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HUMAN-INFRASTRUCTURE INTERACTIONS: STATISTICAL MODELING OF BOTTLED AND FILTERED WATER USE IN U.S. SHRINKING CITIES

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Abstract: The recent water crisis in Flint, Michigan, has focused a great deal of attention, nationwide, on communities' water infrastructure. The Flint crisis, along with other water infrastructure issues, has impacted how people interact with their water infrastructure—whether they consume water, for example, from the tap or from a bottle. In June 2016, a survey was deployed to the general public to assess public views toward their city's water infrastructure and describe their interactions with it. Individuals surveyed were from 21 shrinking U.S. cities—cities that have experienced chronic urban decline and operate underutilized water infrastructures supported by increased per capita costs. Six survey questions of interest pertain to whether the respondent drank bottled/filtered water, how frequently they did so, and whether they used such water for purposes other than drinking. Results indicate that 75% of respondents drank bottled water and 51% did so frequently. Approximately, 65% drank filtered water, with 42% doing so frequently. For purposes other than drinking—e.g., hair washing, teeth brushing, pet care—29% used bottled water and 32% used filtered water. In explaining their water use behaviors, respondents cited cost, convenience, and water quality concerns. To understand the drivers of these human-infrastructure interactions, the survey questions were statistically modeled to identify geographic and demographic parameters that increased/decreased the likelihood of bottled/filtered water use. Insights that this study provides into the water use behavior of end-users can help decision makers implement sustainable strategies that continually evaluate and incorporate human-water infrastructure interactions.

1 INTRODUCTION

The primary aim for water providers is to consistently supply safe drinking water to end-users. Water providers must also consider, though, more frequent and severe water challenges, such as the depletion of water resources and quality factors that impact public health (Gleick 1998; Sorenson et al. 2011). To help with such considerations, researchers at the national and international levels have proposed new approaches that incorporate long-term and sustainable water management strategies (Gleick 1998; Suski and Cooke 2007; Dawadi and Ahmad 2013). Sustainable management considers more than costs and benefits; it incorporates social, cultural, environmental, and human (i.e., end-users) aspects into the decision-making process (Glicker 1992; Hellström et al. 2000). These aspects are sometimes manifested in how end-users selectively interact with water infrastructure systems through means such as substituting products (e.g., bottled water) or filtering tap water due to various factors like aesthetics (appearance, taste, odor) and health concerns (Anadu and Harding 2000; Doria 2006; Jones et al. 2006).

In fact, since the early 1990s, many countries, including the US, have dramatically increased their bottled water consumption (Hobson et al. 2007). Many households have also tried to improve their drinking water quality by adopting various household water treatment technologies (Sobsey et al. 2008). These trends are striking given the fact that the standards and quality of tap water have in recent decades improved in many countries (Doria 2006). The risks of drinking tap water, however, as perceived by users, influence users' decision to use bottled and filtered water (Anadu and Harding 2000). One's subjective judgement as to whether to drink water drawn from the local water system is captured in one's drinking water risk perception. This perception is influenced by social, cultural, and psychological factors; by objective information; and by distrust in the government and water industry (Anadu and Harding 2000).

The literature contains studies on the rationale for using alternative/substitute water sources (e.g., bottled and filtered water) for drinking (e.g., Gleick 1998; Anadu and Harding 2000; Doria 2006), as well as parameters influencing the risk perceptions of drinking water (Hobson et al. 2007). What the literature lacks are studies addressing how human-water infrastructure interactions may have been influenced by possible relationships between public water use behavior and water-related crises (e.g., the Flint water crisis [FWC], Alabama water contamination, Newark Public School lead detection). The FWC occurred after officials changed, in April 2014, the city of Flint's water source from Lake Huron to the Flint River (Dixon 2016). The city failed to implement adequate corrosion treatment to prevent lead from leaching into the drinking water. In September 2015, physicians were encountering children with high lead-blood levels (Bellinger 2016; Snyder 2016). In January 2016, residents were advised to use filtered or bottled water for drinking (Dixon, 2016). Water quality challenges also arose in Birmingham, Alabama, and Newark, New Jersey, where city officials also recommended or advised residents to temporarily use alternative water sources instead of tap water (States News Service 2016; Yawn 2016).

