RACIAL DISPARITIES IN ACCESS TO MUNICIPAL DRINKING WATER: LEAD EXPOSURE RISK AND A RISK COMMUNICATION INTERVENTION

Frank J. Stillo III

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Approved by:

Jacqueline MacDonald Gibson

Courtney Woods

Louise Ball

Wändi Bruine de Bruin

Joachim Pleil

ABSTRACT

Frank J Stillo III: Racial Disparities in Access to Municipal Drinking Water: Lead Exposure Risk and a Risk Communication Intervention
(Under the direction of Jacqueline MacDonald Gibson)

A growing body of research has documented millions of Americans living in peri-urban areas lacking access to municipal water service. Many affected communities are majority-minority and were historically zoned out of municipal boundaries through a process known as "racial underbounding." Residents rely on unregulated private wells, even though their communities are typically encircled by municipal water lines. Little is known about chemical contaminants, such as lead, in drinking water in these communities, in part due to a lack of water quality monitoring.

The overall hypotheses of this thesis are that the risk of exposure to lead in drinking water in underbounded communities is higher than in areas with public water service; that risk awareness is low; and that awareness can be increased through evidence-based risk communication. These hypotheses are explored through a field study to characterize water quality in underbounded areas of Wake County, NC; a population survey of these communities; and a randomized-controlled trial of a risk communication intervention. This research is the first to study lead in kitchen tap water in underbounded communities. In addition, it is the first to examine risk awareness and factors driving decisions to test water quality. Finally, it is the first randomized-controlled trial of a health risk communication in these communities and one of the first targeted at private well owners in any context.

This dissertation provides evidence to support the three hypotheses. The average lead concentrations in the study households was nearly three times as high as in households served by the Raleigh municipal water supply, and lead in water exceeded the Environmental Protection Agency's water-lead action level in 24% of households. Risk awareness was low: only 5.5% of study participants answered "yes" to "My well water may be contaminated with lead." More than half of respondents had not tested their water for at least five years. Participants who recalled seeing the risk communication developed in this dissertation had significantly increased odds of testing their water (OR = 258, p = 0.001).

Overall, these results suggest the need for interventions to raise risk awareness and improve water quality in underbounded communities.

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To my wife and my family, who navigated this process with me, thank you for your unyielding support and encouragement. To my friends, I am grateful to each and every one of you.

PREFACE

This dissertation is organized in a nontraditional format, which includes three manuscripts. Chapter 1 provides an introduction to the dissertation and a description of the significance of the research. Chapters 2, 3, and 4 must stand alone as manuscripts to be submitted for publication and therefore have some redundancies with the earlier chapters. Chapter 5 presents a summary of the findings, policy implications, limitations of the studies, and directions for future research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AGI	acute gastrointestinal illness
BLL	blood lead level
CDC	Communicable Disease Center
CI	confidence interval
DPH	Department of Public Health
EPA	Environmental Protection Agency
ETJ	extraterritorial jurisdiction
IEUBK	Integrated Exposure Uptake Biokinetic Model for Lead in Children
LCR	lead and copper rule
MCL	maximum contaminant level
NC	North Carolina
NS	not significant
NSDWR	National Secondary Drinking Water Regulations
OR	odds ratio
PCA	principal component analysis
SDWA	Safe Drinking Water Act
STD	sexually transmitted disease
UNCC	University of North Carolina at Charlotte
U.S.	United States of America
WCGGIS	Wake County Global Information System
WLL	water lead level

LIST OF SYMBOLS

$BLL_{i,j}$ = blood lead concentration at household *i* for age *j* (in months), µg/dL

ρ = Pearson correlation, unitless

α = Cronbach's alpha, unitless

G = gamma correlation, unitless

CHAPTER 1: INTRODUCTION

This research seeks to determine whether there are racial disparities in exposure to lead in drinking water resulting from the exclusion of minority communities from municipal water infrastructure and, if so, whether a risk communication intervention could raise awareness of these disparities and prompt action by household members. Previous research by the scientific and legal communities has documented racial exclusion through discriminatory built environment practices across the United States (U.S.).[1–4] Yet, little is known about exposure to lead in drinking water and associated health risks in these neighborhoods. This introduction provides background about racially excluded communities, prior evidence of drinking water contamination risks in these communities, awareness of these risks, and how my objectives will build knowledge for these communities.

1.1 Background

1.1.1 Exclusion from Municipal Services

In 1987, demographer Charles Aiken proposed the proposed the term “racial underbounding” to describe peri-urban African-American communities that local officials zoned out of municipal boundaries, thereby denying access to municipal infrastructure, including community water and sewer service, trash collection, paved roads, and streetlights.[1] Decades later, the underbounding phenomenon persists. In 2008, Wilde-Anderson documented underbounding in California, Texas, Florida, and North Carolina (NC); she wrote, “In these understudied contexts, millions of low-income families live outside central cities on pockets of unincorporated land and in economically marginal suburban or rural municipalities."[5] More recently, Schindler found that stakeholders (including courts, lawmakers, and potential challengers) often fail to recognize the impact of the built environment as a form of racial exclusion; she concluded that existing legal precedent remains insufficient to overcome the effects of these zoning practices.[6] In 2014, MacDonald Gibson found a statistically significant association between race and access to municipal water supplies in peri-urban areas of Wake County, NC; every 10% increase in the African-American population proportion of a census block increased the odds of exclusion from municipal water service by 3.8%.[2] Multiple case studies have investigated specific communities experiencing underbounding, including in Chapel Hill,[7] Mebane,[8,9] Pinehurst,[10] and Raeford, NC;[10] Exeter, California;[11] Zanesville, Ohio;[12] and unincorporated areas of Texas.[13]

1.1.2 Exposure to Drinking Water Contaminants in Excluded Communities

To obtain drinking water, residents in many underbounded communities rely on private wells, which are often old, poorly maintained, rarely monitored and in close proximity to septic systems that also may have outlived their design lives, increasing the risk of contamination.[14–16] Prior evidence suggests that these wells are at increased risks of contamination, compared to regulated municipal water supplies.[7,9,11,17] A 2017 study, which I led, collected three temporal tap water samples from 57 homes in underbounded areas of Wake County and tested them for total coliforms, *E. coli*, and *Enterococcus*.[18] We found that 65% of the households tested positive for at least one indicator organism on at least one of these occasions, with 49% testing positive for total coliforms, 14% for *E. coli*, and 28% for *Enterococcus*.[18] A 2011 study of underbounded communities in Mebane, NC, found a similarly high prevalence of bacterial contaminants in 44 households relying on private wells, with 14% testing positive for *E. coli* and 11% testing positive for *Enterococcus*.[9] A 2013 study tested for selected microbiological and chemical contaminants in 12 wells of the underbounded Rogers-Eubanks community in Chapel Hill, NC.[7] Microbial water quality was similar to that in our study in Wake County (with 42% of samples positive for fecal coliforms and >8% positive for *E. coli*).[7,18] Two of the 12 wells tested positive for lead, and one had a lead concentration higher than the 15-ppb action level EPA has established for public water supply systems.[7] Of these North Carolina studies, our group was the only study to estimate the health risks from contaminant exposure. We estimated that 22% of acute gastrointestinal illnesses in the study population could be attributable to microbial contamination of drinking water.[18] Studies in peri-urban Latino communities in Texas have connected poor water quality and sanitation conditions to skin rashes, gastrointestinal illnesses, and hepatitis A.[13]

1.1.3 Why Underbounded Communities May Face Increased Risks of Exposure to Lead in Drinking Water

As noted above, one previous study, in the Rogers-Eubanks neighborhood of Chapel Hill, NC, tested lead in drinking water in an underbounded community. While that study found that 2 of 12 wells tested positive for lead, samples were collected at the well head and outdoor spigots that had been flushed for three minutes, a protocol that is known to substantially underestimate lead exposure risks under realistic indoor water use scenarios.[19] The nearly uniformly low pH of water from these wells—11 of 12 were below the federally recommended lower limit of 6.5 pH units—suggested high potential for plumbing corrosion to serve as a continuing source of metals. Households relying on private wells do not have the benefit of corrosion control measures to inhibit lead leaching into drinking water afforded to municipal water system customers, unless the households are aware of corrosion risks and employ household treatment. Therefore, a lack of municipal water system access could increase the risk of exposure to lead in drinking water, due to the leaching of lead from well components or household plumbing in the absence of adequate corrosion control.[20,21] In 2003, the World Health Organization stated:

> Lead is exceptional in that most lead in drinking-water arises from plumbing in buildings, and the remedy consists principally of removing plumbing and fittings containing it, which requires both time and money. In the interim, all practical measures to reduce total exposure to lead, including corrosion control, should be implemented.[20]

In general, lead contamination is known to occur at higher rates in private wells than in municipal systems; however, underbounded communities have not been sufficiently investigated for this exposure risk.[22]

1.1.4 Potential Health Risks of Exposure to Lead in Drinking Water

To our knowledge, no study has sought to estimate health risk from exposure to lead in private well water in underbounded communities. However, prior evidence suggests that lead in drinking water is associated with increases in lead in children's blood.[23–25] In turn, increased lead in children's blood is associated with neurocognitive impairment in children, as confirmed by decades of evidence.[26–28] More recent studies have found risks of cognitive impairment even at very low blood lead concentrations. For example, a cohort study in 2005 by Lanphear et. al. estimated intelligence lost attributable to blood lead by collecting Wechsler Intelligence

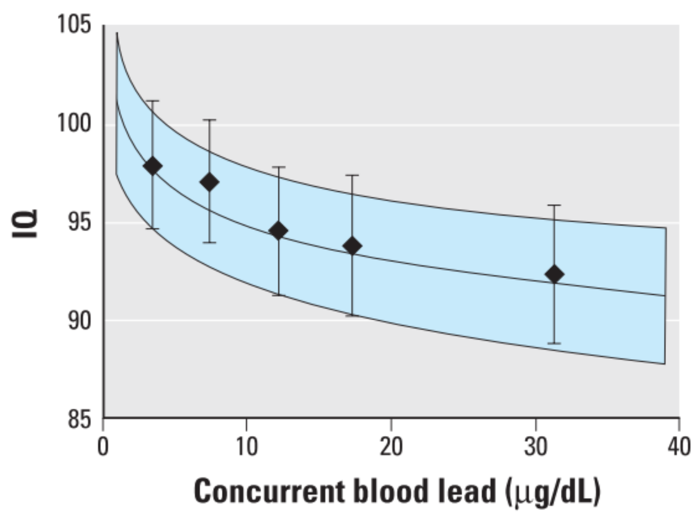

Figure 1.1. Relationship between lead in children's blood and IQ. SOURCE: Lanphear et. al., 2005.

Scales for Children scores and capillary blood samples tested for lead.[29] They found cognitive impairment in children even at low levels of lead in the blood (**Figure 1.1**).[29] A 2008 study in New York found that nonlinear analysis of peak exposure throughout early childhood indicated that blood lead levels as low as 2μg/dL may be associated with declines in child intelligence.[30] In 2012, the Centers for Disease Control and Prevention (CDC) lowered the reference dose for childhood blood lead from 10 μg/dL to 5 μg/dL in response to this research.[31] Recently, the American Academy of Pediatrics recommended that the EPA should "promulgate health-based standards for lead in paint, dust, soil, and drinking water that are designed to prevent all children from having a blood lead concentration greater than 1 μg/dL."[32]

1.1.5 Awareness of Water Contamination Risks in Excluded Communities

Despite evidence of elevated drinking water contamination and health risks in these communities, prior evidence suggests that awareness of the risks is low, in part because routine water quality monitoring is not required and part because of inaccurate perceptions of water quality.

Unlike the water delivered to neighboring areas with municipal water service, drinking water in underbounded communities is not regulated by the Safe Drinking Water Act (SDWA) and therefore not subject to the SDWA's monitoring requirements. The SDWA authorizes the Environmental Protection Agency (EPA) to regulate public water systems, defined as those serving at least 15 service connections or an average of at least 25 people for at least 60 days a year. The individual private wells on which residents of underbounded areas rely do not meet the definition of a public water system. Instead, each state must decide on construction standards and monitoring requirements, if any. In 2008, NC began to require a one-time water quality test for newly constructed private wells, but wells constructed prior to this time were not included.[33] In my prior research, I found that the majority of private wells in underbounded areas of Wake County were built before this one-time testing requirement was established.[34]

Prior evidence suggests that few residents of underbounded communities—and few private well owners more generally—follow recommended guidelines for regular water quality monitoring. Open-ended interviews with 18 private well owners in underbounded areas of Wake County found that only one routinely tested their water.[35] More generally in North Carolina, only 1.2% of the state's estimated 1.3 million private wells were tested for contaminants over a 5-year period (2009-2013).[36] These results are consistent with other studies of private well owners nationwide showing low rates of compliance with water quality testing schedules recommended by local health agencies.[37–39] In New Hampshire, Borsuk et al. found about 40% of private well owners in communities with high arsenic risk had never tested their water.[37] In Pennsylvania, Swistock et al. found that 30% of private well owners had never tested and 44% only tested once previously.[39] While testing alone is insufficient to reduce risks of exposure to waterborne contaminants, increased awareness of these risks could lead homeowners to take action to protect water quality on their own and/or could help them advocate for connections to regulated community water supplies.

In hopes to mitigate risks of consuming contaminated drinking water from private wells, the NC state legislature enacted the Private Well Water Education Act in 2013 requiring local health departments to educate well owners about monitoring their water.[40] However, evidence on how to effectively communicate the need for private well testing is scarce.[39,41,42] Furthermore, to our knowledge, there have not been any evaluations of risk communication interventions to promote water quality testing in underbounded minority communities.

1.2 Objectives of This Dissertation

The research is structured around three aims designed to fill gaps in knowledge about the risk of exposure to lead in drinking water in underbounded communities, awareness of these risks, and interventions to promote water quality testing. While the research focuses on underbounded communities—which, by definition, are adjacent to cities and towns—some of the results also may also apply to rural households relying on private wells. Each of the three objectives below is addressed in a subsequent chapter.

Objective 1: Evaluate the occurrence of lead in kitchen tap water in underbounded communities relying on private wells, and conduct a risk assessment of potential effects on children's cognitive outcomes.

Hypothesis 1.1: Lead occurs in tap water in underbounded communities at concentrations above the EPA 15-ppb action level at a higher frequency than is allowed for community water systems regulated under the SDWA.

Hypothesis 1.2: Children in underbounded communities may have increased risks of having elevated blood lead due to lead in their drinking water.

Objective 2: Assess the frequency of water testing, knowledge and beliefs about private well water, and factors associated with decisions to get a water test in underbounded communities.

Hypothesis 2.1: Well owners in peri-urban neighborhoods perceive their well water quality as of high quality, have low awareness of common contamination sources, and are generally unconcerned about health risks from their water.

Hypothesis 2.2: Well owners in peri-urban neighborhoods do not test their water at frequencies recommended by the NC Division of Public Health (DPH).

Hypothesis 2.3: A belief that contaminants can be detected through sensory perception contributes to lack of water testing in underbounded communities.

Hypothesis 2.4: A lack of knowledge on water testing procedures and how to remove contaminants contributes to a lack of water testing in underbounded communities.

Hypothesis 2.5: The cost of testing and removal of contaminants contributes to a lack of water testing in underbounded communities.

Objective 3: Conduct a randomized-controlled trial of a risk communication intervention developed using the results of Objective 2 to determine its influence on knowledge and beliefs associated with private well water testing and water testing behavior in underbounded communities.

Hypothesis 1a: The majority of those to whom the risk communication is delivered remember seeing the risk communication.

Hypothesis 1b: The demographic profile of those who remember receiving the risk communication is similar to that of the target audience.

Hypotheses 2a: Seeing the risk communication decreases the perception that water contaminants can be detected through sensory perceptions (sight, smell, and taste).

Hypothesis 2b: Seeing the risk communication increases knowledge about how to get a test and the sense of urgency about the importance of testing.

Hypothesis 2c: Increased knowledge about how to test and a higher sense of urgency about the importance of testing decreases the perception of cost as a barrier to testing.

Hypothesis 3a: Those who recall seeing the risk communication are more likely to have gotten a water test since the communication was delivered than those who do not recall seeing the communication.

Hypothesis 3b: Those who recall seeing the risk communication are more likely to say they plan to get a water test in the future than those who do not recall seeing the communication.
Hypothesis 3c: An offer of a free water test increases private well testing.

Hypothesis 4a: The influence of the risk communication on decisions to get a water test is mediated by the effect of the communication on the perception that water contaminants can be detected through sensory perceptions.

Hypothesis 4b: The influence of the risk communication on water testing also is mediated by the communication's effects on knowledge about how to get a water test and a sense of urgency about testing, which in turn is mediated by concerns about costs.

CHAPTER 2: RACIAL DISPARITIES IN ACCESS TO MUNICIPAL WATER SUPPLIES IN THE AMERICAN SOUTH: IMPACTS ON CHILDREN'S HEALTH[1]

OVERVIEW

More than five decades after the Civil Rights Act, systematic exclusion of African-American neighborhoods on the fringes of cities and towns from municipal services, including water service, continues. Throughout the American South, many such neighborhoods still rely on unregulated private wells for their drinking water despite their close proximity to municipal water lines. Little is known about water quality, including lead contamination, in these communities. In this chapter kitchen tap water samples were collected and tested for lead in 29 households recruited from peri-urban African-American communities in Wake County, North Carolina, relying on private wells. The Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children was used to estimate blood lead levels in children resulting from lead in water. Results: In eight (28%) of the 29 households, tap water lead exceeded the 15-ppb health-based action level in at least one of two samples. In seven homes, the average lead in two samples exceeded 15 ppb. The IEUBK model predicts that in 3 (10%) of the households, water lead could elevate children's blood lead above the current 5 μg/dL reference level. Discussion: The lead prevalence in households in this study was comparable to that in the most-exposed

[1] (*Stillo, F. J., & MacDonald Gibson, J. (2018). Racial disparities in access to municipal water supplies in the American South: impacts on children's health.* International Public Health Journal, 10.3.

neighborhoods of Flint, Michigan, during the recent lead-in-water crisis. These results indicate the need for interventions to decrease lead exposure in peri-urban African-American communities excluded from nearby municipal water service.

2.1 Introduction

Several studies in the last 30 years have documented the systematic exclusion of African-American neighborhoods on the fringes of cities and towns from access to municipal services, including water and sewer service, trash collection, paved roads, and police and fire protection.[1,2,7,8,10,43] Demographer Charles Aiken termed this exclusionary zoning practice "municipal underbounding."[1] Aiken and others have documented instances in which cities and towns gerrymandered their boundaries to leave out African-American neighborhoods, even when those neighborhoods were fully enclosed by town boundaries.[1,2,8,10,43–45] Because they lack access to municipal water and sewer service, underbounded neighborhoods rely on private wells for their potable water and on septic systems for their sewage disposal—even though their neighborhoods may be encircled by water and sewer pipes. Unlike in adjacent neighborhoods included within municipal boundaries, each underbounded household must operate and maintain its own private well and septic system, without financial or technical assistance.

Little is known about drinking water quality in underbounded neighborhoods, in part due to lack of private well monitoring.[46] To our knowledge, only three previous research studies have tested water quality in such neighborhoods.[7,9,34] The most recent study (by our team) tested 57 wells in underbounded communities in Wake County, NC, for microbial contaminants; we found contaminants in tap water in 37 (65%) of the households.[34] A 2011 study of an underbounded community in Alamance County, NC, found that 6 (13%) of private well samples tested positive for both fecal coliform and *E coli* bacteria.[9] A 2013 study of the underbounded Rogers-Eubanks community in Orange County, NC, tested for microbial and selected chemical contaminants in 12 wells.[7] This study found fecal coliforms in 5 (42%) of the wells. In addition, in several wells, concentrations of selected metals exceeded federal recommended drinking water limits: five for iron and manganese and one for lead. The nearly uniformly low pH of water from these wells—11 of 12 were below the federally recommended lower limit of 6.5 pH units—suggested high potential for plumbing corrosion to serve as a continuing source of metals.

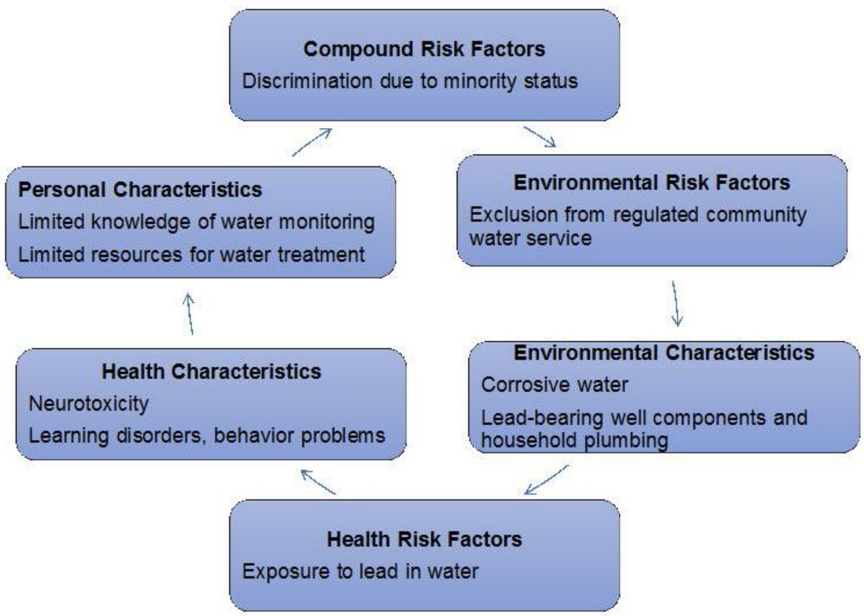

Figure 2.1. Cycle of environmental and health disparities experienced by communities that remain excluded from municipal services on the basis of race. Educating the communities and public health officials on well water quality and subsequent health effects can help to break this cycle of disparity.

In the current study, we examine lead contamination in private wells and the contribution of water lead exposure to health in children 6-84 months old in underbounded neighborhoods of Wake County, NC, excluded from municipal water service. Recent events in Flint, MI, have renewed attention to water as a potentially important source of exposure to lead, a long-established neurotoxin even at low levels.[27,28] On average, lead levels in African-American children are higher than in white or Hispanic children.[47] It is possible that disparities in lead exposure via drinking water could in some cases contribute to this racial disparity in children's blood lead. The aforementioned study in the Rogers-Eubanks community suggests the potential for increased lead exposure in water in underbounded communities, but apart from that study, no research on lead exposure in water in such communities has occurred. The Rogers-Eubanks study may have underestimated lead exposure risks because some samples were collected at the well head or from an outdoor spigot, rather than from an indoor tap, and in all cases the water was run for three minutes prior to sample collection. Flushing of samples and collection from the wellhead rather than the household tap can mask the presence of lead and other metals introduced through corrosion of household plumbing.[48] In this study, we evaluate the concentration of lead in unflushed, indoor tap water samples in 29 underbounded households. We then estimate how lead exposure via drinking water in these households could affect blood lead levels and IQ in children aged 6-84 months.

2.1.1 Cycle of child environmental health disparities

Currently, residents in racially underbounded communities face a cycle of environmental disparities, in comparison to neighboring communities that are included within municipal boundaries. One disparity (shown in **Figure 2.1**) with potentially important impacts on children's health is the lack of protections afforded to municipal water system customers under the EPA Lead and Copper Rule,[49] established in 1991 to prevent lead exposure in drinking water. Under the Lead and Copper Rule, all large community water systems (those serving more than 50,000 people) must treat their water with corrosion inhibitors to prevent lead release from water distribution pipes and household plumbing. In addition, all community systems, regardless of size, must monitor tap water for lead every six months in multiple households throughout their distribution networks, focusing on houses that, due to their age, are most likely to have leaded plumbing or solder. If lead concentrations exceed 15 ppb (the EPA action level) in 10% or more of the samples, then the water utility must implement corrosion control (if it has not done so already), optimize its existing corrosion control, and/or replace lead service lines.

Data from selected municipal water utilities suggest that the preventive measures established under the Lead and Copper Rule have substantially decreased lead exposure in drinking water in households with access to municipal water infrastructure. For example, in New York City, average tap water lead concentrations decreased by 62% (from 4.0 to 1.5 ppb) between 1992 and 2003 due to the addition of orthophosphate corrosion inhibitors to the treated drinking water.[50] The recent lead-in-water crisis in Flint illustrates that lead exposure concerns may remain in some municipal water systems. Nonetheless, the Flint crisis represented an extraordinary occurrence, in which the city failed to implement adequate corrosion control as part of a cost-saving measure initiated by financial managers who took over the city during bankruptcy and in which subsequent data that would have alerted officials to the lead problem were concealed.[51,52] In general, compared to households relying on private wells, those with municipal water service have the benefit of regular water quality monitoring and centrally managed corrosion control to prevent lead exposure in drinking water.

