mack & Wrase, 2017). Mack and Wrase (2017) call attention to a "burgeoning affordability crisis", identifying almost 12 percent of households in 2014 as paying more than 4.5% of their income and projecting this share to increase to over 35% if water rates rise by 41% and household incomes remain relatively stagnant. For context, water and sewer rates increased nationally by 41% between 2010 and 2015, and by 154% in Austin between 2010 and 2018 (Lakhani, 2020; Walton, 2015). To compute these statistics, Mack and Wrase (2017) utilize a standard water rate and volume of water usage across the US, calculate the minimum annual household income needed to meet the EPA affordability standard, and then identify census tracts where the MHI is below this level. While this methodology provides valuable insight into nationwide issues with water affordability, its scale and assumptions limit its accuracy.

Recent scholarship has contended that researchers can improve the accuracy of their evaluations by utilizing community-level water rates, a minimum essential volume of water, and full income distribution rather than MHI (Cardoso & Wichman, 2022; Patterson & Doyle, 2021; Teodoro, 2018). With this methodology, Cardoso and Wichman estimate that households in the lowest decile of earners spend, on average, 6.8% of their annual income on water and sewer services and roughly 10% of households nationally exceed the

4.5% benchmark set by the EPA (2022). The study also demonstrates that water unaffordability is positively correlated with the proportion of Black households after conditioning on poverty levels (Cardoso & Wichman, 2022).

To improve accuracy in measures of affordability, it is necessary to incorporate local nuance into analyses, comparing water prices and income data at a community level (Cardoso & Wichman, 2022; Mack & Wrase, 2017; Teodoro, 2018). While initial analyses of water affordability have attempted to provide this (Cardoso & Wichman, 2022), few have tailored to the study to a specific city or utility. In addition, while some researchers have included a cursory statistical analysis of how socioeconomic factors impact water unaffordability (Cardoso & Wichman, 2022; Mack & Wrase, 2017), none have interrogated why these socioeconomic factors may impact water bills or explored the historical conditions that led to these socioeconomic conditions.

LINKING SOCIOECONOMIC FACTORS TO WATER BILLS

Research has demonstrated that water bills are a highly regressive charge, disproportionately impacting lower income households (Cardoso & Wichman, 2022). In addition, studies focused on conservation have highlighted how socioeconomic factors impact overall levels of water use (Harlan et al., 2009; Tinker et al., 2005; Willis et al., 2013). I aim to connect those areas of research by linking water use to water affordability and equity. In doing this, I will compare how renter-owner status and urban heat (both of which are deeply correlated to race) impact overall water use and thus water costs (Aurand et al., 2021; Benz & Burney, 2021; Snowden & Evangelou, 2022).

It has been well established by researchers that income correlates positively with water consumption (Corral-Verdugo et al., 2003; Hanak & Browne, 2006; Harlan et al., 2009; Willis et al., 2013). That said, research shows that higher incomes only correlate with increased water consumption up to a point (Domene & Saurí, 2006; Harlan et al., 2009; Martínez-Espiñeira & Nauges, 2004). A 2004 analysis of water consumption in Seville, Spain found that there is a baseline threshold of indoor water use that is fairly inelastic for all income levels (i.e., less likely to be immediately influenced by external factors like droughts, pricing changes, or income increases) (Martínez-Espiñeira & Nauges, 2004). A statistical analysis of water use in Austin, Texas found that appraised home value was the greatest predictor water consumption (Tinker et al., 2005). Harlan et al. conducted a study of water use in single family homes in Phoenix, Arizona and found that, of the many socioeconomic factors evaluated, home size had the most significant impact on water use; thus, Harlan et al. (2005) posits that while income is a "major determinant" of residential water consumption, this factor is "mediated primarily by the size of the house" (p. 704). In my research, I aim to normalize the results for home size (and thus, income) by measuring water costs on a per square foot basis.

I hypothesize that a household's renter-owner status will impact the volume of water use per square foot. A majority of renters residing in multi-family housing pay their water bill as a whole through their landlord or leasing agency (Davis, 2022). Because these renters are not the formal account holders, they often cannot access affordability programs designed for low-income water users (Davis, 2022). Utilities often classify these customers as "hard-to-reach renters", which Davis (2022) contends is racially coded language, given that 20 percent of Black households are classified as "extremely low-income renters" compared to six percent of white, non-Latino households (Aurand et al., 2021).

Renters who pay their water bills directly may also face affordability issues. Melvin (2018) found that landlords with tenants who pay the utility bill underinvest in energy efficiency measures. As a result, renters' energy bills are two percent higher than owner-occupied households (Melvin, 2018). Based on this, I extrapolate that landlord underinvestment due to split incentives would likely be applicable to water-efficient appliances as well. Furthermore, Millock and Nauges found that ownership status was a "strong predictor" of whether or not a household would install water-efficient appliances (Millock & Nauges, 2010, p. 539). Research has shown that high-efficiency appliances have significant impacts for indoor end uses such as showers and laundry; in fact, in Australia, households who purchased appliances such as efficient showerheads and low-flow washers recuperated their costs within two years (Willis et al., 2013). Due to landlord underinvestment, renters are less likely to be able to access the benefits of these appliances than homeowners.

Lastly, I hypothesize that increased heat correlates with higher water use. Research has shown that, due to historic disinvestment, neighborhoods with higher proportions of Black, Latino, and Asian residents experience higher temperatures than majority white areas (Benz & Burney, 2021). In a study of water use in China, Qin et al. (2022) found that increased municipal water usage may serve as a coping mechanism during extreme heatwave events; furthermore, the research demonstrated that during heatwaves, low-income households were more likely to substitute water use for electricity use to counter the heat. Additional studies in Phoenix, Arizona and Portland, Oregon have found that water demand increases as temperatures increase (Breyer et al., 2012; Guhathakurta & Gober, 2007). Guhathakurta and Gober (2007) demonstrated that a daily low temperature increase of 1° Fahrenheit in Phoenix correlated with an additional 290 gallons of water usage for a single-family household. Breyer et al. (2012) found that water use in Portland was even more responsive to temperature than water use in Phoenix. In Portland, the temperature sensitivity of water use increased as urban tree canopy (UTC) increased, likely because the prevalence of UTC corresponds to high-income households (Breyer et al., 2012); however, in Phoenix, the temperature sensitivity of water use increased as UTC decreased, which Breyer et al. (2012) assume is due to the higher rates of evapotranspiration in Phoenix. As a result, the hydrological effect of UTC presence dominates the consumptive effect of income (Breyer et al., 2012). As demonstrated by Breyer et al.'s research, these studies are highly dependent on regional climate; thus, replicating a similar study in Austin's geographic area would provide clarity

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As this review demonstrates, water equity is a growing field of study in the United States. In my research, I will employ an intersectional framework to explore how water affordability in Austin, Texas fits into the larger framework of water equity. Namely, I will investigate how socioeconomic factors impact water bills. This study will only examine water affordability; further research should examine how the other components of water equity (i.e., water quality and access), all of which are interconnected (Gerlak et al., 2022). As many studies suggest, the factors I am investigating vary significantly across the United States (Breyer et al., 2012; Cardoso & Wichman, 2022; Mack & Wrase, 2017; Osman & Faust, 2021); thus, it is important to research water affordability at a local scale in Austin. In doing this, I hope to illuminate how the legacies of injustice may continue to burden communities today.

Chapter 3: Austin in Context

It is impossible to contextualize the present-day socioeconomic, racial, and housing data in Austin without grappling with the history of the City's development. The following section will provide a basic history of the development of Austin and the city's publicly owned water utility, Austin Water Utility (Austin Water). Development trends and patterns, as well as Austin Water management decisions, inform my understanding of the quantitative data provided in the following chapter. First, I will provide a brief and incomplete history of the racialized nature of City's development, with a specific focus on water infrastructure and water resources. Then, I will discuss recent gentrification patterns in Austin. A high-level overview of Austin Water, including its management, funding mechanisms, and affordability programs, follows. Ultimately, both topics are far more complex and layered than as described herein and the following is meant only to provide local context for the quantitative findings discussed in Chapter 5.

AUSTIN'S HISTORY

In 1839, Texas lawmakers designated the small village of Waterloo, situated along the banks of the Colorado River and home to roughly 856 settlers, as the capital of their new republic (Kearl, n.d.). By the twentieth century, the village had transformed in a city. Renamed Austin for the ostensible "father of Texas" Stephen F. Austin, the Texas capital was now home to a capitol building, street grid system, university, and, crucially, a dam that stabilized the unpredictable Colorado River (Kearl, n.d.). The 60-foot dam, called the Austin Dam, was used to produce hydroelectric energy for seven years before it catastrophically failed and flooded parts of the City (Kearl, n.d.); however, it was replaced shortly thereafter and laid the foundation for the Highland Dams, a string of six dams along the Colorado River, which continue to supply hydroelectric power today and form the reservoirs known as the Highland Lakes, two of which are currently used as water supply (Wilson, 2018).

At the onset of the twentieth century, Black and Latino Austinites lived throughout the city; however, this changed when the City adopted a comprehensive race-based zoning plan in 1928 (Tretter, 2012). The 1928 Master Plan called for the establishment of racial districts, to segregate the City's Black, Hispanic, and white populations. The City created these racial districts through the zoning of racially-segregated municipal services, rather than through outright exclusionary racial zoning, which the Supreme Court had deemed unconstitutional in 1920 (Tretter, 2012). Black and Latino residents could only access city services, like public schools and sewer systems, in the so-called "Negro District", located in East Austin. Black residents living outside these bounds were denied water services and other basic infrastructure. In fact, a freedman colony in West Austin, Clarksville, did not have municipal water services until the 1970s (Gordon et al., 2023)

Redlining maps and restrictive racial covenants further reinforced the segregation and stratification of East and West Austin. As part of a larger effort to encourage home ownership in the aftermath of the Great Depression, the Home Owner's Loan Corporation (HOLC) developed a rating system to judge the soundness of financial investment based on neighborhood characteristics (Highsmith, 2015). The racial makeup of a neighborhood and the existence of restrictive racial covenants were major criteria in the HOLC rating (Highsmith, 2015). As a result, high-income whites-only neighborhoods were designated as the "best" place to invest, while low-income and minority neighborhoods were designated as "hazardous", in a process known as redlining (*Central Texas Fair Housing Assessment*, 2019). In Austin, the predominantly Black neighborhoods in East Austin were deemed hazardous, and those where Hispanic Austinites resided were found to be "definitely declining" (*Central Texas Fair Housing Assessment*, 2019). Austin's HOLC redlining maps from 1935 are shown in **Figure 1**.

Even after explicitly racist language was prohibited, agencies and banks continued to use these redlined maps and ratings to determine where to invest. For example, the Federal Housing Administration (FHA) encouraged homeownership by extending mortgage periods and incentivizing new single-family home construction; however, the FHA would not support financial investments in redlined neighborhoods, where Black residents lived (Highsmith, 2015). As a result, Black Austinites were excluded from the FHA's creation and subsidization of the middle class. This also led to widespread disinvestment in communities of color, which manifested in the large gaps between the development of services and amenities in East and West Austin. These gaps persisted long after city services were desegregated.