This study addresses the gap between perceived public water use before and after the increased national attention on water-related events and crises, specifically in U.S. shrinking cities. Here, shrinking cities are defined as medium and large cities that have experienced chronic urban decline after their populations peaked at approximately 100,000 or more. This population decline resulted in underutilized water infrastructure, increased water age, and increased per capita costs (Faust et al. 2016). In November 2013, Faust (2015) surveyed U.S. shrinking cities to assess the public perceptions of water infrastructure and water infrastructure service. Included in this study was a question pertaining to any changes in water quality from the previous decade. Approximately 20% of respondents perceived a decrease in the water quality.

In June 2016, in the wake of water quality-related crises, a follow-up survey in the cities surveyed in November 2013 was conducted. The 2016 survey replicated questions from the 2013 survey, including perceived changes in water quality from the previous decade. Approximately twice the number of respondents perceived a decrease in quality. Along with the replicated questions were behavioral questions pertaining to water use. The current study seeks to identify and understand parameters that drive human-infrastructure interactions. Of interest to this study are results from statistical modeling, which estimates significant geographic and demographic parameters influencing the likelihood of using bottled/filtered water, frequency of using bottled/filtered water, and use of bottled/filtered water for other household tasks besides drinking. Having a grasp of these parameters contributes to a better understanding of the end-users' behavior, and may aid decision makers in communicating with the public (Glicker 1992; Anadu and Harding 2000; Doria 2006; Sobsey et al. 2008).

2 METHODOLOGY

To assess public views regarding water infrastructure and public interactions with water infrastructure, a voluntary survey was deployed in June 2016 among current residents over the age of 18 who currently reside in the 21 U.S. shrinking cities (e.g., Buffalo, Cleveland, Detroit, Flint, Pittsburgh). After the survey underwent IRB review at the University of Texas at Austin, it was deployed through a web-based survey company. Prior to deployment, 10 subject-matter experts who had backgrounds in survey analyses, water infrastructure, or management of shrinking cities reviewed the content. Additionally, the survey was pre-deployed to 10 individuals who had limited knowledge about the subject to ensure that the survey was comprehensible and that the expected data would be collected (not included in the final sample). The sample consisted of 451 valid responses, providing a 95% confidence level and a +/- 5% margin of error. As with any study, limitations exist. The survey practiced in this study represents a cross-sectional sample. However, public perceptions are dynamic, changing with new events or information (Li et al. 2015).

Furthermore, as the survey was deployed among shrinking cities only, the results cannot be generalized to cities beyond this category.

The questions of interest were either binary (yes/no) or on a four-point scale (never, occasionally, most of the time, and primarily). Responses from questions on the four-point scale were collapsed to frequently and rarely. Frequently contains primarily and most of the time, while rarely contains occasionally and never. Six binary logit models with random parameters were developed to identify the demographic and geographic parameters that influence the likelihood of the public water use behavior of interest. A binary logit model estimates the likelihood that a dependent parameter takes one of two discrete outcomes depending on the conditions of the observable, independent parameters (Aldrich and Nelson 1984). For instance, when considering the outcome *Bottle*, which predicts whether an individual drinks bottled water, we can estimate such a probability for observation *n* by using Eqn. 1:

[1] $\mathrm{P_n(Bottle)} = \Phi(\frac{\beta_{\mathrm{Bottle}} \mathrm{X}_{Bottle,n}}{\sigma})$

, where Phi (Φ) is the standardized cumulative normal distribution, β_{Bottle} is a vector of estimable parameters for outcome *Bottle*, and X_{Bottle} is a vector of the observable characteristics (i.e. demographic and geographic characteristics) (Washington et al. 2010). A linear function that estimates the discrete outcome, *Bottle*, for observation *n*, T_{Bottle}, is shown in Eqn. 2:

[2] $T_{Bottle,n} = \beta_{Bottle} X_{Bottle,n} + \varepsilon_{Bottle,n}$

, where $\varepsilon_{\mathrm{Bottle}}$, is the disturbance term (Aldrich and Nelson 1984). To account for unobserved heterogeneity and allow the parameters to vary according to a pre-specified distribution function, random parameters are used (Washington et al. 2010) as shown in Eqn. 3:

[3] $\mathrm{P}^{r}_{Bottle}(\mathrm{n}) = \int_x P_n(Bottle) f(\beta|\varphi) \mathrm{d}\beta$

, where $f(\beta|\varphi)\, d\beta$ is the density function of β and φ is a vector of parameters of that density function (Washington et al. 2010). All random parameters in this study are normally distributed.

