ABSTRACT

BELL, IMANI JANE. A Close Look at NC Public Drinking Water Infrastructure to Equitably Minimize the Risk of Exposure to Lead. (Under the direction of Dr. Caren Beth Cooper).

Safe drinking water is a concern for more than just developing countries. Water quality is a growing issue in the US as the number of drinking water-related health problems rise. In this paper, we examined the potential for lead contamination of public drinking water in North Carolina based on drinking water infrastructure. Past research has examined lead contamination through blood and water testing, but leaded water system infrastructure is the source of lead when it occurs in municipal drinking water. This research seeks to leverage data from utilities and local government to pinpoint where leaded systems are present.

After the lead-in-water crisis in Flint, Michigan, local and state governments across the country we're motivated to take a closer look at the drinking water systems serving their communities. Flint, Michigan quickly became the poster child for illustrating that poor water management can cause a public health crisis. Our research addresses the following research questions: 1) What lead bearing materials are present in the drinking water systems managed by government entities and private companies, and in what North Carolina counties are they located? 2) Does race, economics, age, and/or when homes were built explain variation in risk of exposure to leaded water systems in North Carolina?

This paper will examine the problems with the historical legislation behind the lead in drinking water infrastructure in hopes to clarify why lead is still a prominent issue in the United States and specifically for North Carolina. Throughout the paper, we will expose flaws in the Federal and local government as it concerns the mitigation of lead plumbing in NC. A major issue is the lack of sufficient data collection by utilities about the plumbing that transports water to communities they serve. As a response to lack of data on lead line location, the North Carolina Department of Environmental Quality (DEQ) has gathered data about water distribution materials from water utilities serving North Carolinians. We combined NC DEQ data with details from the Environmental Protection Agency's database on Safe Drinking Water Infrastructure Systems (SDWIS), and data from the US Census to identify demographic risk factors in North Carolina. We found that systems managed by local governments were more likely to contain leaded water lines than systems managed by private entities. Local government systems serve the majority of the population throughout North Carolina. We found that a higher

proportion of the population were served by water systems that contained leaded lines in counties with high wealth inequality. Furthermore, we found that counties with higher percentages of Black people and poor white people had a higher percentage of lead-bearing water systems. Counties with higher risk of leaded water infrastructure had higher percentages of children under five years of age.

In several regions of the United States there has been efforts to replace lead service lines. Such efforts are often hampered by the lack of information needed to know where to begin. The implementation of Safe Drinking Water Act (SDWA) and the Lead and Copper Rule (LCR) addressed lead in tap water through mandating utilities to monitor taps for unsafe water and, if unsafe water is detected, to respond by increasing control of pipe corrosion and sharing responsibility for mitigations with consumers through notifications and advice. However, the paradigm of responding to lead exposures is problematic because the health consequences of lead exposure are irreversible. Proactive identification and replacement of leaded pipe infrastructure is needed to prevent lead exposure. As a result of this research we hope to bring awareness to North Carolina communities' risk for lead plumbing exposure and recommend short-term mitigations and long-term solutions for ensuring equity in safe drinking water.

Close Look at NC Public Drinking Water Infrastructure to Equitably Minimize the Risk of Exposure to Lead

By
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DEDICATION

Thank you to my friends and family for support and encouragement. Thank you to my funders at the EPA and NC State for the opportunity to learn about my community and be able to make an impact.

BIOGRAPHY

Imani Bell at a young age decided she would do something she loves, that paid well, but made a positive impact. Her innate calling to be close to nature and find her niche in Earths abundant ecosystem, she decided to explore her interest by pursuing an undergraduate degree at the University of South Florida (USF) Tampa. It is at USF that she discovered her hidden passion for social and environmental advocacy through her friend she met majoring in political science and her growing environmental science education there. Post her undergrad career she explored various research technical jobs—at the Natural Science Museum in Raleigh, and traveling to live in the Florida Everglades and in Fort Bragg in NC— where she got to learn about the need for research in order to understand the problems of the world. That brought her to explore her passions and take her own approach to a social problem (The contamination of drinking water by lead bearing plumbing) of the world through research at North Carolina State University. She hopes that her EPA funded project will have an impact on future research and legislation around equity mitigation of drinking water pollution. She hopes to continue on her journey to find her place in the science, advocacy, and animal world. She has many passions but her one true passion is to make a difference. May she be survived one day by the positive impact she made.

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technical geek and a night owl, the libraries amenities, the school bus, and the Biltmore office will always have my admiration and appreciation, they became second homes to me.

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INTRODUCTION

“Go back and tell DEQ that they have failed us as people, as a community,” Joyner told the advisory board. “We need somebody who’s going to be there for us and not against us” (Bonner, 2019).

Belinda Joyner is an active resident for her North Hampton community, taking a stand against issues that predominately plague the minority communities within North Carolina. She stood, alongside many other environmental justice activists, in front of the Department of Environmental Quality (DEQ) in the fight against the placement of the Atlantic coast pipeline and neighboring hog farms within their communities.

It takes people from their communities to step out and take initiative to investigate and hold firm their human and legal rights to a healthy environment through enforcement of industrial regulations and civil rights law. It only takes a few passionate people to start a movement. Black and brown communities all over the US have acquired lay expertise of science and law and have partnered with professional scientists and lawyers to make their case for their rights to equitable living. There were many instances of environmental inequalities occurring all over the United States that motivated activism. The environmental justice movement began as the intersection of civil rights activism and environmental activism in response to a North Carolina government decision to dump PCB tainted soils in the predominately black Warren County landfills. Residents of Warren County and allies from across the region rallied together in several protests that brought national attention to the issue (Palmer, 2016). While they did not win their battle against the dumping in their landfills, they ignited a war cause against the disproportionate burdening of minorities and low-income communities with environmental hazards. Since then community organizers, local officials, and activist groups and/or organizations have come together to collect and supply the data that exemplifies the excessive impacts on their communities.