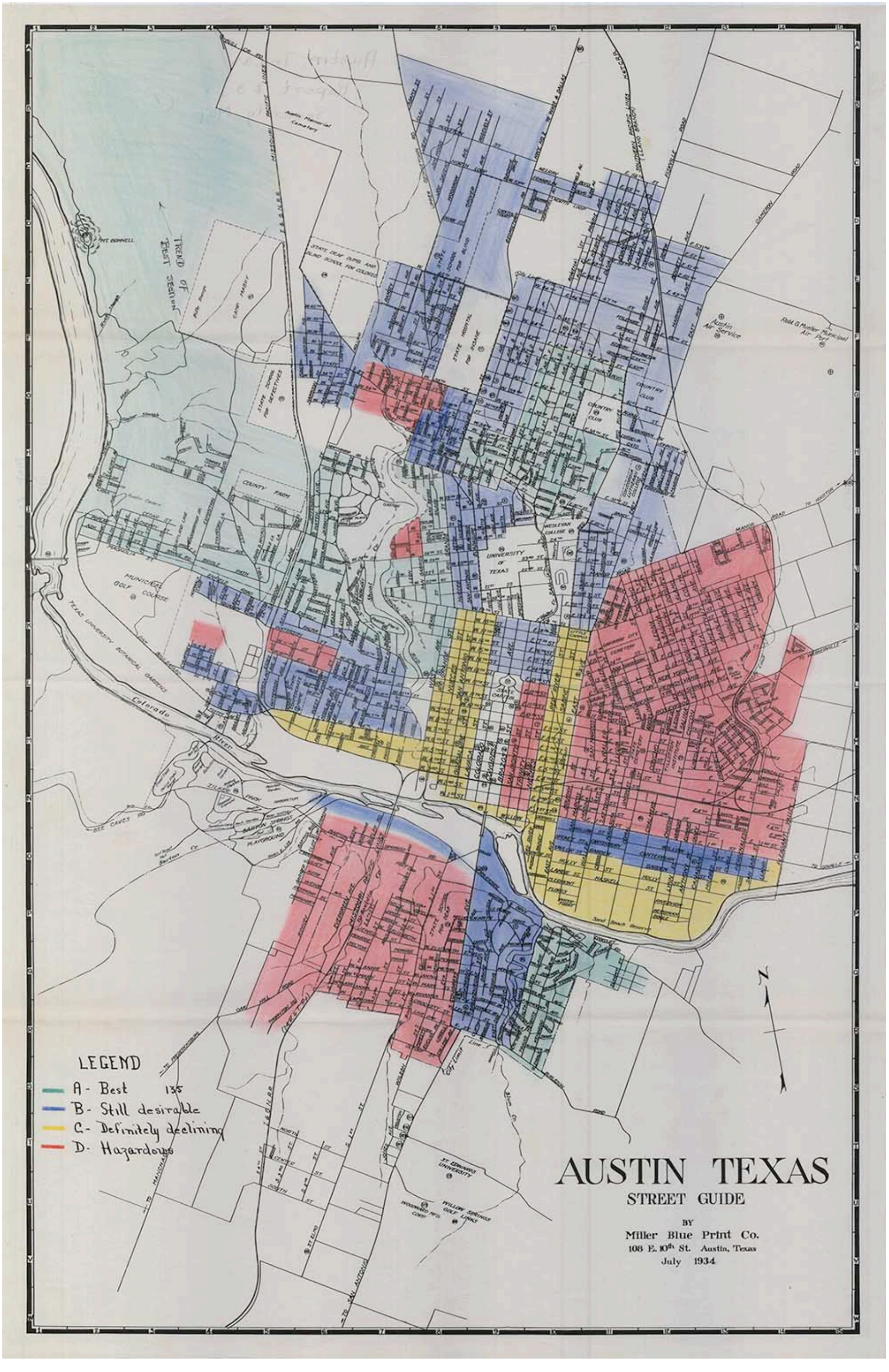

Figure 1: 1935 map of Austin, Texas with HOLC designations (Mapping Inequality, 2016)

Although both East and West Austin enjoy extensive creek systems and important natural resources, those in West Austin have historically been more highly valued and protected (Ogren et al., 2021). The zoning rules dictated by the 1928 Master Plan sited hazardous industrial activities in East Austin (Tretter, 2013). The City further encouraged preservation in West Austin at the expense of East Austin in 1998 when it deemed most of West Austin a "Drinking Water Protection Zone" and most of Central and East Austin as a "Desired Development Zone", shown in **Figure 2** (City of Austin Watershed Protection, 1998; Tretter, 2013). Likely because of the more lenient development regulations in the "Desired Development Zone", roughly one-third of the creeks in Central and East Austin are unsafe for swimming in the summer (Fisher, 2022). There is also still a persistent gap in UTC between East and West Austin, shown in **Figure 3**, which impacts how the most socially vulnerable residents experienced urban heat (*Austin's Urban Forest Plan: A Master Plan for Public Property*, 2013; Halter, 2014). The designation of East Austin as a "Desired Development Zone" also prompted an explosion of growth in the area's real estate market.

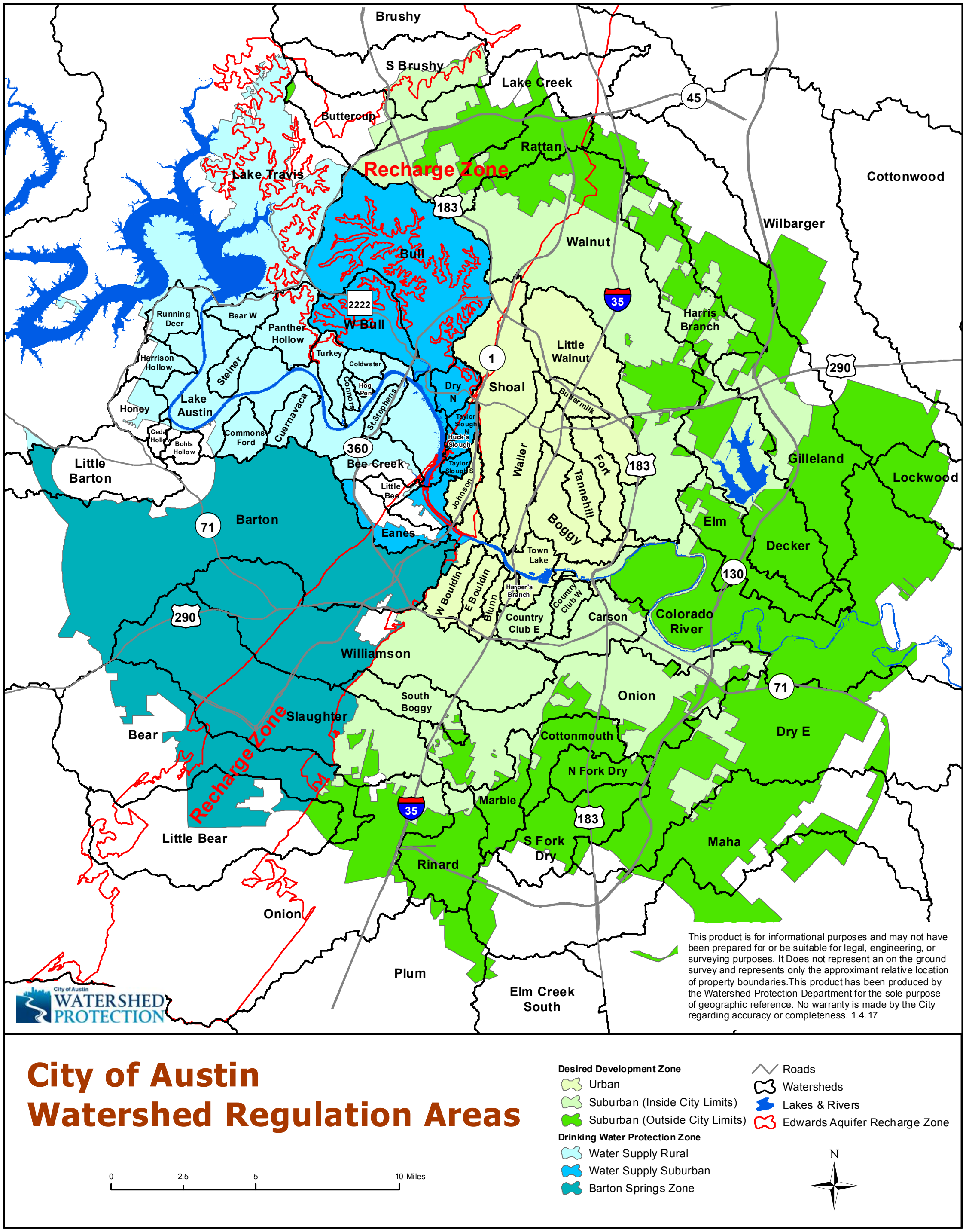

Figure 2: 1998 Smart Growth Initiative map (City of Austin Watershed Protection, 1998)

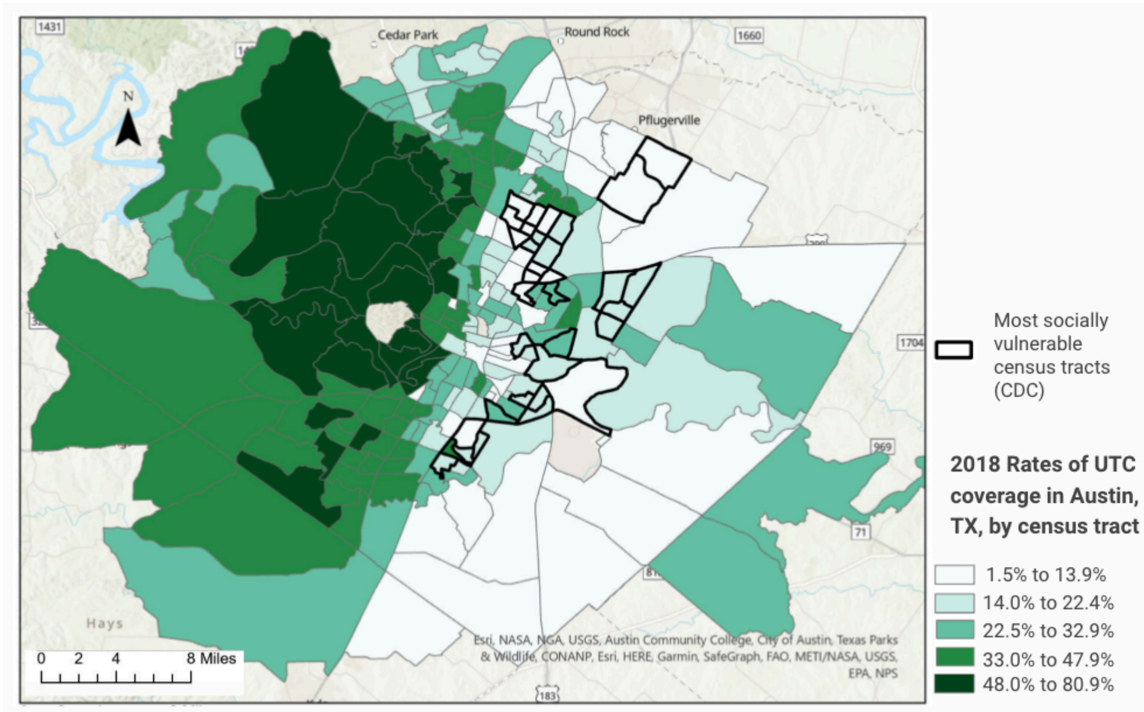

Figure 3: Rates of UTC coverage in Austin by census tract (City of Austin, Texas, 2022)

AUSTIN'S PRESENT-DAY

Artificially depressed property values in East Austin, combined with a concerted effort on the part of the City to attract businesses and grow the local footprint of the tech sector, has led to gentrification in the area. Gentrification is "a process through which higher-income households move into a neighborhood and housing costs rise, changing the character of the neighborhood" (Way et al., 2018, p. 2). It is characterized by a displacement of low-income residents, a transformation of the housing stock, and a change in neighborhood character (Way et al., 2018).

Communities of color, low-earners, and renters are all at high risk of displacement when gentrification occurs (Way et al., 2018). In one historically Black Central East Austin neighborhood, Rosewood, the share of the Black population has declined from 90 percent to 60 percent in the last forty years (Charpentier & McGlinchy, 2023). As part of study of gentrification in Austin, Way et al. (2018) classified neighborhoods as susceptible, early, dynamic, late, and continue loss. As shown in **Figure 4**, in 2016, gentrification was already underway in much of Austin's Eastern Crescent. As a result of this phenomenon, many Black and Hispanic Austinites are moving to Austin's suburbs in the peri-urban area (Charpentier & McGlinchy, 2023).

As an aside, the increased presence of the high-earning tech sector in Austin has also led to an increased MHI. Water utilities often use the average household water cost as a percentage of MHI to track water affordability (Cardoso & Wichman, 2022; Mack & Wrase, 2017); however, critics point out that this metric obscures affordability concerns for the bottom quartile of earners. As the MHI is inflated by the influx of new, high-earning residents, this metric becomes even less useful for determining water affordability.