The Akaike Information Criteria (AIC) was used to determine the best-fit model, and marginal effects were used to interpret the model results. The AIC value is an asymptotically unbiased estimate of expected Kullback-Leibler (K-L) information, which represents the information lost when using a model (Burnham and Anderson 2004). The best-fit model is considered to be the model with the least K-L information (Burnham and Anderson 2004).

Marginal effects are the changes in a dependent parameter when an independent parameter changes from zero to one (for binary parameters), or a one-unit change in the independent parameter, while all other parameters remain constant (Cameron and Trivedi 2009). Positive marginal effects indicate an increased likelihood of the outcome of the dependent parameter (such as, use of bottled/filtered water for drinking or household tasks, or frequency of drinking bottled/filtered water), whereas negative marginal effects indicate a decreased likelihood.

3 RESULTS AND DISCUSSION

Among the survey respondents, approximately 68% were female, 45% were married, and over 60% were younger than 35. A majority of the respondents had attained an education level higher than a high school diploma, specified annual individual incomes of less than $50,000, and were responsible for paying utility bills. Table 1 summarizes descriptive statistics of selected parameters.

Table 1: Descriptive Statistics

Parameters	Min/Max	Mean (Std. Dev.)
Individual Characteristics		
18-25 years old (1 if 18-25 years old, otherwise 0)	0/1	0.24 (0.43)
26-35 years old (1 if 26-35 years old, otherwise 0)	0/1	0.37 (0.48)
36-50 years old (1 if 36-50 years old, otherwise 0)	0/1	0.23 (0.42)
Over 50 years old (1 if over 50 years old, otherwise 0)	0/1	0.16 (0.36)
Single (1 if single, otherwise 0)	0/1	0.44 (0.50)
Number of years you lived in your city (years)	0.5/71	18.10 (14.94)
Highest level of education (1 if some high school, otherwise 0)	0/1	0.03 (0.16)
Highest level of education (1 if high school diploma, otherwise 0)	0/1	0.33 (0.47)
Highest level of education (1 if technical college degree, otherwise 0)	0/1	0.12 (0.33)
Highest level of education (1 if college degree, otherwise 0)	0/1	0.40 (0.49)
Highest level of education (1 if post graduate, otherwise 0)	0/1	0.12 (0.32)
Employed for wages or salary (1 if true, otherwise 0)	0/1	0.61 (0.49)
Responsible for water bill (1 if true, otherwise 0)	0/1	0.88 (0.33)
Household Characteristics		
Number of children under the age of 18 living in household (youth)	0/5	0.90 (1.15)
Number of children under the age of 5 living in household (children)	0/3	0.28 (0.61)
Number of Cars in Household (cars)	0/6	1.67 (0.90)
Income (1 if respondent has no income, otherwise 0)	0/1	0.02 (0.15)
Income (1 if income is less than $19,999, otherwise 0)	0/1	0.12 (0.32)
Income (1 if income is between $20,000-$34,999, otherwise 0)	0/1	0.17 (0.38)
Income (1 if income is between $35,000-$49,999, otherwise 0)	0/1	0.21 (0.41)
Income (1 if income is between $50,000-$74,999, otherwise 0)	0/1	0.22 (0.42)
Income (1 if income is between $75,000-$99,999, otherwise 0)	0/1	0.13 (0.34)
Income (1 if income is above $100,000, otherwise 0)	0/1	0.13 (0.33)

The aggregated survey data indicated that 74% of the respondents drank bottled water and 65% drank filtered water in their households primarily out of concerns regarding their health and the water's odor and taste (Fig.1). Of the 74% who drank bottled water, 22% stated that they drank it only occasionally, 29% drank it most of the time, and 23% drank it primarily. Of the 65% who drank filtered water, 23% drank it only occasionally, 23% drank it most of the time, and 19% drank it primarily. Interestingly, 29% of the respondents were using bottled water and 32% were using filtered water for household tasks besides drinking, such as cooking, making ice, watering plants, water for pets, washing dishes, washing hair, and brushing teeth (Fig.2).