In the wake of recent environmental inequality issues, many have become familiar with the environmental catastrophes made popular by social frenzy. While this did open the eyes of many to the types of environmental hazards that were possible, it did not prompt people to take heed of the problems in their backyards. More specifically, the contamination of the drinking water in Flint, Michigan. The people [ib1] rallied behind the citizens of Flint, to protect their rights for potable drinking water, while many of them not fully comprehending what lead to the problem. There is a lot to learn from the problems with the Flint water crisis, from activism to political blind spots. The issue with Flint's water system was the introduction of a new public water source. The lack of adjustments made to corrosion control treatments for the new water source leads to lead leaching into the public drinking water supply (Smith, Bosman, & Monica Davey, 2015). Meanwhile consumers were told to continue to consume the polluted water by their government, people continued to be misinformed about the risk for contamination. They told families they were safe while the EPA had evidence of the danger that Flint residents were in imminent danger. Michigan Department of Environmental Quality did realize there was a problem with the fact that there was lead lying dormant in the system. Thus, a catastrophe was waiting to happen, to the population it usually happens to. What we learned from the water quality issues in Flint is people are not only motivated by socially driven issues but also, by victims that they can relate to and resemble themselves. Black and brown people, rallied around the people of Flint because they saw another example of environmental racism. Disenfranchised communities often bear the brunt of others' environmental action and policy mistakes. The people are recognizing the disproportionate effects and also realigning themselves with their rights. Now, people can recognize the problems in their backyards. Now, the problems are in their house. This was made possible by the lack of precautionary legislation made since lead was determined to be a health hazard in the United States in 1970. In historian Werner Troeskens' book (2006), The Great Lead Water Pipe Disaster, he reviews 150 years of the political and social denial of lead pipe infrastructure causing health problems in the northeastern US. Troesken (2006) blamed the "long-running environmental and public health catastrophe on the installation of lead bearing plumbing in the late 1800s till it was banned in 1986." For the case of Flint Michigan, "this environmental injustice that endangered families for 18 months was prolonged because the city and MDEQ cheated on water tests, was hostile to outside researchers sounding the alarm, and betrayed the public's trust by repeatedly insisting the brown, smelly, lead-laden water was safe to consume"(Roy, 2017).

The government is slowly updating laws and regulations to meet current times and issues, like implementing governmental legislation that requires the removal of lead pipe and plumbing materials. However, without proper data to validate the need for rules and regulations, like lead line replacements, there will be lots of money wasted trying to find and fix the problem.

Replacing leaded pipe infrastructure is one way of reducing the risk of lead in drinking water. However, significant portions of the below-ground infrastructure for transporting drinking water was built decades ago. The initial Lead and Copper Rule (described below) banned lead pipes in 1991, the same year the World Wide Web became publicly available. Thus, for the water systems most likely to contain lead, there are limited to no digital records of those historic pipes. This research examines the presence of lead in the United States water system. This thesis is guided by two central questions: 1) What lead bearing materials are present in the drinking water systems managed by government entities and private companies, and in what North Carolina counties are they located? and 2) Does race, economics, age, and/or when homes were built explain variation in the risk of exposure to leaded water systems in North Carolina?.

The Lead and Copper Rule and the Safe Drinking Water Act

Water quality is now a hot topic issue in the US as the number of drinking water-related health problems and/or risk are made known. If changes are to be made to benefit public health, then issues of lead in water regulation and enforcement should be made a priority. EPA is taking the steps to do so by funding this research under a program called *National Priorities: Lead in Water*. The goal of this research is to better inform the EPA on the areas of focus for lead plumbing mitigation by finding potential solutions to locating where lead is present.

Lead health and safety concerns

Past research has looked into water systems' reported noncompliance in exceedance of maximum contamination levels (MCL). As a regulatory authority, the EPA protects water by establishing, and enforcing compliance of, maximum contaminant levels (MCL) for drinking water. The MCL is the standard for what are permissible amounts of human-made contaminants that can occur in drinking water without causing harm. If a public water system gets a violation it does not mean there is a health concern, only ones of concern to compliance are violations that meet or exceed the MCL (Allaire et al., 2017). "Generally, water systems in the United States provide reliable and high-quality drinking water. Violations tend to be infrequent. However, in a given year, about 7-8 percent of community water systems (CWSs) report at least one healthbased violation. While this rate is relatively low, improved compliance is needed to ensure safe drinking water nationwide" (Allaire et al., 2017).

According to the World Health Organization and the US Centers for Disease Control and Prevention, lead poisoning is a preventable disease. There is no safe exposure to lead (Epa, U., of Ground Water, O., & Water, D. 2015). Populations most impacted by increased lead exposure are pregnant women, infants, and young children. It was found that water consumption contributes to 10 to 20 percent of a child's lead intake, and 40 to 60 percent of infants because of formula use (Rubin 2013). To prevent lead poisoning, the source of exposure must be removed or controlled. For example, the removal of lead from gasoline and paints has resulted in lower lead levels in human blood (Pirkle et al. 1994; Jones et al. 2009). Efforts related to exposures from lead in tap water have not been focused on prevention (EPA 1993, Levin et al. 2008). Federal law and regulation to address lead in tap water focus on requiring monitoring programs by utilities to detect unsafe water and, if detected, to respond by increasing control of pipe corrosion and sharing responsibility with consumers through notifications and advice. The paradigm of responding to lead exposures is problematic because few Americans understand the complexity of drinking water systems (Attari et al. 2017), communications from utilities are largely incomprehensible to consumers (Roy et al. 2015), and most believe the misconception that providing safe drinking water is entirely the responsibility of the water utility (AWQA 2019). Health and environmental advocacy organizations have noted that, particularly with aging infrastructure, the paradigm should instead be proactive solutions that prevent exposures by replacing all parts of the water infrastructure containing lead (https://www.lslrcollaborative.org/).

Leaded plumbing is still in use despite legislation, EPA regulations, and public concern against it. Although the evidence against the use of lead materials have been known for centuries, only relatively recent laws have restricted the use of lead-bearing plumbing. Consequently, there were decades during which lead-bearing pipes and plumbing were laid in the ground. There are US Federal laws and regulations set standards to protect sources of drinking water from contamination, as well as regulations related to underground infrastructure because drinking water can become contaminated with metals, such as lead, during its transportation. As part of water testing, utilities are required to conduct a series of draws at the tap: collecting water at the faucet a three specific time intervals after water has been stagnant in the pipes for at least six hours. Collecting water at different time intervals corresponds to samples of water that stagnated in different portions of the water system. The first draw samples water in the faucet and home plumbing, the second draw (45 seconds after the first draw is over) samples water in the service line, and the third draw (2 minutes after the second draw is over) samples water in the water main. Thus, the presence of lead in collected water can indicate where in the system the lead could be leaching based on whether it shows up in the first, second, or third draw. In addition to water sampling, blood lead levels have been a system of evaluating the severity of contamination on physical health—especially on children. In the 1960s the Center of Disease Control established 60 milligrams per deciliter as acceptable, and lowered the level to 10 milligrams per deciliter in the 1990s(Rabin 2008). However, further research suggests that IQ declines more rapidly below 10 milligrams per deciliter (Rabin 2008).