As shown in **Figure 2.1**, lack of municipal water system access could lead to an increased risk of exposure to lead in drinking water, due to the leaching of lead from well components or household plumbing in the absence of adequate corrosion control. Private well households typically lack the knowledge and/or the means to adequately monitor their water quality and to install and maintain appropriate treatment when water quality problems are discovered.[15,53,54] Many private wells deliver water with low pH, increasing the risk of lead corrosion, compared to higher pH waters or waters to which corrosion inhibitors have been added.[22] In turn, an increased risk of exposure to lead—even at low levels—increases the risk of permanent loss of intellectual function and behavioral disturbances among children[28,29,55] The identification of lead exposure in drinking water has already helped other communities, like Flint, appreciate and begin to act in an attempt to provide safe drinking water to the community. Educating private well owners and public health officials of lead exposure risks and health effects in underbounded communities can help break the cycle of children's environmental health disparities in these marginalized communities.

2.2 Methodology

2.2.1 Participant recruitment

To characterize lead exposure risks in drinking water in underbounded African-American communities, we conducted a pilot study involving 29 households recruited from majority African-American census blocks within the municipal extraterritorial jurisdictions of Wake County (**Figure 2.2**). In North Carolina, municipalities can control zoning and land use decisions in extraterritorial jurisdictions at a distance of up to 3 miles from city boundaries, depending on population size, without providing municipal services (including public water supply) or voting rights in municipal elections.[56] The 57 participants from our previous study of microbiological water quality in underbounded communities[34] were each contacted by telephone to inquire about their interest in the present study. The first 29 to respond and agree to participate were enrolled (available resources could support sampling only in 29 households). Participants received a $25 gift card as compensation after completing a survey following water sample collection.

2.2.2 Water sample collection

All household water samples were collected during August 2016. One day before sample collection, sample kits were delivered to each household. The kits included detailed instructions for collecting first-draw morning samples from the kitchen tap after an overnight stagnation period and two 10-mL metal-free sampling vials (VWR, Radnor, PA). Instructions for sample collection followed the Environmental Protection Agency's (EPA) Lead and Copper Rule Sample Collection Form,[57] with the exception of the size of the sample collection bottles (smaller than 1 liter). Consistent with EPA-recommended procedures, instructions directed homeowners to collect samples from the kitchen tap using cold water after a minimum 6-hour stagnation period. Participants were instructed to fill both vials without flushing and to label each vial with the date and time. The filled vials were then collected by research staff on the same day. After collected vials were transported to the lab, each 10-mL vial was digested in 70% concentrated nitric acid to a 2% by volume solution for a minimum of 24 hours.

2.2.3 Quantification of lead

Metals (lead along with aluminum, cadmium, copper, nickel, and zinc) were analyzed using standard methods[58] using an inductively coupled plasma mass spectrometer (Agilent Technologies 7500cx, Santa Clara, California). Validity of the data was assessed through analysis of replicate samples (10.3% of total samples), quality control standards spanning concentration ranges of analytes, and blanks. Quality control standards were prepared from National Institutes of Standards and Technology traceable solutions (High Purity Standards, Charleston, South Carolina, USA). The statistical package *R* was used to calculate summary statistics for lead and other metals.

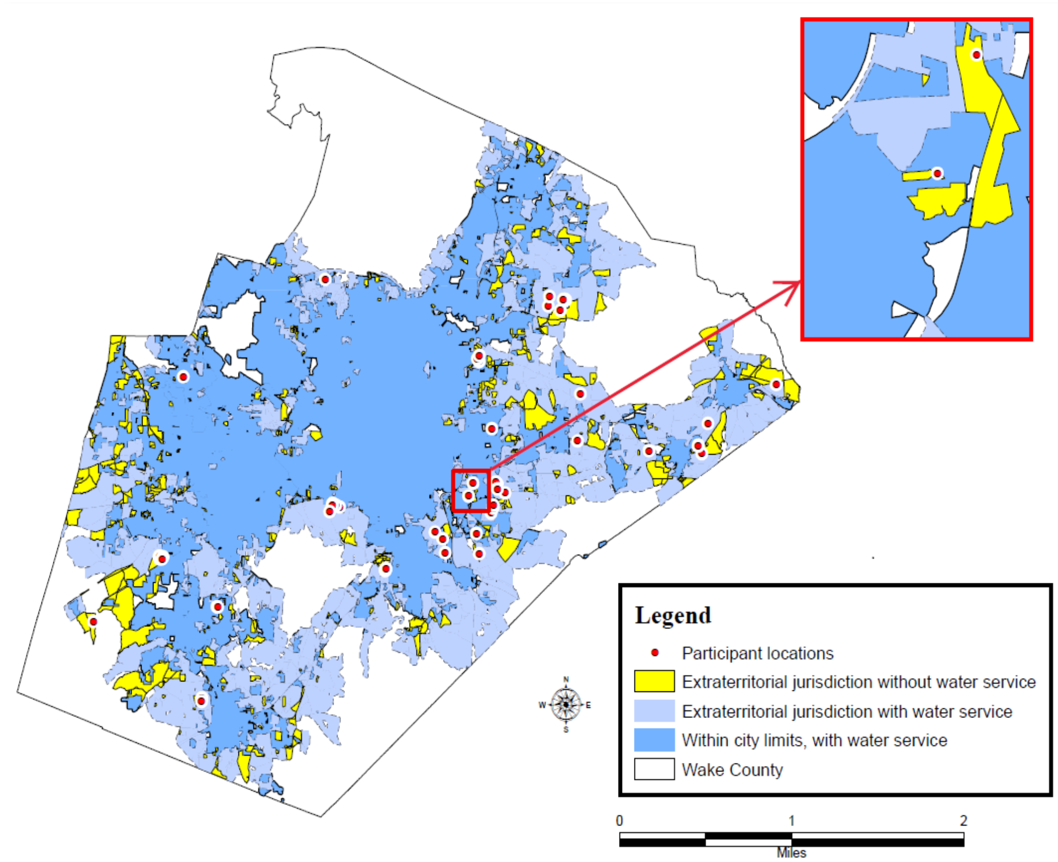

Figure 2.2. Locations of the 29 households participating in this study. Dark blue shading indicates areas that are within municipal boundaries. Participating households were not located within municipal boundaries, even if very close to those boundaries, as shown in the insets. Light blue shading indicates areas that are within extraterritorial jurisdictions of municipalities (meaning the municipalities control land use decisions in those areas) but have community water service, even though they are outside of town boundaries. Yellow areas and all participating households are in extraterritorial jurisdictions but lack community water service.

2.2.4 Comparison to municipal water and rural wells

To compare water lead in the study communities to that in nearby homes served by the Raleigh municipal water supply, we extracted data on lead concentrations in Raleigh municipal water from the Safe Drinking Water Information System (https://www.pwss.enr.state.nc.us/NCDWW2/). We obtained all lead measurements collected during 2016 in single-family households throughout the Raleigh water distribution system (65 samples in total). All sampling locations were labelled as Tier 1, meaning the Raleigh Public Utilities Department has identified them as at highest potential risk of lead exposure in water due to the age and type of the household plumbing and/or service lines delivering water to the homes. All reported samples were first-flush samples collected from the kitchen tap.

We obtained summary statistics on lead concentrations in private wells throughout Wake County from the NC Division of Public Health (NCDPH). The NCDPH maintains a web site (http://epi.publichealth.nc.gov/oee/wellwater/by_county.html) with summary statistics for private well water samples tested by the State Laboratory for Public Health during 1998-2010. In total, the state lab tested 3,188 well water samples for lead during this time period.

2.2.5 Health Impact Assessment

To estimate potential impacts of lead in drinking water on children's blood lead levels, measured water lead concentrations for each household were input into the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK; U.S. EPA 2010, *IEUBKwin32* Lead Model Version 1.1 Build 11).[59] This physiologically based pharmacokinetic model compartmentalizes the human body and predicts the absorption, distribution, metabolism and excretion of lead. The IEUBK model estimates the predicted geometric mean blood lead level for children aged 6-84 mo., in one-month age groups, for a given level of exposure to lead from drinking water and other sources (soil, dust, and air) that the user can specify. The model also estimates the probability of a child in each one-month age group having a blood lead level greater than 5 μg/dL, the current reference level recommended by the Centers for Disease Control and Prevention (CDC) for identifying elevated lead exposure risks. For each household, we ran the IEUBK model twice for each of the two water samples: once using the average water lead level measured in the two samples while assuming no lead exposure from other sources and a second time including the model's default assumptions for lead exposure from soil, dust, and air (200 µg/g, 150 µg/g and 0.1 µg/m^3, respectively). These results were used to estimate the expected excess blood lead attributable to water alone and the chance that water lead exposure could cause a child's blood lead to exceed 5 µg/dL, when considering water exposure and exposure from other sources.

To estimate the potential effects of the estimated blood lead levels on children's IQ, we used the multiple regression model from Lanphear et al.[29] The model was run for each household and each one-month age group. The model form is:

$$\text{IQ Loss} = \beta * \text{Ln}(BLL_{ij}) \qquad \text{(Equation 1)}$$

where β = -2.70 (95% CI = -3.74 to -1.66) is the coefficient from Lanphear et al. for mean adjusted changes in full-scale IQ score associated with an increase in blood lead concentration (25) and $BLL_{i,j}$ is the blood lead concentration estimated by the IEUBK model at household i for age j (in months). Uncertainty in the estimated IQ loss was estimated via Monte Carlo simulation using *Analytica* (Lumina Decision Systems, Los Gatos, CA) (10,000 iterations per household). In the Monte Carlo simulation, β was represented as normally distributed (mean = -2.70, standard

deviation = 0.531). Blood lead levels were estimated as lognormally distributed using the geometric mean estimates from the IEUBK model output and a geometric standard deviation of 1.6 µg/dL (as specified in the IEUBK model user manual).[59]

Table 2.1. Characteristics of study participants and their wells

	Study Participants	Wake County	*p* Value for Difference
Race (n = 21)			
Black/African-American	62%	21%	<0.001
White	33%	69%	<0.01
Asian/Asian American	5%	7%	NS
Other	0%	3%	NS
Education (n = 20)			
High school or higher	95%	92%	NS
Bachelor's degree or higher	60%	49%	NS
Home ownership (n = 20)	100%	64%	<0.01
Median household income (n = 20)	$62,500	$67,309	NS
Median age of well (n = 19)	30 years	NA	NA

Note: Some participants did not respond to the demographic questions on our survey. Numbers responding to each question are indicated in parentheses. NS = not significant; NA = information not available.

2.3 Results

Enrolled participants were located throughout underserved areas of Wake County. As **Figure 2.3** illustrates, participating households were in neighborhoods that are surrounded by areas with community water supplies, as indicated with blue shading. However, these households lack access to the nearby community water supplies.

Among participating households, a significantly ($p < 0.001$) higher percentage (62%) identified as African American than in Wake County (21%) (**see Table 2.1**). The median household income among participants ($62,500) was slightly lower than that in Wake County ($67,309), although this difference was not statistically significant. The study population had a larger proportion with bachelor's degrees or higher (60%) than Wake County as a whole (49%), but this difference was not statistically significant. The study population had a much higher rate of home ownership than Wake County (100% as compared to 64%, $p < 0.01$). This latter finding is consistent with previous studies of racially underbounded communities in North Carolina,[8,60] which have documented generations of land ownership within the same family, in some cases dating back to land granted to freed slaves after the Civil War. Current patterns of racial underbounding thus have longstanding historical roots.

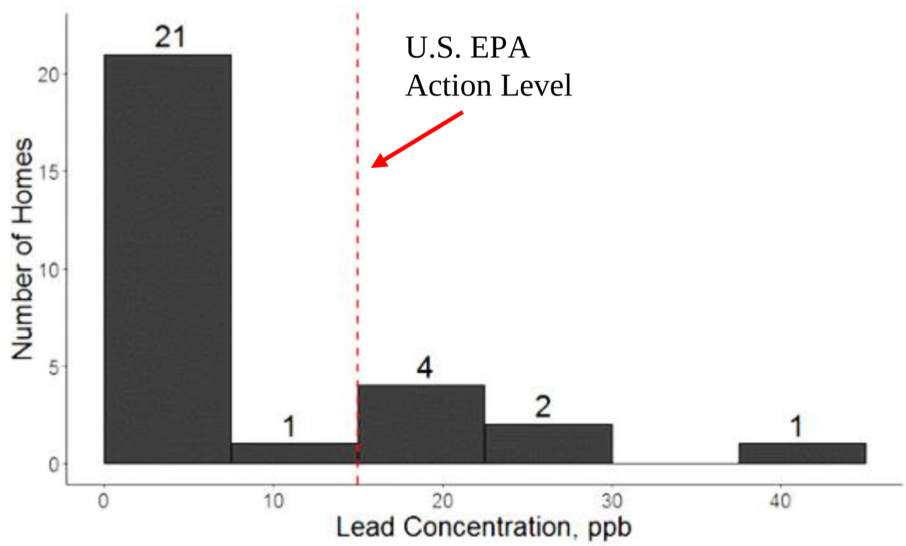

Figure 2.3. Average concentration of lead in tap water from 29 households, each sampled twice, in African American peri-urban communities excluded from the public drinking water system in Wake County, NC, USA. U.S. Environmental Protection Agency (EPA) action level is health based standard for drinking water.

2.3.1 Lead prevalence

To evaluate exposure to lead in drinking water in the participating households, two first-flush water samples were collected from the kitchen faucet and analyzed for lead. In eight (28%) of the households, the tap water lead concentration exceeded the 15-ppb health-based action level in at least one of the two samples. In seven (24%) of the homes, the average of the two samples exceeded 15 ppb (**see Figure 2.3**). Across all 58 samples, the average concentration was 8.19 ppb, and the maximum was 79.4 ppb (**see Table 2.2**).

2.3.2 Lead sources

To evaluate potential lead sources, we also tested concentrations of other metals known to be associated with plumbing corrosion (**see Table 2.2**). We found strong and statistically significant ($p < 0.01$) correlations between lead and zinc ($\rho = 0.51$), nickel ($\rho = 0.49$), and aluminum ($\rho = 0.34$) (**see Figure 2.4**).

Table 2.2. Metals (µg/L) in drinking water in private wells in peri-urban areas of Wake County

Constituent	Mean	Median	Max	Standard[a]	Samples Exceeding Standard
Aluminum	36.3	6.50	436	50-200 (NSDWR)	3.45%
Cadmium	0.591	0.0355	19.7	5 (MCL)	1.72%
Nickel	8.57	1.17	129.1	NA	NA
Zinc	1,562	388	9,346	5,000 (NSDWR)	12.1%
Copper	629.5	135.4	5,645	1,300 (action level)	10.3%
Lead	8.19	3.00	79.4	15 (action level)	15.5%

[a]MCL: Maximum Contaminant Level, established for contaminants associated with risk to human health. National SMCL: Secondary Drinking Water Standard, established for contaminants that may cause aesthetic problems. Action level, established for contaminants regulated on the basis of treatment technologies; if exceeded in more than 10% of homes, the system must undertake additional action to control corrosion and inform the public; (n=29).

The high correlation with zinc suggests that corrosion of galvanized pipes may be a lead source. Galvanized pipes are lined with a zinc coating also containing up to about 2% lead. Recent research has concluded that these pipes can be a major source of lead in drinking water.[61]

To further explore the hypothesis that galvanized steel is a lead source, we compared the lead concentrations in samples without and with detectable cadmium, which can serve as another marker of galvanized steel corrosion.[61] The mean lead concentration in the 11 samples without detectable cadmium was 0.607 ppb. By comparison the mean lead concentration in the 47 water samples also containing cadmium was 9.96 ppb—16 times higher than in the samples without cadmium. This difference was highly statistically significant (one-tailed *t*-test $p < 0.0001$), even though the concentrations of lead and cadmium were not significantly correlated ($\rho = 0.075$, $p = 0.57$). The finding of much higher lead concentrations in samples with cadmium than in those without supports the hypothesis that galvanized steel corrosion may be introducing lead into the water.

Corrosion of brass fittings, which contain 60-80% copper along with zinc (4-32%) and lead (2-8%), could be another lead source.[22] The presence of high copper concentrations in some of the samples (with 10% exceeding the federally recommended action level of 1300 µ/L, as shown in **Table 2.2**) indicates potential brass corrosion. However, the correlation between lead and copper ($\rho = 0.21$) did not reach statistical significance.

Other potential sources include lead solder and nickel-plated brass, the latter suggested by the significant correlation ($\rho = 0.49$) between lead and nickel.

2.3.3 Comparison to lead in municipal water and in other Wake County private wells

To compare lead concentrations in the study households to concentrations in households served by municipal water supplies and in other Wake County households with private wells, we extracted water sample test results from relevant NC databases. The average lead concentrations in the study households is nearly three times as high as in households served by the City of Raleigh municipal water supply (8.19 vs. 2.83 ppb, $t = 2.38$, $df = 46$, $p = 0.01$). In addition, the

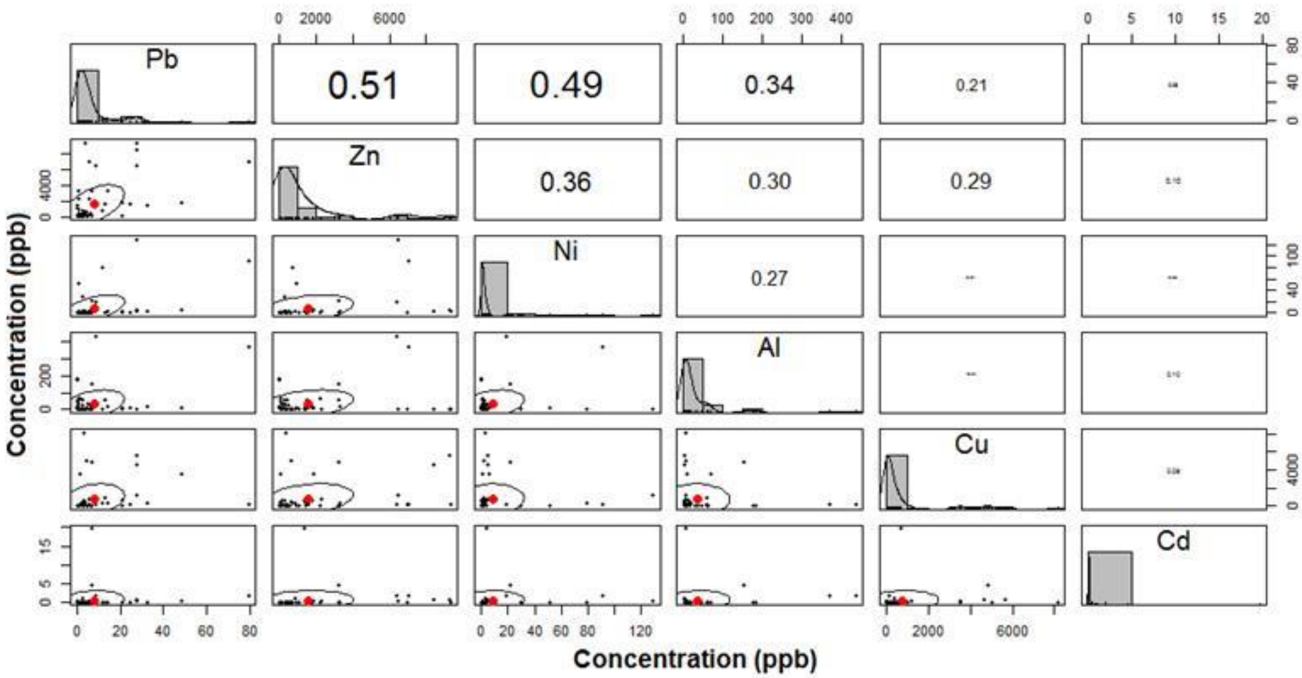

Figure 2.4. Bivariate correlation plots of metals in tap water from 29 households, each sampled twice, in African American peri-urban communities in Wake County, NC, relying on private wells. Ellipses show 95% confidence regions; red dots are confidence region centroids.

proportion of households testing above the 15-ppb action level is significantly higher in the study sample than in community samples (24% versus 1.5%, chi-square = 13.2, $df = 1$, $p = 0.00014$). The average concentration in the study households is greater than that in the 3,188 Wake County wells tested between 1998 and 2010 (8.19 vs. 7.8 ppb), but this difference is not significantly different. However, the proportion of wells exceeding 15-ppb in the study samples is nearly five times higher than in the other Wake County wells (24% versus 5.4%, chi-square = 19.2, $df = 1$, $p = 5.8 \times 10^{-6}$). These results indicate that lead exposure risks in drinking water are higher in the underbounded neighborhoods of this study than in neighborhoods served by the Raleigh municipal water supply and also are higher than in other areas of Wake County served by private wells (for example, rural areas outside of municipal extraterritorial jurisdictions).

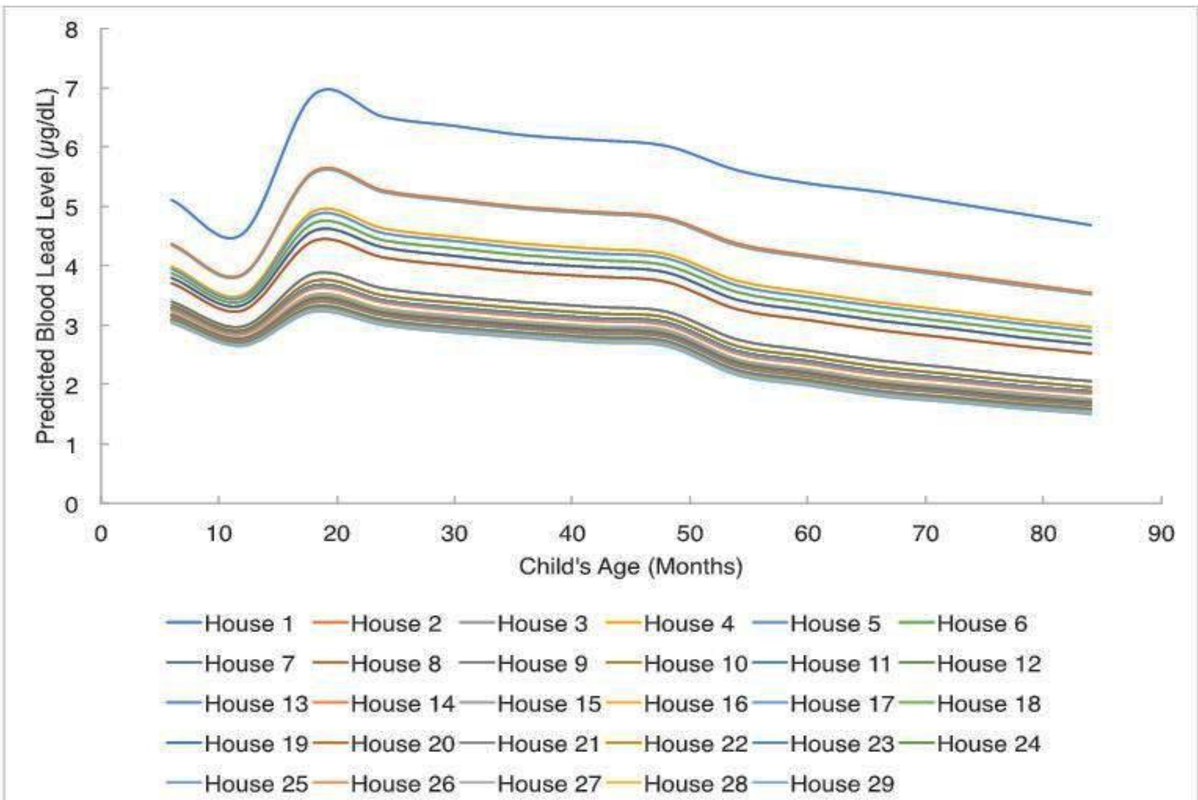

Figure 2.5. Predicted blood lead levels in children consuming water with lead levels as measured in the study households.

2.3.4 Health impacts of lead contamination

To estimate the potential impact of lead contamination on children's health in the participating households, we applied the IEUBK model to predict the how the observed water lead levels could affect the concentration of lead in children's blood. Among the 29 households, considering children aged 6 months to 7 years, the average predicted blood lead level arising from water lead alone was 1.06 µg/dL, and the maximum was 4.55 µg/dL.