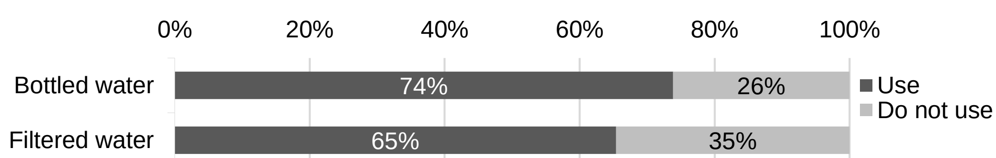

Figure 1: Use of bottled and filtered water for drinking

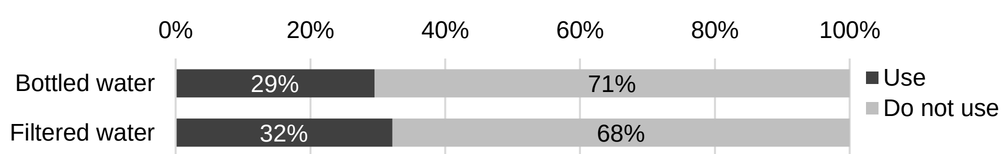

Figure 2: Use of bottled and filtered water for other household tasks besides drinking

Tables 2 and 3 show the results of the statistical models estimating the parameters that influence the likelihood of drinking bottled water and filtered water. Residents of New Jersey and of Flint, Michigan, were more likely to drink bottled water (Table 2). However, no geographic parameters were statistically significant in influencing the likelihood of drinking filtered water (Table 3). The New Jersey state indicator may reflect local media attention on local water quality issues including those of the public schools in Newark, New Jersey, in the tap water of which there were detected high lead levels (Kiefer 2016). Based on the advice to use alternative water sources from the Department of Environmental Protection (DEP), the Newark Public School system immediately shut off water fountains at identified schools and delivered alternative supplies of drinking water (e.g., bottled water; State News Service 2016). Considering the Flint city parameter, the results may be capturing that Flint declared a state of emergency and recommended residents to use bottled or filtered water (Dixon 2016).

Demographic parameters that influence the likelihood of drinking bottled or filtered water include the following: age, gender, employment status, ethnicity, length of time lived in the city, location born and raised, number of cars in the household, presence of children under the age of 18, awareness of the water quality report from local utilities, whether the household has outdoor water use, and if the household uses low-flow appliances. Respondents between 18 and 25 years of age and between 18 and 35 years of age were more likely to drink bottled water and filtered water, respectively (Tables 2 and 3). It is interesting to note that respondents over the age of 50 were modeled as a random parameter, exhibiting heterogeneity across the population, with 60% of respondents over the age of 50 being less likely to drink filtered water, and 40% being more likely to drink filtered water (Table 3). This may support the finding that younger respondents are more likely to be dissatisfied with the quality of tap water (de França Doria 2010).

Table 2: Parameters influencing the likelihood of drinking bottled water

Independent Variable	Parameter (t-statistic)	St. Dev. (t-statistic)	Marginal Effects
Fixed parameters			
Constant	0.89 (1.68)	*fixed*	
Age (1 if between 18 and 25, otherwise 0)	1.02 (3.39)	*fixed*	0.174
Youth present in household (1 if children under age of 18 live in household, otherwise 0)	0.83 (3.91)	*fixed*	0.142
Employment status (1 if out of work, otherwise 0)	1.56 (2.57)	*fixed*	0.264
Ethnicity (1 if not Hispanic or Latino, otherwise 0)	-0.98 (-2.02)	*fixed*	-0.166
Location born and raised (1 if born and raised in city currently residing in, otherwise 0)	0.37 (1.79)	*fixed*	0.063
Gender (1 if female, otherwise 0)	-0.40 (-1.85)	*fixed*	-0.068
Outdoor water use (1 if regularly have outdoor water use, otherwise 0)	0.64 (3.13)	*fixed*	0.109
New Jersey state indicator (1 if currently reside in NJ, otherwise 0)	1.12 (2.34)	*fixed*	0.191
Flint, MI indicator (1 if currently reside in Flint, MI, otherwise 0)	1.42 (1.92)	*fixed*	0.242
Random parameters			
Number of cars (1 if household owns more than one cars)	-0.15 (-0.71)	1.98 (7.08)	-0.025
Residence period (1 if resided in current city for less than 5 years, otherwise 0)	0.60 (1.94)	2.48 (5.21)	0.101
Log likelihood at convergence	*-229.141*		
AIC	*486.3*		
Number of observation	*451*		