Despite federal oversight of state programs to comply with Federal laws, underperforming systems exist and low income and minority communities are the most likely to be served by water systems not meeting safety standards (Allaire et al. 2017).

In 2020, revisions of the Lead and Copper Rule are underway, with emphasis on the need to help prevent exposure equitably and on all scales. The US Lead and Copper Rule (LCR) is simply a treatment technique (NDWAC 2015) meaning that instead of public water systems enforcing the prevention of systems exceeding a maximum contaminant level, they respond after lead contamination levels reach legally actionable levels. The maximum contamination level is based on the health effects, the action level is the process for screening for corrosion control (NDWAC 2015). If the water system is unable to make those changes then they can replace the pipes. The problem with the current LCR is that instead of trying to find lead pipes and creating a program to replace them, it first seeks ways to reduce lead leaching (corrosion) into the water from the pipe plumbing materials.

The History of Lead Pipes

By the 1900s, more than 70 percent of cities' water systems were serving over 30,000 people via lead lines (Rabin, 2008). Between the 1930s and 1950s, concerns over the health effects of lead pipes caused hesitation in the use of lead service lines (LSLs_. Installation of lead materials slowed during this period, though in many cities continued to use it. During that same period, conflicting journals and the lead industries associations continued promoting its use. Plumbers, and even the American Water Works Association, were not convinced of the negative health effects of lead (Rabin, R. 2008). Gradually, concern over lead contamination from a pipe, fittings, and solder(lead was used for soldering faucets and other connections) resulted in less lead use in drinking water systems, including service lines and household plumbing. In the United States, the Safe Drinking Water Act (SDWA) of 1974 was put in place to put a limit on the amount of lead that was allowed to be in various pipes, plumbing, and fixtures. In 1984, the EPA found that 112 of the 185 public water systems had lead service lines (Rabin, 2008), and 91 of those systems served over 100,000 people. An amendment of the LCR in 1986 prohibited the use of lead pipe and plumbing material in public and residential areas.

The 1991 EPA Lead and Copper Rule established a shared responsibility between water consumers and water suppliers for reducing exposure to lead in water. Water quality is a shared responsibility between the people, the state, and the federal government. In 1996, the safe drinking water act was amended to prohibit the buying and selling of piping or plumbing fixtures that were not certified "lead-free". . In 2011, the Reduction of Lead in Drinking Water ct was enacted to change the maximum amount (percent and weighed) of lead that can come in direct contact with drinking water. The 2011 amendment also required compliance on a federal level, which extended the list of plumbing devices needing to be "lead-free".

The Unequitable distribution of safe drinking water

Many studies in the US, link disparate environmental health effects by using ethnicity as an indicator of socioeconomic status (Bolte, G., Pauli, A., & Hornberg, C. 2011). Past research has shown that the distribution of safe and potable drinking water across the nation exhibits trends that reflect environmental racism. Concepts like environmental racism, environmental equity, and environmental justice, all flow into one another and have been nuanced differently over time. Bolte et al. (2011) defined environmental racism as the "disparate impact of hazardous waste sites and other polluting facilities located in or near distressed neighborhoods with high concentrations of ethnic minorities and economically disadvantaged populations.” We can extend this definition to include disparate impacts of any environmental hazards, including leaded drinking water infrastructure, within marginalized communities. We also investigated the occurrence of municipal lead infrastructure in the context of environmental justice (EJ) initiatives and movements. The EPA defines EJ as "seek[ing] the equitable treatment people of all races, cultures, incomes, and educational levels in the development, implementation, and enforcement of the environmental programs, laws, rules, and policies"(Bolte, G., Pauli, A., & Hornberg, C. 2011).

Although CWSs don't collect demographic information, connections have been made about water quality data and community demographics by using census data. For example, Allaire et al. (2017) found that communities of color were served by water systems with higher rates of violations. A look into the statistics of underperforming water systems found negative and positive correlations between demographics and compliance. McDonald and Jones (2018) found that areas with high incomes had a greater likelihood of better water quality because the residents had the money to fix, upgrade, and maintain their systems. "The median household income was non-significant for initial violations in the medium stratum [a level or class to which people are assigned according to their social status, education, or income]but had a significantly increased odds ratio (OR) for repeat violations". Renters were also negatively correlated with initial violations in medium strata. Low education usually correlates with lower socioeconomic status and thus heightened risk. However, in this study, having less than a high school education decreased the odds of initial violations across all strata. This is interesting but could be explained; the individuals within this "population may reside within a multigenerational household" therefore making up for the gap in knowledge and/ or income. For non-Hispanic whites, there is also a decreased OR with initial and repeat violations—in small strata. The small to very small strata has the highest OR for violations but non-Hispanic whites remain the lowest OR in this strata. Within the small strata, Hispanics increased the OR for repeat violations, not initial while in all other strata's, Hispanics increased the OR for initial violations, not repeat; that too can be explained by the presence of non-minorities and higher income. Minorities face the most exposure with poor water quality in CWSs serving large populations which highly correlates with the areas with initial and repeat violations. Racial/ethnic and uninsured populations had increased OR. However, median household income correlated with decreased OR for initial and repeat violations. Although racial/ethnic subgroups tend to be exposed to higher risk, McDonald et al findings do not show counties with higher proportions of these subgroups with lower social-economic status as having more "disproportional burden with repeat violations". That may be the case but the OR associated with the "proportion of non-Hispanic blacks and Hispanics were higher for repeat violations than for initial violations in the large stratum" (McDonald and Jones, 2018).

Beyond the demographic correlations, there are outlying factors that play a part in the distribution of water quality. "Fluctuations in the number of violations can be attributed to a variety of factors, including regulatory changes, enforcement capacity, raw water quality, and treatment capabilities (Allaire et al, 2017). When there are changes in regulations, immediate spikes in violations may indicate a time-lag as utilities adjust to the changes. As expected there were spikes in violations after new federal regulations (Allaire et al, 2017). The EPA requires states to report lead in water system occurrences, however, the agency lacks 72 percent of such data (Fields, 2006) partially because the LCR is usually tricky to enforce. This is because the contaminants in question are out of the control of the water utilities. After all, lead is usually introduced to drinking water in service lines (connects the building to water main) which are owned by the person, not the utility (Fields, 2006).

Lead issues in NC

For this study, North Carolina will be the population of interest. While Flint created awareness, not every state took initiative towards the national priority to identify and replace lead lines. North Carolina was one of the few states that began to work on a drinking water pipe inventory. The data collected recently by the Department of Environmental Quality provides new insight into the public water systems of North Carolina. North Carolina is a prime state for analysis because it is a demographically diverse state.