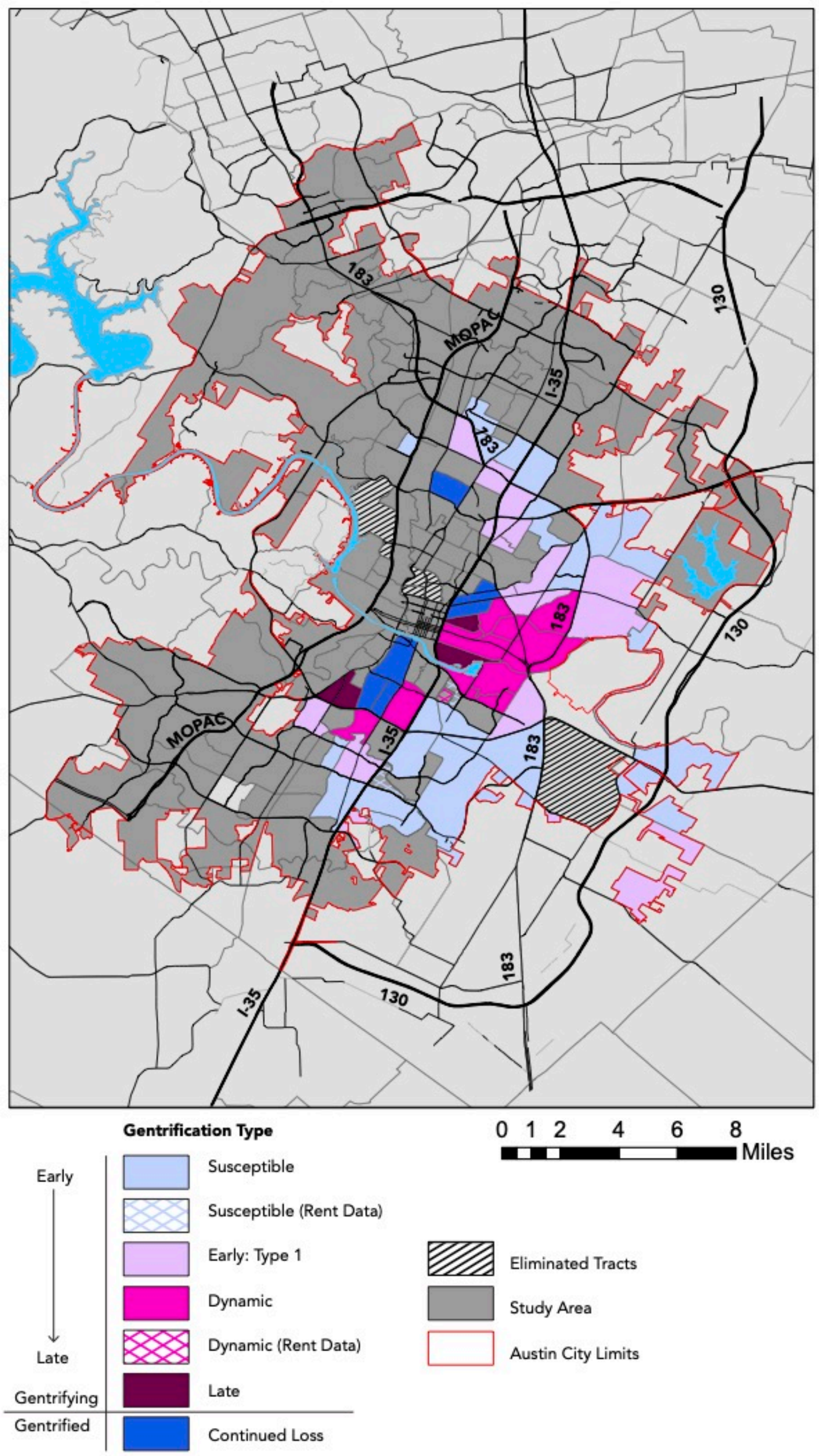

Figure 4: Status of gentrification in Austin by neighborhood (Way et al., 2018)

AUSTIN'S WATER UTILITY

In Austin's early days, settlers commonly sourced drinking water through rainwater collection or hauling water from the Colorado River (Robbins, 2020). A privately-owned water supplier, City Water Company, was the City's first organized water system, establishing in 1871 and pumping water from the Colorado River to settlers (Austin Water History, 2023; Robbins, 2020). City Water Company and City of Austin officials worked together to construct the previously discussed Austin Dam in 1893 (Robbins, 2020). Prompted by the Austin Dam's historic and catastrophic failure in 1900 and residents' complaints of price gouging on the part of City Water Company, the City of Austin eventually bought out the City Water Company and formed Austin Water (Robbins, 2020).

Today, Austin Water still sources its water from the Colorado River, pumping it to one of three water treatment plants, which have a combined capacity of 335 million gallons per day (Austin Water History, 2023). Austin Water's service area, shown in **Figure 5** extends slightly past the bounds of the City itself and includes almost one million customers and 3,674 miles of water mains throughout the City and its surrounding area (Austin Water Utility, 2009; Shoal Creek Conservancy, 2023). Wastewater is conveyed to one of the City's two wastewater treatment plants, after which it is pumped further downstream into the Colorado River or used in the City's nascent but growing reclaimed water system (Austin Water History, 2023).

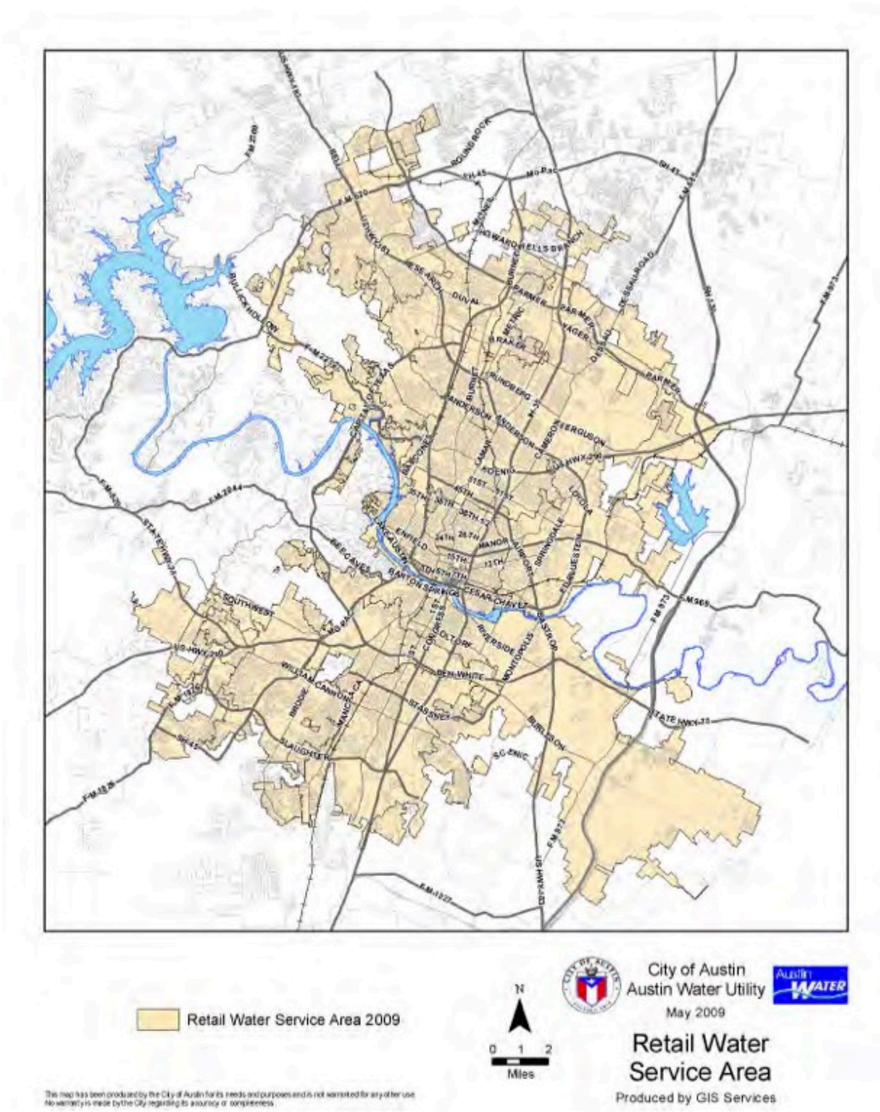

Figure 5: Austin Water service area (Austin Water Utility, 2009)

Funding mechanisms

Austin Water receives funding for expanding, updating, and improving water infrastructure through a combination of sources. First, the Texas Water Development Board (TWDB) uses federal and state dollars to issue below-market interest rate loans through the Drinking Water State Revolving Fund (DWSRF), Clean Water State Revolving

Fund (CWSRF), and State Water Implementation Fund for Texas (SWIFT). These loans give utilities the opportunity to invest in infrastructure improvement without needing to raise water or wastewater rates (US EPA, 2015). Rate increases are another way that utilities can raise funds for infrastructure investments.

Because Austin Water is publicly owned, all rate increases must first be approved by City Council. Research showed that, due to rate increases between 2010 and 2018, water bills in Austin rose by 154% in this period (Lakhani, 2020). While the utility has not increased rates since 2018, the Austin Daily Herald reports that rates will increase by 9 percent for all customer classes in the 2023-2024 fiscal year, which will translate to an average of $3 per month for residential water customers (Daily Herald, 2022)

Rate increases often serve a dual purpose for utilities. First, they may increase revenue, as customers are now paying more for water; however, the higher rates may also discourage customer water usage (Davis, 2022). For this reason, utilities often view raising rates as a tool for encouraging conservation; however, critics argue that this acts as a way to "control the behavior… of those who cannot afford water rising prices", while wealthier customers continue to use excess water during drought periods (Davis, 2022, p. 1495). For example, during a recent drought, wealthy West Austin residents even resorted to drilling private wells in their yards to avoid Austin Water's irrigation restrictions and high utility bills (A. Smith, 2013).

Planning efforts

From 2008 to 2016, Central Texas experienced an historic drought that supplanted the previous drought-of-record. In this period, inflows into the chain of Highland Lakes upstream of Austin hit a record low (Water Forward, 2018). Climate change modeling suggests that drought conditions will increase in severity in the coming years, "dry periods will be hotter and drier wet periods will be wetter" (Water Forward, 2018, p. 2-2). These concerns prompted Austin Water to initiate an integrated water planning effort, focused on ensuring there is clean, safe, reliable, affordable, and abundant water supply for the City of Austin throughout the next century.

Austin Water's integrated water resources planning effort, titled Water Forward: Integrated Water Resource Plan (Water Forward), outlines the utility's plan to manage the water demand facilitated by the City's rapid population growth, as well as improve water portfolio diversity and resilience moving forward. As such, Water Forward recommends that the utility pursue robust conservation measures, including a tiered rate structure to be implemented during droughts. Austin Water anticipates that the cost of the recommended resilience efforts will total $1.32B in capital costs and $407M in operation and maintenance costs through 2040 (the extent of the planning period) (Water Forward, 2018).

Customer conservation and affordability programs

Table 1 details Austin Water's ongoing initiatives to encourage water conservation for residential customers, per Water Forward. Most programs for single family households require participants be account holders. If the residents are not the owner, Austin Water asks that they receive written permission from their landlord (the homeowner) before applying for the rebates shown in **Table 1** (Austin Water, personal communication, July 26, 2023). For programs serving multi-family facilities and developments, the leasing company or the homeowner's association (HOA) must decide to participate in the program. Austin Water also offers an extensive variety of rebates for water-efficient improvements (*Water Forward*, 2018).

Table 1: Conservation programs for residential Austin Water customers (Water Forward, 2018)

Program Name	Program Description	Eligible Participants
Residential customer programs		
Controller 101 Workshops	Free workshop reviewing irrigation controllers	Residential customers
Dropcountr	Free home water use reports	Residential customers
Irrigation System Evaluations and Rebates	Free evaluations of irrigation system, with the opportunity for a $400 rebate for improvements	Residential customers with in-ground sprinkler systems that use either more than 25,000 gallons in a month or more than 20,000 in two consecutive months
Landscape Survival Tools Rebate	Up to $180 in rebates for improvements that help retain soil moisture in landscaping	Residential customers who have invested in mulch, composting, and lawn aeration
Low Income Water Efficiency Assistance[1]	Free high efficiency aerators and showerheads	Low-income residential customers
Pool Cover Rebate	A rebate totaling half the purchase price of a new manual pool cover or up to $50 (whichever is less), or up to $200 for a mechanical pool cover	Residential customers owning in-ground and aboveground pools
Pressure Regulating Valve Rebate	A rebate up to $100 for the purchase and installation of a pressure regulating valve	Residential customers
Rainwater Harvesting Rebate	A rebate up to $5,000 for the purchase of rainwater capture equipment	Residential, multi-family, and commercial customers
Watering Timer Rebate	A rebate up to $50 or 50% of the purchase cost for up to two hose timers	Residential customers

[1] Austin Water is also currently developing more programs directly targeted at low-income single family water customers: a direct assistance plumbing repair program and water lateral repairs (*Water Forward*, 2018). Water laterals are small pipes that connect from the water main into residents' homes.

Table 1 (cont.)