As shown in Table 2, females were less likely to drink bottled water. Individuals who have children younger than 18 in their households were more likely to drink bottled water (Table 2). This may be capturing factors, such as the perceived risk of drinking water quality associated with children after children were found to have high lead-blood levels during the FWC (Chambers 2016). Parameters indicating that a respondent had briefly lived in the current city exhibited considerable heterogeneity across the population. Long-term residents, in contrast, were modeled as a fixed parameter. Approximately 59% of the individuals who resided in the current city for fewer than five years were more likely to drink bottled water while the other 41% were not (Table 2). Residents who had resided in the current city for more than 20 years were less likely to drink filtered water (Table 3). These parameters may reflect the idea that relatively new residents are more likely to be skeptical of local water quality. This would be consistent with the findings from Humphries and Wilding (2004), who found that trust is developed through long-term collaborative relationships between customers and utility providers. Respondents were more likely to drink filtered water if they were aware of the water quality reports released by utility providers (Table 3).

Table 3: Parameters influencing the likelihood of drinking filtered water

Independent Variable	Parameter (t-statistic)	St.Dev. (t-statistic)	Marginal Effects
Fixed parameters			
Constant	-2.26 (-5.37)	*fixed*	
Age (1 if between 18 and 35, otherwise 0)	0.91 (3.41)	*fixed*	0.154
Number of youth (1 if more than three children under age of 18 live in household, otherwise 0)	-1.79 (-2.76)	*fixed*	-0.299
Residence period (1 if resided in current city for more than 20 years, otherwise 0)	-0.80 (-3.24)	*fixed*	-0.135
Appliances (1 if use at least one water conserving appliances in household, otherwise 0)	2.89 (6.93)	*fixed*	0.492
Random parameters			
Age (1 if over 50, otherwise 0)	-1.34 (-3.09)	5.31 (5.68)	-0.211
Outdoor water use (1 if regularly have outdoor water use, otherwise 0)	0.88 (3.27)	3.31 (7.91)	0.161
Report (1 if aware of water utility's water quality report, otherwise 0)	0.94 (3.29)	3.67 (7.42)	0.138
Log likelihood at convergence	*-247.667*		
AIC	*517.3*		
Number of observation	*451*		

Tables 4 and 5 show statistically significant parameters influencing the likelihood of frequently drinking bottled and filtered water. In terms of geographic parameters, residents in Michigan had an increased likelihood of frequently drinking bottled water (Table 4). This may reflect the increased concern towards water quality in Michigan after the FWC. Moreover, residents living in Baltimore, Maryland were less likely to drink filtered water frequently (Table 5).

The frequency of drinking bottled or filtered water was influenced by the following statistically significant demographic parameters: age, gender, education, length of time lived in the current city, number of cars, presence of children under age of 18 in the household, whether the respondent is responsible for utility bill payment, and outdoor water use. Interestingly, the parameter capturing respondents between the ages of 18 and 35 had a negative impact (on average) on bottled and filtered water use. These respondents had a decreased likelihood of frequently drinking bottled water (Table 4). However, 51.1% of 18 to 35-year-olds had an increased likelihood of frequently drinking filtered water; 48.9% showed decreased likelihood of frequently drinking filtered water (Table 5). Respondents who did *not* have children younger than 18 in their household were less likely to frequently drink bottled water, while those who did have such children were less likely to drink filtered water (Tables 4 and 5). Individuals with more than three cars in their households were less likely to frequently drink bottled water (Table 4). The number of cars within a household often corresponds with wealth (Dargay 2001). Hence, according to this study, wealth may not be a driver of using bottled water. Similar to the results found in Table 2 (use of bottled water), 56.6% of the respondents who lived in the current city for fewer than five years were more likely to frequently drink bottled water, while the rest, 43.4%, were not (Table 4).

Table 4: Parameters influencing the likelihood of frequently drinking bottled water

Independent Variable	Parameter (t-statistic)	St.Dev. (t-statistic)	Marginal Effects
Fixed parameters			
Constant	0.98 (2.73)	*fixed*	
Age (1 if between 18 and 35, otherwise 0)	-0.49 (-2.25)	*fixed*	-0.106
Number of cars (1 if household owns more than three cars)	-1.63 (-2.29)	*fixed*	-0.355
Youth (1 if no children live in household, otherwise 0)	-0.37 (-1.89)	*fixed*	-0.080
Utility bill (1 if responsible for utility bill payment, otherwise 0)	0.69 (2.41)	*fixed*	0.149
Education (1 if have college degree or post graduate degree, otherwise 0)	-0.43 (-2.15)	*fixed*	-0.094
Outdoor water use (1 if regularly use outdoor water, otherwise 0)	-0.37 (-1.72)	*fixed*	-0.081
Michigan state indicator (1 if currently reside in MI, otherwise 0)	0.56 (1.89)	*fixed*	0.121
Random parameters			
Residence period (1 if resided in current city for less than 5 years, otherwise 0)	0.44 (1.47)	2.71 (4.60)	0.097
Log likelihood at convergence	*-187.276*		
AIC	*394.6*		
Number of observation	*333*		