Research questions

In the wake of revelations about lead contamination of drinking water in Flint, Michigan, a magnifying glass has been put on government oversight and the roles and responsibilities of community water systems. To prevent future incidents like that of Flint, I seek to answer two questions as they pertain to lead plumbing and piping in North Carolina; 1) What lead bearing materials are present in the drinking water systems managed by government entities and private companies, and in what North Carolina counties are they located? and 2) Does race, economics, age, and/or when homes were built explain variation in the risk of exposure to leaded water systems in North Carolina?

METHODS

For this study, we used data sets downloaded from publically available state and federal government websites. We used one dataset from NC DEQ composed of information provided by water utilities serving residents of North Carolina. We used data from the EPA's Safe Drinking Water Information Systems (SDWIS) for additional details about each water utility serving North Carolinians. We used data from the US Census to characterize the social, racial, and economic characteristics of each county in North Carolina. We merged the DEQ and SDWIS data to address research question 1. Then we summarized the DEQ-SDWIS water utility data by county and merged with US Census data into one comprehensive file for analyses to address research question 2.

Working with NC data

In North Carolina, there are almost 6,000 public water systems with about 75 percent of its population served at home by approximately 2,000 community water systems. While lead service line replacement became a national priority, not every state took initiative towards the national priority to identify and replace lead lines. North Carolina was one of the few states that began to work on a drinking water pipe inventory, thus enabling an examination of the prevalence, management, and distribution of leaded infrastructure across the state.

The EPA defines a public water system (PWS) as a system of provisions for water that's for "human consumption[,] through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves at least 25 individuals for at least 60 days a year. A PWS becomes a CWS when it serves the same community year round" (2017). CWSs are defined by the source of water coming into the system, the population it services, and the type of ownership (Allaire et al, 2017). There are non-transient water sources and there are two types. Non transient means they provide water to non-communities like school districts. Transient non-community systems serves areas that do not serve the same people for more the 6 months, i.e, rest areas. Repeat violations in residential areas could be due to neglect/lack of enforcement in this area because of pressure to have higher enforcement for defaulting systems providing drinking water to areas like school or offices, because these are areas with more potential to be affected, given that there are kids and larger amounts of people. So these non-transient areas get more enforcement/penalties because of the greater consequences. Therefore, CWSs will be more likely to violate than non CWSs. (Rahman et al, 2009). “Publically owned PWS are owned and operated by the federal, state, or local government”, a privately owned water systems are privately owned entities registered with the state” (Rahman et al, 2009).).

Department of Environmental Quality Data (DEQ): NC Pipes and plumbing

For this research, we used NC DEQ data self-reported by water systems on leaded drinking water pipe infrastructure. The NC DEQ continues to request pipe material data from utilities, thus the information is constantly being updated. The DEQ gave each utility three forms in which utilities reported information like corrosion control treatment, and the presence of various plumbing material. DEQ provides the data via download on their website. For this study, we used data downloaded from the DEQ website on 19 March, 2020 with approximately 97% of water systems reported.

North Carolina Safe drinking water information systems (SDWIS) data

We downloaded the SDWIS data in 3 files from the EPA website: system details, system service details, and system geographical area. The SDWIS data includes information on each system such as where they are located, system name, the number of service connections, the water source (e.g, groundwater or surface water), the ownership type (e.g, federal, state, local, private), who they serve (residential, mobile home, suburbs), counties they serve, etc. Unfortunately, SDWIS data for North Carolina has only missing information for the variable zip code served. For this study, having the specific zip code served by each utility would have permitted a more refined analysis to address research question 2. There were data on county served for each utility. Consequently, we address research question 2 at the county level.

Demographics

We downloaded US Census data from Social Explorer, a website in which we could query data specific to North Carolina counties (Social explorer, 2017). We downloaded data for variables related to those that form the EPA's EJ index, as well as data related to when homes were built.

Data processing

To address research question one (RQ1), we combined data from DEQ with SDWIS data to identify ownership of each water system. We retained PWS that served homes which we defined as those in the SDWIS database with service area classification of residential, trailer, and subdivision (Table 1). We excluded the PWS if it only served other categories, which included municipality, school, restaurant, service station, daycare, industrial agriculture, hospital, hotel, summer camp, institution, or other transient customers. There were 107 PWS IDs that entered data twice (in earlier year and later year) and we removed the earlier record. Some PWS served multiple types of service areas and the final set of PWSs serving homes was 2,009.

Statistical Analysis for RQ 1

What lead bearing materials are present in the drinking water systems managed by government entities and private companies, and where are they located in North Carolina?

We summarized the number of systems that reported lead water mains, lead service lines, lead goosenecks, and lead solder. We computed the percent of water systems reporting lead per county and identified the "top 10", i.e., the 10 counties with highest percentage of water systems reporting lead. We computed the percent of the population served by water systems reporting lead per county and identified the "top 10", i.e., the 10 counties with the highest percent of their population served by systems reporting lead.

To examine differences in leaded infrastructure between systems managed by government entities and private companies, we completed Chi-squared tests. We tested whether the observed occurrence of lead pipe/plumbing material in community water systems across NC differs from the frequency that lead pipe/plumbing material is used overall. The results of a chi squared test are expressed as a p-value. The p-value has to be less than or equal to 5 percent to conclude that the likelihood of lead occurrence and distribution within community water systems are not a coincidence (or by chance). The chi-squared statistic was computed testing the number of utilities reported as having lead against the water system owner type, i.e. government (state, local, and federal) vs non-government (private, public/private).

Statistical analysis for RQ2

Does race, economics, age, and/or when homes were built explain variation in risk of exposure to leaded water systems in North Carolina?

To address research question two (RQ2), we chose population demographic variables used to designate social vulnerability in the EPA EJ index. These variables were downloaded from the Social Explorer cite (Table 2).

To understand the extent that indicators of environmental injustice (e.g. race, income) account for variation in the presence of lead-bearing plumbing and pipes beyond the influence of housing stock age, we used multivariate generalized linear models. For this study, I analyzed variation in two dependent variables. First, I used the dependent variable percent of the county population served by systems that reported leaded infrastructure. 5. Second, I used the dependent variable percent of water systems within a county reporting leaded infrastructure.

Each generalized linear model included the same independent variables in Table 2.