Program Name	Program Description	Eligible Participants
WaterWise Landscape Rebate	A rebate of $35 for every 100 square feet of landscape converted to xeriscaping, up to $1,750	Residential customers
WaterWise Rainscape Rebate	A rebate up to $500 for the installation of landscape features that retain stormwater	Residential customers
Incentive programs for homeowner associations and multi-family facilities		
Multi-Family Efficiency Program	Free high efficiency aerators and showerheads	Multi-family facilities with low-income tenants
Pressure Reduction Valve Rebate	Up to $500 for the purchase and installation of pressure reduction valves	Multi-family facilities
Rainwater Harvesting System Rebate	Up to $5,000 for the purchase of rainwater capture equipment	Multi-family facilities
WaterWise Landscape Rebate	A rebate of $35 for every 100 square feet of landscape converted to xeriscaping, up to $1,750	Homeowner associations

In addition to the conservation programs listed in **Table 1**, Austin Water has implemented a "conservation-oriented tiered rate structure" (detailed in Section 3) and a range of ordinances restricting water use in droughts, conducted several water conservation outreach programs, and begun piloting the installation of advanced meter infrastructure (AMI) (Water Forward, 2018, p. 6-11). AMI involves installing 'smart' meters, which frequently report water usage to customers and Austin Water and provide recommended conservation targets based on data from aerial imagery (Water Forward). Through the new My ATX Water Program, Austin Water will replace over 250,000 analog meters with smart meters, which include an online customer dashboard that displays hourly water usage metrics and leak alerts. Households must be account holders to access their My ATX Water dashboard. The installation of smart meters is currently in progress throughout the City, as shown in **Figure 6**.

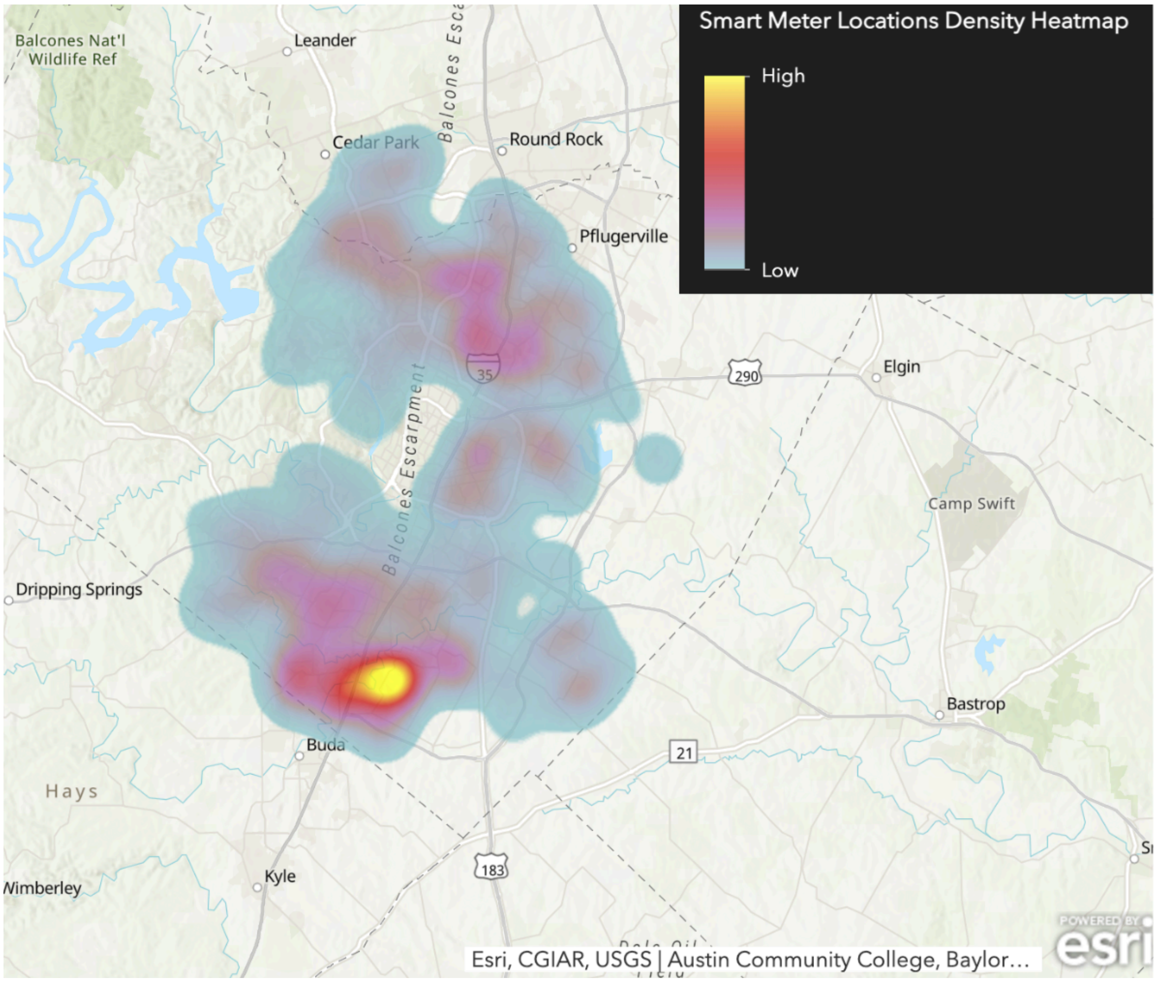

Figure 6: My ATX smart meter density (Austin Water, 2023)

Water Forward does not discuss the utility's planned affordability programs beyond conservation and demand management measures. Although conservation programs and affordability programs are inextricably linked because great conservation ultimately amounts to lower household water costs, Austin Water also has a slate of programs targeted specifically at low-income and vulnerable programs, shown in **Table 2**.

Table 2: Affordability programs for Austin Water customers (*Water Forward*, 2018)

Program Name	Program Description	Eligible Participants
Residential Customer Assistance Program (CAP) bill rate reductions	Provides waivers for fixed fees and volumetric rate discounts, amounting to a 45% discount or $560 savings on average[2]	Households where at least one resident is participating in certain state, federal, and local assistance programs[3] may apply
Financial Support Plus 1	Provides emergency financial help	Households that are "current clients" of an agency of emergency
Go Repair program	In partnership with Neighborhood Housing and Community Development, offers up to $150,000 per year for plumbing repairs[4]	Households earning up to 80 percent of the MFI
COVID-19 rate reduction program[5]	Reduces volumetric charges by 10% for water tiers 1-3 and wastewater tiers 1-2	All Austin Water residential customers

Austin Water's CAP bill reductions are somewhat unique on a national scale, as they extend to renters in multi-family buildings, while the majority of other CAP efforts nationally only provide benefits to homeowners or single-family home residents (Davis, 2022). The program is also unique in its focus on racial equity – City Council passed the

[2] This figure factors in savings on all utility bills, including wastewater, electricity, and water.
[3] Eligible programs include Medicaid, Supplemental Nutrition Assistance Program (SNAP), Children's Health Insurance Program (CHIP), Telephone Lifeline Program, Comprehensive Energy Assistance Program (CEAP), Medical Access Program (MAP), Veterans Affairs Supportive Housing (VASH), and Supplemental Security Income (SSI). Households earning less than 200 percent of the federal poverty line (FPL) are also eligible.
[4] The Go Repair program also encompasses weatherization and repairs to improve accessibility; however, Austin Water funds only go towards plumbing repairs (Sudborough, 2019).
[5] Although this program was initiated in April 2020, Austin Water anticipated in 2022 that it would continue through at least 2027 (Austin Water, 2022).

current iteration of the CAP program in 2020 with the "express purpose of increasing the program's racial equity" (Davis, 2022, p. 1508)

Current state of water affordability

Throughout Water Forward, Austin Water recognizes that "affordability" is a key community value, and stresses that "social equity will continue to be a key consideration in the development of ordinances, incentive programs, and water supply projects" (Water Forward, 2018, p. 1-10). According to Joseph Gonzales, Austin Water's financial services assistant director, the utility aims to ensure that customers spend less than 1.5 percent of their income on water bills.

Austin Water publishes an annual Affordability Metrics Report. The report, which City Council commissioned in 2018, computes and compares nine affordability metrics. **Table 3** highlights the two metrics that specifically contend with water costs for low-income Austin residents. Both metrics come at the recommendation of Teodoro's 2018 article published by the AWWA, Measuring Affordability for Water and Sewer Utilities. Both metrics assume 4,000 gallons of water consumption and 4,000 gallons of sewage flows. Teodoro based this on the level of household water and wastewater use assumed necessary for "basic health and sanitation needs" (Austin Water, 2022).

Table 3: Affordability metrics measuring water burden for low-income Austinites (Austin Water, 2022)

Metric Name	Metric Calculation	Austin Water Goal	Progress
Affordability Ratio (AR_{20})	Measures the share of their income that low-income customers (i.e., those earning equal to or less than the 20th percentile of household income) spend on their water and sewage bills, after they have paid for other essentials (such as food and housing)	Less than 5%	5.9%, as of May 2022
Hours Minimum Wage	Measures the number of hours per month a person must work at a minimum wage job (excluding taxes) to pay for their water and sewage bill	Less than 8 hours	9.3 hours, as of May 2022

As shown in **Table 3**, Austin Water has tried to understand the prevalence of water affordability issues in the City; however, these metrics do not seem to contend with the depth of water unaffordability for low-income residents. Independent research brought to light significant affordability concerns for low-income Austinites (Colton, 2020; Lakhani, 2020). Colton found that in 2018, 60 percent of low-income households (i.e., those earning below 200 percent of the FPL) faced water and sewage bills that exceeded four percent of their income, and 15 percent of low-income households face water bills that exceed 12 percent of their income (2020).

This quantitative study focuses on how socioeconomic, racial, and housing factors may influence water bills. As this chapter describes, historic racist planning and policy decisions have shaped the present-day landscape of home ownership, economic opportunity, social vulnerability, and urban heat exposure. A preliminary study by the City of Austin estimates that “cumulative dispossession of Black landownership between 1920 and today” has cost Black families in Austin more than $290 million (Freer, 2022). Homeownership rates “vary dramatically” according to race and ethnicity in the City of Austin, with 52 percent of the non-Latino white population owning homes and only 32 percent and 35 percent of the Black and Latino populations, respectively (City of Austin Comprehensive Housing Market Analysis, 2020). Although the City of Austin aims to improve services in East Austin, this effort coincides with the area’s ongoing gentrification and the displacement of native Black and Latino Austinites from East Austin (Charpentier & McGlinchy, 2023). Furthermore, as Black and Latino Austinites move to the city’s suburbs to escape the rising cost of living, they leave the AW service area, and thus lose access to high-quality AW services, including the utility’s affordability programs. This process illustrates the layered and interconnected nature of water equity that Gerlak et al. refers to (2022).

Chapter 4: Methodology

My research compares household water bills and their relationships to socioeconomic and racial factors through quantitative analysis, although further analysis contextualizes these results through the qualitative lens of Austin's past development patterns. The research relies upon a 2020 study by Ayala et al., which includes both monthly water use and sociodemographic information for households over a five-year period. First, published Austin Water rate information was used to calculate monthly water bills based on monthly water usage. Then, each household address was linked to a range of additional socioeconomic factors and housing factors, including urban heat index, social vulnerability, lot size, living area size, persons per household, and apartment complex size, if applicable. These values were used to calculate an annual average household water bill over the five-year study period, as well as water bill per person and a water bill per square foot of home and square foot of lot size. Finally, a statistical and spatial analysis of the resulting data was conducted.

INTRODUCING THE DATASET

The crux of this research is a dataset collected as part of a study assessing whether public perceptions on conservation aligned with residential water usage (Araya et al., 2020). In 2016, Araya et al. distributed a Qualtrics survey to customers across 29 zip codes within the Austin Water service area. Of the survey's 53 questions, 24 were focused on the socio-demographic characteristics of the respondent and included information such as race and renter-owner status. A copy of the survey is included in **Appendix A**. Austin Water then matched monthly water consumption records over a five-year period (2012 to 2017) to each valid respondent's address and paired it with the respondents' survey responses.

To understand representativeness of the sampled data, the racial and socioeconomic characteristics of the dataset were compared with those of the City of Austin (COA), as measured by the 2017 American Community Survey (ACS) 5-year estimate. Based on the comparison, shown in **Table 4**, it can be observed that the following categories are over- or underrepresented in the sampled data:

- High-income households (i.e., those earning more than $100,000 per year) are underrepresented by roughly 20 percent
- White households are overrepresented by roughly 12 percent
- White, non-Hispanic households are overrepresented by roughly 24 percent
- Renters are underrepresented by roughly 11 percent

Table 4: Racial and socioeconomic characteristics of the dataset compared to COA

Racial/socioeconomic characteristic	Number of respondents	Percent of respondents	COA Distribution (2017 ACS)
Reported Income			
Not reported	22	6.7%	-
Under $20,000	40	12.3%	13.2%
$20,000 - $35,000	55	16.9%	12.9%
$35,000 - $50,000	52	16.0%	12.9%
$50,000 - $75,000	79	24.2%	18.3%
$75,000 - $100,000	43	13.2%	12.2%
Above $100,000	35	10.7%	30.4%
Reported Racial/Ethnic Identity[6]			
White	270	82.8%	75.0%
Black / African-American	22	6.7%	7.6%
Asian	16	4.9%	7.0%
American Indian or Alaska Native	3	0.9%	0.5%
Other	15	4.6%	10.0%
Hispanic/Latino	42	12.9%	34.5%
White alone, not Hispanic	239	73%	48.6%
Reported Renter-Owner Status			
Rented	142	43.6%	55%
Owned with mortgage	122	37.4%	45%[7]
Owned without mortgage	62	19.0%	

CALCULATING WATER BILLS

Historical records of Austin Water rates were used to calculate household water bills (Proposed Retail Water Rates, 2010; Water Service Rates, 2013; Current Rate Schedule, 2015). Note that this study focuses on water bills alone, and analyses do not

[6] Racial and ethnic categories were chosen to match those included in the U.S. Census Bureau estimate.
[7] Data published by the U.S. Census Bureau does not differentiate between owners with and without mortgages.

include sewerage charges. In addition, the impacts of any cost reduction or affordability programs instituted by Austin Water are not considered in this analysis (see **Chapter 3** for a full discussion of the utility's affordability efforts).