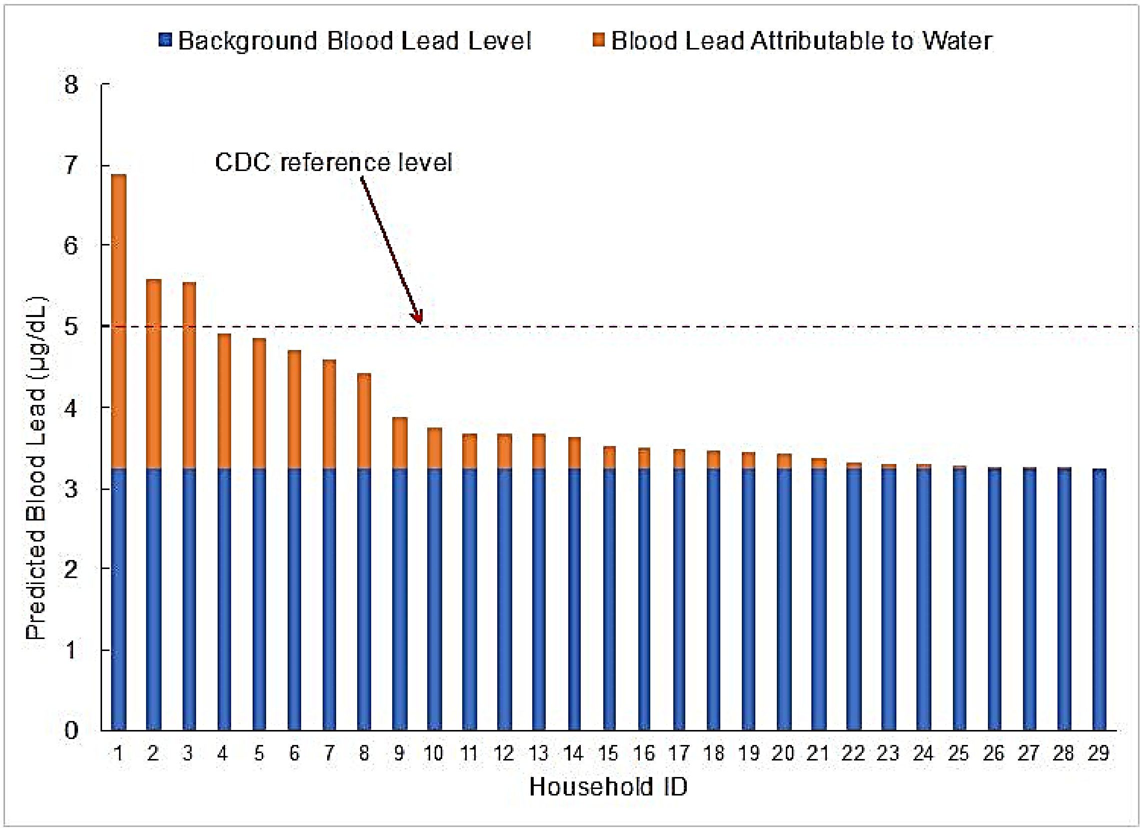

Figure 2.6. Predicted median blood lead levels in 18-month-old children consuming water with lead levels as measured in the study households.

Because exposure to lead in water must be considered in the context of other lead sources, we also evaluated whether exposure to lead in water could elevate a child's blood lead above the CDC high-blood-lead threshold of 5 µg/dL, when added to lead exposure from other sources. On average across households and ages, the IEUBK model predicted that blood lead levels would be 3.03 µg/dL, when considering combined lead exposure from water, soil, dust, and air, with a maximum of 6.88 µg/dL. **Figure 2.5** shows that predicted blood-lead levels are highest for children aged 18 months. For this age group, the contribution of lead from water results in a total blood lead level of greater than 5 µg/dL in three households (**see Figure 2.6**). In another five houses, water lead in combination with lead from other sources results in a predicted blood lead level within 1 µg/dL of the 5 µg/dL threshold among 18-month-old children.

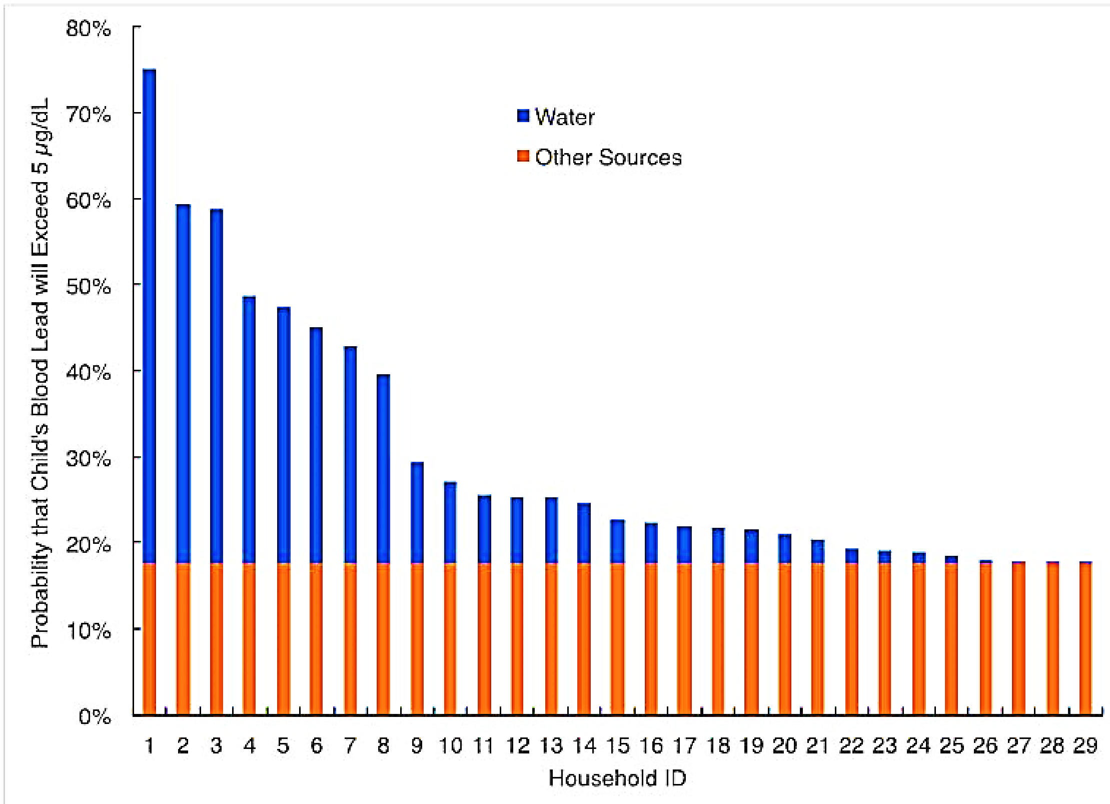

Figure 2.7. Predicted probability that blood lead in an 18-month-old child in the stuy households will exceed the µg/dL reference level established by the Centers for Disease Control and Prevention.

For each household, we also used the uncertainty features in the IEUBK model to estimate the probability that the child's blood lead level could exceed 5 µg/dL. On average across all households and age groups, the risk that water lead alone will result in a blood lead levels above 5 µg/dL is 1.9%. Across households and among 18-month-old children, the IEUBK model predicts a 3.1% risk of having an elevated blood lead level from water lead alone, on average, and a 42% risk of exceeding this threshold in the highest-risk household (**see Figure**

2.7). When considering water in addition to other lead sources among 18-month-olds, the average probability that blood lead levels will exceed 5 µg/DL is 30% across the 29 houses, with a probability greater than 50% in three homes and a maximum of 75%.

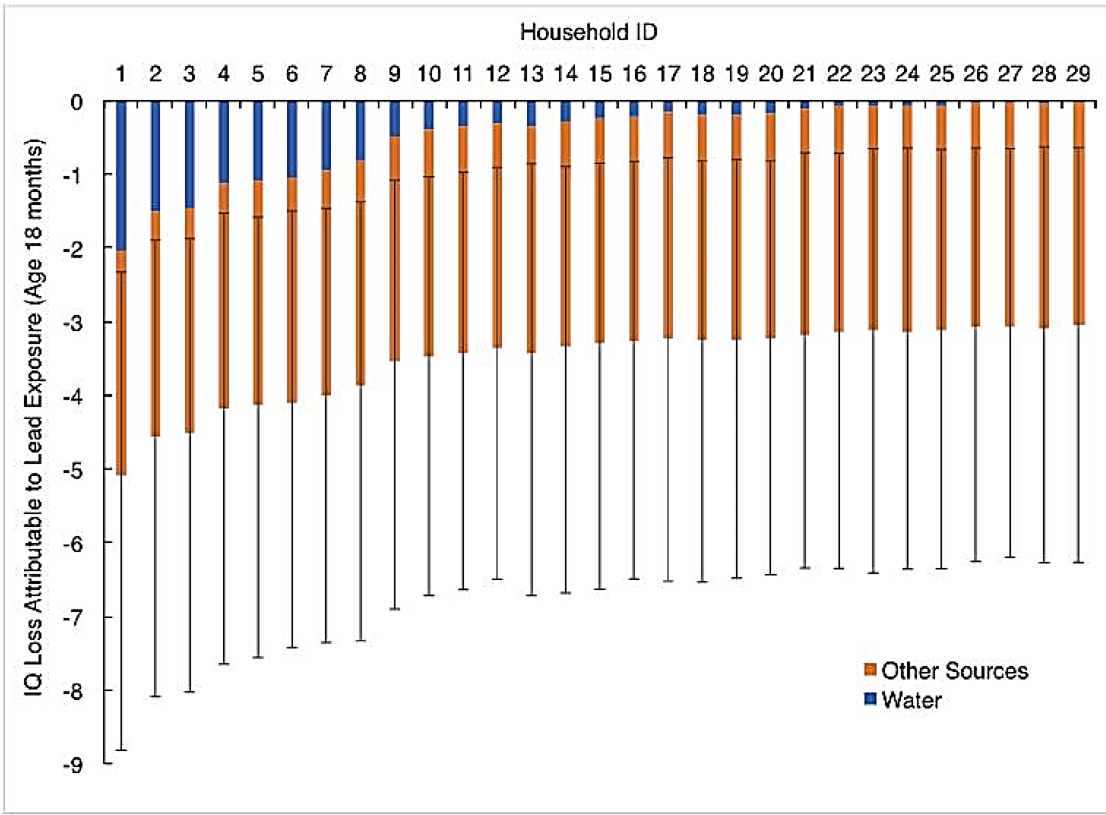

Figure 2.8. Predicted median IQ loss associated with exposure of an 18-month-old child to environmental lead in the study households. NOTE: Error bars represent 95% confidence intervals on total IQ loss.

To estimate the potential effects of lead on childhood IQ, we combined the IEUBK model output with statistical estimates of the relationship between blood lead and IQ developed by Lanphear et al.[29] Across households and among 18-month-olds, the mean predicted IQ loss attributable to water alone was estimated to be -0.86 IQ points (median = -0.24), with the highest household exposures resulting in an estimated mean -4.1 IQ points (median = -4.0) lost attributable to water alone (**Figure 2.8**). When considering total exposure to lead (water in addition to the default assumed background exposure from other sources), the mean IQ loss across all 29 households was -3.6 points (median = -3.4). The mean value in the highest-risk household was -5.2 points (median = -5.1) (**see Figure 2.8**). Previous studies have indicated a decrease of about 2% in lifetime earnings with each one-point decrease in IQ.[62] As a result, a child relying on water from this highest-risk household could experience a decrease of more than 10% in lifetime earnings.

2.4 Discussion

Our results suggest that lead contamination is prevalent at concentrations that exceed the EPA 15-ppb action level in racially underbounded Wake County, NC, neighborhoods excluded from municipal water service. Lead exposure in these communities may increase the risk of elevated blood lead levels in young children, potentially causing permanent neurological damage. Exposure to lead in water is just one of the environmental disparities these communities may face. Our previous research, for example, documents a much higher risk of exposure to bacterial contaminants in drinking water in underbounded communities of Wake County than in areas served by municipal water supplies.[34] It is possible that exposures to other drinking water contaminants may be higher, as well, but these exposures have yet to be assessed. The potential for synergistic effects resulting from these exposures is unknown.

Notably, the prevalence of elevated waterborne lead in the samples we collected is similar to that observed in Flint during the recent water crisis. At least one of the two samples we collected exceeded the 15-ppb action level in 8 (28%) of the 29 houses we sampled. By comparison, Hanna-Attisha et al.[23] reported that during the Flint water crisis, the percentage of samples with lead above 15 ppb ranged from 10-32% across Flint's nine wards; they defined wards with more than 25% of samples having elevated lead as "high water lead-level (WLL)" areas. By this definition, the underbounded communities we sampled would qualify as having high WLL.

Our water quality results show a somewhat higher lead prevalence than observed in previous studies of rural private wells. A study of private water systems (private wells, springs, and cisterns) in the rural Blue Ridge-Piedmont region of Virginia found that 19% of 2,144 households tested had lead levels above 15 ppb.[22] A study of 251 Pennsylvania private wells reported 12% of households had elevated water lead levels.[39] Variation in lead prevalence, as suggested in both studies, could be the result of private water system characteristics (e.g., well type, plumbing components, use of household filters)[22,39] and geologic characteristics (e.g., pH, alkalinity) of the aquifer from which the wells draw their water.[63] Both studies found that household age was highly correlated with lead concentration: the Virginia study found that lead concentrations were significantly higher in homes built before 1988 than in those constructed after 1988, and the Pennsylvania study reached a similar conclusion for houses constructed before 1991 as compared to after 1991. The authors of the Virginia study suggested that these differences could "reflect the 1986 Lead Ban, which required the use of 'lead-free' plumbing components in the installation or repair of any . . . residential building . . . connected to a municipal system after June 1988." The authors suggest that although the lead ban did not apply to private wells, the increased demand for lead-free components could have influenced the availability of such components for newer private well households. Half of the wells included in our study were constructed before the lead ban.

Like the Virginia study, our results also suggest corrosion of plumbing components as a likely lead source. The Virginia study found strong ($\rho > 0.50$) and statistically significant correlations between lead and zinc, copper, and nickel (in order of decreasing correlation) and a weak but significant correlation between lead and aluminum ($\rho = 0.27$). Similarly, our study found a strong ($\rho = 0.51$) correlation between lead and zinc and significant but weaker correlations between lead and aluminum and nickel. The Virginia study authors noted that brass is composed largely (60–80%) of copper and also includes a large proportion of zinc (4-32%), along with lead (2-8%); on this basis, they hypothesized that brass plumbing is a major lead source. The relatively low and statistically insignificant correlation between lead and copper in our study ($\rho = 0.21$) could suggest that components other than brass are a more important source of lead in these households, compared to in the Virginia households.

To our knowledge, only one previous study has analyzed water samples for lead in underbounded African-American neighborhoods excluded from community water service.[7] The previous study found that 1 of 12 private wells in the Rogers–Eubanks community in Orange County, NC, exceeded the 15 ppb action level.[7] However, some of the samples were collected from the wellhead or outdoor spigot, rather from an indoor tap, therefore overlooking household plumbing as a lead source. In addition, water taps were flushed for three minutes prior to sample collection, also potentially masking key lead sources and underestimating the prevalence of lead.[64]

The IEUBK model prediction that water lead in the underbounded households in this study would increase the risk of elevated BLL by 1.9%, on average, in children ages 6-84 is similar to the 2.5% observed increase in the prevalence of elevated blood lead levels in Flint during the water crisis.[23] The model prediction that children in this community would, on average, have blood lead levels of 3.03 µg/dL is similar to the concentration of 2.4-3.4 µg/dL predicted by the IEUBK model for a sample of children in Montreal households, the majority of which had lead service lines.[65]

2.4.1 Limitations

There are a number of limitations of our study. The samples were collected in August, when temperatures in NC peak and lead releases are expected to be highest. As a result, exposures during other months could be lower. On the other hand, samples were collected at low flow rates due to the small mouths of the sample collection bottles, which could have underestimated exposures due to lower release of lead particles than occurs under standard water flow rates. Similarly, the sample collection bottles we used were smaller than the 1L wide-mouth containers the EPA recommends (although there are no standardized sampling protocols for private wells). Lack of temporal sampling may have resulted in an underestimate of particulate lead due to the failure to capture episodic releases of lead particles.

Our estimates of blood lead levels and associated IQ impacts are based on models rather than measurements. The background exposure to soil and dust lead assumed in the IEUBK model, and used in our analysis, could be too low, especially given the older age of some of the households in our study. For example, Lanphear et al.[55] reported that measured soil lead concentrations were more than 12 times as high as default assumptions in the IEUBK model. In addition, a previous systematic review of racial and ethnic differences in childhood blood lead levels found that African-American children have the highest mean blood lead levels,[66] but the IEUBK model does not account for the effects of race. At the same time, the IEUBK estimates of the probability of having lead above the CDC reference level (5 µg/dL) do not agree with observed data from blood lead monitoring in Wake County. From 2011-2015, 96 out of 10,294 children (0.933%) tested in Wake County had blood lead levels above 5 µg/dL.[67] On the other hand, this sample of children may not be representative of the underserved communities in this research.

2.5 Conclusion

Our results suggest that many homeowners in underbounded communities of Wake County, NC, are not adequately managing lead corrosion within their private well water system. Children in these communities potentially face increased risk of exposure to lead compared to neighboring children consuming municipal water, with 24% of the study households exceeding the 15-ppb action level for lead in water, in comparison to 1.5% of households served by the nearby Raleigh municipal water supply. In addition, these children may be at increased risk of exposure to lead from sources other than water due to the older housing in their neighborhoods. The lead exposure risks may be a legacy of a practice of municipal underbounding, contributing to a continuing cycle of increased exposure to environmental lead. To break the cycle of increased risks in these communities, financial and technical support may be needed to enable communities to either advocate for connections to the municipal water supply or to follow recommended well water testing, treatment, and maintenance procedures.

CHAPTER 3: WELL WATER TESTING IN AFRICAN AMERICAN COMMUNITIES WITHOUT MUNICIPAL INFRASTRUCTURE: BELIEFS DRIVING DECISIONS[2]

Overview

Some peri-urban African-American communities in North Carolina remain excluded from nearby municipal water service, forcing them to rely on unregulated private wells. Despite evidence of elevated drinking water contamination risks in these communities, water monitoring is rare. To identify factors influencing decisions to test private wells, we developed and administered a survey to residents of affected areas. A factor analysis identified three constructs significantly associated with a decreased likelihood of water testing: (1) the misconception that contaminants can be detected by sensory perception, (2) concerns about costs of testing and/or water treatment, and (3) not knowing how to get a water test or having time to do so. Increased knowledge about how to test and the importance of testing was significantly associated with a decreased concern about costs which, in turn, was significantly associated with an increased odds of testing. These results suggest the need for targeted risk communications that correct the misperception that contaminants can be tasted, smelled, or seen. The results also suggest the need for clear information about how to get a water test and for low- cost testing

[2] *Stillo III, F.J., Bruine de Bruin, W., Zimmer, C., MacDonald Gibson, J. 2019. Well water testing in African American Communities without municipal infrastructure: Beliefs driving decisions.* Science for the Total Environment; *In-press.*

programs. Increased monitoring could empower residents to take protective actions and potentially mobilize political support for water service extensions.

3.1 Introduction

Development of municipal water and sewer infrastructure has been called "the most important public health intervention of the twentieth century" in the United States.[68] This infrastructure was largely responsible for eliminating the "urban penalty"—the higher mortality rates in urban populations during the nineteenth century.[68] Yet, not everyone in and around U.S. cities and towns benefited. Discriminatory zoning practices led to the exclusion of some minority communities from municipal water and sewer services, and some of these disparities persist.[1,2,4,8,10,44,69] Residents of these excluded areas rely on private wells and septic systems for their water and sanitation needs, even though they are adjacent to or in some cases encircled by town water and sewer pipes. Legal scholar Michelle Wilde-Anderson has called these under-recognized areas "cities inside out." She writes,

> [S]uch neighborhoods lie where the sidewalks, and the city borders, end. On patches of unincorporated land at the municipal fringe, low-wage workers live without water or sewage lines, sidewalks or paved roads, drainage or flood control. Health and safety risks plague local water and soil, as communities rely on rural-character services in urbanized areas built on environmentally damaged or disaster-vulnerable land.[4]

A growing body of research has shown elevated risks of drinking water contamination and associated health risks in these marginalized communities. For example, private wells in the majority-Latino Tooeleville community in California's Central Valley are contaminated with nitrates and bacteria.[11] Poor water quality and sanitation conditions in peri-urban Latino communities in Texas have been associated with skin rashes, gastrointestinal illnesses, and hepatitis A.[13] In North Carolina (NC), high rates of bacterial contaminants and lead have been found in in peri-urban African-American communities relying on private wells.[7,9,34,70] One study found that the prevalence of elevated lead in these NC neighborhoods was comparable to that in Flint during the recent water crisis, with 28% of households affected.[70] Whether residents of peri-urban areas relying on private wells are aware of the contamination risks is not well understood. We recently reported on semi-structured interviews with 18 residents of peri-urban, majority African-American neighborhoods of Wake County, NC, relying on unregulated private wells.[71] Interviewees generally rated their water as having good quality, equal to that of city water, despite our prior research finding that tap water samples from these communities were much more likely to contain bacterial contaminants and lead than samples from nearby households with city water.[34,70] In addition, half of the 18 interviewees said they had never tested their water, could not remember testing, or had not done so for at least 10 years.[71] Increased private well water testing in such under-served peri-urban communities could raise awareness of the risks so that residents can take protective actions, such as installing water filters or disinfecting their wells. Ideally, increased awareness also would mobilize political support for extending infrastructure to these areas. For example, in 2014, commissioners in New Hanover County, NC, voted to extend city water and sewer lines to a peri-urban neighborhood when the county health director documented overflowing septic systems and increased water contamination risks.[72] A county official commented, “I think the health director saying this is a community health hazard . . . that means you’ve got to take care of it . . .. That ended the argument.”[72] To our knowledge, no population-level survey of private well owners in peri-urban African- American communities has been conducted to assess their current well water testing practices and factors influencing those practices.[42,71] Information about such influential factors is needed to develop targeted risk communications to promote water testing in these areas. We are seeking to fill this gap by using the Mental Models Approach to Risk Communication.[73] Risk communication experts have used this approach to create materials (such as brochures and videos) that effectively reduced behaviors associated with multiple kinds of risks, ranging from carbon monoxide poisoning and radon mitigation to sexually transmitted diseases.[74–76]

3.1.1 Mental Models Approach: Overview

The Mental Models Approach aims to identify the knowledge gaps and misperceptions influencing risky behaviors.[73,75,76] This information, in turn, is used to design risk communications to decrease risky behaviors by correcting important misperceptions and filling relevant knowledge gaps. The Mental Models Approach involves four steps. The first step is to identify what people should know to make informed decisions. The goal is to create an "expert model" of the risk—an influence diagram illustrating how experts conceive of the risk and how to intervene to decrease it. The diagram is created by reviewing scientific literature and interviewing experts. We completed an expert model of how private well owners should take care of their wells, including how to monitor water quality, in our previously published research.[71] The second step of the Mental Models Approach has two parts. In the first part, the research team elicits a lay model of the risk from semi-structured interviews with the target audience. This lay model is then compared to the expert diagram to highlight misperceptions and knowledge gaps. We completed this part in our prior study involving interviews with 18 residents of peri-urban, African-American communities without municipal water service.[71] Our comparison of the lay and expert models identified several misperceptions and knowledge gaps that could influence private well testing. These included not knowing how to get water tested, concern about costs, lack of understanding of how wells can be contaminated and affect health, and a misperception that contaminants can be detected through appearance, taste, or odor. However, due to the semi- structured nature of the interviews and small sample sizes, such unstructured interviews are not sufficient to establish which categories of knowledge and beliefs significantly influence behavior. The second part of step two is therefore to administer a population-based survey of the target audience. The survey is designed to assess the prevalence of knowledge gaps and misperceptions and to assess whether they influence the risky behavior. The third and fourth steps of the Mental Models Approach are to design communication content to address knowledge gaps and misperceptions and to test the communication's effectiveness. Communication content is designed to fill the key gaps and correct the key misperceptions using language familiar to the target audience. Ideally, a randomized-controlled trial tests the effects of the communication on knowledge and risky behavior.

3.1.2 Study Objectives

Our overall objective was to develop information that can be used to design risk communication materials that promote the testing of private well water quality in NC peri-urban African-American communities, using the Mental Models Approach. Building on our prior, unstructured interviews with residents of such communities,[71] we had three objectives:

1. Characterize knowledge and beliefs about well water quality, contamination sources, and health risks.
2. Determine the percent of well owners in NC peri-urban African-American neighborhoods adhering to well water testing guidelines established by the NC Division of Public Health (DPH).