RESULTS

Research Question 1: Descriptive stats and Chi-squared test

We classified a PWS as having lead if they reported any lead components (Table 3). Some water systems reported more than one component of their system as having lead. We tallied the number of other pipe materials reported by each system by adding reports of the following: galvanized, brass, steel, cast, ductile, copper, glass, coal tar, asbestos, vinyl asbestos, cement, PVC, polybutylene, polyethylene. Most water systems reporting a leaded component also reported the presence of other pipe materials.

For all subsequent analyses, we classified water systems reporting any lead component (Table 3) as containing leaded infrastructure and those reporting only other components as infrastructure without lead. . The 2,009 PWS distributing water to NC homes serve approximately 9 million people (Table 4). Of these water systems, 227(~11%) did not report any information to DEQ about their system. Meaning that of the total population served, 2.6 % (230,872) were not accounted for because of lack of reporting by their water providers. Almost 90% of the population receiving municipal water is served by water systems that reported some lead components.

All of the PWSs in one county, Gates, failed to provide reports to DEQ. In other counties, 60% or fewer of PWSs failed to provide reports to DEQ, and these included Edgecombe, Scotland, Swain, Madison, Nash, Franklin, Hertford, Mitchell, Cherokee, Granville, Caswell, New Hanover, McDowell, Greene, Montgomery, Columbus, Martin, Onslow, and Richmond.

Counties with 100% of the PWS providing reports to DEQ included: Chowan, Jones, Davidson, Davie, Beaufort, Union, Dare, Person, Pasquotank, Alexander, Cleveland, Harnett, Chatham, Robeson, Avery, Orange, Yancey, Bladen, Clay, Alleghany, Camden, Anson, Tyrrell, Perquimans, Hyde, Pamlico, and Currituck.

Of those counties with at least some PWSs reporting, the top 20 counties with the highest percentage of the population served by PWS with leaded infrastructure are: Edgecombe, Scotland, Greene, Richmond, Washington, Wayne, Halifax, Chowan, Jones, Davidson, Craven, Bertie, Duplin, Davie, Hoke, Pitt, Lee, Mecklenburg, Forsyth, and Beaufort.

The top 20 counties with the highest percentage of PWS reporting leaded infrastructure are: Edgecombe, Scotland, Greene, Richmond, Washington, Wayne Halifax, Chowan, Jones, Craven, Duplin, Caldwell, Beaufort, Hoke, Dare, Montgomery, Anson, Davidson, and Bertie.

A chi-squared test of significance was used to determine whether or not there was a significant difference of lead reported in one system type to the other. The chi-square(x^2) yielded a value of $x^2(2, N=2009)$ 2402.0, $p<0.0001$.. With the significant results, we were able to reject the null hypothesis and assert that the type of ownership and the occurrence of lead are not independent of one another. Ultimately, there is a significant difference in the frequency of lead in government vs non-government systems.

Table 5 showed lead data based on the different water systems ownership types. The zero and ones represent a presence-absence of the corresponding lead material for that specific number of systems associated with that ownership type. The sum represented both the PWS's that reported lead and the ones that reported they didn't predict lead in the system. This further breaks down the specifics of what the above data, the difference is that this table shows how many systems have each type of material versus the abundance of materials. The above shows that the state government-owned systems didn't report about their PWS's. Based on the table, Local government has reported the presence of the most lead materials. Local government has the highest totals of present lead via goosenecks, solder, and pipes (water main). Local government-owned systems reported a total of 123 systems that reported a presence of lead pipes. Local government reported that out of the total 140 PWS's that reported on their goosenecks, 87 of them reported lead in the system, while 53 reported none. As for the 313 PWS's that reported on the solder, 104 of them reported a presence, while 209 of them did not. Both the federal government and private PWS's reported the fewest numbers respectively. While private PWS's reported the only 6 systems with a presence of lead pipes (5), gooseneck (1), and service lines (0), and solder (5). The federal PWS's reported only having lead pipes (6), gooseneck (4), and solder (5) with a presence of lead. Overall, in terms of priority and lead removal, the abundance of each lead material from most to least is as follows: Lead solder (634 systems), Lead goosenecks (146), Lead main pipe (134), and lead service lines (21).

Research Q2: the multivariate regression

We calculated a generalized linear model to predict the percent of the county population served by PWS with lead (%population) based on county-level estimates of race, economics, age, and home age. We found $F(9,89) = 19155.6$, $p=0.002$, with an $R2$ of 0.25. The percent of the population served by PWS with lead equals 256 (gini; $p=0.002$) + 10 (%under 5; $p=0.01$) (Table 6). As county wealth inequality increased, the percent of the population served by PWS with lead increased. As the percent of children under five years of age increased, the percent of the population served by PWS with lead increased.

We calculated a generalized linear model to predict the percent of PWS with lead (%PWS) based on county level estimates of race, economics, age, and home age. We found

F(9,89) = 21300, p=0.0003, with an R2 of 0.29. The percent of PWS with lead equals 1.1%Black (p=0.03) + 1.8%poorwhite (p=0.04) + 8.1%under5 (p=0.04) (Table 7). Counties with higher percentages of Black people, and poor white people, and children under 5 years of age were counties with higher percentages of water systems that contain leaded infrastructure.

DISCUSSION

In North Carolina, economics, race, and age were important factors explaining variation in receiving service by a water system with leaded infrastructure. North Carolinians living in counties with high wealth inequality were more likely to be served by water systems that reported lead in their infrastructure than those living in counties with low wealth inequality and higher percentages of children under five years of age. Furthermore, counties in which high percentages of water systems reported lead in their infrastructure were those with high percentages of Black people (irrespective of their wealth), as well as those with high percentages of white people living below poverty level, and higher percentages of children under five years of age. Similar to studies that have found racial and economic disparities in underperforming water systems (e.g., McDonald and Jones XX, <others>), we found racial and economic disparities in service by leaded water systems. Of additional concern is the greater potential for exposure of lead to the young children, who are highly vulnerable to the irreversible impacts of lead.

The number of utilities that report having lead in their system serves a majority population of the state of North Carolina. The majority of North Carolinians are served by water systems managed by local governments, and these systems are more likely to contain leaded infrastructure. Although few systems reported lead service lines, and just over seven percent reported lead goosenecks, about a third of water systems reported lead solder. Thus, while most lead mitigation programs focus on lead service lines, the majority of the lead is present as lead solder across all system owner types. While lead soldering has been banned, the current ban against “lead-containing solder” are ones made of half lead and half tin (“Copper & the Environment: Drinking Water Plumbing Systems,” n.d.). In the right conditions (low alkaline, acidic, soft) water passing through can pick up lead particulate. Removing and replacing lead solder is more challenging because the solder is a small material present in random and inconvenient places. This will also mean that the mitigation for solder may call for people to adopt different habits to mitigate their exposure. Based on the results of RQ1, the need for lead mitigation falls most heavily on local governmental water systems.