Water rates used to calculate bills are shown in **Table 5** through **Table 7**. The years each rate was active are reflected in the tables as well, as rates were adjusted twice during the study period. Volumetric water charges (**Table 7**) are calculated at a marginal rate.

Separate calculations were used for single family and multi-family households. A household's status as single or multi-family was determined by the meter type associated with the address. Duplexes were classified as single-family households. Wholesale meters and commercial meters were excluded from this analysis. If a meter reported zero gallons of usage, it was assumed that the meter was inactive during that month of the study; thus, the bill would be zero dollars.

Table 5: Monthly charges for residential water meters sized 5/8-inch (Proposed Retail Water Rates, 2010; Water Service Rates, 2013; Current Rate Schedule, 2015)

Dates Rates Effective	Total Monthly Charge[8]
1/1/12 – 1/31/13	$7.10
2/1/13 – 10/31/15	$7.10
11/10/15 – 12/31/16	$7.10

[8] Total monthly charges include the customer charge, the meter charge, and the fire protection charge.

Table 6: Five-tiered fixed charges for residential water users (Proposed Retail Water Rates, 2010; Water Service Rates, 2013; Current Rate Schedule, 2015)

Dates Rates Effective	Tier of Water Usage (by gallons of water)	Fixed Charge
1/1/12 – 1/31/13	0 – 2,000	$0.00
	2,001 – 9,000	$0.00
	9,001 – 15,000	$0.00
	15,001 – 25,000	$0.00
	25,001+	$0.00
2/1/13 – 10/31/15	0 – 2,000	$2.00
	2,001 – 6,000	$4.50
	6,001 – 11,000	$7.45
	11,001 – 20,000	$12.55
	20,001+	$12.55
11/1015 – 12/31/16	0 – 2,000	$1.20
	2,001 – 6,000	$3.45
	6,001 – 11,000	$8.75
	11,001 – 20,000	$27.35
	20,001+	$27.35

Table 7: Five-tiered volumetric charges for residential water users (Proposed Retail Water Rates, 2010; Water Service Rates, 2013; Current Rate Schedule, 2015)

Dates Rates Effective	Tier of Water Usage (by gallons of water)	Volumetric charge ($/per thousand gallons)
1/1/12 – 1/31/13	0 – 2,000	$1.06
	2,001 – 9,000	$2.78
	9,001 – 15,000	$7.15
	15,001 – 25,000	$9.88
	25,001+	$10.99
2/1/13 – 10/31/15	0 – 2,000	$1.25
	2,001 – 6,000	$2.80
	6,001 – 11,000	$5.60
	11,001 – 20,000	$9.40
	20,001+	$12.25
11/1015 – 12/31/16	0 – 2,000	$3.16
	2,001 – 6,000	$4.84
	6,001 – 11,000	$7.88
	11,001 – 20,000	$11.90
	20,001+	$14.16

Single family water bills

All single-family households were assumed to have a 5/8-inch meter, which Austin Water reports is the average residential customer meter size (Current Rate Schedule, 2015). To calculate a monthly single-family water bill, monthly charges, fixed charges, and volumetric charges determined using the reported monthly water usage, then summed. Single family water meters attributed to mobile homes were removed from the data, as these charges are split between multiple households and thus not actually describing a single family household.

Multi-family water bills

Multi-family water meters measure the total volume of water used by all households connected to the meter; thus, it is not possible to measure exactly how much water was used by each multi-family household. Here, it was assumed that water usage and water bills were split evenly amongst all households connected to the meter. However, this calculation was further complicated by the fact that there was no official record of how many households/units are connected to each meter. The number of units per apartment complex was estimated using public records associated with each apartment complex, generally listed on Apartments.com (if units were owned by a single agency) or Travis County Appraisal District (if units were owned individually). For the purposes of this study, it was assumed that all units of an apartment complex split the charge evenly.

Austin Water generally approximates a multi-family household is equivalent to 0.7 single family homes in terms of water use (J. Smith, personal communication, February 16, 2023). According to Table 3 of the Water and Wastewater Impact Fees Report, only 440 service units (a term Austin Water uses interchangeably with single family households) can be served by the maximum meter size (Austin Water, 2018). The equivalent maximum number of multi-family units that the largest meter could serve would be 628 units. As a result, it was assumed that apartment complexes with more than 628 units were serviced by multiple water meters.

Lastly, there is no standard meter size for multi-family units. This metric is used to calculate each household's monthly charge. Austin Water calculates the number of service units (i.e., single family homes) served by a specific meter size and type (Austin Water, 2018; J. Smith, personal communication, February 16, 2023). For this research, the number of units in each apartment complex was used to assume the appropriate meter size for each apartment complex and this meter size was in turn used to calculate a water bill. The figures used for conversions are shown in **Table 8**.

Table 8: Assumed meter size based on number of households/units (Austin Water, 2018)

Meter Size (in. dia.)	Pump Type[9]	Number of single family homes served	Number of multi-family households served
5/8	Positive displacement	1.0	1.43
1	Positive displacement	2.5	3.57
1 1/2	Positive displacement	5	7.14
2	Turbine	16	22.86
3	Turbine	35	50.00
4	Turbine	65	92.86
6	Turbine	140	200.00
8	Turbine	240	342.86
12	Turbine	440	628.57

LINKING DESCRIPTIVE DATA

As stated, the survey distributed by Ayala et al. included 24 questions collecting socio-demographic data. In addition to that, descriptive socioeconomic and housing data were compiled from a variety of sources and linked to each address. Descriptions of these data and their sources are shown in **Table 9**.

[9] For consistency and simplicity, it was assumed that all pumps with less than a 2-inch diameter were positive displacement pumps, and all pumps with a greater than 2-inch diameter with turbine pumps.

Table 9: Data linked to household addresses

Data	Source	Description of Data
Household Income	2016 survey conducted by Ayala et al.	Used to understand how household income correlates with household water bill. Respondents had five answer options: (1) Under $20k; (2) $20k - $35k; (3) $35k - $50k; (4) $50k - $75k; (5) $75k - $100k; (6) Above than $100k During the analysis, these options were condensed into four income brackets: Options (1) and (2) were combined to create a 'Below $35k' category, and Options (3) and (4) were combined to create a '$35k - $75k' category.
Household Owner-Renter Status	2016 survey conducted by Ayala et al.	Used to understand how household owner-renter status correlates with household water bill. Respondents had three answer options: (1) Rented; (2) Owned with mortgage; (3) Owned without mortgage
Household Race	2016 survey conducted by Ayala et al.	Used to understand how race correlates with household water bill. Respondents had six answer options: (1) American Indian or Alaska Native; (2) Asian; (3) Black or African American; (4) Native Hawaiian or Other Pacific Islander; (5) White; (6) Other
Household Ethnicity	2016 survey conducted by Ayala et al.	Used to understand how ethnicity correlates with household water bill. Respondents had two answer options: (1) Hispanic or Latino; (2) Not Hispanic or Latino
Urban Heat Exposure	2021 study conducted by Bixler et al., using the Urban Imperviousness and Tree Canopy layers of the 2016 National Land Cover Database	Used to understand how urban heat exposure variability correlates with household water bills. This number represents both night- and day-time heat risk. Linked to a specific census block group.

Table 9 (cont.)

Data	Source	Description of Data
Social Vulnerability Index - Normalized	2021 study conducted by Bixler et al., using the ACS 2017 5-year estimate	Used to understand how social vulnerability correlates with household water bills. This number represents an adaptation of the SoVI®, specific to the context in Austin. Linked to a specific census block group.
Household Size	ACS 2017 5-year estimate	Used to calculate the water bill per person. Linked to a specific census block group.
Median Year Structure Built	ACS 2017 5-year estimate	Used to understand how home age impacts water bill. Linked to a specific census block group.
Lot Size Square Footage (Single family)	2017 TCAD Assessment	Used for single-family homes to calculate the water bill per square foot of lot. Linked to a specific address.
Living Area Square Footage (Single family)	2017 TCAD Assessment	Used for single-family homes to calculate the water bill per square foot of living area. Describes the main area of living space (excluding garages, patios, et cetera). Linked to a specific address.
Living Area Square Footage (Multi-family)	Public listing (Generally Apartments.com; 2017 TCAD assessment used when available)	Used for multi-family homes to calculate the water bill per square foot of living area. Unit assumed to be the smallest 2-bedroom apartment available.

After descriptive data was linked to each address, the following dependent variables were calculated:

- Drinking water bill (\$/household/year)
- Drinking water bill per person (\$/person/year)
- Drinking water bill per square foot of living area (\$/sf/year)

- Drinking water bill per square foot of lot[10] ($/sf/year)

CONDUCTING A STATISTICAL ANALYSIS

The dependent variables (i.e., water bills) were compared to racial, socioeconomic, and housing data. To understand the impact of categorical variables (such as race, renter-owner status, and income bracket), a descriptive analysis was conducted for each dependent variable using Excel. To understand the impact of numerical variables (such as SVI and urban heat exposure), a correlational analysis was conducted for each dependent variable using R. Finally, using the patterns that emerged during the descriptive analysis and correlational analysis as a guide, a regression analysis was run on the data using R.

[10] This statistic is only relevant for single-family households.

Chapter 5: Results

The quantitative findings from the descriptive analysis, correlational analysis, and regression analysis are presented at the beginning of this section. Then, each of the socioeconomic, racial, and housing factors that were theorized to impact household water bills are discussed separately. In each section, single family and multi-family households are considered separately, as there was a significant and consistent difference across single and multi-family household water use (see **Table 13**). A composite table with the R output for single family households, multi-family households, and all households is saved in **Appendix B**.

FINDINGS

Descriptive statistics comparing the dependent variable outcomes within different categorial variables (including income, owner-renter status, and race/ethnicity) are shown in **Table 10**. Note that **Table 10** includes the average dependent variable for each category within the dataset.

Correlation coefficients (ρ) measuring the strength of the relationship between each numerical variable and the dependent variables are shown in **Table 11**. The numerical variables studied are home age, SVI, and heat exposure scores. Higher coefficients signify stronger relationships and correspondence between the variables.

Lastly, the results of the regression analysis are shown in **Table 12**. The figures shown in **Table 12** represent the increased (or decreased, if negative) cost likely attributable to each variable alone. The range of error is shown beneath each figure. There must be a reference category for each categorical variable studied, so the relative impact of the other categorical variables can be measured. For income, the lowest income bracket ('Below $35k') is used as the reference category; thus, the figures shown represent how much more (or less) a household in another income bracket may spend on drinking water based on its income alone. For owner-renter status, homeownership is used as the reference category; thus, the figures represent how much more (or less) a household that is renting may spend on drinking water based on its status as a renter alone. Lastly, for race and ethnicity, whiteness is used as a reference category; thus, the figures represent how much more (or less) a non-white household may pay for drinking water based on race and ethnicity alone.