Table 5: Parameters influencing the likelihood of frequently drinking filtered water

Independent Variable	Parameter (t-statistic)	St. Dev. (t-statistic)	Marginal Effects
Fixed parameters			
Constant	0.57 (2.36)	*fixed*	
Youth (1 if children live in household, otherwise 0)	-0.64 (-2.49)	*fixed*	-0.129
Baltimore, MD indicator (1 if currently reside in Baltimore, MD, otherwise 0)	-1.35 (-2.01)	*fixed*	-0.273
Random parameters			
Age (1 if between 18 and 35, otherwise 0)	0.10 (0.39)	3.81 (6.99)	0.021
Gender (1 if female, otherwise 0)	1.01 (3.56)	1.99 (5.86)	0.203
Log likelihood at convergence	*-187.301*		
AIC	*388.6*		
Number of observation	*295*		

Tables 6 and 7 show statistically significant parameters influencing the likelihood of using bottled water and filtered water for other household tasks other than drinking. Residents of Ohio were more likely to use bottled water for other tasks (Table 6). Residents of Camden, New Jersey, and of Michigan were more likely to use filtered water for other tasks. Residents of St. Louis, Missouri, were less likely to use filtered water for other tasks (Table 7).

The likelihood of using bottled or filtered water for other household tasks was influenced by the following demographic parameters: age, gender, employment, education, home ownership, location born and raised, presence of youth in the household, whether individual attempts to conserve water, whether the household has outdoor water use, whether the household uses low-flow appliances, awareness of the water quality report from local utilities, and trust level of water providers. Consistent with previous models (Tables 3 and 5), individuals between 18 and 35 were more likely to use bottled and filtered water for household tasks (Tables 6 and 7). Not surprisingly, individuals who did not trust their water providers to make decisions in residents' best interest were more likely to use bottled water for other household tasks (Table 6). Respondents were more likely to use bottled water for household tasks if they were employed, actively conserved water, regularly had outdoor water use in their household, or were aware of utility's water quality report (Table 6). However, 66.5% of those without children under the age of 18 in their households and 69.7% of those with a college degree or higher were less likely to use bottled water for household tasks (Table 6). Finally, the random parameter indicating gender shows that 57.6% of the female respondents were less likely to use filtered water for household tasks, while 42.4% of them were not (Table 7).

Table 6: Parameters influencing the likelihood of using bottled water for household tasks

Independent Variable	Parameter (t-statistic)	St. Dev. (t-statistic)	Marginal Effects
Fixed parameters			
Constant	-3.21 (-5.70)	*fixed*	
Age (1 if between 18 and 35, otherwise 0)	0.41 (2.07)	*fixed*	0.077
Employment status (1 if employed for wages or salary, otherwise 0)	0.47 (2.24)	*fixed*	0.089
Hometown (1 if grew up in an urban area, otherwise 0)	0.55 (2.75)	*fixed*	0.103
Location born and raised (1 if born and raised in city currently residing in, otherwise 0)	0.69 (3.44)	*fixed*	0.130
Trust (1 if respondent does not trust water provider, otherwise 0)	0.83 (2.30)	*fixed*	0.157
Conservation (1 if actively attempt to conserve water, otherwise 0)	1.20 (2.39)	*fixed*	0.227
Outdoor water use (1 if regularly use outdoor water, otherwise 0)	0.64 (3.04)	*fixed*	0.121
Report (1 if aware of utility's water quality report, otherwise 0)	0.64 (3.26)	*fixed*	0.122
Ohio state indicator (1 if currently reside in OH, otherwise 0)	-0.47 (-2.02)	*fixed*	-0.089
Random parameters			
Youth (1 if no children live in household, otherwise 0)	-0.58 (-2.90)	1.36 (5.72)	-0.109
Education (1 if have college degree or post graduate degree, otherwise 0)	-0.84 (-3.85)	1.63 (6.42)	-0.158
Log likelihood at convergence	*-230.604*		
AIC	*489.2*		
Number of observation	*451*		