Sometimes Americans take the safety of drinking for granted because we are taught that what comes out of our pipes is safe—as long as it appeals to the senses. The problem with that is, water can seem right to the senses and still have hidden issues. People cannot detect lead in water by taste, sight, or smell. The narrative around what is "clean" drinking water should change. Unfortunately, laws and regulations are put in place but compliance is not always being enforced. Using preventative measures as opposed to reactive makes for safer and healthier lives.

Immediate Mitigation based on NC needs

Some of the most used and promising immediate fixes for lead-contaminated water are a point of use (POU) filtration systems. POU systems include filters on kitchen faucets as well as filters in water pitchers. Other fixes include Point of Entry systems “those that are installed at or near where water enters a building and is connected to the plumbing, whereas POU systems are those installed near where water is directly used and may be connected to plumbing or not (Hamouda, et. al., 2012). "Point-of-use (POU) systems treat the water where you drink or use your water, and include water pitchers, faucet filters and reverse osmosis (RO) systems. Wholehouse/point-of-entry (POE) systems treat the water as it enters a residence. They are usually installed near the water meter (municipal) or pressurized storage tank (well water). Whole-house treatment systems include UV microbiological systems, water softeners or whole-house filters for chlorine, taste, odor, and particulates." (National Sanitation Foundation, 2018). Reverse osmosis is a universal method of filtration because it reduces all contaminants, while most commonly used filters are ones that use granular activated carbon(GAC) to reduce lead (Rozelle, 1987).

In NC there remains a few leaded water mains and goosenecks reported by water systems. NC might consider making their lead removal programs focus on mains and goosenecks rather than only service lines. The fact that there are few lead service lines may indicate past lead line replacement efforts and/or the industry no longer using lead lines. Fortunately for consumers, the water main and gooseneck are publicly owned meaning it is a government responsibility. Knowing where the lead is present is an incentive for consumers to urge their local, state, or federal government to cover costs to replace materials and ultimately ensure public health.

Lead as an Environmental Justice issue

According to McDonald and Jones (2018), there are three initiatives needed to be in place to address water quality. First, educating the public about the SDWA, including information on provisions for citizens to take civil action against any federal agency failing to enforce the SDWA. Second, citizen engagement is imperative to call upon leaders for actions in addition to regulation, such as investing in safe infrastructure, technical assistance and training of CWS personnel, and additional reporting resources to assist with oversight and enforcement of violations and to support customer partnerships with the utilities. Third, public health practitioners need to partner with the government to evaluate the effectiveness of the state primacy practice (McDonald et al, 2018).

Citizens can only benefit from multiple approaches to better water quality. Therefore, a customer with a home water POU filter would still benefit from periodic dislodgment and removal of particulate material via high-velocity flushing (Brown and Cornwell, 2015).

The local, state and federal government are essential partners in the long term changes needed to be made. There need to be policy changes to the Lead and Copper Rule. The first review of the Lead and Copper Rule was a result of Washington, D.C. exceeding the lead action level in 2002 (Pontius, 2002). The most recent review, currently in progress, is heavily informed by lessons from the Flint Water Crisis.

Rather than reviews linked to responses to crises, together, both the citizens and government can make effective changes through systems thinking. In systems thinking, the problem that needs to be addressed is a publically raised and important one that is reoccurring throughout history. However reoccurring, attempts to remediate have failed. Which is very much that case of the approach to lead in drinking water. Systems thinking is important for both "public policymakers [to apply to the lead issue] to fully understand which parts of the integrated systems are most at risk" and for people to see where they fall in that category (add REF for quote). The Lead and Copper rule is necessary but not sufficient in its current application.

Without proper water regulations and proper systems thinking, bad things will happen to community health and trust for its government (Attari et. al, 2017).

Future recommendations: Community engagement & implementation

Community-based science or Citizen Science can help people take initiative to address the issues locally within their communities. By implementing a citizen science project we can involve communities in being more proactive about their wellbeing. A new citizen science project, Crowd the Tap, offers partnerships with water quality organizations and minority social organizations, to recruit people from various communities nationwide with a focus on community water systems (CWS). This program should be adopted by each state in collaboration with the local government and utilities of that state. Getting people engaged may be a challenge. Many people don't know about the public water system nor their rights to clean water. This project will bring people closer as a community through shared learning experiences, by educating them on their community water system, and the unspoken responsibility they share with their utility to maintain clean drinking water. As Attari et al. (2017) noted, "[A] greater understanding of the water system among laypeople will be necessary in order for municipalities and larger levels of government to confront new exceedingly complex risks to the water systems" because it is the citizen who ultimately makes the decisions about changes in tax hikes "[used] to address water shortages [due to contamination] and [municipal water] infrastructure upkeep." To create a better understanding, citizens will be engaged in a project that will implore them to explore their water system and get in contact with their supplying utility. One goal of this project is bridging a gap in knowledge for participants, and learn the shortcomings of the lead and copper rule, that is who it is helping and who it is neglecting.

A key component to engaging water consumers with this project is that it will fill the gap of missing information that most governments and municipalities lack. There is little to no data on the materials on the private side of the plumbing. While the utilities can use historical data and estimation, it is not always accurate and does not account for changes that may have taken place over time. The only way to obtain accurate data is to do water testing or pipe testing.

For this citizen science project, I propose doing pipe tests on the consumers' plumbing within their home. The first step is sending pipe testing kits to all individual residential areas nationwide willing to participate in a citizen science project. Every household participating in the project can receive an identification testing kit that will help identify lead pipes, as well as other types (copper, galvanized steel, copper, etc.). The kit will be used to test the water service line connected to the house and the home plumbing materials. In the kit, there will be a penny, a magnet, and a small postcard with instructions on how to use the kit. Simply, it is a scratch and a magnet test. The participant will scrape the pipe with the penny if it scratches shiny, and the magnet doesn't stick, it is safe to deduce that the pipe is lead (an example of instructions can be found on http://gbwater.org/media/82002/lead-pipe-identification-brochure.pdf). The point of the kit is to provide citizens with an inexpensive, easy DIY (do it yourself) project to test and learn about their pipes, and in turn, provide unbiased explicit data.

There are barriers to the project that need to be addressed for more accurate data collection and complete participation such as there is no easy way to test for lead solder and it requires volunteers to find their water pipes which may be in cellars and crawl spaces. Despite those few drawbacks, it is a good start and a great alternative when consumers do not have immediate access to affordable water testing. Water testing is great for assessing if there is lead present in the system but it does not account for where the lead is coming from in the system.