3. Assess the role of knowledge and beliefs on decisions to get a well water test.

3.2 Methods

3.2.1 Overview of Survey Design

We designed and administered a survey to assess the population prevalence of beliefs and knowledge gaps about private wells and how to take care of them in peri-urban African-American communities without municipal water service. The survey also was intended to identify how knowledge and beliefs are associated with well water testing. The survey built on what we learned in the aforementioned semi-structured interviews with 18 residents of the target communities.[71] Although our research is the first to investigate private well stewardship in peri-urban African- American communities, others have studied well testing behaviors in rural areas.[15,38,39,76–79] Our survey also drew questions from these prior rural studies in case any relevant concepts were overlooked in our semi-structured interviews. Survey questions were pilot tested in think-aloud sessions with three private well owners.[75] The final survey's Flesch-Kincaid reading grade level was 6.4.[71]

3.2.2 Survey Measures

The survey was divided into 14 sections, each with related questions. **Appendix A, Table A.1** (supporting information) summarizes these sections and provides example questions from each. The final survey included 129 questions assessing well testing behavior, knowledge, and beliefs, along with 14 demographic questions. The complete survey is available in the supporting information (**Appendix A.1**).

3.2.2.1 Knowledge and Beliefs About Well Water

To assess knowledge and beliefs about well water, the survey included 11 sections (**Appendix A, Table A.1**, sections 3-13, and **Appendix A.1**, supporting information) with 114 questions to elicit knowledge and beliefs ranging from where to get a water test to perceptions about water pollution sources and health risks. Multiple related questions were included in each section and across some sections to develop summary measures of knowledge and beliefs. For example, section 3 ("Your Opinions About Testing Your Well Water") asked participants to express their agreement or disagreement (on a five-point Likert scale) with 26 statements related to beliefs about water testing, including:

- "As long as my well water looks, tastes, and smell good, I do not need to test it for contamination."
- "My well water does not need to be tested because I've been drinking it for years without problems."
-

3.2.2.2 Water Testing Frequency

To determine the frequency of well water testing, section 2 of the survey asked "Has your well ever been tested?" (yes/no/not sure). Then, participants were asked the open-ended question, "If you have tested your well, about how long ago was it?"

3.2.3 Survey Administration

The survey was mailed in December 2016–January 2017 to 934 households in majority African-American census blocks in "municipal extraterritorial jurisdictions" of Wake County, NC. In brief, a municipal extraterritorial jurisdiction is a community bordering or encircled by a city or town over which the municipality exercises zoning authority but is not obliged to provide municipal services. Cities and towns can legally claim zoning rights over areas of up to three miles from their administrative borders.[56] We located these neighborhoods using tax parcel data from the Wake County Government Global Information Systems web site31 and racial composition data from the 2010 U.S. Census.[80] Surveys were mailed in over-sized envelopes with a recruitment letter offering a $15 gift card for survey completion and a postage-paid return envelope.

Of 934 mailed surveys, 97 (10%) were returned to sender due to vacant lots or other unknown reasons. From the remaining 837 households, we received 122 (15%) partially or fully completed surveys. Our 15% response rate is comparable to that observed among African-American populations in other mail surveys.[81] Of the 122 returned surveys, 5 were omitted due to incomplete responses, 7 because respondents did not have a private well, and 34 because we had tested the respondent's water in our prior research (potentially biasing their answers). Our analyses are based on the remaining 76 surveys**.** **Appendix A, Figure A.1** (in the Supporting Information) shows the general locations of survey respondents in relation to municipal boundaries and drinking water sources. **Table 3.1** summarizes demographics of survey respondents in comparison to those of households in majority African-American, peri-urban areas without water service (as estimated using 2010 U.S. Census block and block group data).[83] Survey respondents were significantly more likely to be female (63% versus 50%) and were significantly older (median age 64 versus 44 years) than the targeted population. Although the majority of respondents self-identified as African-American, the percent of African Americans was significantly lower (54% versus 67%) than in the peri-urban areas targeted in our mailing. Survey respondents were also significantly more educated (22% versus 9% had a graduate degree) and had significantly higher median income ($62,500 versus $59,100) than the target

Table 3.1. Characteristics of study participants compared to Wake County, NC

Demographic	Survey Respondents, Self- Reported (n=76)	Peri-Urban Blocks in Wake County Where Survey Respondents Live* (n=3598)	Peri-Urban Blocks in Wake County without Community Water Service* (n=9821)
Sex/ Race / Age			
Female	63.4%	49.9%	50.1%
Black/African-American	54.4%	63.8%	66.8%
Median age	64.0 years	42.8 years	43.7 years
Education Attainment			
Less than high school	11.4%	11.4%	10.5%
High school or GED	10.0%	23.9%	24.0%
Some college to bachelor's degree	55.7%	56.3%	55.5%
Graduate school	22.9%	8.4%	9.9%
Household Income			
Median household income	$62,500	$56,400	$59,100

Note: Some survey respondents did not complete the demographic questions on our survey. Sex, age and race are reported for census blocks, while education and income represent block groups. Percentages may not equal 100% due to rounding. *From US Census, 2010.[82]

population. Race was marginally associated with water testing: those identifying as African-American had lower odds of having tested their water within the past two years (odds ratio=0.37, p=0.075) compared to other races. However, none of the other demographic variables (gender, age, education, or income) was significantly associated with water testing. These latter results lend confidence to the generalizability of our results despite the differences between the survey respondents and residents in peri-urban, majority African-American neighborhoods without water service.

3.2.4 Data Analysis

To characterize knowledge and beliefs about private well water, we computed summary statistics for survey items that asked about perceptions of water quality, knowledge of contamination sources, and concerns about health risks. To examine the percent of survey respondents who adhered to DPH guidelines for well water testing, we compared responses to questions about previous water testing to DPH recommendations. Relevant survey questions were “Has your well ever been tested?” and “If you have tested your well, about how long ago was it?” The DPH recommends annual testing for bacteria; biennial testing for heavy metals, nitrates, nitrites, lead, and copper; and testing every five years for pesticides and volatile organic compounds.[84] To assess the role of knowledge and beliefs on decisions to get a well water test, we conducted a three-step process involving principal components analysis (PCA), logistic regression, and structural equation modeling. The first step was to use PCA to identify groups of like concepts and reduce the dimensionality of survey responses. Some questions were pertinent to the topics of multiple sections. For example, multiple sections asked about costs (of water in general, of testing well water, of maintaining wells). In such cases, questions were included in the PCA of each relevant section. PCA was conducted using the principal components extraction method with promax oblique rotation in SPSS (version 24.0.0.1). Promax rotation was selected due to high ($r > 0.32$) correlations among factors (suggesting > 10% variance overlap).[85] Interpretation of the rotated matrix was applied unless only one factor had an eigenvalue greater than 1 (Kaiser’s criterion); in those cases, the unrotated matrix was analyzed. Each interpretation involved the evaluation of four elimination criteria: (1) each question had a one-factor solution, with no cross loadings or questions in multiple factors; (2) each factor had a logical interpretation (with a common theme among questions); (3) loadings averaged above 0.7;[86] and (4) the variance explained was > 60%.[85,86] Eighteen survey questions were eliminated on the basis of these four elimination criteria. The second step was to assess whether factors identified in the PCA played a role in decisions to get a water test. This analysis was carried out via univariate logistic regressions (in SPSS, version 24.0.0.1) of water testing on each factor. Our main analysis focused on whether respondents had tested their water within the past two years. A subsequent analysis considered whether they had tested within the past five years. In the third step, factors that were significantly associated with water testing as identified in the binary logistic regression were included in a structural equation model to estimate direct and indirect effects. Structural equation modeling was conducted in Mplus (version 8.1). Demographic variables having statistically significant ($p \leq 0.05$) associations with water testing were included as covariates.

3.2.5 Human Subjects Research Approval

This study was approved by the University of North Carolina Institutional Review Board (#16-2172936).

3.3 Results

3.3.1 Knowledge and Beliefs About Private Well Water

Analysis of survey responses indicated that participants generally perceived their well water as of high quality, had low awareness of common contamination sources, and were unconcerned about health risks from their water.

3.3.1.1 Beliefs About Water Quality

Most respondents believed their well water was clean, even though our prior research has identified a high prevalence of contaminants in the targeted communities. For example, our prior research found that 65% of sampled households had bacterial contaminants in their water,[34] but only 9.5% of respondents answered "yes" to "My well water may be contaminated with bacteria." Similarly, we have found elevated lead concentrations in 28% of households tested,[70] but only 5.5% of respondents answered "yes" to "My well water may be contaminated with lead." Overall, 83% of respondents rated their well water quality as "somewhat good" or "very good" (the two top choices for Likert-type responses to this question). In comparison, only 42% of respondents rated city water as "somewhat" or "very" good. Similarly, 19% of respondents somewhat or completely agreed with the statement "City water is safer than well water." Thus, respondents perceived their well water quality as better than that of city water, even though our prior research has documented much higher contamination risks in the target neighborhoods than in nearby areas with municipal water service.[34,70]

3.3.2 Knowledge of Contamination Sources

Survey responses suggest that few respondents were aware of common contamination sources, including septic systems (a source of bacterial and chemical contaminants) and plumbing corrosion (a source of lead and other metals). Only 14% of respondents "somewhat" or "completely" agreed that their septic system could be a source of contamination, even though 99% of respondents said they had septic systems, and, among these, 24% said they had experienced problems with their septic systems. Respondents were somewhat more concerned about their neighbors' septic systems: 32% "somewhat" or "completely" agreed that their neighbors' system could be a contamination source. Similarly, most respondents were unaware of household plumbing as a potential contamination source, with only 36% "somewhat" or "completely" agreeing that corrosion of plumbing and fixtures is a potential contamination source. This low awareness is a concern because plumbing corrosion has been documented as the main source of lead in houses served by private well water.[19,22,70] Overall, respondents seemed more concerned about contamination sources, such as landfills, that were out of their control. For example, 41% "somewhat" or "completely" agreed that landfills could contaminate their well water, in comparison to the 14% agreement that the household's septic system is a potential contamination source.

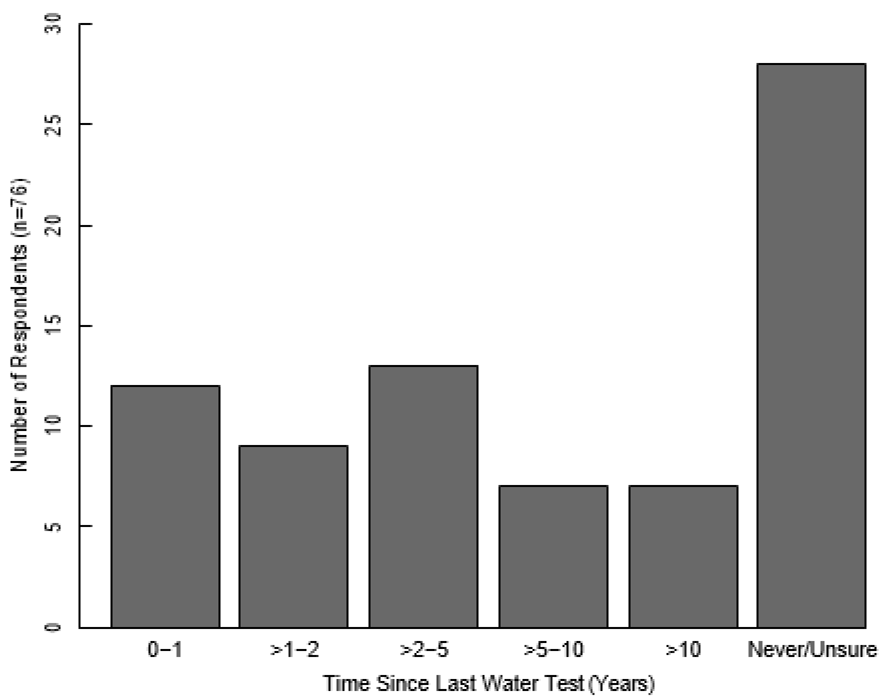

Figure 3.1. Frequency of well water testing reported by survey respondents.

3.3.3 Concerns About Health Risks of Contaminated Water

Most respondents expressed low concern about potential health risks from well water contamination. Among respondents, 80% "somewhat" or "completely" agreed with the statement, "My well water is safe to drink." Two-thirds "somewhat" or "completely" agreed they would feel "comfortable allowing a baby to drink water from my well," despite our prior research showing a relatively high risk of lead exposure,[70] which is especially risky to infants and children.[27] Most respondents completely disagreed (36%), somewhat disagreed (16%), or were neutral (20%) in responding to the question "I am worried about possible health problems caused by contamination of my well water."

3.3.4 Adherence to Water Testing Guidelines

Of the 76 survey respondents, 16% answered that they had tested their drinking water within the past year (**Figure 3.1**). An additional 12% had done so within the past two years, and another 17% said they had a water test 2–5 years ago. The rest had not tested their water for at least five years (18%), or had never tested their water or could not remember having done so (37%). The DPH recommends testing for bacteria every year, metals every two years, and pesticides and volatile organic compounds every five years.[87] Thus, 84% of survey respondents do not follow the recommended frequency for bacterial testing; 72% do not test at the frequency recommended for metals; and 55% do not follow the schedule recommended for organic compounds. Since July 1, 2008, North Carolina has required a one-time test of all newly constructed wells.[56] However, only 6.6% (n=5) of participants' wells were constructed after this date. The mean age of the respondents' wells was 36 years (SD= 16 years) (**Figure 3.2**). This result indicates that very few survey respondents have benefited from the legislative mandate for initial water quality testing of new wells.

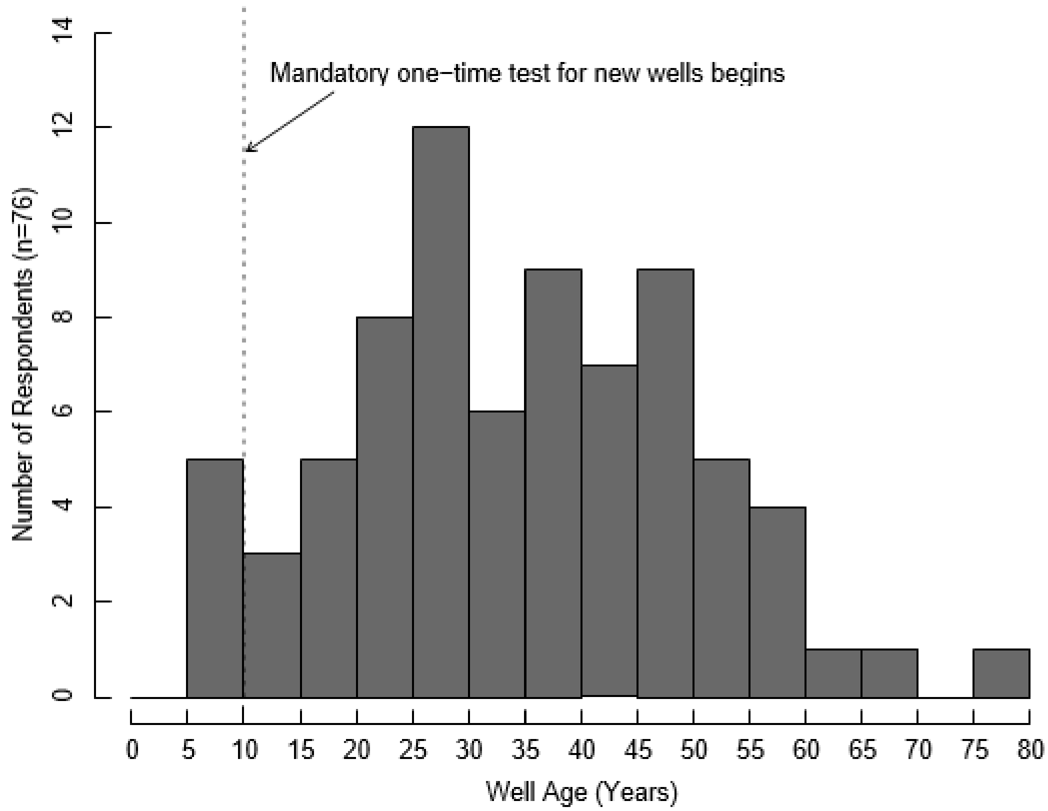

Figure 3.2. Ages of the private wells that survey respondents use for their drinking water.

3.3.5 Role of Knowledge and Beliefs in Water Testing Practices

From 129 survey questions, the PCA identified 19 factors representing cognitive constructs of survey respondents (**Appendix A, Table A.1**, supporting information). However, only three factors were significantly associated with whether respondents had tested their water within the past two years— the main testing frequency considered for this analysis (see **Appendix A, Table A.1**, last column). We have titled these factors “sensory perceptions,” “lack of knowledge and urgency,” and “cost barrier” (**Table 3.2**). Cronbach’s alpha was at least 0.83 for all three factors, indicating strong internal consistency within factors (**Table 3.2**).

3.3.5.1 Factor 1: Sensory Perceptions

A higher score on the "sensory perceptions" factor indicates stronger agreement that contaminants can be detected via sight, taste, or smell. For example, this factor included the question, "My well water does not need to be tested because it looks clear, has no smell, and tastes clean," which respondents answered on a 0 (completely disagree) to 4 (completely agree) scale. Respondents who had not tested their water within the past two years scored significantly higher on this factor than those who had tested their water (mean=1.7, SD=1.4 vs. mean=0.98, SD= 1.1, t(df)=74, $p<0.01$) (**Table 3.2**). The non-testers' higher scores suggest that countering the misperception that contaminants can be detected through sensory perception could encourage well owners to test their water.

3.3.5.2 Factor 2: Lack of Knowledge and Urgency

A higher score on the "lack of knowledge and urgency" factor represents both placing lower priority on water testing and uncertainty about how to do so. For example, this factor includes the statement, "I don't have time to get my well water tested," with a higher score indicating stronger agreement. It also includes "I don't know how to get my well water tested," with a higher score indicating less knowledge. Respondents who had not tested their water within the past two years scored higher on this factor than those who had tested (mean=1.9, SD=1.1 vs. mean=1.1, SD=1.1, t(df)=74, $p<0.01$) (**Table 3.2**). This result suggests that providing information about the importance of testing and how to do so could increase well water testing rates.

3.3.5.3 Factor 3: Cost Barrier

A higher score on the "cost barrier" factor represents a bigger concern about the costs of well water testing, along with a stronger belief that well water should be free. For example, this factor includes responses to "I can't afford the cost of testing my well water," with a higher score indicating stronger agreement. It also includes the statement "Getting water from a well is free," with a higher score indicating a stronger belief that well water should have no cost. Respondents who had not tested their water within the past two years scored higher on this factor than testers (mean=2.1, 1.0 vs. mean=1.4, SD=0.95, t(df)=74, p<0.01) (**Table 3.2**). These results suggest that offering free or reduced-price water testing could increase the rate of private well monitoring. The results also suggest the need for education about the value of water.

3.3.5.4 Water Testing Decision Model

Structural equation modeling showed that the "sensory perceptions" and "cost" factors were directly associated with decisions to test private well water, while the effects of "knowledge and urgency" were mediated by concerns about cost (**Figure 3.3**). Every unit increase (on a five-point Likert scale) in the perception that water quality can be detected through the senses decreased the odds of having tested water within the past two years by 47% (1-exp(=0.47). Similarly, every one- point increase in concern about costs decreased the odds of testing by 57% ((1-exp(=0.57). A one-unit decrease in the sense of uncertainty about how to get water tested—that is, an increase in knowledge about how to get water tested and the importance of testing—decreased concerns about costs by 64%, which in turn increased the odds of getting a water test. Well age was also associated with whether the respondent had tested their water, with the odds of testing increasing by 5.4% for every one-year increase in age. A structural equation model of whether respondents had tested their water within the past five years yielded results

Table 3.2 Summary Statistics for Three Latent Factors Significantly Associated with Whether Survey Respondents Had Tested Their Water Within the Past Two Years

Factor	Factor Loadings	Tested (n=21) (mean (SD))	Did Not Test (n=55) (mean (SD))
Sensory Perceptions (α = 0.92)**		0.98 (1.1)	1.7 (1.4)
As long as my well water looks, tastes, and smells good, I do not need to test it for contamination.NS	0.91	1.3 (1.3)	1.8 (1.5)
My well water does not need to be tested, because I've been drinking it for years without problems.**	0.92	0.70 (1.1)	1.6 (1.6)
My well water does not need to be tested because it looks clear, has no smell, and tastes clean.*	0.94	0.90 (1.1)	1.7 (1.5)
Lack of Knowledge and Urgency (α = 0.87)**		1.1 (1.2)	2.1 (1.1)
I plan to test but haven't gotten around to it yet.*	0.61	1.5 (1.5)	2.1 (1.1)
I don't have time to get my well water tested.*	0.581	0.70 (1.0)	1.3 (1.2)
I don't know where to get my well water tested.*	0.892	1.0 (1.5)	1.7 (1.5)
I don't know how to get my well water tested.*	0.882	1.0 (1.5)	1.7 (1.6)
I don't know what to test my well water for.**	0.877	1.2 (1.6)	2.2 (1.5)
I wouldn't know what to do if my well water were tested and found to be contaminated.*	0.761	1.5 (1.7)	2.3 (1.5)
Cost Barrier (α = 0.83)**		1.4 (1.0)	2.1 (1.0)
I couldn't afford the cost of testing my well water.**	0.82	0.80 (1.4)	1.9 (1.5)
I couldn't afford to fix my well water if it were tested and found to be contaminated with bacteria.**	0.91	1.0 (1.3)	1.9 (1.5)
I couldn't afford to fix my well water if it were tested and found to be contaminated with chemicals.**	0.85	1.1 (1.2)	2.2 (1.5)
I would prefer to drink city water if it were free.	0.62	1.5 (1.3)	1.7 (1.5)
Getting water from a well is free.**	0.51	1.8 (1.4)	2.6 (1.4)
I would install a home water filter if I could afford it.	0.64	2.4 (1.4)	2.6 (1.2)

NS=Not Significant; * $p \leq 0.05$; ** $p \leq 0.01$

similar to the two-year model. The "sensory perceptions" factor was significantly and directly associated with water testing, with the same direction and magnitude as in the two-year model (**Appendix A, Figure A2**, supporting information). The association with water testing of the "lack of knowledge and urgency" factor also was mediated by cost, with the same direction and magnitude of association as in the two-year model. The "cost barrier factor" was also directly related to testing, but the effect was smaller (odds ratio of 0.63 instead of 0.43) than in the two-year model. In the five-year model, well age was no longer significantly associated with water testing.

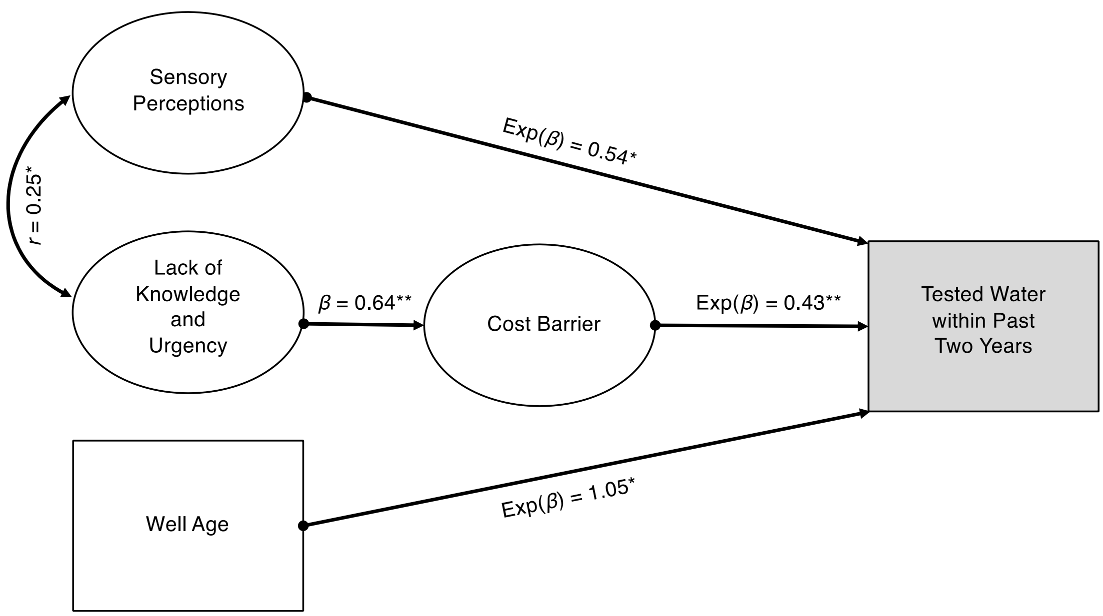

Figure 3.3 Factors associated with decisions to test private well water in peri-urban African American communities in Wake County, NC. Exp(β) = odds ratio from logistic regression; r = Pearson's correlation; **$p \leq 0.01$; *$p \leq 0.05$.