Table 10: Results of descriptive analysis – Average water costs, by household characteristics

Household Type	Household Characteristic	n	Average annual water bill ($/yr)	Average annual bill per person ($/p/yr)	Average annual bill per square foot of living area ($/sf/yr)	Average annual bill per square foot of lot size ($/sf/yr)
By Income Bracket						
Single family	Under $35k	56	$342.42	$140.15	$0.19	$0.04
	$35k-$75k	80	$391.60	$156.40	$0.20	$0.04
	$75k-$100k	28	$360.16	$145.53	$0.20	$0.05
	Above $100k	30	$510.39	$212.50	$0.21	$0.05
Multi-family	Under $35k	39	$141.79	$67.67	$32.68	
	$35k-$75k	50	$105.87	$49.08	$12.88	
	$75k-$100k	15	$147.76	$71.31	$39.85	
	Above $100k	5	$90.16	$36.01	$12.96	
By Owner-Renter Status						
Single family	Renter	43	$342.42	$140.15	$0.19	$0.04
	Owner	168	$391.60	$156.40	$0.20	$0.04
Multi-family	Renter	99	$141.79	$67.67	$32.68	
	Owner	15	$105.87	$49.08	$12.88	
By Race/Ethnicity						
Single family	White	158	$398.56	$162.02	$0.20	$0.04
	Black	12	$323.24	$115.00	$0.19	$0.04
	Hispanic/Latino	24	$338.38	$125.50	$0.20	$0.05
	Asian	11	$332.69	$141.00	$0.15	$0.05
	Other	6	$296.28	$117.84	$0.13	$0.03
Multi-family	White	80	$123.07	$62.41	$28.12	
	Black	9	$141.37	$49.88	$34.44	
	Hispanic / Latino	18	$101.76	$47.02	$35.08	
	Asian	4	$533.49	$217.26	$30.41	
	Other	2	$92.44	$42.83	$43.75	

Table 11: Results of correlational analysis – Relationships between household characteristics and water bills

Household Characteristic Measured	Household Type	Annual water bill ρ	Bill per person ρ	Bill per square foot of living area ρ	Bill per square foot of lot size ρ
SVI	Single family	-0.19**	-0.29***	0.05	-0.07
	Multi-family	-0.12*	-0.22***	0.08	
Heat exposure	Single family	-0.16*	-0.07	0.03	0.00
	Multi-family	-0.26**	-0.18***	0.23***	
Home age	Single family	0.06	0.11	0.11	-0.05
	Multi-family	0.06	0.09	-0.08	

Notes:
* = less than 10% chance of erroneous relationship
** = less than 5% chance of erroneous relationship
*** = less than 1% chance of erroneous relationship

Table 12: Results of regression analysis – Financial impact of household characteristics on water bills

Household Type	Household Characteristic Measured	Impact on average water bill	Impact on bill per person	Impact on bill per square foot of living area	Impact on bill per square foot of lot size
By Income					
Single family	$35k - $75k	-$101.61	$31.68	$0.01	-$0.01
	Range of error	*±$118.09*	*±$43.54*	*±$0.07*	*±$0.02*
	$75k - $100k	$51.25	$19.82	$0.01	-$0.01
	Range of error	*±$69.05*	*±$25.62*	*±$0.07*	*±$0.02*
	Over $100k	-$23.97	-$16.70	$0.003	$0.005
	Range of error	*±$80.12*	*±$29.64*	*±$0.04*	*±$0.01*
Multi-family	$35k - $75k	$31.42	$14.20	-$3.78	
	Range of error	*±$80.63*	*±$30.26*	*±$10.61*	
	$75k - $100k	$54.83	$20.19	$4.97	
	Range of error	*±62.05*	*±$24.38*	*±$8.53*	
	Over $100k	$104.06	$38.86	-$0.82	
	Range of error	*±70.03*	*±$27.60*	*±$9.70*	
By Owner-Renter Status[11]					
Single family	Renter	$119.31*	$40.88	- $0.01	$0.02*
	Range of error	*±$68.01*	*±$25.16*	*±$0.04*	*±$0.01*
Multi-family	Renter	-$23.03	-$5.58	$23.10**	
	Range of error	*±$75.45*	*$29.73*	*$10.13*	
By Race/Ethnicity[12]					
Single family	Black	- $37.96	-$6.83	$0.01	-$0.01
	Range of error	*±$130.73*	*±$47.96*	*±$0.07*	*±$0.02*
	Hispanic	$65.74	$17.93	-$0.01	-$0.001
	Range of error	*±85.51*	*±31.73*	*±$0.05*	*±$0.02*
	Asian	-$183.29*	-$54.17	-$0.08	-$0.004
	Range of error	*±$103.55*	*±$38.29*	*±$0.06*	*±$0.02*
	Other	-$267.06*	-$102.83**	$0.015**	-$0.03
	Range of error	*±$137.45*	*±$50.39*	*±$0.09*	*±$0.03*

[11] Ownership was used as a reference variable in this analysis; thus, figures in Table 12 show the impact of being a renter in comparison with being an owner.

[12] Whiteness was used as a reference variable in this analysis; thus, figures in Table 12 show the impact of being non-white in comparison.

Table 12 (cont.)

Household Type	Household Characteristic Measured	Impact on average water bill	Impact on bill per person	Impact on bill per square foot of living area	Impact on bill per square foot of lot size
Multi-family	Black	-$52.23	-$14.98	-$0.73	
	Range of error	*±$96.05*	*±$36.01*	*±$12.64*	
	Hispanic	-$49.12	-$14.08	$5.28	
	Range of error	*±$68.51*	*±26.85*	*±$9.43*	
	Asian	$408.64***	$146.08***	-$8.33	
	Range of error	*±$104.77*	*±$41.22*	*±$14.34*	
	Other	-$28.75	-$20.09	$9.15	
	Range of error	*±152.75*	*±$60.18*	*±$21.10*	
By SVI					
Single family	SVI	$110.16	-$72.32	- $0.0003	-$0.07
	Range of error	*±$394.50*	*±$110.91*	*±$0.14*	*±$0.05*
Multi-family	SVI	-$241.34	-$28.77	-$0.96	
	Range of error	*±$287.17*	*$84.18*	*$29.54*	
By Heat Exposure					
Single family	Heat exposure	$147.64	$123.51	$0.08	$0.01
	Range of error	*±$252.35*	*±$89.01*	*±$0.11*	*±$0.04*
Multi-family	Heat exposure	-$29.06	-$38.14	-$0.21	
	Range of error	*±$194.54*	*$68.29*	*$23.95*	
By Home Age					
Single family	Home age	-$1.36	-$0.62	-$0.002	$0.0003
	Range of error	*±$2.01*	*±$0.73*	*±$0.001*	*±$0.0003*
Multi-family	Home age	$1.62	$0.60	$0.10	
	Range of error	*±$2.08*	*$0.81*	*$0.27*	

Notes:
* = less than 10% chance of erroneous relationship
** = less than 5% chance of erroneous relationship
*** = less than 1% chance of erroneous relationship

HOUSEHOLD TYPE

Research has shown that housing typology significantly influences water consumption, with households in higher density areas generally consuming less water per capita than those in lower density areas (Domene & Saurí, 2006; Zhang & Brown, 2005). Researchers theorize that the difference in water consumption is due to a combination of factors including the higher presence of irrigated gardens and swimming pools in single family homes (Domene & Saurí, 2006; Morote et al., 2017).

This study supported prior research. As shown in **Table 13**, single family households included in this study spent on average $245 more in drinking water bills per year than multi-family households. In addition, because apartments and condominiums generally have a lower square footage, multi-family households pay significantly more per square foot of living area. Based on the differences between water use in these household types, the statistical analysis was separately for each group.

Table 13: Differences in dependent variables between single family and multi-family households

	Single family	Multi-family
Average square footage of living area (sf)	2029	959.9
Average annual water bill ($/yr)	$381.36	$136.76
Average annual water bill per person ($/p/yr)	$153.02	$65.06
Average annual water bill per square foot of living area ($/sf/yr)	$0.20	$29.91

INCOME BRACKET

Descriptive statistics indicate that in single family homes, the highest earners have higher rates of water use and thus higher water bills, on average. When water bills for single family homes are examined on a per square foot basis, most income groups spend generally the same amount. This indicates that while higher income households use more water, this may be a function of their larger home size. The regression analysis indicates that income alone did not have a statistically significant impact on single family water bills.

The regression analysis also did not yield a statistically significant relationship between income and water bills for multi-family homes; however, descriptive statistics did show that lower income households living in multi-family homes actually spent more on water than high-income households living in multi-family homes. Because multi-family homes are generally smaller than single family homes (as shown in **Table 13**) and are less impacted by water-intensive landscaping (including pools), this difference between single and multi-family homes is feasible.

Although multiple studies have found a relationship between high water use and high income in single-family homes (specifically due to water-intensive landscaping), other sources have also suggested that water demand is somewhat inelastic (Domene & Saurí, 2006; Martínez-Espiñeira & Nauges, 2004; *Water and Wastewater Pricing: An Informational Overview*, 2002). As Martínez Espiñeira and Nauges (2004) find, in households where water bills make up a small share of the household's disposable income, income and pricing do not fully explain water use.

HOUSEHOLD OWNER-RENTER STATUS

Initial descriptive statistics suggested that in single family homes, renters pay slightly less than homeowners for water overall, but pay roughly the same per square foot of living area and lot size; however, the regression analysis, which examined the impact of renting alone on single family household water costs, revealed a statistically significant relationship between ownership status and water costs. The regression analysis revealed that renting a single family home was associated with an increased water bill.

Analysis also showed that renters living in multi-family homes paid significantly more than multi-family home owners for water, as measured by each dependent variable. This finding was partially supported by the regression analysis, which found that renters' water bills are roughly $23 more per square foot of living area per year. Based on the findings of the regression analysis, there is a 95 to 99 percent chance that being a renter is related to increased water bill costs.

RACE AND ETHNICITY

Neither the descriptive nor the regression analysis demonstrated a strong relationship between race and the dependent variables. It should be noted that there is a statistically significant relationship showing households categorized as "Other" as paying less in overall water bills and cost per person but paying more when the cost is measured as a function of living area size.

In general, descriptive statistics show that households, regardless of race, pay a similar amount per square foot of their living area or lot size. The differences in overall water bills are generally not statistically significant and likely a result of a small sample size and the documented income differences between and within racial groups. White non-Hispanic and Asian households earn the highest median incomes, but at the same time, there is a significant disparity between ethnic groups within the broad "Asian" census category (Banjaree, 2022; City of Austin Housing and Planning Department, 2020).

NORMALIZED SOCIAL VULNERABILITY INDEX (SVI)

In general, higher levels of social vulnerability were associated with lower water bills overall (with a less than five percent chance of error) and per person (with a less than one percent chance of error). However, this relationship is reversed (to a lesser degree) when considering the bill per square foot of living area. In other words, while households with higher social vulnerability generally spend less on water overall and per person, when the bill is normalized by household square footage, they may be paying more. This is true for both single and multi-family households.

The regression analysis revealed that there was not a statistically significant relationship between SVI and the dependent variables. In other words, it did not demonstrate that the social vulnerability of a household, taken on its own, would increase annual water bills by any measure; thus, we can assume that the link between higher SVI and other socioeconomic and housing factors (such as income, race and multi-unit structures) accounts for the correlative relationships shown in **Error! Reference source not found.** (Bixler et al., 2021).

HEAT EXPOSURE INDEX

Higher levels of heat exposure were associated with lower total water bills for both single family and multi-family households; however, for multi-family households, higher levels of heat exposure were also associated with a higher water bill per square foot of living area. In other words, while households situated in hotter microclimates generally spend less on water overall and per person, when the bill is normalized by household square footage, they may be paying more. Multi-family households appear to be much more likely than single family households to experience this increased cost per square foot.

The regression analysis revealed that there is not a statistically significant relationship between urban heat exposure and the dependent variables. In other words, there was no evidence that the microclimate of a household, taken on its own, would increase annual water bills by a significant amount. In Austin, income negatively correlates with heat exposure (i.e., higher income households are more likely to experience higher levels of UTC and lower levels of heat exposure) (*Austin's Urban Forest Plan: A Master Plan for Public Property*, 2013); thus, the relationship between heat exposure and water consumption may be overpowered by the relationship between income and water consumption.

HOME AGE

No form of statistical analysis revealed any significant correlation between the year a home was built and the dependent variables. In general, households with a higher home age pay slightly more on average and per person (although multi-family households with a higher home age may pay less per square foot), but there is no strong evidence that the year a home or apartment complex was built, taken on its own, would increase annual water bills by any measure.

LIMITATIONS

There are two major limitations to the quantitative analysis. First, as described in the sections above, significant assumptions were made to calculate multi-family drinking water bills, including the number of units served by each meter, the meter size, pump type, and the apartment layout (which impacts unit square footage). While these assumptions are informed and supported, they may result in imprecise findings. Possibly because of these assumptions, there is extreme variability in the drinking water bills for multi-family households. In addition, some multi-family bills are not paid for by individual households but rather included in monthly rent by landlords and property management companies. The impacts of water bills' incorporation into rental payments are not considered in this research.

Second, the drinking water bills calculated for this analysis do not include any financial discounts provided by the affordability programs that Austin Water has instituted (see **Table 2**). Households are not automatically enrolled in Austin Water's affordability programs based on certain characteristics, nor is there is no public record of the households taking advantage of these programs. Furthermore, because this research is interested in the basic links between water bills and socioeconomic, racial, and housing factors, factoring in the effects of affordability programs specific to Austin Water may make these relationships less apparent. Thus, I chose to ignore Austin Water's affordability programs altogether in my quantitative analysis.