Another goal of a citizen science project is to show people different avenues to do science. Science is not meant to be a secret society; everyone can have a part. Involving people in a project working towards major initiatives through a simple and inexpensive task allows for a gap to be bridged between researchers and citizens. A task someone may see as needing to be done by someone "more qualified" turns out to be a very simple task that can be done by anyone. This will help people feel more involved and educated in what happens to them, their home, and health. It allows people to find out vital information about their home and health and show them that they don't need to wait for a scientist to come around asking questions for them to take action on things that directly impact them.

Aside from offering short term resolutions for people at home, like remediation, civic action, and community participation, the action taken and the information collected will aid in the shift in local, state, and the federal government treatment of this prominent issue in the long run. There is a lot that can be done with accurate demographic data, especially when there is spatial data associated with it. By having data specific to homes, zip codes, and areas served by certain utilities, action can be made and other questions can be researched. For example, whether or not certain populations are disproportionately affected by a lead plumbing issue could be examined at local neighborhood levels rather than at the county scale. With more fine-scale data, research questions can yield better answers and goals can be achieved. This can be done by creating data spatial maps to show where there are clusters of SDWA violations occur—hot spot analysis.

Hot spot analysis offers the advantage of determining whether clusters of violations are significant. Targeting facilities that are underperforming is one approach to improve compliance and consistently provide safe drinking water (Allaire et al, 2018). Identifying hot spots and vulnerability factors associated with violation could better direct enforcement activity and inform the allocation of federal grant funds that assist state-level enforcement.). Part of the reason there is a current problem with lead pipe and infrastructure data is that local governments have not enforced record keeping on utilities. Utilities need to take initiative on their end by keeping a record of the materials they see when they are in the field. Now that there is awareness, citizens and utilities can work together to help identify where the lead is, by submitting actual data about their homes. By participating in imputing data, citizens would also correspond with their utility and swap and compare the information.

There are several things that the utilities could partner with communities to do to help underperforming systems. First, prioritization of technical guidance and financial assistance; expanding training and assistance could address operational issues. Second there should be a consolidation of systems that could reduce the likelihood of favoritism. Given that systems with combined resources tend to be less likely to face violations (Allaire et al, 2018). With more precise data doing a hot spot analysis of violations can show utilities the spatial clusters they need to focus on for remediation. Hot spot analysis can only be done with point data. Another shortcoming of this study is that because the data is broad (based on counties and cities) the spatial data is comprised of polygons.

Recommendations based limitations of study

For municipalities and larger levels of government to deal with the complexities of the water system, laypeople need to also have an understanding of the water system (Attarti et al., 2017). The lack of community understanding can be demonstrated with a study by Attari where only the students with environmental science backgrounds had a better understanding of the water system. Thus, those students with a relevant education background have a better understanding of perceived risk within the drinking water system. Fifty five percent of the surveyed students couldn't identify aspects of the water system. The participants of the study represented the demographic of citizens that have higher education vs those who have none (Attarti et al., 2017). That fact is that the majority of the population do not have higher education, and even the ones who do still lack a complete understanding of the science of things around them, let alone their own water system. Many people are so far removed from the process of drinking water transportation. Yet, changing people's perceptions of water will ultimately lead to greater long term resolutions.

In the US, like other developed countries, safe water coming out of the home faucet is a social expectation. Many consumers see their water and know very little about where it comes from. Thus the water system is “out of sight, out of mind” and fits "what you don't know won't hurt you" culture. Culture theory can be used to assess people's individual water use habits and to understand the values and beliefs of social systems at the group water use level. Koehler et al. (2018) used Culture Theory to explain preferences for changing cultures of water point management concerning environmental (water viability and quality), operational (functionality of water point), financial (cost of services), and institutional organization of water point management) risks. Koehler et al. (2018) assert that to have universal changes there has to be a compromise at the local level, which will lead to conflict. This is where cultural (attitudes that stabilize an organization…and experiences function to attribute value to experiences that provide criteria for courses of action, shared experiences and expectations) changes needed to be made and shared (Koehler et al., 2018). From Koehler et al. (2018), a different cultural perspective is needed to manage water points. The cultural theory postulates four basic cultures—"egalitarian, individualism, hierarchy and fatalism—which correspond with recognized 'management cultures' in the rural water sector—community, individualist and bureaucratic management—as well as fatalism, a characteristic of those who fail to actively organize for managing their water point but adjust to its failure—which corresponds (Koehler et al., 2018). To achieve universal, safely managed and equitable water services for rural water users require them to be sufficient, safe, affordable, equitable, and universal depending on arrangements of water points and diverging risk perceptions of water users (Koehler et al. 2018)

A hybrid of the cultures, what Koehler et al. (2018) call a "clumsy" approach, combines the four to create policy styles that connect creative market forces with government planning, including the possibilities for local and civic action, this creates room for flexibility and varying strategies. A combination of cultures helps eliminate gridlock from trying to impose another culture on another. "For example, community water pints can be organized as fully egalitarian common pool resources with rules for usage behavior or as clubs with distinct membership criteria, which combine community managed and individual cultures—as the ownership is public, yet the management is outsourced to a private entity" (Koehler et al., 2018).

Economic implications - the cost of public health

“Agencies, including the U.S. Centers for Disease Control and Prevention (CDC), have continued to put innocent lives at risk as they have periodically dismissed the seriousness of lead exposure from drinking water, while the water industry has taken cover under a weak Lead and Copper Rule so that they may avoid their obligation to protect public health.”- Siddartha Roy, 2017.

The delay by local and federal government to implement and enforce new rules and amendments to the LCR will yield a bigger economic loss in the long run. A lot of money and energy goes into water facilities and treatment. It is "estimated that 2-3 percent of energy use in the world is due to pumping and treating water, and 15-20" of that comes from the US (Watergy, 2002). The energy put into protecting drinking water should be used efficiently and effectively. When problems arise in the system more energy and money are needed to rectify the issue. Given that the data estimates that there is various lead bearing material, the opportunity of lead leaching is high. This dissolving of metals from plumbing and fixtures is corrosion. The cost to fix the results of corrosion are astronomical; the direct cost of public drinking water corrosion is $22 billion (Brongers, 2002; Edwards, 2004). The only way that lead can corrode into water is by lead pipes and fixtures to be present in the system. To understand the gravity of the issue, there needs to be a conversation about money. A further look into the budget can open eyes to see the problems within the public water infrastructure is the hesitation to spend money fixing the problem. As stated above, when utilities are out of compliance of the LCR, they have to act by “optimizing” there corrosion treatment, begin efforts to remove lead pipes, and inform residents that their water is not safe for consumption. However, agencies are falsifying records and manipulating the collection techniques to minimize the amount of lead they report (Roy, 2017). With utilities and agencies evading the truth, it delays the ability to see commonalities and reoccurrences within the system that can lend to prevention rather than reparations. "The estimates for public water infrastructure needs are estimated to be about twice the anticipated costs of all water treatment" with "upgrades to water transmission system alone are expected to cost utilities between $77-325 billion over the next 20 years, [upwards to] $1.02 trillion over 20 years if operations, maintenance, and finance [are] included (Win, 2000; Edwards, 2004). Continuing to prolong mitigation will result in a higher bill later as well public mistrust of their government and utilities, which could result in more lawsuits (Roy, 2017).