3.4 Discussion

This study sought to determine whether residents of peri-urban, majority African-American neighborhoods of NC lacking connections to nearby, regulated and monitored municipal water supplies follow public health department guidelines for testing their water quality. We also sought to assess knowledge beliefs about well water and to identify which categories of knowledge and beliefs are associated with decisions to get a water test. We found that

- survey respondents perceived their water as having high quality but had low knowledge of water contamination sources and health risks, despite evidence of relatively high contaminant prevalence in the surveyed neighborhoods;
- only 16% of survey respondents followed DPH guidelines for annual water testing;
- perceptions that contaminants can be tasted, smelled, or seen and concerns about costs were directly associated with a lower likelihood of testing well water, while the role of knowledge about how to get water tested was mediated by concerns about costs.

Risk communications targeted at encouraging well owners to get a water test typically try to motivate action by emphasizing health risks. For example, one website designed to assist well owners states on its cover page, "Learn how to protect this precious resource and safeguard your family's health through properly constructed and maintained water well systems" (emphasis added).[88] The county health department web site serving the neighborhoods we targeted begins with an emphasis on health risks: "Wake County encourages all private well users to have their water tested regularly to ensure that it is safe for drinking" (emphasis added).[89] Our results suggest that, at least for our target audience, such health-related information is not the most relevant to their decision- making about water testing.

3.4.1 Comparison to Studies of Rural Well Owners

To our knowledge, our project is the first to study private well testing in U.S. peri-urban areas without water service. However, multiple studies have surveyed rural well owners about water testing.[15,38,39,76–79,90] The low water testing rate we observed is similar to that in prior, rural studies. For example, only 10% of rural well owners responding to Wisconsin survey had tested their water within the prior year.[91] Multiple studies have found that large percentages (20-47%) of well owners have never tested their water, similar to our finding that 37% of our respondents had never tested or could not remember having done so.[37,39,79] Although prior surveys of well owners in rural communities have asked respondents why they have not tested their water, to our knowledge, our study is the first to fully characterize the relationships between well owners' knowledge and beliefs and their decisions to test water. Nonetheless, results of prior rural studies lend support for our main findings about factors influencing decisions to test water. Previous surveys in rural Wisconsin and New Jersey found a high percentage of respondents (82%-90%) stating their water "does not smell or taste bad" as part of the reason for not testing.[92,93] Similarly, 66% of surveyed Wisconsin well owners said they had not tested their water because they "have been drinking the well water for years without any problem."[91] Another study of rural Wisconsin private wells postulated that using sensory experiences is likely more influential than receiving concrete information like testing results and safety information.[94] Residents may not look for information regarding risks of their drinking water if they do not notice aesthetic problems.[53,95,96] Several studies have identified gaps in knowledge about testing procedures,[91–93] uncertainty in how to remove contaminants if detected,[15,54,97] and the inconvenience of testing as common barriers to testing.[15,93,97,98] Previous rural studies, one in Central Maine and one from five northeastern states, found that the cost of treating water after testing may be a burden that well owners could not afford and therefore may deter testing.[54,99] All of these results suggest that the barriers to water testing that we observed may not be unique to peri-urban, majority African-American communities.

3.4.2 Limitations

Like many survey-based studies, our response rate was lower than we would have liked. This limitation is increasingly common in mail surveys, and research has shown it need not lead to nonresponse bias.[100] In addition, our respondents had a higher proportion of females and were older than our target population. Our analysis showed, however, that these demographic covariates were not associated with whether respondents had tested their water. Our samples size (n=76) was somewhat small for PCA. Hair et. al. mentions sample size in relationship to factor-analytic methods, stating that factor analysis should not be performed on fewer than 50 participants and try to achieve a 10:1 ratio for participants to variables.[86] To obtain this ratio, we focused our analyses on individual survey subsections, each covering related topics, conducting separate PCAs for each broad topic to identify potentially influential factors.

3.4.3 Implications

African-American communities unserved by nearby municipal water infrastructure must be stewards of their own water quality, without the resources available to their neighbors with municipal services. We have shown that few residents of these areas follow state guidelines for water testing. Further, most residents are unaware of the potential risks to their water quality or the associated health impacts. The Mental Models Approach to Risk Communication provides one framework to promote drinking water quality stewardship in these neighborhoods. We have demonstrated that Mental Models surveys were effective in uncovering factors associated with private well testing. Future risk communications to these communities should emphasize these factors. Outreach materials should (1) convey that contaminants cannot be detected through sensory perceptions, (2) provide easily understood information about how to get a water test, and (3) reference programs for reduced-cost testing (available in Wake and some other NC counties). Communications should avoid including information (such as health risks) not directly associated with testing behaviors.

In the longer term, extending municipal water and sewer service to these areas will surely be a more cost-effective solution to ensuring residents have clean drinking water. These areas are in relatively densely populated neighborhoods in close proximity to water and sewer lines—often across the street from or encircled by these services (see **Appendix A**, **Figure A1**). Continuing to rely on individual household residents to serve as engineers of their own water and sanitation systems is inefficient, given the economies of scale available when connecting to municipal systems. Indeed, as Wilde-Anderson writes, such "'islands' or 'peninsulas'" of underserved areas "surrounded by property within city lines create noncompact and noncontiguous service areas . . . —a situation that runs against the most basic principles of efficiency in urban planning and service provision."[3] She argues that state- and federal-level policy changes, such as empowering counties to influence municipal annexation decisions and establishing funding for infrastructure extensions, are needed to address this problem of urban inequality.[3] If increased monitoring confirms the water quality problems documented in the small number of studies in such "lost neighborhoods" conducted to date,[7,9,34,70] the resulting data could help community members and health officials build political support for such long-overdue policy changes. Although we focus on peri-urban African-American communities in NC, the results could have broader relevance to other underserved peri-urban communities and rural areas relying on private wells for their water. Indeed, the need for improved outreach to promote private well stewardship in the United States has been recognized by the Centers for Disease Control and Prevention and others in multiple publications over the past decade.[42,101,102]

CHAPTER 4: WELL WATER TESTING IN AFRICAN-AMERICAN COMMUNITIES WITHOUT MUNICIPAL INFRASTRUCTURE PART II: A RANDOMIZED-CONTROL TRIAL OF A MENTAL MODELS RISK COMMUNICATION[3]

4.1 Introduction

As Chapter 3 described, we found that three factors are associated with decisions to test or not test well water in underbounded African-American communities of Wake County (**Figure 3.3**):

1. the belief that water contaminants can be detected through sensory perceptions (sight, smell, and taste),
2. knowledge about how to get a test and the sense of urgency about the importance of testing, and
3. concerns about the affordability of well water testing and the costs of removing contaminants if detected, along with a belief that well water should be free.

As described in Chapter 3, those who believed more strongly that water contaminants can be detected through sensory perceptions were less likely to have tested their well water within

[3] (Stillo III, F.J., Wood, E., Bruine de Bruin, W., MacDonald Gibson, J. 2019. In preparation for the journal Risk Analysis as the second part of a two-part manuscript about the design and testing of a risk communication.

the past two or five years. Similarly, those who were concerned about costs also were less likely to have tested their water. However, increasing knowledge about how to test water and a sense of urgency about testing was associated with decreased concerns about the cost of testing and, in turn, an increased likelihood of having gotten a water test within the past two or five years.

On the basis of these findings, we designed a risk communication intended to promote private well testing in underbounded minority communities by addressing these factors.[103] The risk communication was designed to exclusively address the above-referenced factors found in Chapter 3 to be associated with private well testing behavior in peri-urban African-American communities (communication design was led by Erica Wood and is fully discussed as part I of an article in preparation for the journal Risk Analysis of which I am co-author).[103] Although the perception that the cost of testing or removing contaminants after testing was shown to be a barrier to private well testing, without programs from health departments removing or subsidizing these costs, information about these costs may not influence testing. Furthermore, the concerns about cost factor mediates the knowledge and urgency to test factor, which indicates that by improving knowledge of testing and a sense of urgency about the importance of testing, interventions may impact the effect of concerns about the cost of testing. Therefore, we did not include any explicit messages about cost in our final postcard. Instead, we examined the concerns about the cost of testing factor by offering a free test (reducing concerns about costs directly) to a subset of participants.

Our previous surveys in Chapter 3 identified mailed post cards as the most preferred format for information about private well testing among members of the target population .[104] Therefore, the communication was designed as an over-sized post-card that state and local health departments can distribute by mail. Designed communications were pilot tested to ensure they effectively conveyed risk information and in a format that can be easily distributed by health departments. Cognitive pilot tests of communications were conducted in think-aloud sessions with five peri-urban private well owners to ensure topics were interpreted coherently.[75] The Flesch-Kincaid reading level of the risk communication was 6.6.[105] The final risk communication is shown in **Appendix B, Figure B1a-B1b.**

This chapter presents the results of a randomized-controlled trial to test this risk communication. The trial was designed to answer multiple questions and test hypotheses about the potential effectiveness of the risk communication in increasing private well testing. Our first research question examined the influence of the risk communication and an offer of a free test had on water testing:

- *Hypothesis 1a:* Participants mailed the risk communication will be more likely to get a water test within 30 days of receiving the communication than those who do not get a risk communication.
- *Hypothesis 1b:* Participants mailed an offer of a free test will be more likely to get a water test within 30 days of receiving the free test offer than those not offered a free test.
- *Hypothesis 1c:* Participants mailed both the risk communication and free test offer will be more likely to get a water test within 30 days of receiving the communication than those that did not receive both interventions.

Our second research question examined the influence of the risk communication and an offer of a free test had on knowledge about how to get a test and the sense of urgency about the importance of testing:

- *Hypotheses 2a:* Participants mailed the risk communication will have more knowledge and a greater sense of urgency about water testing than those that were not mailed a risk communication.
- *Hypothesis 2b:* There will be no differences in knowledge about how to get a water test and sense of urgency about testing between those offered a free test and those offered no intervention.

Our third research question examined the influence of the risk communication and an offer of a free test had on the perception that water contaminants can be detected through sensory perceptions:

- *Hypotheses 3a:* Participants mailed the risk communication will be less likely to believe that water contaminants can be detected through sensory perceptions than those not mailed a risk communication.
- *Hypothesis 3b:* There will be no differences in the belief that water contaminants can be detected through sensory perceptions between those offered a free test and those offered no intervention.

Our fourth research question examined the influence of the risk communication and an offer of a free test had on concerns about the costs of water testing:

- *Hypotheses 4a:* Participants mailed the risk communication will be less concerned about the costs of water testing than those not offered a risk communication.
- *Hypothesis 4b:* Participants mailed an offer of a free test will be less concerned about the costs of water testing than those not mailed an offer of a free test.

- *Hypothesis 4c:* Participants mailed both the risk communication and free test offer will be less concerned about the costs of water testing than those not mailed both interventions.

4.2 Methods

4.2.1 Study Population

Our target audience were households who rely on private wells for drinking water in Wake and Gaston counties, NC. Different processes were used to generate the mailing list for each county due to differences in data availability. For Wake County, tax parcel data indicated whether each property parcel had a connection to a community water supply. If not, we assumed they relied on a private well. We overlaid census block racial composition from the 2010 census and a map of extraterritorial jurisdiction (ETJ) boundaries obtained from Wake County Government Global Information Systems (WCGGIS) to identify target neighborhoods.[106] (Chapter 2 and 3 discuss the definition of an ETJ) NC law allows municipalities to claim such extraterritorial land as within their zoning power for areas up to three miles from the town boundary.[56] For Gaston County, we obtained a list of households that had applied for private well permits from the Gaston County Department of Health, obtained and verified by the University of North Carolina at Charlotte (UNCC).[107] In total, our mailing list included 2,178 households in peri-urban communities of Wake (n=1,225) and Gaston (n=953) counties who rely on private wells.

Of the 2,178 mailed surveys, 236 (9.2%) were returned to sender due to vacant lots or other unknown reasons leaving 472 mailed to group 1, 484 to group 2, 492 to group 3 and 494 to group 4. From the remaining 1,942 households, we received 193 (10%) partially or fully completed surveys. Of the 193 returned surveys, 31 were omitted: 29 because the respondent answered “no” to having a private well, and 2 due to incomplete responses on questions necessary to understand influences on water testing behavior. Our analyses are based on the remaining 162 surveys (group 1: n=44, group 2: n=35, group 3: n=38, and group 4: n=45) (**Table 4.1**).

4.2.2 Randomized-Controlled Trial Design

We assessed the effectiveness of the risk communication through a randomized-controlled trial involving residents of peri-urban areas in Wake and Gaston Counties, NC, without municipal water service. The trial was a 2x2 design testing the effects of the risk communication, along with the effects of an offer of a free water test (**Table 4.1**). One-quarter of the participants were mailed the risk communication only, one-quarter received an offer of a free test only, one-quarter received both, and the remaining participants did not receive a communication or free test offer. To offer free tests, we created postcards of the same size and with the same contact information and color scheme as the risk communication, but with only information about how to contact us for a free test. To communicate both the key information in the risk communication and the offer of a free test, we used the risk communication postcard and added the same text about a free test, without removing any of the original content. The final risk communications were designed as part of a Master’s thesis by Erica Wood (in collaboration with myself and are shown in **Appendix B, Figure 1)**. Effects of the interventions were assessed via a follow-up survey, with measures of knowledge and beliefs about private well testing, and self-reported well testing behavior.

Table 4.1. Randomized control trial of a risk communication assessing private well testing

		Risk Communication Intervention	
		No Risk Communication	**Risk Communication**
Financial Intervention	**No Free Water Test**	Group 1 (control) n=543	Group 2 n=547
	Free Water Test	Group 3 n=544	Group 4 n=544

Note: (n) represents the number of returned surveys in each group after 34 were omitted for ineligibility (31), being an outlier (1) or incomplete (2).

Risk communications were mailed in June 2018, and follow-up surveys were sent one month later. The follow-up surveys included a recruitment letter offering a $15 gift card for survey completion. It provided two methods of responding: by pre-paid return envelope or by Qualtrics online survey using a link and password provided in the recruitment letter.

4.2.2.1 Follow-up Survey Design

The survey was designed to answer questions about the impact of the risk communication and free test interventions. The 37 question survey asked about use of well water, testing of well water, knowledge and beliefs about well water, whether they had seen the postcard and demographic questions. The Flesch-Kincaid readability for the follow-up survey was grade 4.8. The complete survey is available in **Appendix B.1**.

4.2.2.2 Survey Measures

Testing behavior

To measure water testing, the survey asked, “Has your well been tested since June 11th [in the last 30-days]?” (yes / no / not sure). Not sure answers were coded as no for this analysis.

Beliefs and knowledge gaps about water testing

The follow up survey measured only the beliefs and knowledge that previous research had identified as influencing private well testing.[35,108] This previous research found three factors significant in influencing private well testing: (1) the perception that water contaminants can be detected through sensory perceptions, (2) knowledge about how to get a test and the sense of urgency about the importance of testing, and (3) concerns about the affordability of well water testing and removing contaminants, along with a belief that well water is free. The follow-up survey used exact wording from the questions comprising each of these factors.[108] For each question, respondents expressed their agreement or disagreement on a five-point Likert scale from 0 ("completely disagree") to 4 ("completely agree). Factor scores for each participant were computed using the regression method for each factor in SPSS 24. Cronbach's alpha values for each factor were sufficient to warrant the computation of factors ($\alpha \geq 0.76$) (**Table 4.2**).

Table 4.2. Internal Consistency Scores for Three Latent Factors Used in the Design and Testing of a Risk Communication Promoting Private Well Testing

Factor	Follow-up Survey
Sensory Perceptions	**α = 0.94**
As long as my well water looks, tastes, and smells good, I do not need to test it for contamination.	
My well water does not need to be tested, because I've been drinking it for years without problems.	
My well water does not need to be tested because it looks clear, has no smell, and tastes clean.	
Lack of Knowledge and Urgency	**α = 0.81**
I plan to test but haven't gotten around to it yet.	
I don't have time to get my well water tested.	
I don't know where to get my well water tested.	
I don't know how to get my well water tested.	
I don't know what to test my well water for.	
I wouldn't know what to do if my well water were tested and found to be contaminated.	
Cost Concerns	**α = 0.76**
I couldn't afford the cost of testing my well water.	
I couldn't afford to fix my well water if it were tested and found to be contaminated with bacteria.	
I couldn't afford to fix my well water if it were tested and found to be contaminated with chemicals.	
I would prefer to drink city water if it were free.	
Getting water from a well is free.	
I would install a home water filter if I could afford it.	

α = Cronbach's alpha.

4.2.3 Analysis Plan

To assess the randomization of participants between study groups, we compared dichotomized participant demographic characteristics (i.e. county, race, gender, income, and education) and other household characteristics (i.e. well age and home age) between the control group (**Table 4.1, group 1**) with those mailed an intervention (**Table 4.1, groups 2, 3, 4**). One-way ANOVAs were used for multiple comparisons followed by Bonferroni post-hoc testing in SPSS 24. *P* values of <0.05 were considered significant.

4.2.3.1 Question 1: Influence of risk communication and free test offer on water testing

To assess the main effects of whether the risk communication or an offer of a free test increased the odds of water testing, we used logistic regression, shown in equation 1:

$$Water\ Test = \frac{1}{1 + \exp -(\beta_0 + \beta_1 RC \ + \beta_2 FT)}$$

(Equation 1a)

where whether the respondent reported that they had tested their water within the past 30 days was the dependent variable, the β values are the coefficients for mean adjusted changes in testing behavior, RC (**Table 4.1, Groups 2 and 4**) is an indicator variable for the participants who were mailed our risk communication, and FT (**Table 4.1, Groups 3 and 4)** is an indicator variable for the participants who were mailed our offer of a free test.

To assess the interaction of the main effects on water testing, we added an interaction term to equation 1a.:

$$Water\ Test = \frac{1}{1 + \exp -(\beta_0 + \beta_1 RC + \beta_2 FT + \beta_3 RC \times FT)}$$

(Equation 1b)

where whether the respondent reported that they had tested their water within the past 30 days was the dependent variable, RC×FT (**Table 4.1, Group 4)** are participants who were mailed both the risk communication with an offer of a free test.

4.2.3.2 Question 2: Influence of risk communication and free test offer on knowledge and urgency about water testing

To assess the main effects of whether the risk communication or an offer of a free test increased the knowledge and urgency about testing, we used a univariate logistic regression (shown in equation 2):

$$Knowlege\ and\ urgency\ about\ testing = \beta_0 + \beta_1 RC + \beta_2 FT$$

(*Equation 2a)*

where knowledge about how to get a test and the sense of urgency about the importance of testing was the dependent variable.

To assess the interaction of the main effects on the knowledge and urgency about testing, we used multivariate linear regression (shown in equation 2a):

$$Knowlege\ and\ urgency\ about\ testing = \beta_0 + \beta_1 RC + \beta_2 FT + \beta_3 RC \times FT$$

(Equation 2b)

4.2.3.3 Question 3: Influence of the risk communication and free test offer on the belief that water contaminants can be detected through sensory perceptions

To assess the main effects of whether the risk communication or an offer of a free test decreased reliance on sensory perceptions, we used a univariate logistic regression (shown in equation 3):

$$Relying\ on\ sensory\ perceptions\ to\ test = \beta_0 + \beta_1 RCG + \beta_2 FT$$

(Equation 3a)

where the perception that water contaminants can be detected through sensory perceptions was the dependent variable.

To assess the interaction of the main effects on the reliance on sensory perceptions to test, we used multivariate linear regression (shown in equation 3a):

$$Relying\ on\ sensory\ perceptions\ to\ test = \beta_0 + \beta_1 RCG + \beta_2 FT + \beta_3 RC \times FT$$

(Equation 3b)

4.2.3.4 Question 4: Influence of the risk communication and free test offer on concerns about the costs of water testing

To assess the main effects of whether the risk communication or an offer of a free test decreased concerns about the cost of testing we used a univariate logistic regression (shown in equation 4):

$$Concerns\ about\ the\ cost\ of\ testing = \beta_0 + \beta_1 RCG + \beta_2 FTG$$

(Equation 4a)

where concerns about the affordability of well water testing and removing contaminants, along with a belief that well water is free was the dependent variable.

To assess the interaction of the main effects on concerns about the cost of testing we used multivariate linear regression (shown in equation 4a):

$$Concerns\ about\ the\ cost\ of\ testing = \beta_0 + \beta_1 RCG + \beta_2 FT + \beta_3 RC \times FT$$

(Equation 4b)

4.3 Results

4.3.1 Participant Characteristics

Among survey respondents, 37% were African American (**Table 4.3**). Although this was lower than our target (majority African American), it is higher than the mean African American population proportions of the counties to which the risk communication was mailed (21% and 18% for Wake and Gaston counties, respectively). Self-reported incomes were higher than median incomes in Gaston County ($46,626) but lower than in Wake County ($73,577). Two-thirds of respondents were female. Respondents were mostly highly educated, with 74% having at least some college education. Demographic characteristics (e.g. race, gender and education) did not differ among the four experimental groups. Participants in the Free Test Group (FTG) had significantly less representation in Gaston County than in the control group, but county of residence was not significant in any of the regression models. However, county affiliation was not significant in any of the regressions reported. There no baseline differences between randomized groups in median household income and other household characteristics (i.e. well age and home age) (**Table 4.3**).

Table 4.3. Participant characteristics (n=162)

Demographic	Self-reported score
African American race	37%
Female gender	67%
Self-reported household income	Mean=$64,000 (min=<$15,000, max=>$200,000)
Well age, years	Mean=28 (min=2, max=145)
Home age, years	Mean=38 (min=1, max=161)
Residence in Gaston County	40%
Educational attainment	
Less than high school	2.6%
High school or GED	23%
Some college or bachelor's degree	60%
Graduate degree	14%

4.3.2 Question 1: Influence of risk communication and free test offer on water testing

Among the four experimental groups, those receiving both the risk communication and the free water test offer (group 4) were most likely to report that they had ordered a water test after the date on which our communications were mailed (**Table 4.4**). Those receiving the free test offer were second-most likely to have tested their water. Surprisingly, those in the risk communication only group were less likely to report testing their water than those in the control group. The summary statistics in Table 4.3 suggest that the risk communication alone did not induce participants to get a water test but that providing a free test offer did so and that providing the risk communication along with the test was the most effective approach for encouraging testing. As discussed below, the increased testing among those in the free test group was statistically significant, but the additional benefit of providing the risk communication with the free test offer did not quite reach statistical significance.

Table 4.4. Survey respondents reporting they had ordered a water test

	Mailed the Risk Communication (Groups 2 and 4)	
Mailed a Free Test (Groups 3 and 4)	No	Yes
No	14% (N=44)	2.9% (N=35)
Yes	21% (N=38)	27% (N=45)
N=total participants for each group		

4.3.3 <u>Participants in the risk communication group will be more likely to test versus control (hypothesis 1a)</u>

The risk communication, on its own, did not significantly influence the odds of water testing, therefore, we reject hypothesis 1a (**Table 4.5, row 2**).

Table 4.5. Logistic regression of water testing on risk communication and free test offer

Explanatory Variable	**Odds Ratio**	***P* Value**	**95% Confidence Interval**
Logistic Regressions of Main Effects			
Mailed a risk communication	0.84	0.68	0.36, 2.0
Mailed a free test offer	3.3	0.011*	1.3, 8.4
Main Effects and Interaction			
Mailed a risk communication	0.19	0.13	0.021, 1.6
Mailed a free test offer	1.7	0.38	0.53, 5.4
Mailed risk communication and free test offer	7.3	0.10	0.67, 80

*$p < 0.05$

4.3.3.1 Participants in the free test group will be more likely to test versus control (hypothesis 1b)

Those who had been mailed an offer of a free water test were significantly more likely to have ordered a water test than those who were not mailed a free test offer (OR=3.3; p=0.01), (**Table 4.5, row 3**).

4.3.3.2 Participants in the group sent both the risk communication and free test offer will be more likely to get a water test (hypothesis 1c)

Although the proportion of water testers among those who were mailed both the risk communication and free test offer was greater than that in the other experimental groups (**Table 4.4**), this interaction effect did not quite reach statistical significance when included in a model with the main effects (**Table 4.5, last row**).

4.3.4 Question 2: Influence of risk communication and free test offer on knowledge and urgency about water testing

4.3.4.1 Participants in the risk communication group will have more knowledge and urgency to test versus control and free test groups (hypothesis 2a)

Table 4.6. Knowledge and sense of urgency about private well testing by group

	Mailed the Risk Communication (Groups 2 and 4)	
Mailed a Free Test (Groups 3 and 4)	No	Yes
No	-0.18	0.27
Yes	0.12	-0.12
Note: Factor scores were calculated where a positive mean score is greater knowledge about testing procedures and urgency to test private well water.		