Table 7: Parameters influencing the likelihood of using filtered water for household tasks

Independent Variable	Parameter (t-statistic)	St. Dev. (t-statistic)	Marginal Effects
Fixed parameters			
Constant	-3.36 (-6.58)	*fixed*	
Age (1 if between 18 and 35, otherwise 0)	0.66 (3.07)	*fixed*	0.120
Home ownership (1 if first home owned, otherwise 0)	0.64 (3.17)	*fixed*	0.118
Location born and raised (1 if born and raised in city currently residing in, otherwise 0)	0.82 (3.81)	*fixed*	0.150
Appliances (1 if use at least one water conserving appliances in household, otherwise 0)	1.58 (3.69)	*fixed*	0.289
Camden, New Jersey indicator (1 if currently reside in Camden, NJ, otherwise 0)	0.82 (1.69)	*fixed*	0.150
Michigan state indicator (1 if currently reside in MI, otherwise 0)	0.91 (3.14)	*fixed*	0.165
St. Louis, MO indicator (1 if currently reside in St. Louis, MO, otherwise 0)	-1.14 (-2.15)	*fixed*	-0.207
Random parameters			
Gender (1 if female, otherwise 0)	-0.63 (2.84)	3.28 (8.54)	-0.115
Log likelihood at convergence	*-254.847*		
AIC	*529.7*		
Number of observation	*451*		

4 SUMMARY AND CONCLUSION

End-users selectively interact with water infrastructure services through such means as using bottled or filtered tap water for their drinking water. This study sought to identify and understand geographic and demographic parameters that, in U.S. shrinking cities, influence the likelihood of using bottled and filtered water, the frequency of drinking bottled and filtered water, and the use of bottled and filtered water for other household tasks. The statistical modeling conducted in this paper revealed a variety of parameters affecting these water use behaviors. All the geographic variables were modeled as fixed parameters, demonstrating a homogeneous impact on the likelihood of use (drinking and household tasks) and frequency of drinking bottled or filtered water. This may indicate that human-infrastructure interactions with regard to bottled and filtered water use are strongly influenced by localized factors (e.g., the local media, social and political environment, communication between end-users and providers).

Interestingly, the trust in water providers was significant in only one model, where it influenced the use of water for household tasks when a provider was not trusted. Several demographic parameters were revealed as being random parameters (e.g., age, gender, education, number of cars, children presence in household, length of time living in a city, awareness of the local water quality report), exhibiting in their impact heterogeneity across the population. The following parameters were statistically significant in more than three models: representing a particular age group (28-35), presence of children, outdoor water use, and the location born and raised. Additionally, parameters that were significant in multiple models typically had the same directional impact (either increasing or decreasing the likelihood) on the occurrence of the dependent parameters. For example, the parameter indicating location born and raised increased the likelihood of drinking bottled water and using bottled and filtered water for other household tasks (Tables 2, 6, and 7).

The public has generally grown more concerned about its drinking water. To aid in infrastructure management, policy makers and utility providers can draw on the implications of the quantitative analysis from the survey to inform themselves about the behavior of public water use. This study also shows the viability of the statistical modeling approach in analyzing survey responses to assess human-infrastructure interactions. Identifying and understanding parameters that influence the likelihood of using bottled and filtered water can aid decision makers in implementing strategies that incorporate these human-infrastructure interactions and ensure that the current water infrastructure systems are able to serve the end-users' needs. Future analysis involving qualitative analysis of data that explain why respondents use bottled or filtered water and what household tasks besides drinking they are using it for may facilitate the understanding of water use behavior among the public.

References

Aldrich, J. H. and Nelson, F. D. 1984. *Linear probability, logit, and probit models* (Vol. 45). Sage.

Anadu, E. C. and Harding, A. K. 2000. Risk perception and bottled water use. *American Water Works Association. Journal*, **92**(11), 82.

Bellinger, D. C. 2016. Lead contamination in Flint—an abject failure to protect public health. *New England Journal of Medicine*, **374**(12), 1101-1103.

Burnham, K. P. and Anderson, D. R. 2004. Multimodel inference understanding AIC and BIC in model selection. *Sociological methods & research*, **33**(2), 261-304.