There is a shared responsibility between municipalities and homeowners that was established by the LCR however, most water consumers do not understand their responsibility to hold their water utilities accountable and requesting updates on the data surrounding their water system. (AWQA 2019). Since some utilities are avoiding responsibility, the fault falls on the individual homeowners to have say over the water supplied to their home. Corrosion damages are more than that of the budget of all public water supply. In this one-sided relationship, "water utilities have historically been responsible only for corrosion problems up to the costumer's service connection (Edwards, 2002) but the "water quality association survey reveals 70 percent of consumers believe water quality and safety [within their home] are the responsibility of the municipality supplying the water (Miazga, 2016).

Along with prevention and removal, equitable mitigation of affected areas on the consumer side of the water system should be included in the budget. The government can afford to cover the areas that are their responsibility but that shouldn’t leave the remaining lead present untreated and at the discretion of the consumer burdened by it. While there are simple techniques for lead detection and mitigation, there are still a looming amount of consumers who cannot afford to fix such issues themselves. There are also people who don’t know the details of what is happening in their home, let alone their tap. Creating community engaged opportunities can address such issues like wage barriers, lack of access, and knowledge gaps. Accountability held against local government to address issues in disenfranchised communities is harder to invoke and yields slower results. When time to address issues of the community like civil work needing to be done, budgets can be adjusted, but to expect consumers to adjust their budgets to address historically beyond their control and with solutions that are beyond their means or an extra bill.

A community engaged project is an unbiased approach to identifying lead in home plumbing and is also a way to address concerns around lead removal. A community engaged project can provide a platform for people to share solutions and also clarify their need for economic assistance. Projects that seek to address these issues should supply subsidized or donated options for consumers who qualify. Community-engaged research projects that subsidize POU filters or help organize for political action will minimize further inequities that otherwise come from scientist using communities for gathering data, and leaving the communities to deal with the problem. People are more likely to feel fairly treated when scientists coming to investigate a problem also stay to help find a solution. The problem with community partnership with organizations, government, and scientist they are made to feel like research subjects on matters of their own back yards and left only with the results of their study. Community members have the ability to be their own scientist as well as their own advocate.

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Social Explorer Tables: ACS 2017 (5-Year Estimates)(SE), ACS 2017 (5-Year Estimates), Social Explorer; U.S. Census Bureau

Table 1. The data set for analysis included only Community Water Systems serving households.

CWS serving homes	**Number of CWS**
Residential	1,117
Mobile Home	430
Subdivision	476

Table 2. Independent variables were similar to the demographic indicators used in the EPA's EJ Screen tool as well as related to the timing of home construction.

EPA EJ Screen Demographic indicators	Census specific variables from Social Explorer used for analysis
Percent Low Income	
%White in poverty	= number white people below poverty level (SE_A13001A_002) / total white population (SE_A13001A_001)
%Black in poverty = number Black people below poverty level / total Black pop	SE_A13001B_001 / SE_A13001B_002
% Less than High school education = Individuals without a high school diploma / total population	SE_A12002_002 /SE_A00001
%under5 = Individuals Under age 5/ total population	SE_A01001_002/ SE_A00001
%Individuals over age 64 = (ages 64-74, ages 75-84, and over 85) / total population	(SE_A01001_011+SE_A01001_012+SE_A01001_013) /SE_A00001
Percent Minority	
%White alone = white individuals / total population	SE_A03001_002 / SE_A00001
%Black alone= black individuals/ total population	SE_A03001_003 / SE_A00001
Other Relevant Variables	
Median year home built	SE_A10057_001
Gini Index	SE_A13001A_001

Table 3. Number of Public Water Systems reporting lead materials serving North Carolinians.

Lead Component	***Number of PWS***
Main	***119***
Service line	***21***
Gooseneck	***150***
Solder	***649***

Table 4. The population served and number of systems that did not provide reports to DEQ, reported some leaded component in their infrastructure, or reported no lead materials.

System Report	Population Served	Number Systems
No report	230,872	227
No lead	722,715	1101
Lead	7,999,434	681
TOTAL	8,953021	2,009

Table 5. The number of systems managed by government entities or private companies that reported leaded components of their infrastructure, no leaded components, or failed to report.

Type of Ownership	Presence or absence of lead			
	Lead absent	Lead present	No data	Total
Government	126	377	61	564
Non-Government	975	304	166	1445
Total	1101	681	227	2009

Table 6. Parameter estimates of variables accounting for 25% of the variation in the percent of the population of a county served by Public Water Systems with leaded infrastructure.

Parameter	Estimate	Standard Error	P value
Intercept	2299.6	1342.1	NS
%white	0.9	0.5	NS
%Black	−0.09	0.6	NS
Mean Year Homes Built	−1.2	0.7	NS
%no High School diploma	−1.9	1.2	NS
%poor white	0.9	0.9	NS
%poor Black	−0.3	0.2	NS
Gini coefficient	256	106.2	0.02
%under 5	10.3	4.1	0.01
%over 65	0.3	0.9	NS

Table 7. Parameter estimates for variables accounting for almost 30% of the variation in the percent of water systems per county with leaded infrastructure.

Parameter	Estimate	Standard Error	P value
Intercept	1729.8	1276.4	NS
%white	0.5	0.5	NS
%Black	1.1	0.5	0.03
Mean Year Homes Built	−0.9	0.6	NS
%no High School diploma	−0.6	1.2	NS
%poor white	1.8	0.9	0.04
%poor Black	−0.02	0.2	NS
Gini coefficient	−65	101	NS
%under 5	8.1	2.9	0.04
%over 65	0.84	0.9	NS

Figure 1. Diagram of drinking water infrastructure with public and private portions where leaded plumbing can exist.