Among the experimental groups, the highest scores were among those mailed the risk communication only (**Table 4.6**), with a mean score of 0.27 on a normalized scale. (The mean score on knowledge across all participants was 0.0, with a standard deviation of 1.) The second-highest score was in the free test group. The lowest mean score (indicating least knowledge) was in the control group. However, the main effects of the risk communication and free test offer on participants' knowledge did not reach statistical significance (**Table 4.7**). Interestingly, when the risk communication was combined with an offer of a free test, participant knowledge and urgency was lower than when provided a risk communication or free test offer alone, and this interaction effect was statistically significant (OR=-0.69; p=0.033) (**Table 4.7**).

Table 4.7. Linear regression of knowledge and urgency to test water on risk communication and free test offer

Explanatory Variable	**Coefficient**	***P* Value**	**95% Confidence Interval**
Linear Regression of Main Effects			
Mailed a risk communication	0.11	0.50	-0.21 ; 0.43
Mailed an offer of a free test	-0.49	0.76	-0.37 ; 0.27
Main effects and interaction			
Mailed a risk communication	0.46	0.046*	0.0091 ; 0.91
Mailed an offer of a free test	0.30	0.19	-0.15 ; 0.75
Risk communication x Free test	-0.69	0.033*	-1.3 ; -0.057

*$p < 0.05$

4.3.4.2 <u>There will be no differences in knowledge and urgency about testing between those in the free test group and those in the control group (hypothesis 2b)</u>

There were no differences in knowledge and urgency to test between those in the free test group and those in the control group (**Table 4.7**).

4.3.5 Influence of risk communication and free test offer on reliance on sensory perceptions to water test

4.3.5.1 Participants in the risk communication group will be less likely to rely on sensory perceptions than those in the control and free test groups (hypothesis 3a)

Table 4.8. Reliance on sensory perceptions to indicate when to test private wells by group

	Mailed the Risk Communication (Groups 2 and 4)	
Mailed a Free Test (Groups 3 and 4)	No	Yes
No	-0.047	0.077
Yes	-0.12	0.089
Note: Factor scores were calculated where a positive mean score is greater reliance on sensory perceptions to indicate when to test private well water.		

4.3.6

Among the experimental groups, the lowest scores were among those mailed the free test offer only (**Table 4.8**), with a mean score of -0.12 on a normalized scale (indicating least reliance on sensory perceptions). Interestingly, the highest mean scores (indicating more reliance on sensory perceptions) was in the groups that received a risk communication. The risk communication group were not significantly less reliant on sensory perceptions than those in the control or free test group, thus, we reject hypothesis 3a (**Table 4.9**).

4.3.6.1 There will be no differences in sensory perceptions between those in the free test group and those in the control group (hypothesis 3b)

There were no differences in reliance on sensory perceptions to indicate when to test between those in the free test group and those in the control group (**Table 4.9)**.

Table 4.9. Linear regression of reliance of sensory perceptions to test water on risk communication and free test offer

Explanatory Variable	Coefficient	*P* Value	95% Confidence Interval
Linear Regression of Main Effects			
Mailed a risk communication	0.17	0.29	-0.15 ; 0.49
Mailed an offer of a free test	-0.033	0.84	-0.35 ; 0.28
Main effects and interaction			
Mailed a risk communication	0.12	0.59	-0.33 ; 0.58
Mailed an offer of a free test	-0.078	0.73	-0.52 ; 0.37
Risk communication x Free test	0.090	0.78	-0.54 ; 0.72

$^*p < 0.05$

4.3.7 Influence of risk communication and free test offer on concerns about the cost of testing

4.3.7.1 Participants in the risk communication group will be less concerned about the costs of water testing than those in the control group (hypothesis 4a)

Table 4.10. Concerns about the costs of private well testing by group

	Mailed the Risk Communication (Groups 2 and 4)	
Mailed a Free Test (Groups 3 and 4)	No	Yes
No	0.16	-0.22
Yes	-0.098	0.10
Note: Factor scores were calculated where a positive mean score is greater concerns about the cost to test private well water.		

Among the experimental groups, the lowest scores were among those mailed the risk communication followed by those that received the free test offer only (**Table 4.10**), with a mean score of -0.22 and -0.098 respectively on a normalized scale (indicating least concerns about costs). The highest mean scores (indicating more concerns about costs) was in the control group. Participants in the risk communication group had no significantly different concerns about the cost of water testing than those in the control group, thus, hypothesis 4a was rejected (**Table 4.11**).

4.3.7.2 Participants in the free test group will be less concerned about the costs of water testing than those in both the control and risk communication groups (hypothesis 4b)

There were no differences in concerns about the cost of testing between those in the free test group and those in the control or risk communication groups (**Table 4.11**).

4.3.7.3 Participants in the group sent both the risk communication and free test offer will be less concerned about the costs of water testing than those in the control, risk communication alone, and free test alone groups (hypothesis 4c)

Participants sent both a risk communication with an offer of a free test were not significantly different than those in the other groups tested, thus, rejecting hypothesis 4c (**Table 4.11**).

Table 4.11. Linear regression of concerns about the cost of testing on risk communication and free test offer

Explanatory Variable	**Coefficient**	***P* Value**	**95% Confidence Interval**
Linear Regression of Main Effects			
Mailed a risk communication	-0.088	0.59	-0.41 ; 0.23
Mailed an offer of a free test	0.037	0.82	-0.28 ; 0.36
Main effects and interaction			
Mailed a risk communication	-0.38	0.097	-0.83 ; 0.070
Mailed an offer of a free test	-0.26	0.26	-0.71 ; 0.19
Risk communication x Free test	0.58	0.072	-0.053 ; 1.21

$^*p < 0.05$

4.4 Discussion

This study examined well water testing behavior in response to a risk communication intervention in peri-urban communities of NC who rely on private wells. The odds of private well testing significantly increased for participants who were mailed an offer of a free test. However, the risk communication did not have a significant impact on testing or factor knowledge. This preliminary evaluation suggests that programs that offer free water testing may significantly increase private well testing, however, the limited exposure to the one-time mailer did not significantly change factor knowledge suggesting alternative methods to increase intervention exposure are needed.

The intervention that offered a free water test was effective at increasing private well testing behavior for those who recall seeing it. Only one previous Mental Models study looked at behavior change after viewing a risk communication. Study participants were given an intervention at 1, 3, and 6 months and checked for knowledge gained immediately after viewing the materials.[109] They found women in the control group were twice as likely to be diagnosed with an STD as women who viewed their risk communication at the final visit.[109] These results suggest that even our conservative approach of a one-time mailer resulted in behavior change. The previous results suggest that educational programs that increase exposure to these materials may improve on our results.

The Mental Models designed risk communication in this study did not find improved factor knowledge among respondents versus control. Since participants only received the communication once much of the expected knowledge improvement from seeing a risk communication may have been lost. This is consistent with previous research that found correcting controversial issues (misperceptions) may have unexpected or counterproductive results.[110–112] The confidence in understanding testing procedures, reliance on sensory perceptions, and concerns about the cost of testing for participants who tested after receiving a free test offer continued, despite being able to and executing a water test. This suggests that one-time mailed risk communications would not sustainably change public perceptions.

A common limitation to studies that rely on mailed surveys is a low response rate. Although our response rate was lower than expected, especially given the incentive of a free water test, research has shown this may not lead to nonresponse bias.[100] Our 10% response rate is slightly lower than our previous survey (detailed in Chapter 3 of this dissertation) of majority African-American peri-urban communities in Wake County, NC, who reported 14%.[108] However, our previous survey sent repeated mailers and reminders to increase survey response. Our trial design chose the most conservative approach by sending a one-time mailer to persuade private well owners to test their water to mimic areas where public funding for educational programs are low. Thus, it was imperative that residents respond during the same time frame to reduce information loss from long term survey redistribution. Future implementation and testing of interventions should include multiple modalities (i.e. repeated mailers and face-to-face interviews) to increase exposure and recruitment, as this study only tested one.[81,113] In addition, we did not measure baseline knowledge of follow-up survey participants before seeing the risk communication and waited 30 days to test respondent knowledge. Hence, we are unable to test if participants actually gained knowledge from the risk communication. Therefore, our conclusion that factor knowledge was not associated with the reported effects on testing behavior may be premature due to the small sample size.

4.5 Implications

Peri-urban communities excluded from nearby municipal water infrastructure are not afforded the protections of the SDWA such as continuous monitoring and expert training. Lack of testing and training leaves residents unaware of the potential increased risks of negative health outcomes associated with contaminated water, such as cognitive impairment in children from excessive lead consumption or acute gastrointestinal illness from consuming pathogens.[29,114] Furthermore, previous research using nationally representative data to examine differences in tap water perceptions found that residents who take action to mitigate actual or perceived water quality problems report lower perception of risk.[115] This lower risk perception among the population may increase tap water consumption, especially for minorities, which could positively impact childhood obesity.[115,116] Our findings suggest that the Mental Models Approach was effective in promoting private well testing. Indeed, this approach could be relevant to other underserved peri-urban areas and rural communities relying on private wells. However, for any intervention to be successful, implementers must maximize exposure to the communication to obtain the desired behavior change.

While 12 previous research studies have used the Mental Models Approach to develop and test evidence-based risk communications for many applications,[74] no previous work has sought to develop a Mental Models risk communication encouraging private well owners to test their water. In addition, this study is only the sixth randomized-controlled trial of a mental models risk communication.[74] As such, this research contributes not only to the potential for targeted risk communications to improve private well testing, but also to the evidence base for the mental models approach to risk communication. Public health authorities within NC and nationally could benefit from this approach to designing and testing evidenced-based interventions that promote private well testing.

CHAPTER 5: CONCLUDING REMARKS AND IMPLICATIONS

Majority African-American communities on the fringes of urban development have been excluded from public water infrastructure and therefore must rely on private wells for their drinking water. This dissertation built on the limited body of knowledge of water quality in these communities and developed the first evidence-based risk communication intervention to improve well water testing rates. We examined the risk of exposure to lead in drinking water for underbounded communities who rely on private wells. Furthermore, this research identified perceptions and beliefs about risk factors and water quality monitoring in these communities to develop and test a risk communication to encourage increased water testing. This work found that private well owners in underbounded communities face increased exposure to lead and associated health risk for children compared to neighboring children consuming municipal water (Chapter 2). Chapter 3 reports that few residents of these areas follow state guidelines for water testing and many are unaware of the potential risks to their water quality or the associated health impacts. It also describes the factors associated with private well testing in these communities, as uncovered by the Mental Models surveys (Chapter 3). This dissertation demonstrated that a Mental Models designed risk communication is effective at promoting private well testing in underbounded communities (Chapter 4). The research expands on current knowledge of underbounded communities in North Carolina, but could inform future research of other, more general, communities who rely on private wells. The knowledge gained may be useful in refining models for risk assessment of neurological impairment in children from exposure to lead in drinking water. Furthermore, the Mental Models approach could be useful in designing future risk communications to encourage water testing in other communities.

5.1 Underbounded Communities Face Increased Risk of Lead in Drinking Water

Chapter 2 found increased risk of lead exposure for households in underbounded communities compared to neighboring households in public water systems, which is especially concerning for children under 7 years old who rely on private wells for drinking. This evidence contributes to the small but growing body of evidence suggesting racial disparities in access to safe drinking water for underbounded private well owners.[7,18,70] Furthermore, these results indicate the need for interventions to decrease lead exposure in majority African-American peri-urban communities excluded from nearby municipal water service. A recent meta-analysis on the control of lead sources addressed challenges to eliminating lead exposure by concluding:

> There are future challenges, particularly from the inequitable distribution of lead hazards among some communities. Maintaining federal, state, and local capacity to identify and respond to populations at high risk can help eliminate lead exposure as a public health problem. The results of this review show that the use of strong evidence-based programs and practices, as well as regulatory authority, can help control or eliminate lead hazards before children and adults are exposed.[117]

Indeed, underbounded communities face continued challenges from waterborne lead exposure; however, without increased capacity to communicate these to private well owners, such challenges will persist.

5.2 Underbounded Communities Are Unware of Potential Risks from a Lack of Water Testing

This dissertation identified that few residents in underbounded communities follow state guidelines for water testing. As a result, most are unaware of the potential risks to their water. Low testing rates for underbounded residents were associated with (1) the belief that contaminants can be detected through sensory perceptions, (2) lack of understanding about how to get a water test or remove contaminants combined with a lack of urgency to test, and (3) the belief that costs associated with testing and contaminant removal are not affordable. These findings are consistent with other studies regarding perceptions of well water in rural areas. In rural Wisconsin, Severtson et. al. postulated that using sensory experiences (i.e. smell, taste, sight) is likely more influential than receiving concrete information like testing results and safety standard information.[94] Furthermore, residents may not look for information regarding risks of their drinking water, in part because well owners may perceive their water quality to be good if there are no noticeable changes to aesthetics.[53,95,96] In the Waterloo Region of Ontario, Canada, Hexemer et al. found that offering free water tests (removing the cost barrier) increased well water testing rates (from 24 to 47%).[98] However, because more than 50% of households failed to respond, Hexemer concluded that free sample kits alone are not sufficient to overcome all of the barriers to private well testing.[98] Follow-up surveys indicated that lack of time was the major reason households did not respond to the free test offer.[98] Although we focus on underbounded majority African-American communities in NC, these similar findings in rural communities suggest the results presented here could have broader relevance to other underserved communities and rural areas relying on private wells for their water.

5.3 Underbounded Communities Increased Private Well Testing After Seeing a Risk Communication

This dissertation demonstrated that a Mental Models–designed risk communication was effective at promoting private well testing for underbounded majority African-American communities in NC. While previous research has used a mental models approach to develop evidence-based risk communications for other topics,[118–122] no previous work has sought to develop a Mental Models risk communication encouraging private well owners to test their water. In addition, this study is only the sixth randomized-controlled trial of a Mental Models risk communication.[74] A previous scoping review of Mental Models–designed risk communications reported that all 6 studies found significant improvement in participant knowledge versus control.[74] Only one previous Mental Models study looked at the secondary outcome of behavior change. They found women in the control group were twice as likely to be diagnosed with an sexually transmitted disease as women who viewed the risk communication.[109] These findings suggest that the Mental Models approach to designing a risk communication could be an effective way to not only improve knowledge of private well owners, but change testing behavior. As such, this research contributes not only to the potential for targeted risk communications to improve private well testing, but also to the evidence base for the Mental Models approach to risk communication.

5.4 Conclusions

This research documented that there are racial disparities in exposure to lead in drinking water resulting from the exclusion of majority African-American communities from municipal water infrastructure. Wilde-Anderson argues that investing in infrastructure extensions and policy changes to promote municipal annexation of underserved areas are needed to address this problem of inequality.[3] Schindler suggests that updating state and federal environmental impact statements during infrastructure projects to consider impacts on the exclusion of underbounded communities and an obligation to mitigate them could offer one solution to prevent future cycles of disparity.[6]

Although local governments, whose budgets may be strained, may object to extending services to underbounded areas,[72] infrastructure investment in underbounded communities could be viewed as finishing a job left undone in previous eras, when these areas were systematically excluded from benefits received by their municipally incorporated neighbors.[3] In addition, extending municipal water to these areas would have the added benefit of reducing lead exposure risk due to the corrosion control measures, routine water quality monitoring, and regular communication of water quality information to customers that municipal utilities are required to do under the Safe Drinking Water Act. In the long run, decreasing the risk of lead exposure among children can benefit the entire community through improving children's educational outcomes and long-term earning potential.

In the near term, and in the absence of policy changes to support the extension of municipal infrastructure to underbounded communities, private well owners remain their own stewards of safe drinking water. They lack the technical support and risk information afforded to neighboring areas served by municipal water supplies. The data on lead exposure risk and risk communication materials developed in this dissertation can help public health officials support private well owners in these areas in making informed decisions about their water.

APPENDIX A: CHAPTER 3 SUPPLEMENTAL INFORMATION

The supplemental materials contain the following information:

- Map of Wake County Population Highlight Underbounded Peri-Urban Residents
- The 19 factors found during principal components analysis
- Model of factors associated with private well testing (every 5 years)
- Final Survey

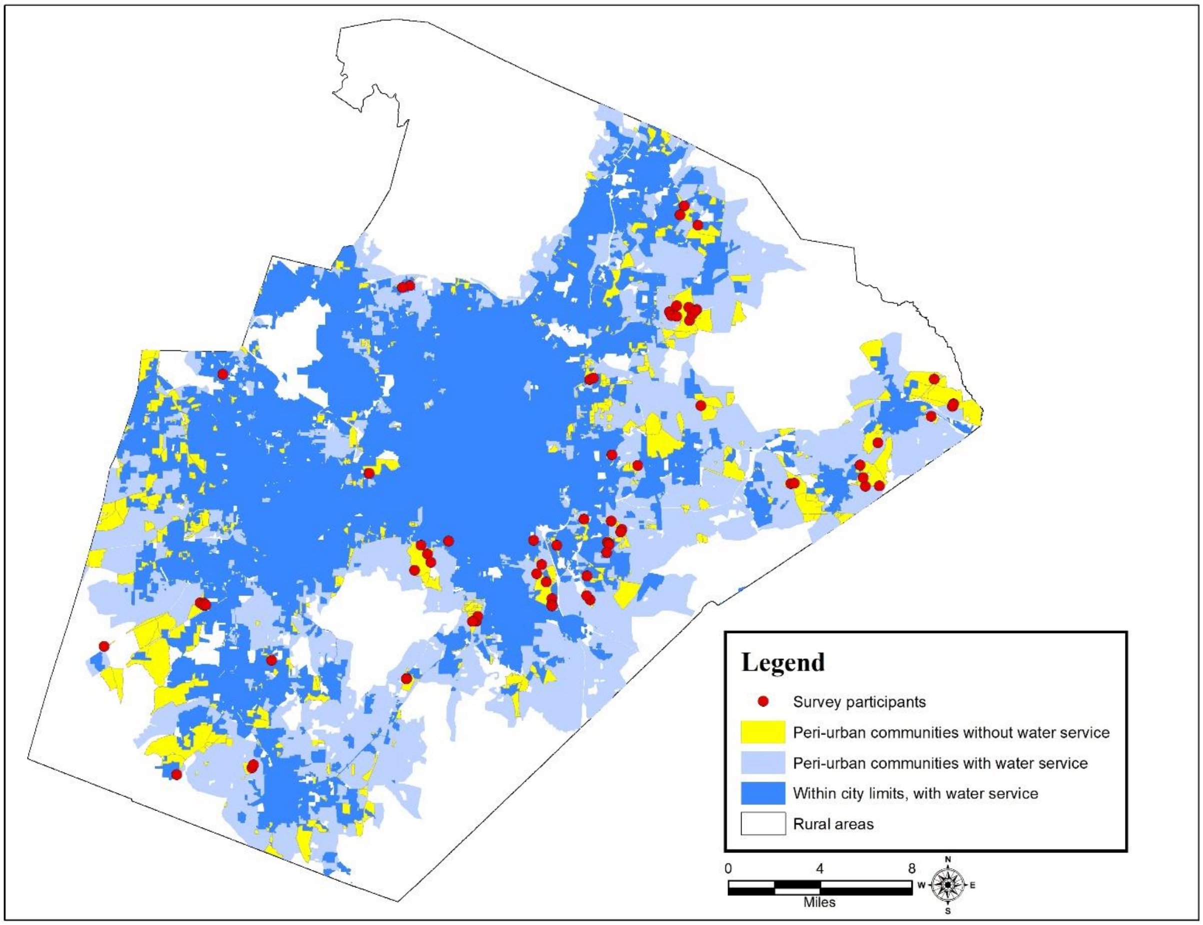

Figure A.1. Participants of the mental models survey distributed to peri-urban communities without water service in Wake County, North Carolina.

Table A.1. Factors Identified from Principal Components Analysis of Survey Responses

Factor	Questions Loading on Factor	Cronbach's Alpha	Association with Biennial Water Testing (*p* value)
1.	As long as my well water looks, tastes and smells good, I do not need to test it for contamination.	0.92	0.048
	My well water does not need to be tested because I've been drinking it for years without problems.		
	My well water does not need to be tested because it looks clear, has no smell, and tastes clean.		
2.	I don't have time to get my well water tested.	0.87	0.015
	I plan to test my well water but haven't gotten around to it yet.		
	I don't where to get my well water tested		
	I don't how to get my well water tested.		
	I don't know what to test my well water for.		
	I wouldn't know what to do if my well water were tested and found to be contaminated.		
3.	I can't afford the cost of testing my well water.	0.83	0.0061

	I couldn't afford to fix my well water if it were tested and found to be contaminated with bacteria.		
	I couldn't afford to fix my well water if it were tested and found to be contaminated with chemicals.		
	I would prefer to drink city water if it were free.		
	Getting water from a well is free.		
	I would install a home water filter if I could afford it.		
4.	I would trust the Wake County Department of Public Health to test my well water.	0.95	0.77
	I would trust the North Carolina Division of Public Health to test my well water.		
5.	My well water may be contaminated with bacteria.	0.93	0.19
	My well water may be contaminated with lead.		
	My well water may be contaminated with copper.		
	My well water may be contaminated with nitrate / nitrite.		
	My well water may be contaminated with arsenic.		
	My well water may be contaminated with iron and / or manganese.		
	My well water may be contaminated with pesticides and / or herbicides.		

	My well water may be contaminated with volatile organic compounds.		
	My well water may be contaminated with gross alpha radiation.		
6.	Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests? Bacteria: $25	0.96	0.91
	Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests? Inorganic chemicals (nitrates, lead, arsenic, copper, iron, etc.): $50		
	Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests? Pesticides: $50		
	Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests? Herbicides: $50		
	Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests? Volatile organic chemicals: $50		
	Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests? Radon: $50		

	Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests? Gross alpha radiation: $50		
	Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests? Bacteria, inorganic chemicals, volatile organic compounds, pesticides, and herbicides: $275		
7.	Where do you go to get information about water testing and water safety? North Carolina Division of Public Health	0.69	0.89
	Where do you go to get information about water testing and water safety? Wake County Department of Public Health		
8.	Where do you go to get information about water testing and water safety? Friend or family member	0.83	0.086
	Where do you go to get information about water testing and water safety? Neighbors		
	Where do you go to get information about water testing and water safety? University		
	Where do you go to get information about water testing and water safety? Private well driller		
	Where do you go to get information about water testing and water safety? Plumber		

9.	Even if I could get access to city water, I would prefer to drink my well water. Overall, I have enjoyed having well water. If I had the choice, I would prefer to drink water from a city water system. I would prefer to drink bottled water.	0.79	0.76
10.	I prefer drinking well water to city water because city water tastes like chlorine. I prefer well water to city water because I fear that city water could be contaminated by a terrorist attack. I prefer drinking well water to city water because I have control of my water. I prefer drinking well water to city water because well water is more natural. I prefer drinking well water to city water because the city puts chemicals in the water.	0.86	0.228
11.	I prefer well water to city water because I don’t want to pay a water bill. I would not be able to afford water bills from the city.	0.66	0.47
12.	Sometimes my well water tastes funny. Sometimes my well water looks funny.	0.90	

	Sometimes my well water smells funny. My water has a sulfur (rotten egg) smell. Please rate the quality of your well water in comparison with city water. The quality of your well water.		
13.	My well water is safe to drink. I would feel comfortable allowing a baby to drink water from my well.	0.82	0.58
14.	I am worried about possible health problems caused by contamination of my well water. If my septic system fails, it could contaminate my well water and make me or someone in my family sick.	0.77	
15.	I have been sick before from contamination of my well water. Someone in my family has been sick before from contamination of my well water.	0.89	0.32
16.	My septic system is a possible source of well water contamination. My neighbors' septic systems are a possible source of well water contamination. Corrosion of the parts of my well is a possible source of well water contamination.	0.79	0.79

	Corrosion of my household plumbing pipes or fixtures is a possible source of well water contamination.		
17.	Nearby farms are a possible source of well water contamination. Wastes (for example, containers of oil) left in my yard are a possible source of well water contamination. Nearby oil or natural gas wells (fracking) are a possible source of well water contamination. Nearby landfills are a possible source of well water contamination. Nearby industrial facilities (for example, the power company) are a possible source of well water contamination. Roads and highways are a possible source of well water contamination. Nearby mining activities are a possible source of well water contamination.	0.95	0.76
18.	My septic system is currently causing problems. My septic system has had problems in the past.	0.64	0.53
19.	Failed septic systems can contaminate my well water.	0.81	0.89

Failed septic systems can cause sewage to overflow in the yard.
Failed septic systems can cause sewage to overflow in the home.