Chapter 6: Conclusion

As discussed in **Chapter 3**, racist planning decisions and development patterns in Austin have preserved wealth and vegetation in West Austin. The purpose of this study was to ascertain how these processes that have made Black and Latino Austinites vulnerable (e.g., redlining, segregation, gentrification) also have material impacts on something as seemingly neutral as a water bill. The socioeconomic, racial, and housing factors examined in this study are closely linked with one another and thus have overlapping and compounding influences.

In this chapter, I will first review and contextualize the findings of the quantitative study conveyed in **Chapter 5**. In addition, I will compare the findings to Austin Water's current affordability measures and identify opportunities to improve affordability and equity in Austin. Lastly, I will highlight areas of future research that may strengthen water equity efforts in Austin and nationally.

DISCUSSION AND CONTEXTUALIZATION OF FINDINGS

This study found that housing typology, heat exposure, social vulnerability, and status as a renter or owner all impacted household water bills, to varying degrees. Where one of these conditions is present, another is likely occurring alongside it. Studies have found that areas with increased heat exposure generally have higher levels of social vulnerability (Benz & Burney, 2021). The very measurement of social vulnerability (through SVI) considers factors like race, housing types, and income (Bixler et al., 2021). In Austin, race correlates with income, housing typology, and heat exposure: in 2019, White Austinites earned 1.8 and 1.6 times as much as Black and Latino Austinites, respectively (Singh, 2019); the neighborhoods with the highest temperatures are disproportionately made up of Black and Latino residents (Fisher, 2021); and Black and

Latino Austinites are significantly more likely than White Austinites to be renters (Buchele, 2016). While race did not have a direct impact on household water costs, its connection to one's status as a renter, heat exposure, and social vulnerability suggests that the impact of increased water costs is racialized.

It has been established to some degree that higher income single-family households generally use more water (Domene & Saurí, 2006; Tinker et al., 2005), but by examining water costs as a function of living area square footage, I hoped to negate the impact that home size had on this phenomenon. Instead, this asks the question: if two houses were the exact same size, what factors might lead one household to spending more on water than another? (In addition, most research to-date related to water use and conservation is focused on single-family homes, as they are generally larger water users. There is insufficient data describing water use trends in multi-family housing.)

The quantitative study showed that rentership had the strongest and most statistically significant impact on increased water bills in both single and multi-family homes. I theorize that this may be due to the lack of owner investment in water-efficient appliances, the lack of access to accurate metering technologies, and slower rates of leak repair. Renters generally have less agency to fix leaks or water issues in their homes; furthermore, renters in Austin generally have lower incomes than homeowners (*U.S. Census Bureau QuickFacts*, 2022) and may then have access to less capital to spend money on repairs.

Austin Water is unique in that its affordability programs do specifically reach households that are not the sole account holders (Davis, 2022); however, many of Austin Water's conservation measures hinge upon a rebate system, where a residents invests in water-saving technology and the utility later partially reimburses them for that investment. Lower-income households may not have the disposable income to make these investments, the time to spend on repairs, or the institutional capital to feel confident and comfortable seeking out a rebate with Austin Water. We can assume that renters may be even less likely to make long-term investments in the appliances or landscaping in their temporary housing. Landlords also have little motivation to make repairs and improvements if the water bill is the tenant's responsibility, and tenants may not feel comfortable asking for or demanding these updates. While Austin Water does offer some programs available for HOAs or multi-family housing complexes to take advantage of, the utility do not present a clear incentive for these groups to participate.

While Austin Water has a commendable selection of affordability programs, these results indicate that reaching renters should be a priority for the utility moving forward. By specifically focusing on renters who are low-income and in neighborhoods with disproportionate heat exposure, Austin Water can also work to improve racial equity. More specific research may highlight other opportunities for Austin Water to foster water equity.

RECOMMENDATIONS FOR FURTHER RESEARCH

Further research may highlight more opportunities for Austin Water to improve water equity in its service area. First and foremost, this quantitative study was severely limited by the quality of water use data available for multi-family homes. I recommend that future studies specifically focus on multi-family homes to get a more accurate picture of how water use and water costs vary among residents. Second, water equity is a function of water affordability, quality, and access (Fox & Shafer, 2021; Osman & Faust, 2021). Future research may examine how to improve each of these facets of water equity in Austin.

Water affordability

Utilities should better understand how effectively their ongoing water affordability measures are providing aid to those in their community that need it, specifically low-income renters. In addition, researchers and utilities in Philadelphia and Detroit are experimenting with how equity can be built into rate design through designing income-based water rates (Davis, 2022). Chan recommends an output-based model, used in Chilean water systems, that provides water subsidies to households based on both their socioeconomic characteristics and consumption levels (Chan, 2015). In addition, Barberàn and Arbués use water rates applied in Zaragoza, Spain as a model to propose for per capita water pricing, which would reduce water use penalties often levied on large households that use high volumes of water (Barberán & Arbués, 2009). Future studies may be focused on determining the feasibility for an alternative rate structure in Austin.

Water conservation

The specter of worsening droughts looms large over Austin, and conservation measures are imperative. It is necessary for Austin Water, and other Central Texas utilities, to explore how conservation measures can be applied equitably. Simply increasing rates is likely to exacerbate gaps between water users and disproportionately harm low-income residents (who are likely consuming less overall and thus, contributing less to the climate change processes driving the drought). Research in this area may focus on exploring low-cost or free strategies for renters and landlords to improve conservation.

Water access

Ultimately, Austin Water is a publicly owned utility that actively pursues affordability and equity measures within its service area; however, living within the Austin Water service area is becoming increasingly expensive. As gentrification pushes low-income households and people of color further and further away from the city (Way et al., 2018), fewer people in need may actually be able to access Austin Water's affordability programs. Private water companies, who generally use market-based pricing schemes that result in higher water prices, operate in the outskirts of Austin (Aker, 2016). Future efforts to improve water equity in Austin may partner with the city's Housing and Planning Department to ensure affordable housing and thus access to quality, price-controlled water from Austin Water. In addition, future research may explore the equity implications of Austin Water expanding its service area.

This study takes on just one aspect of water equity: water affordability in Austin, Texas and how it is impacted by socioeconomics factors and legacies of racism. I found that, by and large, households that rent are paying more per square foot of their living area than households that own. This finding alone highlights the connections between the City of Austin's Housing and Planning Department and Austin Water, and the opportunities that exploring a deeper partnership further may bring. It is my hope that future studies further connect water equity to issues of racial equity and housing justice. I second Gerlak et al.'s view that these components of water equity are all deeply intertwined with one another, as well as rooted in legacies of settler colonialism and racism (2022); as such, future efforts to improve water equity in Austin must also contend with these forces.

Appendix A: 2016 Water Infrastructure Survey

The University of Texas at Austin is conducting a study investigating public perceptions and concerns regarding current water infrastructure services and water use trends. We are requesting you to complete this survey, which includes general questions about your perception and concerns about water infrastructure in your city (e.g., new water projects, the current state of your water infrastructure systems) and your household water use trends. The questionnaire will take about 10-15 minutes of your time to complete. The information collected will be kept confidential and it will only be used for academic purposes. You may skip any question you do not wish to answer in the survey. Your participation in this survey is completely voluntary and anonymous. Participants maybe 18 years or older.

A survey question asks for your household address. This information is sought to match willing participants to water meter data provided by the city, to understand your household water use. After the water meter data is matched to your household survey responses, this identifying data will be destroyed and will not be included in the study or analysis. The household survey responses and meter data will be matched by the local water utility, and the specific addresses associated with the water meter (water use) data will remain anonymous to researchers at UT Austin. This study is important for use to understand how utility customers use water and to understand the human interaction with this critical infrastructure system.

If you have any concerns regarding confidentiality or the study, please contact Dr. Kasey M. Faust (faustk@utexas.edu). Thank you for your time!

The water infrastructure is the network and components necessary to deliver safe and clean drinking water throughout communities. Examples of components comprising this infrastructure system include pipelines, valves, reservoirs, and pumping stations. Conservation in this study is defined as reduced water use in your household (considering indoor and outdoor use).

Participation in study: (1) I willingly participate in this study, providing my address to be matched with my household water use data, (2) I do not wish to participate in this study

PUBLIC PERCEPTIONS, ATTITUDE, KNOWLEDGE, AND AWARENESS (human-infrastructure interactions)

My household address is:

(1) Street 1:_______________
(2) Street 2 (Apt. etc.)_________
(3) City_______________
(4) State___________________
(5) Zip code___________________

Q1: Over the past decade, my city has: Faced a loss in population (1); Gained population (2); Has had no significant changes in population (3); I do not know (4)

Q2: How has your water bill changed in the past decade? No noticeable change (1); my water bill has increased (2); my water bill has decreased (3); I don’t know (4)

Q3: The level of service (defined as uninterrupted, clean, safe WATER, at an adequate pressure) from my WATER provider has changed in the past 10 years? Not applicable, I have not lived in the city more than 10 years (1); The quality of service has decreased dramatically (2); The quality of service has decreased slightly (3); There is no noticeable change in service (4); The quality of service has improved slightly (5); The quality has improved dramatically (6)

Q4: My city needs to (choose all that apply): Invest in more water infrastructure. (1); Remove or decommission (i.e., cease to use) components of the water infrastructure system (2); Repurpose some components of the water infrastructure system (3); Invest in maintaining the current water infrastructure system (4); Do nothing to the current water infrastructure system (5)

Q5: How much MORE would you be willing to pay for improved reliability (specifically, pressure and reduced interruption of service) of your WATER service? Leave the slider at "0" if you would not be willing to pay more for your water service for a more reliable system
______ Percent (%) increase in current water bill (1)

Q6: How much MORE would you be willing to pay for improved quality (smell, taste, etc.) of your WATER service? Leave the slider at "0" if you would not be willing to pay more for your water service for a more reliable system
______ Percent (%) increase in current water bill (1)

Q7: At the current rates, do you worry about having the ability (i.e., having the financial resources) to pay your water bill?______

Q8: Based on your understanding of the WATER infrastructure system, please indicate your opinion on the following statements:

	True (1)	False (2)	I do not know (3)
The water utility is responsible for the water infrastructure system UP TO the water meter (1)	❍	❍	❍
The water utility is responsible for the water infrastructure system UP TO the house (2)	❍	❍	❍
The water utility is responsible for the water infrastructure system INSIDE my house (3)	❍	❍	❍
The water utility is responsible for the water infrastructure system UP TO the street/property line (4)	❍	❍	❍
I (my household) collect(s) rainwater from your roof for outdoor use? (6)	❍	❍	❍
I (my household) have a home filter installed on your kitchen sink? (7)	❍	❍	❍
I (my household) have a water filtration pitcher (e.g., Brita, ZeroWater) that you use regularly in your household? (8)	❍	❍	❍

Q9: Based on your understanding of the WATER infrastructure system, please indicate your opinion on the following statements:

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	I do not know (6)
The water infrastructure system in my city is aging (i.e., very old) and needs to be upgraded (1)	❍	❍	❍	❍	❍	❍
The water infrastructure system in my city is sustained by revenues solely generated by water bills (2)	❍	❍	❍	❍	❍	❍
My water provider is fiscally strained (i.e., very tight on financial resources) (3)	❍	❍	❍	❍	❍	❍
I trust my water provider to make appropriate decisions that are in my best interest (4)	❍	❍	❍	❍	❍	❍
I would like to be actively involved in the decision-making process for the water infrastructure system in my city (5)	❍	❍	❍	❍	❍	❍

Q10: I (my household) actively attempt(s) to conserve water? Yes (1); No (2)

Q11: During the recent drought, I (my household) changed behavior to reduce water consumption? Yes (1); No (2)
If yes, HOW did your household actively try to reduce water consumption? ________________

Q12: I (my household) regularly has outdoor water use, such as watering the lawn? Yes (1); No (2)
Q13: If yes, how many TIMES PER WEEK do you use water outdoors? ________

Q14: On average, how many showers are taken daily in your household (including everyone in your household) ________
Q15: On average, how long (in minutes) are the showers ________

Q16: Based on your understanding of THE APPLIANCES IN YOUR HOME, please indicate your opinion on the following statements:

	Yes (1)	No (2)	I do not know (3)
I have low-flow appliances in your household (1)	❍	❍	❍
I have a low-flow washing machine (2)	❍	❍	❍
I have a low-flow dishwasher (3)	❍	❍	❍
I have AT LEAST one low-flow toilet (4)	❍	❍	❍
I collect rainwater for outdoor use (6)	❍	❍	❍
I have a home filter installed on my kitchen sink (7)	❍	❍	❍
I have a water filtration pitcher (e.g., Brita, ZeroWater) that is used regularly (8)	❍	❍	❍