Cameron, A. C., and Trivedi, P. K. 2009. *Microeconometrics using stata* (Vol. 5). College Station, TX: Stata press.

Chambers, J. 2016. Lawsuit filed for kids in Flint water crisis. *The Detroit News*. Retrieved November 13, 2016

Dargay, J. M. 2001. The effect of income on car ownership: evidence of asymmetry. *Transportation Research Part A: Policy and Practice*, **35**(9), 807-821.

Dawadi, S., and Ahmad, S. 2013. Evaluating the impact of demand-side management on water resources under changing climatic conditions and increasing population. *Journal of environmental management*, **114**, 261-275.

Dixon, J. 2016. How Flint's water crisis unfolded. *Detroit Free Press*. Retrieved February 11, 2016, from http://www.freep.com/pages/interactives/flint-water-crisis-timeline/
de França Doria, M. 2010. Factors influencing public perception of drinking water quality. *Water policy*, **12**(1), 1-19.
Doria, M. F. 2006. Bottled water versus tap water: understanding consumers' preferences. *Journal of water and health*, **4**(2), 271-276.
Faust, K. M. 2015. Impact assessment of urban decline on coupled human and water sector infrastructure systems (Doctoral dissertation, PURDUE UNIVERSITY).
Faust, K. M., Abraham, D. M., & McElmurry, S. P. 2016. Water and Wastewater Infrastructure Management in Shrinking Cities. *Public Works Management & Policy*, **21**(2), 128-156.
Gleick, P. H. 1998. Water in crisis: paths to sustainable water use. *Ecological applications*, **8**(3), 571-579.
Glicker, J. L. 1992. Convincing the Public That Drinking Water is Safe. *Journal-American Water Works Association*, **84**(1), 46-51.
Hellström, D., Jeppsson, U., and Kärrman, E. 2000. A framework for systems analysis of sustainable urban water management. *Environmental Impact Assessment Review*, **20**(3), 311-321.
Hobson, W. L., Knochel, M. L., Byington, C. L., Young, P. C., Hoff, C. J., and Buchi, K. F. 2007. Bottled, filtered, and tap water use in Latino and non-Latino children. *Archives of pediatrics & adolescent medicine*, **161**(5), 457-461.
Humphries, A. S. and Wilding, R. D. 2004. Long term collaborative business relationships: The impact of trust and C3 behaviour. *Journal of Marketing Management*, **20**(9-10), 1107-1122.
Jones, A. Q., Dewey, C. E., Doré, K., Majowicz, S. E., McEwen, S. A., David, W. T., Eric, M., Carr, D. J., and Henson, S. J. 2006. Public perceptions of drinking water: a postal survey of residents with private water supplies. *BMC public health*, **6**(1), 94.
Kiefer, E. 2016. Newark Schools Shut Off Water Taps In 30 Buildings: Elevated Lead Found, DEP Says. *Newark Patch*. Retrieved January 27, 2017.
Li, X., Hsu, C. H., and Lawton, L. J. 2015. Understanding residents' perception changes toward a mega-event through a dual-theory lens. *Journal of Travel Research*, **54**(3), 396-410.
Washington, S. P., Karlaftis, M. G., and Mannering, F. 2010. Statistical and econometric methods for transportation data analysis. CRC press.
Snyder, R. 2016. Flint Water Advisory Task Force (Final Report). https://www.michigan.gov/documents/snyder/FWATF_FINAL_REPORT_21March2016_517805_7.pdf
Sobsey, M. D., Stauber, C. E., Casanova, L. M., Brown, J. M., and Elliott, M. A. 2008. Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environmental science & technology*, **42**(12), 4261-4267
Sorenson, S. B., Morssink, C., and Campos, P. A. 2011. Safe access to safe water in low income countries: water fetching in current times. *Social science & medicine*, **72**(9), 1522-1526.
States News Service. 2016. Joint Release from Dep and Newark Public Schools on Temporary Use of Alternate Water Sources after Elevated Levels of Lead Found in Recent District Sampling. 2016. *States News Service*. Retrieved January 27, 2017.
Suski, C. D. and Cooke, S. J. 2007. Conservation of aquatic resources through the use of freshwater protected areas: opportunities and challenges. *Biodiversity and Conservation*, **16**(7), 2015-2029.
Yawn, A. J. 2016. Eight north Alabama water systems contaminated with man-made chemicals. *Montgomery Advertiser*. Retrieved November 4, 2016