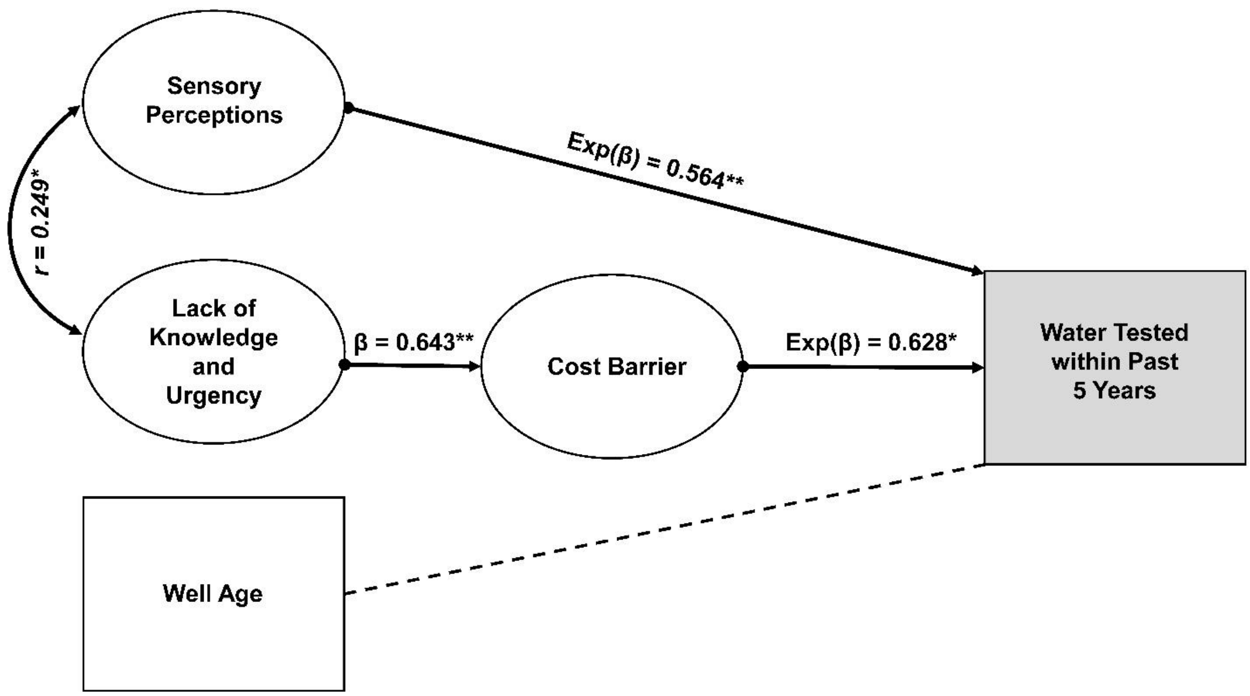

Figure A.2. Factors associated with whether survey respondents had tested their private well water within the past five years. Exp(β) = odds ratio from logistic regression; r = Pearson's correlation; $^{**}p \leq 0.01$; $^{*}p \leq 0.05$.

APPENDIX A.1: CHAPTER 3 SUPPLEMENTAL INFORMATION SURVEY

Dr. Jacqueline MacDonald Gibson
UNC Gillings School of Global Public Health
Campus Box 7431
Chapel Hill, NC 27599-7400

Questions About Your Water

Dr. Jacqueline MacDonald Gibson is a professor in the Gillings School of Public Health at the University of North Carolina, Chapel Hill. She is studying what people think of their well water quality and how they maintain their wells. Dr. Gibson wrote the survey questions you see here. Your answers are very important to her research. We greatly appreciate your help.

This survey is being sent to 1,000 people in Wake County who own or use a private well for their water supply. If you have any questions, please write to Dr. Gibson at jackie.macdonald@unc.edu or at the address above.

The **first 200 people** to mail back completed surveys will receive a **$15 Starbucks gift card** by mail. If your survey is postmarked by **January 6, 2017,** you will be entered into a **drawing to win a free iPad**. The winner will be drawn at random from all surveys completed and postmarked by January 6.

The survey will take 20-25 minutes to complete. When you're finished, please mail the survey back in the provided postage-paid envelope. Your answers are confidential. Nobody other than Dr. Gibson's research team will see them.

Thank you very much for your help. If you are not sure what to answer, please give us your best guess.

1. Where You Get Your Water

- Does your water come from a private well? ☐ yes ☐ no

  If you answered "no," you do not need to finish the rest of the survey.

- About how old is your well? ________years

2. Where You Get the Water You Use for Drinking and Cooking

For the next two questions, please fill in a number from 0 to 100 and make sure the two numbers add up to a total of 100 percent.

- How much of the water you **drink** at home comes from your well? ____percent
  (a number from 0 to 100)

- How much of the water you **drink** at home comes from bottled water? ____percent
  (a number from 0 to 100)

Just like you did for the previous two questions, for the next two questions please fill in a number from 0 to 100 and make sure the two numbers add up to 100 percent.

- How much of the water that you **cook with** at home comes from your well? ____ percent (a number from 0 to 100)
- How much of the water that you **cook with** at home comes from bottled water? ________ percent (a number from 0 to 100)

3. Your Opinions About Testing Your Well Water

Below are some statements about well water testing. We'd like to know how much you disagree or agree. Please check the box that is closest to your beliefs. If you are not sure, please give us your best guess.

As long as my well water looks, tastes, and smells good, I do not need to test it for contamination.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
My well water does not need to be tested because I've been drinking it for years without problems.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
My well water does not need to be tested because it looks clear, has no smell, and tastes clean.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
Public health experts recommend testing well water every year.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I plan to test my well water but haven't gotten around to it yet.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I don't have time to get my well water tested.	☐ completely	☐ somewhat	☐ neither	☐ somewhat	☐ completely

Statement	completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree
I don't know where to get my well water tested.	☐	☐	☐	☐	☐
I don't know how to get my well water tested.	☐	☐	☐	☐	☐
I don't know what to test my well water for.	☐	☐	☐	☐	☐
I can't afford the cost of testing my well water.	☐	☐	☐	☐	☐
I would test my well water if the test were free.	☐	☐	☐	☐	☐
I wouldn't know what to do if my well water were tested and found to be contaminated.	☐	☐	☐	☐	☐
I don't test my well water because there's nothing anyone can do to get rid of contaminants in my water.	☐	☐	☐	☐	☐
I couldn't afford to fix my well water if it were tested and found to be contaminated with bacteria.	☐	☐	☐	☐	☐
I couldn't afford to fix my well water if it were tested and found to be contaminated	☐ completely	☐ somewhat	☐ neither	☐ somewhat	☐ completely

- I am concerned that a bad test result might cause the value of my property

☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

- I haven't tested my well water because I forgot.

☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

- If I test my water, I understand what the water test results I get back mean.

☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

- I'm afraid of asking the health department to test my well water because they would force me out of my home if they found a problem.

☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

- I don't trust the government to test my well water.

☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

Below is a list of organizations that test well water. Please indicate whether or not you would trust each organization to test your well water.

- I would trust the **Wake County Department of Public Health** to test my well water. ☐ yes ☐ no
- I would trust the **North Carolina Division of Public Health** to test my well water. ☐ yes ☐ no
- I would trust **a local university** (for example, N.C. Central, N.C. State, UNC, or Duke) to test my well water. ☐ yes ☐ no
- I would trust **a nonprofit, nongovernment organization** (for example, Clean Water for North Carolina) to test my well water. ☐ yes ☐ no
- I would trust **a private lab** to test my well water. ☐ yes ☐ no
- I would trust **a water treatment company** (for example, Sears, ☐ yes ☐ no

4. Testing Your Well Water

Below are questions about tests of your well water. For each question, please give us your best guess, even if you are not sure.

- Has your well ever been tested? ☐ yes ☐ no ☐ not sure

- If you have tested your well, about how long ago was it? _______years

- When your well was last tested, what was it tested for?
  If you don't remember, please check "not sure."

Bacteria	☐ yes	☐ no	☐ not sure
Lead	☐ yes	☐ no	☐ not sure
Copper	☐ yes	☐ no	☐ not sure
Nitrate/nitrite	☐ yes	☐ no	☐ not sure
Arsenic	☐ yes	☐ no	☐ not sure
Iron/manganese	☐ yes	☐ no	☐ not sure
Pesticides/herbicides Volatile	☐ yes	☐ no	☐ not sure
organic compounds Gross	☐ yes	☐ no	☐ not sure
alpha radiation	☐ yes	☐ no	☐ not sure

- Have any of these contaminants been found in your water?

Bacteria	☐ yes	☐ no	☐ not sure
Lead	☐ yes	☐ no	☐ not sure
Copper	☐ yes	☐ no	☐ not sure
Nitrate/nitrite	☐ yes	☐ no	☐ not sure
Arsenic	☐ yes	☐ no	☐ not sure
Iron/manganese	☐ yes	☐ no	☐ not sure
Pesticides/herbicides Volatile	☐ yes	☐ no	☐ not sure
organic compounds Gross	☐ yes	☐ no	☐ not sure
alpha radiation	☐ yes	☐ no	☐ not sure

Below are statements about the chance that your well could contain different pollutants. For each, please check the box that is closest to your beliefs about whether your well could be contaminated.

- My well water may be contaminated with **bacteria**. ☐ yes ☐ no ☐ maybe ☐ i don't know what bacteria are
- My well water may be contaminated with **lead**. ☐ yes ☐ no ☐ maybe ☐ i don't know what lead is
- My well water may be contaminated with **copper**. ☐ yes ☐ no ☐ maybe ☐ i don't know what copper is
- My well water may be contaminated with **nitrate and/or nitrite**. ☐ yes ☐ no ☐ maybe ☐ i don't know what nitrate and/or nitrite is
- My well water may be contaminated with **arsenic**. ☐ yes ☐ no ☐ maybe ☐ i don't know what arsenic is
- My well water may be contaminated with **iron and/or manganese**. ☐ yes ☐ no ☐ maybe ☐ i don't know what iron and/or manganese are
- My well water may be contaminated with **pesticides and/or herbicides**. ☐ yes ☐ no ☐ maybe ☐ i don't know what pesticides and/or herbicides are
- My well water may be contaminated with **volatile organic compounds**. ☐ yes ☐ no ☐ maybe ☐ i don't know what volatile organic compounds are
- My well water may be contaminated with **gross alpha radiation** ☐ yes ☐ no ☐ maybe ☐ i don't know what gross alpha radiation is

These questions ask about different tests for well water and the cost of the tests.

- **Imagine it has been a few years since you last tested your well. Would you would be willing to pay for these tests?**

Bacteria: $25	☐ yes	☐ no
Inorganic chemicals (nitrates, lead, arsenic, copper, iron, etc.): $50	☐ yes	☐ no
Pesticides: $50	☐ yes	☐ no
Herbicides: $50	☐ yes	☐ no
Volatile organic chemicals: $50	☐ yes	☐ no
Radon: $50	☐ yes	☐ no
Gross alpha radiation: $50	☐ yes	☐ no
Package including bacteria, inorganic chemicals, volatile organic	☐ yes	☐ no

If you have tested your water before, where did you have it tested?

Wake County Department of Public Health	☐ yes	☐ no
Certified private laboratory	☐ yes	☐ no
Water treatment company (Sears, Culligan, etc.)	☐ yes	☐ no
Local city water company	☐ yes	☐ no
Other (please explain):	☐ yes	☐ no

____

We are interested in your opinions about where to get information about well water testing and safety.

Where do you go to get information about water testing and water safety?

Internet search	☐ yes	☐ no
North Carolina Division of Public Health	☐ yes	☐ no
Wake County Department of Public Health	☐ yes	☐ no
Water treatment company (Sears, Culligan, etc.)	☐ yes	☐ no
Local city water company	☐ yes	☐ no
Friend or family member	☐ yes	☐ no
Neighbors	☐ yes	☐ no
Religious or community organization	☐ yes	☐ no
Local university or college	☐ yes	☐ no
Professional well driller	☐ yes	☐ no
Plumber	☐ yes	☐ no
Other (please explain):	☐ yes	☐ no

____

Which approach is the BEST way to provide information about well water testing? Please indicate your top three choices using the numbers 1 through 3.

_______ Postcards
_______ Wake County tax bills
_______ Door hangers
_______ Real estate agents informing clients
_______ Social media (Facebook or Twitter)
_______ Government websites
_______ Religious or community organizations
_______ Water treatment company (Sears, Culligan, etc.)
_______ Your doctor's office

5. Maintaining Your Well

- When was the last time you hired a professional to inspect your well for cracks, holes, corrosion, and other problems?

  ☐ years ago ☐ never

  ________ (how many?)

- When was the last time you personally inspected your well for cracks, holes, corrosion, and other problems?

  ☐ years ago ☐ never

  ________ (how many?)

- If you have previously tested your well water and learned it was contaminated, what did you do to address the contamination?

  ☐ Nothing
  ☐ Disinfected the well
  ☐ Installed whole-house water treatment system
  ☐ Installed under-sink water filter
  ☐ Began using a Brita or other commercial brand filter
  ☐ Used bottled water instead of well water
  ☐ I have never tested my well water.
  ☐ Other (please specify): ________________________________

- If you had a question about your private water well, where would you go for an answer? Please rank the <u>three</u> most likely sources of information with "1" being the most likely source, "2" being the second most likely, and "3" being the third most likely.

  ________ Friend or family member
  ________ Local or state department of environmental protection
  ________ Water testing laboratory
  ________ Internet search
  ________ Water treatment vendor
  ________ Professional well driller
  ________ Plumber
  ________ Other (please explain): ________________________________

6. Treating Your Water

- Do you have any water treatment equipment in your home? ☐ yes ☐ no

  If "no," please skip to Section 7.

- If "yes," what type of treatment equipment do you have?

Water softener	☐ yes	☐ no	☐ not sure
Iron filter	☐ yes	☐ no	☐ not sure
Sediment filter	☐ yes	☐ no	☐ not sure
Carbon filter	☐ yes	☐ no	☐ not sure
UV disinfection	☐ yes	☐ no	☐ not sure
Constant chlorination	☐ yes	☐ no	☐ not sure
Reverse osmosis	☐ yes	☐ no	☐ not sure
Other (please explain):	☐ yes	☐ no	☐ not sure

____

- What contaminants does your treatment system remove?

Bacteria	☐ yes	☐ no	☐ not sure
Lead	☐ yes	☐ no	☐ not sure
Copper	☐ yes	☐ no	☐ not sure
Nitrate/nitrite	☐ yes	☐ no	☐ not sure
Arsenic	☐ yes	☐ no	☐ not sure
Iron/manganese	☐ yes	☐ no	☐ not sure
Pesticides/herbicides	☐ yes	☐ no	☐ not sure
Volatile organic compounds	☐ yes	☐ no	☐ not sure
Gross alpha radiation	☐ yes	☐ no	☐ not sure
Other (please explain):	☐ yes	☐ no	☐ not sure

____

- If you shock chlorinate your well, which of these contaminants are removed?

Bacteria	☐ yes	☐ no	☐ not sure
Lead	☐ yes	☐ no	☐ not sure
Copper	☐ yes	☐ no	☐ not sure
Nitrate/nitrite	☐ yes	☐ no	☐ not sure
Arsenic	☐ yes	☐ no	☐ not sure
Iron/manganese	☐ yes	☐ no	☐ not sure
Pesticides/herbicides	☐ yes	☐ no	☐ not sure
Volatile organic compounds	☐ yes	☐ no	☐ not sure
Gross alpha radiation	☐ yes	☐ no	☐ not sure
Other (please explain):	☐ yes	☐ no	☐ not sure

- **Why do you have water** treatment equipment?
  - ☐ It was already installed when I purchased the home.
  - ☐ Water tests indicated that I needed treatment equipment.
  - ☐ There was an obvious taste, odor, or staining problem.
  - ☐ It was difficult to rinse off soap.
  - ☐ Other (please explain): ______________________

- About how much did your equipment cost, including installation? $______________
  - ☐ don't know

- **How often is your water** treatment equipment maintained?
  - ☐ more than once a year ☐ once a year ☐ every few years ☐ never

7. Your Preferences for a Water Source

Below are some statements about different sources of drinking water, from well water to city water to bottled water. Please check a box for each statement to let us know how much you agree or disagree.

Statement					
Overall, I have enjoyed having well water.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
If I had the choice, I would prefer to drink water from a city water system.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
Even if I could get access to city water, I would prefer to drink my well water.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I prefer well water to city water because well water is cheaper.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I would prefer to drink bottled water.	☐ completely	☐ somewhat	☐ neither	☐ somewhat	☐ completely

	completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree
I prefer well water to city water because I fear that city water could be contaminated by a terrorist attack.	☐	☐	☐	☐	☐
I prefer drinking well water to city water because city water tastes like chlorine.	☐	☐	☐	☐	☐
I prefer drinking well water to city water because I have control of my water.	☐	☐	☐	☐	☐
I prefer drinking well water to city water because well water is more natural.	☐	☐	☐	☐	☐
I prefer drinking well water to city water because the city puts chemicals in the water.	☐	☐	☐	☐	☐
City water is safer than my well water.	☐	☐	☐	☐	☐
I would not be able to afford water bills from the city.	☐	☐	☐	☐	☐

8. Costs of Water

- How much do you spend every year to maintain your well? $______________________________

- How much would you be willing to pay **each year** to have city water instead of well water?

$______________________________

i would not use city water even if it were free. ☐

- If you don't have a home water filter now, how much would you be willing to pay to buy and install a home filter?

$______________________________

i would not use a home water ☐

Below are some additional statements about the costs of water. Please check a box for each statement.

	completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree
I prefer well water to city water because I don't want to pay a water bill.	☐	☐	☐	☐	☐
I would prefer to drink city water if it were free.	☐	☐	☐	☐	☐
Getting water from a well is free.	☐	☐	☐	☐	☐
I would install a home water filter if I could afford it.	☐	☐	☐	☐	☐

9. The Quality of Your Drinking Water

Please rate the quality of your well water in comparison with city water.

	very poor	somewhat poor	neither good nor	poor	somewhat good
The quality of your well water	☐	☐	☐	☐	☐

- The quality of city water

very poor	somewhat poor	neither good nor poor	somewhat good	very good
☐	☐	☐	☐	☐

Below are some statements about the quality of your well water. Please check a box for each statement to let us know how much you agree or disagree.

- I really like the taste of water from my well.

completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree
☐	☐	☐	☐	☐

Statement					
Sometimes my well water tastes funny.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
Sometimes my well water looks funny.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
Sometimes my well water smells funny.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
My water leaves a reddish stain or slime in my toilet, my laundry, or other fixtures.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
My water has a sulfur (rotten egg) smell.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I am worried about the quality of my well water.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
If my well water were contaminated, there are ways to clean the water using filters or other methods.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

10. Water and Your Health

Below are some statements about your water and health. Please check a box for each statement to let us know how much you agree or disagree.

Statement					
My well water is safe to drink.	☐ completely	☐ somewhat	☐ neither	☐ somewhat	☐ completely

If my septic system fails, it could contaminate my well water and make me or someone in my family sick.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I am worried about possible health problems caused by contamination of my well water.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I have been sick before from contamination of my well water.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
Someone in my family has been sick before from contamination of my well water.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I would feel comfortable allowing a baby to drink water from my well.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

11. Sources of Pollution in Drinking Water Wells

Below are some statements about possible sources of well water contamination. Please check a box for each statement to let us know how much you agree or disagree.

My septic system is a possible source of well water contamination.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
My neighbors' septic systems are a possible source of well water contamination.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
Corrosion of the parts of my well is a possible source of well water contamination.	☐ completely	☐ somewhat	☐ neither	☐ somewhat	☐ completely

- Corrosion of my household plumbing pipes or fixtures is a possible source of well water contamination.

☐	☐	☐	☐	☐
completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree

- Wastes (for example, containers of oil) left in my yard are a possible source of well water contamination.

☐	☐	☐	☐	☐
completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree

- Nearby oil or natural gas wells (fracking) are a possible source of well water contamination.

☐	☐	☐	☐	☐
completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree

- Nearby landfills are a possible source of well water contamination.

☐	☐	☐	☐	☐
completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree

- Nearby industrial facilities (for example, the power company) are a possible source of well water contamination.

☐	☐	☐	☐	☐
completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree

- Roads and highways are a possible source of well water contamination.

☐	☐	☐	☐	☐
completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree

- Nearby mining activities are a possible source of well water contamination.

☐	☐	☐	☐	☐
completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree

- Nearby farms are a possible source of well water contamination.

☐	☐	☐	☐	☐
completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree

- Nearby commercial development (for example, new housing construction) is a possible source of well water

☐	☐	☐	☐	☐
completely disagree	somewhat agree nor	neither disagree	somewhat agree	completely agree

12. Amount of Water You Get from Your Well

- **My well sometimes fails to provide enough water:**

  - ☐ More than once a year
  - ☐ Once a year
  - ☐ Once every__________years (please fill in)
  - ☐ Never

- **What do you give up when your well fails to provide enough water?**

  ____ (please fill in)

- **In the past, my well has not provided enough water because of:**

Freezing	☐ yes	☐ no
Pump failure	☐ yes	☐ no
Power failure	☐ yes	☐ no
Leaking pipe	☐ yes	☐ no
Dry weather or drought	☐ yes	☐ no
Other (please explain):	yes	no ______________________

13. Sewage Disposal in Your Home

- Does your home have a septic system? ☐ yes ☐ no

  If you answered "no," please skip ahead to Section 14.

- Has your septic system ever overflowed into your yard or home? ☐ yes ☐ no

- About how old is your septic system?

  - ☐ Less than one year
  - ☐ One to three years
  - ☐ Four to 10 years
  - ☐ 11 to 20 years
  - ☐ More than 20 years

- How often do you have your septic system pumped out?

  ☐ every__________years (how many?) ☐ never ☐ not sure

Below are some statements about septic systems. Please check a box for each statement to let us know how much you agree or disagree.

Statement	completely disagree	somewhat disagree	neither agree nor disagree	somewhat agree	completely agree
My septic system is currently causing problems.	☐	☐	☐	☐	☐
My septic system has had problems in the past.	☐	☐	☐	☐	☐
A bad odor is the best way to know that a septic system needs to be pumped.	☐	☐	☐	☐	☐
Failed septic systems can cause sewage to overflow in the yard.	☐	☐	☐	☐	☐
Failed septic systems can cause sewage to overflow in the home.	☐	☐	☐	☐	☐
Failed septic systems can contaminate my well water.	☐	☐	☐	☐	☐

14. Questions About You

- Have you participated a UNC study of well water before? ☐ yes ☐ no

- What is your sex? ☐ male ☐ female

- How old are you? ________ years

- How many people live in your household? ________

- How old are the other people in your household? ________ ________ ________ ________

  ________ ________ ________ ________

- Would you describe yourself as:

  ☐ American Indian / Native American
  ☐ Black / African American
  ☐ Asian / Asian
  ☐ American Hispanic
  ☐ / Latino White /
  ☐ Caucasian
  ☐ Other (please specify): ________________________________

- Which of the following types of housing units best describes your home?

  ☐ Single-family detached house
  ☐ Single-family attached house (row
  ☐ house) Apartment building with two to
  ☐ four units Apartment building with five
  ☐ or more units Mobile home
  ☐ Other (please explain): ________________________________

- Do you rent or own your home?
  - ☐ Rent
  - ☐ Own
  - ☐ Other (please explain): ____________________

- How long have you lived in your home? ________years

- How old is your home? ________years

- If you currently have a cell phone, can you receive text messages? ☐ yes ☐ no ☐ don't have a cell phone

- Do you currently have access to the internet at home?
  - ☐ Yes, only on my phone
  - ☐ Yes, only on my computer
  - ☐ Yes, on my phone <u>and</u> my computer
  - ☐ No

- What is the highest level of education you have completed?
  - ☐ Less than high school
  - ☐ High school / GED
  - ☐ Some college
  - ☐ Two-year or technical college (associate's degree)
  - ☐ Four-year college (bachelor's degree)
  - ☐ Graduate school (master's, J.D., M.D., or Ph.D.)

What is the total income of all the adults in your home?

- ☐ Less than $15,000
- ☐ $15,000–$29,999
- ☐ $30,000–$49,999
- ☐ $50,000–$74,999
- ☐ $75,000–$99,999
- ☐ $100,000–$124,999
- ☐ $125,000–$149,999
- ☐ $150,000–$174,999
- ☐ $175,000 or more

This is the end of the survey. Thank you very much for your time and your responses. Please see the next page for details on how to return the survey to us and enter the drawing for an iPad.

Returning Your Survey

Thank you again for your participation in this survey, which will greatly help our research on well water quality. Please return the survey in the postage-paid envelope provided. If you are one of the first 200 people to respond, you will receive a $15 Starbucks gift card by mail within two weeks of sending back your survey.