Q17: I drink bottled water at home? Yes (1), No (2)

If yes, the frequency I drink bottled water at home is? Never (1); Occasionally (2); Most of the time (3); Primarily drink bottled water
If yes, why do you drink bottle water at home? __________

Q18: I use filtered water for any other household tasks besides drinking water (e.g., showering, water plants)? Yes (1), No (2)
If yes, what tasks and why______________

Q19: I use bottled water for any other household tasks besides drinking water (e.g., showering, water plants)? Yes (1), No (2)
If so, what tasks and why______________

Q20: I have noticed problems with the TASTE of my water? Yes (1), No (2)
Q21: If yes, how often? Once per year (1); 3 months per year (2), 6 months per year (3), 9 months per year (4), All of the time (5); Other _____(6)

Q22: I have noticed problems with the ODOR of my water? Yes (1), No (2)
Q23: If yes, how often? Once per year (1); 3 months per year (2), 6 months per year (3), 9 months per year (4), All of the time (5); Other _____(6)

Q24: Based on your understanding of PIPES IN YOUR HOME, please indicate your opinion on the following statements:

	Yes (1)	No (2)	I do not know (3)
I had a water leak in my household that required a repair (1)	❍	❍	❍
I have an ongoing leak INSIDE my house (2)	❍	❍	❍

I have had a water leak outside of my house in the yard that required a repair (3)	❍	❍	❍
I have had an ongoing leak OUTSIDE my house (i.e., yard) (4)	❍	❍	❍

Q25: I receive information from the utility through (choose all that apply)? Email (1); Paper mail (2); Radio (3); Citywide Meetings (4); Focus groups (5); Television (6); Twitter (7); Facebook (8); Other Social Media________ (9) Other ____________________

Q26: The methods that are effective for providing me with the information are (choose all that apply)? Email (1); Paper mail (2); Radio (3); Citywide Meetings (4); Focus groups (5); Television (6); Twitter (7); Facebook (8); Other Social Media________ (9) Other____________________

Q27: The current effectiveness of providing me information from the utility is? Extremely not effective (1); Not effective (2); Neutral (3); Effective (4); Very effective (5); I do not know (6)

Q28: In addition to the above methods, I would prefer to receive information via (e.g., phone app): 1=PHONE APP 2=TEXT 3=EMAIL

DEMONGRAPHIC QUESTIONS

Address (please include full address including apartment number if relevant, city, state, and zip code):

Zip code (this is requested twice, in the above question as well):

Q29: Gender: Female (1); Male (2)

Q30: What is your age? 18-25 (1); 26-35 (2); 36-50 (3); Above 50 (4)

Q31: Marital Status: Single (1); Married (2); Civil Union (3); Divorced (4); Separated (5)

Q32: What is your identified ethnicity? Hispanic or Latino (1); Not Hispanic or Latino (2)

Q33: What is your identified race (choose all that apply)? American Indian or Alaska Native (1); Asian (2); Black or African American (3); Native Hawaiian or Other Pacific Islander (4); White (5); Other (6) ____________________

Q34: How would you classify the area you grew up in? Urban (1); Suburban (2); Rural (3)

Q35: Did you grow up in the city you are currently living in? Yes (1); No (2)

Q36: Were you born in the city you currently live in? Yes (1); No (2)

Q37: How long have you lived in your city? _________

Q38: What is the highest completed level of education? Some high school (1); High school diploma (2); Technical college degree (3); College Degree (4); Post Graduate Degree (5)

Q39: How many people live in your household? _________

Q40: How many children under the age of 18 live your the household? _________

Q41: How many children under the age of 5 live in your household? _________

Q42: How many cars does your household have? _________

Q43: How would you describe your household? House (1); Apartment (2); Condo (3); Mobile home/Trailer (4); Other _____ (5)

Q44: Is your household...? Owned by you or someone in this household with a mortgage or loan (1); Owned by you or someone in this household free and clear (without a mortgage or loan) (2); Rented (3); Other (4) ____________________

Answer (1) or (2) | Q45: How old is your household?___________

Q46: Is this the first household you have owned? Yes (1); No (2); Not Applicable (3)

Answer If Is this the first household you have owned? Yes Is Selected | Length of time you have owned this home?

Q47: What is your approximate annual income? No income (1); Under $19,999 (2); $20,000-$34,999 (3); $35,000-$49,999 (4); $50,000-$74,999 (5); $75,000-99,999 (6); $100,000 and above (7)

Q48: What is the approximate annual household income of the household you consider home? No income (1); Under $19,999 (2); $20,000-$34,999 (3); $35,000-$49,999 (4); $50,000-$74,999 (5); $75,000-99,999 (6); $100,000 and above (7)

Q49: Are you responsible for your water utility bill: Yes (1); No (2)

Q50: What is your employment status (choose all that apply)? Employed for wages or salary (1); Self-Employed (2); Out of work and looking for work (3); Out of work but not currently looking for work (4); A homemaker (5); A student (6); Retired (7); Unable to work (8)

Q51: What is your primary source of news (choose all that apply)? Newspaper (1); Internet (2); Television (3); Radio (4); Social Media (5); Other (6) ____________________

Q52: Frequency of following the news: At least once per day (1); At least once per week (2); At least once per month (3); Never (4)

Q53: Political Views: Republican (1); Democrat (2); Independent (3); Other (4) _____

Do you have any comments or concerns about the WATER infrastructure system in your city?

Appendix B: Raw regression analysis results

Austin Water Equity Analysis Only Single Family

	Dependent variable:			
	Average Water Bill	Bill per person	Bill per sqft	Bill per lot size
	(1)	(2)	(3)	(4)
svinorm	110.16	-72.32	-0.0003	-0.07
	(394.50)	(110.91)	(0.14)	(0.05)
heat	147.64	123.51	0.08	0.01
	(252.36)	(89.01)	(0.11)	(0.04)
popdensity	-0.01	-0.004	-0.0000	0.0000
	(0.01)	(0.004)	(0.0000)	(0.0000)
age	-1.36	-0.62	-0.002	0.0003
	(2.01)	(0.73)	(0.001)	(0.0003)
raceBlack	-37.96	-6.83	0.01	-0.01
	(130.73)	(47.96)	(0.07)	(0.02)
raceHispanic	65.74	17.93	-0.01	-0.001
	(85.51)	(31.73)	(0.05)	(0.02)
raceAsian	-183.29*	-54.17	-0.08	-0.004
	(103.55)	(38.29)	(0.06)	(0.02)
raceOther	-267.06*	-102.83**	-0.15*	-0.03
	(137.45)	(50.39)	(0.09)	(0.03)
100k	-23.97	-16.70	0.003	0.005
	(80.12)	(29.64)	(0.04)	(0.01)
75k	51.25	19.82	0.10***	0.02
	(69.05)	(25.62)	(0.04)	(0.01)
35k	101.61	31.68	0.01	-0.01
	(118.09)	(43.54)	(0.07)	(0.02)
renter	119.31*	40.88	-0.01	0.02*
	(68.01)	(25.16)	(0.04)	(0.01)
lotsize	0.001	0.0005	0.0000	
	(0.002)	(0.001)	(0.0000)	

sqft	0.20***	0.07***		
	(0.05)	(0.02)		
avghshldsize	52.25			
	(61.02)			
Constant	2,498.91	1,236.71	3.32	-0.46
	(3,972.91)	(1,447.64)	(2.01)	(0.68)
Observations	100	100	186	185
R^2	0.36	0.30	0.09	0.05
Adjusted R^2	0.24	0.19	0.02	-0.02
Residual Std. Error	256.55 (df = 84)	95.21 (df = 85)	0.19 (df = 172)	0.06 (df = 172)
F Statistic	3.09*** (df = 15; 84)	2.64*** (df = 14; 85)	1.24 (df = 13; 172)	0.69 (df = 12; 172)
Note:				*p**p***p<0.01

Austin Water Equity Analysis Only Multi-Family

	Dependent variable:		
	Average Water Bill	Bill per person	Bill per sqft
	(1)	(2)	(3)
svinorm	-241.34	-28.77	-0.96
	(287.17)	(84.18)	(29.54)
heat	-29.06	-38.14	-0.21
	(194.54)	(68.29)	(23.95)
popdensity	-0.005	-0.002	-0.001
	(0.005)	(0.002)	(0.001)
age	1.62	0.60	0.10
	(2.08)	(0.81)	(0.27)
raceBlack	-52.23	-14.98	-0.73
	(96.05)	(36.01)	(12.64)
raceHispanic	-49.12	-14.08	5.28
	(68.51)	(26.85)	(9.43)
raceAsian	408.64***	146.08***	-8.33
	(104.77)	(41.22)	(14.34)
raceOther	-28.75	-20.09	9.15
	(152.75)	(60.18)	(21.10)
100k	104.06	38.86	-0.82
	(70.03)	(27.60)	(9.70)
75k	54.83	20.19	4.97
	(62.05)	(24.38)	(8.53)
35k	31.42	14.20	-3.78
	(80.63)	(30.26)	(10.61)
renter	-23.03	-5.58	23.10**
	(75.45)	(29.73)	(10.13)
sqft	-0.04	-0.01	
	(0.11)	(0.04)	
avghshldsize	119.50		
	(77.72)		

Constant	-3,173.34	-1,076.70	-188.65
	(4,082.67)	(1,601.77)	(539.73)
Observations	82	82	82
R^2	0.28	0.24	0.15
Adjusted R^2	0.12	0.09	0.005
Residual Std. Error	195.88 (df = 67)	77.23 (df = 68)	27.13 (df = 69)
F Statistic	1.82* (df = 14; 67)	1.63* (df = 13; 68)	1.03 (df = 12; 69)
Note:			*p**p***p<0.01

Austin Water Equity Analysis Including Multi-family Units

	Dependent variable:		
	Average Water Bill	Bill per person	Bill per sq ft
	(1)	(2)	(3)
svinorm	48.56 (235.98)	-38.50 (67.77)	-6.96 (8.63)
heat	-81.20 (155.33)	5.01 (54.75)	-2.06 (7.10)
popdensity	-0.01 (0.004)	-0.002 (0.002)	-0.0005^{*} (0.0003)
age	-0.63 (1.40)	-0.42 (0.51)	0.05 (0.07)
raceBlack	-26.86 (80.61)	-11.78 (30.29)	-1.05 (4.28)
raceHispanic	35.05 (55.96)	11.03 (21.04)	2.55 (2.97)
raceAsian	38.62 (74.91)	24.44 (28.08)	-1.18 (4.06)
raceOther	-170.35 (103.94)	-66.05^{*} (38.98)	1.52 (5.83)
100k	31.75 (53.75)	12.56 (20.22)	-0.34 (2.56)
75k	24.27 (46.92)	9.47 (17.63)	2.78 (2.35)
35k	21.19 (68.63)	3.34 (25.38)	-2.14 (3.61)
multifamily	-150.04^{***} (55.43)	-61.51^{***} (20.42)	29.93^{***} (2.70)
renter	104.58^{**} (48.79)	36.47^{**} (18.34)	7.01^{***} (2.57)
sqft	0.17^{***} (0.04)	0.06^{***} (0.01)	
avghshldsize	46.52 (46.44)		
Constant	1,240.69 (2,778.20)	898.40 (1,022.72)	-94.01 (131.65)
Observations	182	182	268
R^2	0.37	0.31	0.56
Adjusted R^2	0.32	0.25	0.53
Residual Std. Error	240.88 (df = 166)	90.61 (df = 167)	14.87 (df = 254)
F Statistic	6.57^{***} (df = 15; 166)	5.39^{***} (df = 14; 167)	24.48^{***} (df = 13; 254)
Note:			*p**p***p<0.01

Acronym Glossary

ACS	American Community Survey
AMI	advance metering infrastructure
AW	Austin Water
AWWA	American Waterworks Association
CAP	customer assistance program
CEAP	Comprehensive Energy Assistance Program
CHIP	Children's Health Insurance Program
COA	City of Austin
CPI	consumer price index
CWSRF	Clean Water State Revolving Fund
DWSRF	Drinking Water State Revolving Fund
EPA	U.S. Environmental Protection Agency
FHA	Federal Housing Administration
FPL	Federal poverty line
HOA	homeowners' association
HOLC	Home Owner's Loan Corporation
MAP	Medical Access Program
MHI	Median household income
SNAP	Supplemental Nutrition Assistance Program
SSI	Supplemental Security Income
SVI	social vulnerability index
SWIFT	State Water Implementation Fund for Texas
TCAD	Travis County Appraisal District

TWDB	Texas Water Development Board
UTC	urban tree canopy
VASH	Veterans Affairs Supportive Housing

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