Entering the Drawing for an iPad

To be entered into a drawing to win an iPad, your completed survey must be postmarked by **January 6, 2017**. A winner will be drawn at random on January 17, 2017, from all eligible completed surveys. The winner will be contacted by mail. Please provide your name and mailing address below so that we can contact you if you are the winner. Your name and mailing address will not be used for any other purpose without your permission.

If you do not want to be entered into the iPad drawing and do not wish to receive a $15 Starbucks gift card, you do not need to provide your contact information.

☐ yes, enter me into the drawing!

____
name

____
street address

____
street address line 2

____________________, nc __________
city zip code

May we contact you about your survey if we have any follow-up questions?

☐ yes ☐ no

Please return this survey to:

Dr. Jacqueline MacDonald Gibson
UNC Gillings School of Global Public Health
Campus Box 7431
Chapel Hill, NC 27599-7400

APPENDIX B: CHAPTER 4 SUPPLEMENTAL INFORMATION

<u>The supplemental materials contain the following information:</u>

- Post card versions of the risk communications and the offer of a free water test
- Well ages for African-Americans and non-African Americans
- Final Follow-up Survey

Figure B.1a. Front of risk communication postcard designed to increase testing for peri-urban communities who rely on private wells (Wood et. al., *In preparation*).[103]

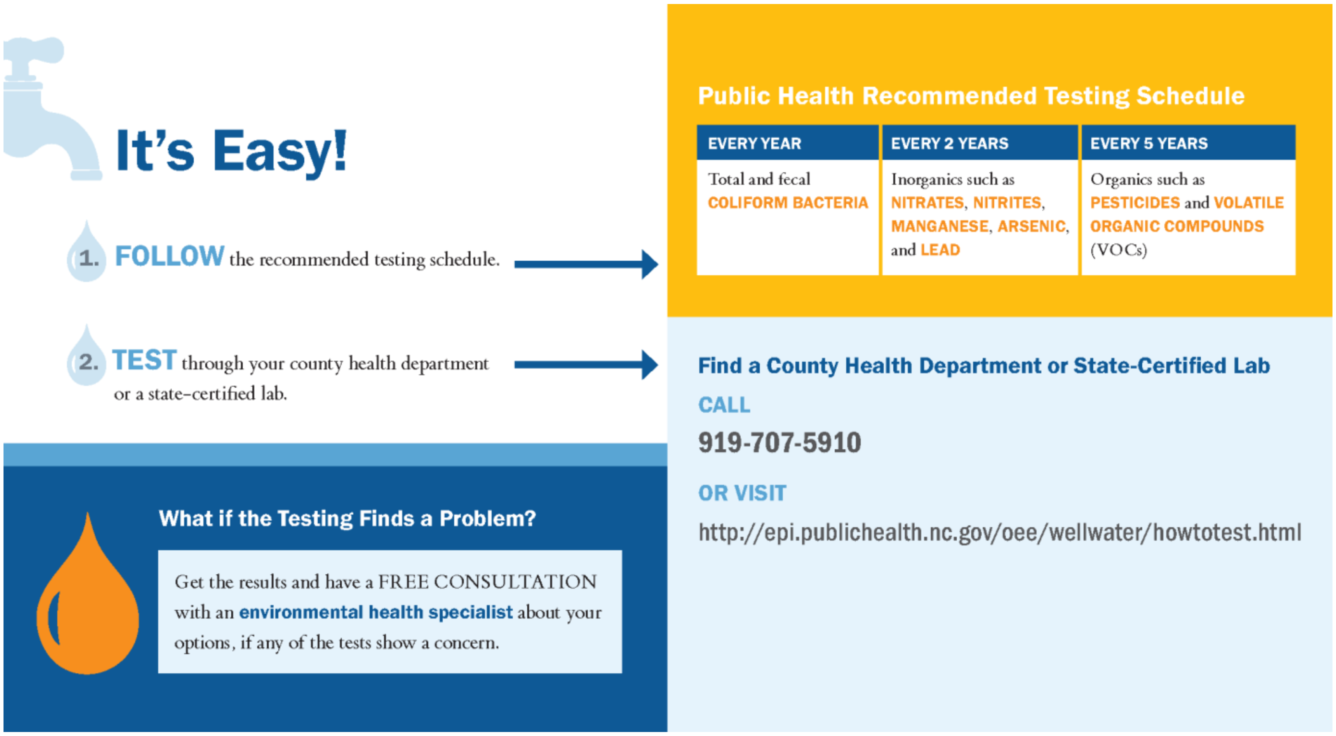

Figure B.1b. Back of risk communication postcard designed to increase testing for peri-urban communities who rely on private wells (Wood et. al., In preparation).[103]

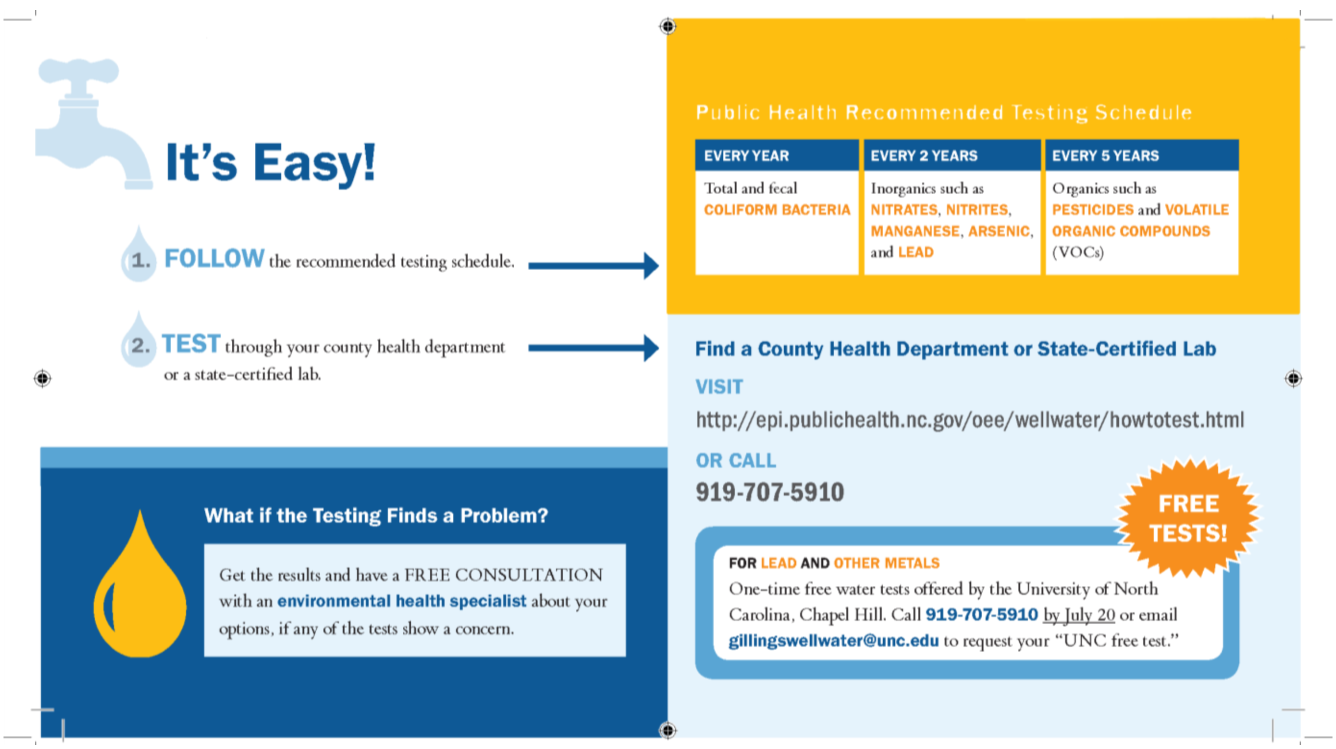

Figure B.1c. Back of risk communication (with the addition of a free test offer) postcard designed to increase testing for peri-urban communities who rely on private wells (Wood et. al., In preparation).[103]

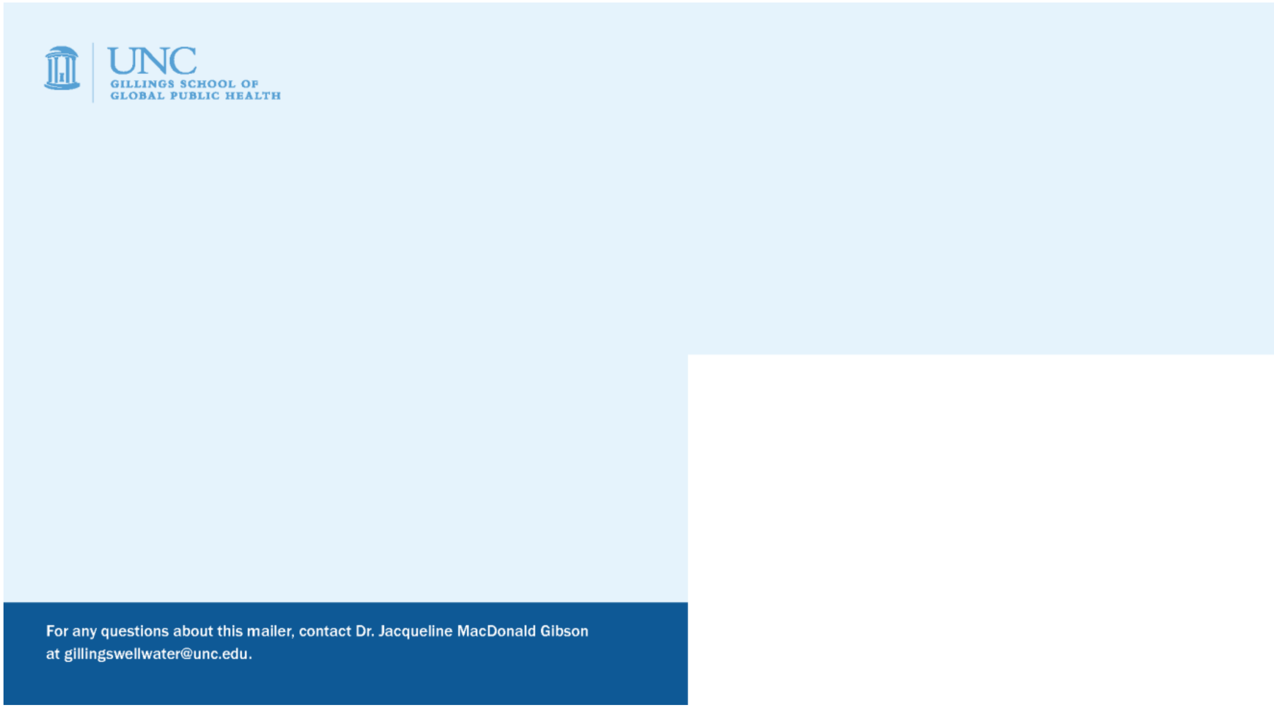

Figure B.1d. Front of free test offer postcard designed to increase testing for peri-urban communities who rely on private wells (Wood et. al., In preparation).[103]

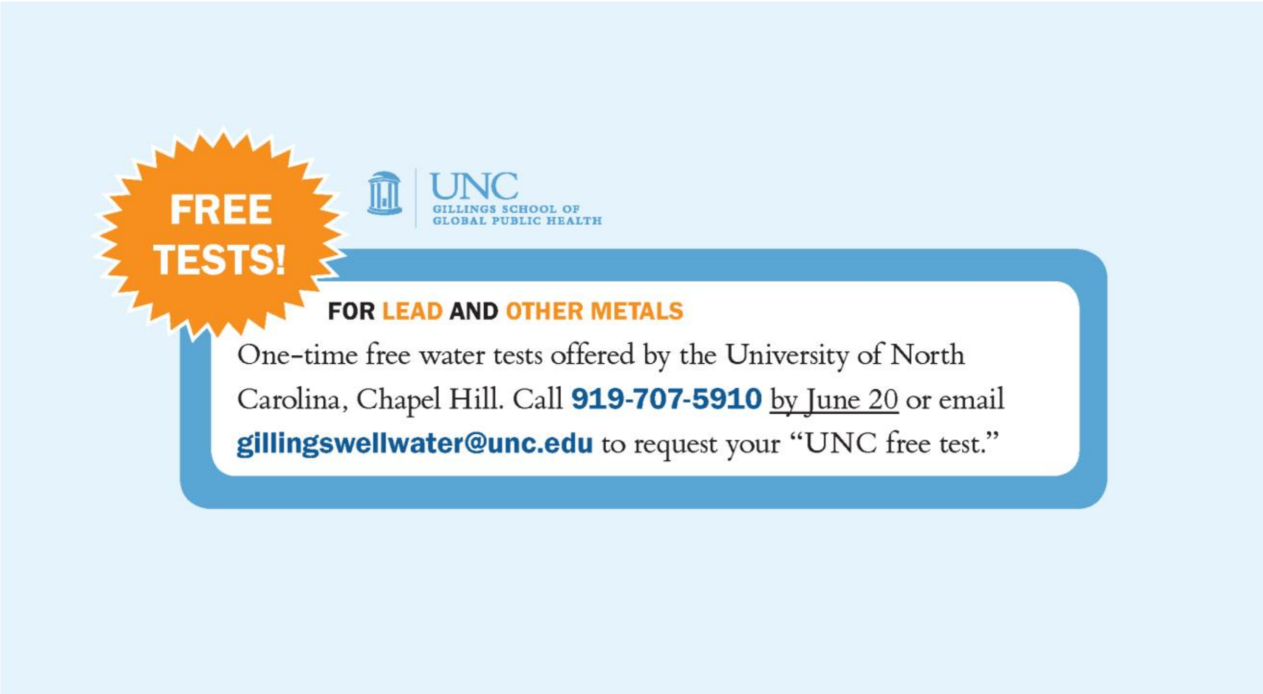

Figure B.1e. Back of free test offer only postcard designed to increase testing for peri-urban communities who rely on private wells (Wood et. al., In preparation).[103]

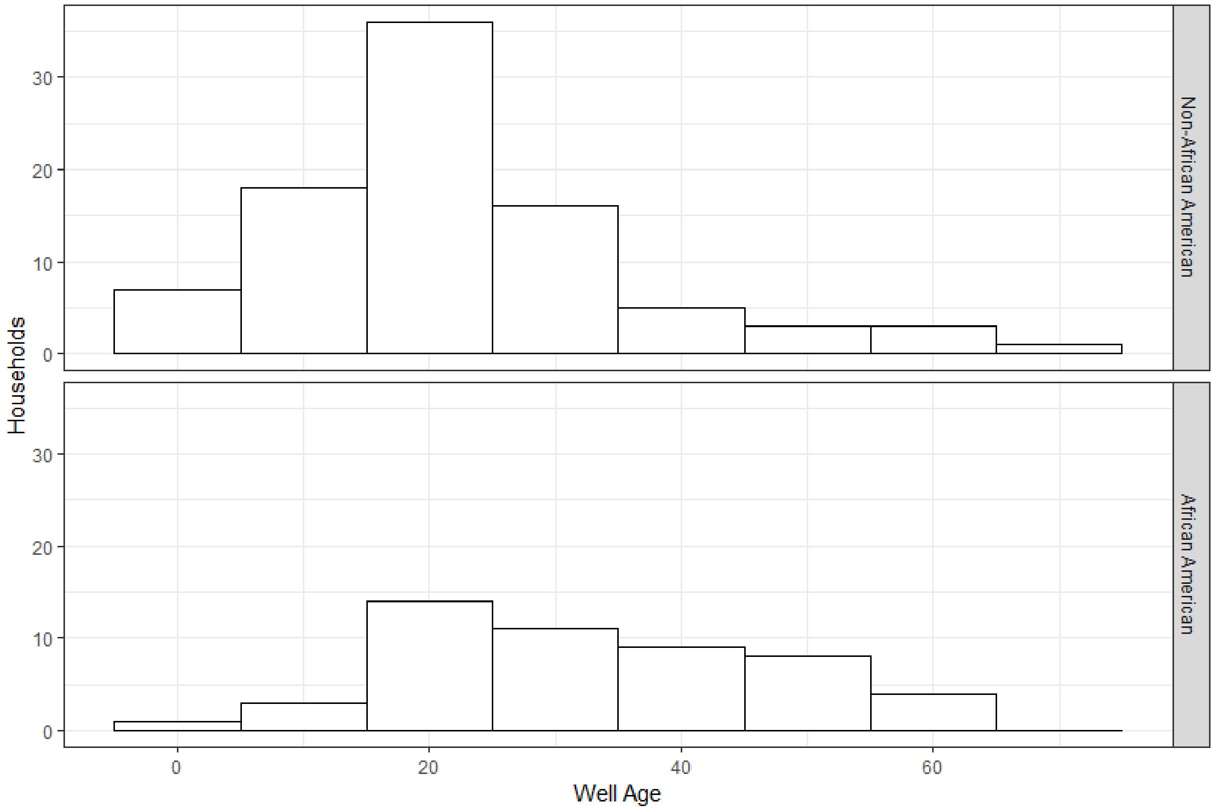

Figure B.2. Well ages for African-Americans and non-African Americans in peri-urban communities without water service in Wake and Gaston counties, North Carolina.

APPENDIX B.1: CHAPTER 4 SUPPLEMENTAL INFORMATION FOLLOW-UP SURVEY

UNC GLOBAL PUBLIC HEALTH

Dr. Jacqueline MacDonald Gibson
UNC Gillings School of Global Public Health
Campus Box 7431
Chapel Hill, NC 27599-7400

Questions About Your Water

This survey was created by Dr. Jacqueline MacDonald Gibson, a professor in the Gillings School of Public Health at the University of North Carolina, Chapel Hill. Your answers are very important to our research and will be used to help inform residents about their wells. **Anyone who completes a survey by August 22nd, 2018, will receive a $15 gift card by mail. The survey will take 5-10 minutes to complete.** Your answers are confidential. Nobody other than Dr. Gibson's research team will see them.

This survey is being sent to 2,232 people in Wake and Gaston counties who use a private well for their water supply. If you have any questions, please write to Dr. Gibson at jackie.macdonald@unc.edu or at the address above. Although there are no foreseeable risks to completing the survey, some questions may be uncomfortable to answer. Although you may choose not to respond to any question, each one is important to our research. When you're finished, please return to us in person or mail the survey back in the provided postage-paid envelope.

Thank you very much for your help. If you are not sure what to answer, please give us your best guess.

1. Do You Have A Private Well

- Does your water come from a private well? ☐ yes ☐ no

If you answered "No," you do not need to finish the rest of the survey.

2. Testing Your Well Water

Below are questions about tests of your well water. For each question, please give us your best guess, even if you are not sure.

- Has your well been tested since June 11th? ☐ yes ☐ no ☐ not sure
- What is the age of your well? ______________________

If you tested your well since June 11th, what was it tested for? If you don't remember, please check "not sure."

Bacteria	☐ yes	☐ no	not sure
Lead	☐ yes	☐ no	not sure
Copper	☐ yes	☐ no	not sure
Nitrate/nitrite	☐ yes	☐ no	not sure
Arsenic	☐ yes	☐ no	not sure
Iron/manganese	☐ yes	☐ no	not sure
Pesticides/herbicides	☐ yes	☐ no	not sure
Volatile organic compounds	☐ yes	☐ no	not sure
Gross alpha radiation	☐ yes	☐ no	■ not sure

Why didn't you test your well since June 11th? (Choose all that apply) Skip this question if you tested your well.

- ☐ My well water tastes, looks and smells fine
- ☐ Cost of well testing
- ☐ Cost of maintenance if a problem exists
- ☐ No time to test
- ☐ Did not know how to test
- ☐ Did not know where to test
- ☐ Did not know what to do if I failed a test
- ☐ Didn't test because I recently tested my well

Do you still intend to test your well in the future?

☐ yes ☐ no

When do you plan to test your well water next?

____

- In your next test, what do you plan to test for? If you don't know, please check "not sure."

Bacteria	☐ yes	☐ no	☐ not sure
Lead	☐ yes	☐ no	☐ not sure
Copper	☐ yes	☐ no	☐ not sure
Nitrate/nitrite	☐ yes	☐ no	☐ not sure
Arsenic	☐ yes	☐ no	☐ not sure
Iron/manganese	☐ yes	☐ no	☐ not sure
Pesticides/herbicides	☐ yes	☐ no	☐ not sure
Volatile organic compounds	☐ yes	☐ no	☐ not sure
Gross alpha radiation	☐ yes	☐ no	☐ not sure

3. Your Opinions About Testing Your Well Water

Below are some statements about well water testing. We'd like to know how much you disagree or agree. Please check the box that is closest to your beliefs. If you are not sure, please give us your best guess.

As long as my well water looks, tastes, and smells good, I do not need to test it for contamination.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
My well water does not need to be tested because I've been drinking it for years without problems.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
My well water does not need to be tested because it looks clear, has no smell, and tastes clean.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I plan to test my well water but haven't gotten around to it yet.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
I don't have time to get my well water tested.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

ü I don't know where to get my well water tested.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
ü I don't know how to get my well water tested.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
ü I don't know what to test my well water for.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
ü I can't afford the cost of testing my well water.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
ü I wouldn't know what to do if my well water were tested and found to be contaminated.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
ü I couldn't afford to fix my well water if it were tested and found to be contaminated with bacteria.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
ü I couldn't afford to fix my well water if it were tested and found to be contaminated with chemicals.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
ü I would prefer to drink city water if it were free.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree
ü Getting water from a well is free.	☐ completely disagree	☐ somewhat disagree	☐ neither agree nor disagree	☐ somewhat agree	☐ completely agree

- I would install a home water filter if I could afford it. ☐ ☐ ☐ ☐ ☐

4. Where You Get the Water You Use for Drinking and Cooking

For the next two questions, please fill in a number from 0 to 100 and make sure the two numbers add up to a total of 100 percent.

- How much of the water you **drink** at home comes from your well? ________percent (a number from 0 to 100)

- How much of the water you **drink** at home comes from bottled water?_______percent (a number from 0 to 100)

Just like you did for the previous two questions, for the next two questions please fill in a number from 0 to 100 and make sure the two numbers add up to 100 percent.

- How much of the water that you **cook with** at home comes from your well? ______percent (a number from 0 to 100)

- How much of the water that you **cook with** at home comes from bottled water? ________percent (a number from 0 to 100)

5. Did you receive a postcard in the mail

- Do you remember receiving a postcard asking you to test your water?

☐ yes ☐ no

- Who sent you the postcard?

University of North Carolina at Chapel Hi ☐
County ☐
Government ☐
Private Water Company ☐
I do not know/ I do not remember

- What was the message of the postcard?

  - [ ] Everybody
  - [ ] does it It's time to
  - [ ] test your well
  - [ ] Test your well to protect your healt
  - I do not remember

- How many postcards did you receive? ______________________

6. Questions About You

- What is your sex? [ ] male [ ] female

- Would you describe yourself as:

  - [ ] American Indian / Native American
  - [ ] Black / African American
  - [ ] Asian / Asian American
  - [ ] Hispanic / Latino
  - [ ] White / Caucasian
  - [ ] Other (please specify): ______________________
  - [ ] Prefer not to answer

- Do you rent or own your home?

  - [ ] Rent
  - [ ] Own
  - [ ] Other (please explain): ______________________

- How old is your home? ________years

- What is the highest level of education you have completed?

  - [ ] Less than high school
  - [ ] High school / GED
  - [ ] Some college
  - [ ] Two-year or technical college (associate's degree)
  - [ ] Four-year college (bachelor's degree)
  - [ ] Graduate school (master's, J.D., M.D., or Ph.D.)

What is the total income of all the adults in your home?

- ☐ Less than $15,000
- ☐ $15,000–$29,999
- ☐ $30,000–$49,999
- ☐ $50,000–$74,999
- ☐ $75,000–$99,999
- ☐ $100,000–$124,999
- ☐ $125,000–$149,999
- ☐ $150,000–$174,999
- ☐ $175,000 or more

This is the end of the survey. Thank you very much for your time and your responses. Please see the next page for details on **how to return the survey to us and receive your gift card.**

Returning Your Survey

Thank you again for your participation in this survey, which will greatly help our research on well water quality. Please return the survey in the postage-paid envelope provided. The first 150 people to complete the survey by August 22nd, 2018 will receive a $15 gift card by mail within 30 days of sending back your survey.

Please fill out your address information to be used only to send your gift card.

____

name

____

street address

____

street address line 2

_________________________, nc ___________

city zip code

May we contact you about your survey if we have any follow-up questions?

☐ yes ☐ no

Preferred contact number and/ or email:____

Please return this survey to:

Dr. Jacqueline MacDonald Gibson
UNC Gillings School of Global Public Health Campus Box 7431
Chapel Hill, NC 27599-7400

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